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Electrical power generation has been revolutionized by growing demand and use of Renewable Energy (RE) sources such as Solar Photovoltaic (SPV) as the main electricity source in modern times. The main objective of this bibliometric analysis is to understand the scope of the literature available for SPV performance characterization. This detailed reviewed was performed on the documents related to SPV research considering all the subject categories from Scopus and Web of Science (WoS) databases. The patterns for the particular set of keywords were broke down with the recuperated outcomes from Scopus database in the language, publication type, year of publication, distribution conveyance by nations, subject classes, association, authors, financing organizations, and patents filed. The articles on SPV characterization revealed a remarkable improvement which gains importance of review paper in this research area. This research study reports some significant research gaps and shows future perspectives for research in this field.

Keywords: Bibliometric Analysis; Current-Voltage Characteristics; Solar Photovoltaic; Performance Characterization

1. Introduction

All-inclusive significance of clean and eco-friendly power source expands step by step to become self-supported. Sun-powered photovoltaic energy is the need of the day and developing quickly as the developing need of mankind for the electricity(Wang et al. 2020). The Renewable Energy (RE) source is vitality delivered from sources that don't exhaust during a human's lifetime (Hewitt 2011). In the previous three decades, there has

been a profound enthusiasm for sustainable power sources (S. Kurtz 2012, D. J. Friedman et al. 2013, K. Branker, M. Pathak, and J. M. Pearce 2011). This opened up various sub-areas of RE source, their persuasive application and their performance measurement (Akbari et al. 2019, Colclough, Griffiths, and Hewitt 2012, Redpath et al. 2011). The extensive usage of Solar Photovoltaic (SPV) is intended to boost the continuous monitoring system. The widely viable SPV module has a significant drawback due to its low conversion efficiency ($\eta < 20\%$) and the non-linearity of the Current-Voltage (I - V) yield curve (E. Kandemir, N. S. Cetin, and S. Borekci 2017). The performance characterization of the outdoor SPV setup with the help of I - V curve tracing and their interpretation the grabs attention of the researcher and it ought to be investigated (S. Spataru et al. 2015, Sayyad and Nasikkar 2019, Huang, Wai, and Gao 2019, Fadhel et al. 2019, F. J. Vorster and E. E. Van Dyk 2005).

This curves helps to measure key electrical parameters which are essential in terms of the well-being of the SPV system (E. Q. B. Macabebe, C. J. Sheppard, and E. E. Van Dyk 2011, Velilla, Cano, and Jaramillo 2019, Ortega, Aranguren, and Jimeno 2019). This abatement the Operation and Maintenance (O&M) cost just as workforce necessity for that (Nehme et al. 2017, H. B. Chi et al. 2019). These curves are useful for planning, commissioning, calibration, maintenance, diagnosis and ideal execution investigation of the SPV power generators (H. Amiry et al. 2018, M. A. Bohórquez et al. 2005, M. R. Maghami et al. 2016). Exactness and recurrence of these captured curves should be extended to better understand degradation and reduce O&M costs. These curves are stored in local memory and analyzed afterwards to examined a short time later to calculate exceptionally significant electrical parameters. The application of the Internet of Things (IoT) in the area of SPV characterization allows evaluating data more efficiently, commercially from a distant place (H. B. Chi et al. 2019, Nasikkar and Sayyad 2020,

López-Vargas, Fuentes, and Vivar 2019, Hishikawa et al. 2015). Most researchers have used simulation to address this issue using a single diode and double diode analysis of SPV characterization (Sayyad and Nasikkar 2020, Masmoudi, Salem, and Derbel 2016, Bana and Saini 2016).

This review article conducted a detailed bibliometric analysis of the numerous publications in the field of performance characterization of the SPV system. In our view, this is the main such review that has been completed in this field. This paper also shows some research gaps which can be a future research scope in this field. Following the research paper survey procedure further, this study paper has chosen to carry out a bibliometric analysis of all conveyed steady grouping and learning theories using Scopus and WoS databases thus far.

2. Bibliometric Review

The researcher needs to have an in-depth literature review basis to better understand the advancement of science and technology in their particular field of study. A huge number of researchers doing investigate in the same field of interest and offer their insight with different perspective and specialists by presenting papers in conferences, publishing journals, books and article. Publications reviewed by peer researchers and provided reviews to ensure a right direction for the author. This publication helps to identify research problems and research gap. This also gives a brief idea about future scope in the specific field of research (Dong et al. 2012). Because of the advancement of innovations, a few different snippets of data about research appear.

There are numerous techniques utilized for examining the patterns in different fields which incorporates H-list, scientometric, webometrics and bibliometric (Kadam, Bandyopadhyay, and Patil 2016, Kuralkar, Mulay, and Chaudhari 2020, Mohan and

Kumbar 2020). This investigation utilizes a kind of distribution, subject areas, the year-wise pattern of distribution, topographical distributions, and references technique for dissecting the research.

The popular repositories for the dissemination are Google Scholar, Research Gate, Scopus, SCImago, ScienceDirect, DBLP, Mendeley, and Clarivate, etc. Scopus is the largest peer-reviewed theoretical and reference database for writing research in the fields of engineering & technology, science, medicine, sociology, the arts and humanities. The author used the Scopus and WoS database to develop writing for the bibliometric survey. There are a number of common approaches are used to obtain the information needed from repositories. A few mixtures were constructed surrounding the catchphrases and description of the study paper on SPV output characterization and the complex technique used for outdoor output characterization.

2.1 Framing of the keywords

The section brings the Scopus database into consideration with the aid of important keywords found for ongoing SPV analysis. The Scopus database query was grouped into three squares as primary, secondary and optional keywords. The proposed keywords strategies applied for this exploration as referenced in Table 1. In the wake of evaluating different combinations of the keywords, concluded on the accompanying arrangement of keywords:

Table 1. Planned search tactic for set of keywords

Primary-Keyword (AND)	("Photovoltaic" OR "PV") AND ("Cell" OR "Module" OR "Array" OR "String" OR "System" OR "Device" OR "Plant")
Secondary-Keywords (AND)	("Outdoor" OR "Performance measurement" OR "Performance monitoring" OR "Performance characterisation")

Optional-Keyword (AND)	("Current Voltage" OR "Current-Voltage" OR "/V" OR "/-V") AND ("Curve tracer" OR "Curve" OR "Characteristic" OR "Characterization")
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2.2 Analysis using the Scopus database

This section presents an articulated bibliometric overview of information given by the Scopus database. As stated in the Introduction, SPV is a focused research area. The papers dedicated to SPV research anywhere between the 1984 and 2010 period have been summed up in the database Scopus is the source of this analysis document. Fundamental investigating through the structured search technique for keywords generated in each of the 333 publications.

The language-wise trend analysis

Such publications are restricted to the English language and as seen in Figure 1 provide 324 publications.

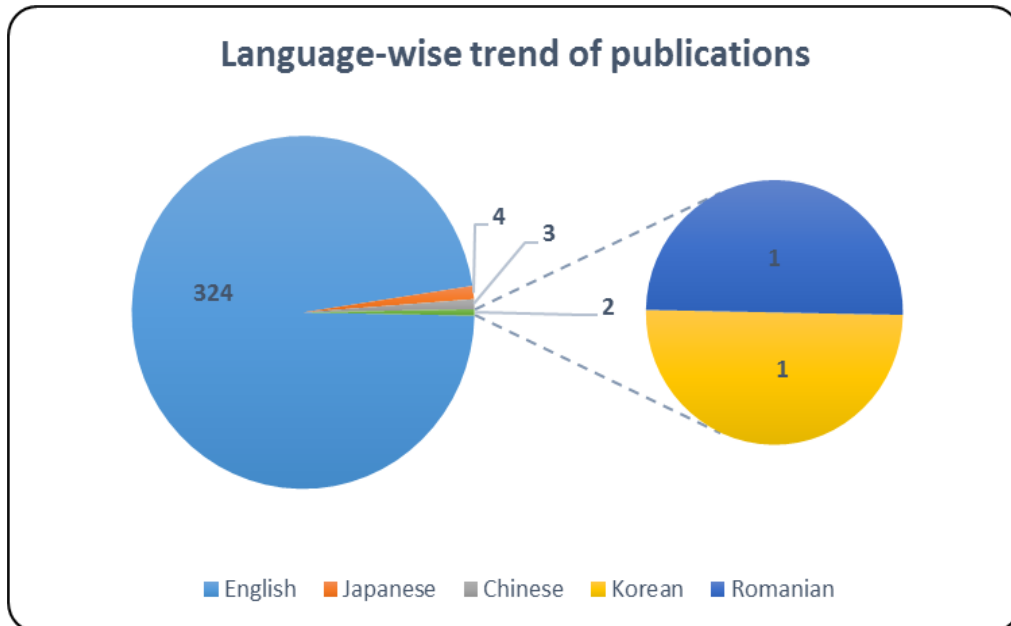


Figure 1. The language-wise trend of Scopus indexed publication accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Document type-wise trend analysis

While analyzing based on publication type, the researchers in SPV characterization research area have published near about 49.55% of total publications in journals and articles whereas 46.55% in conferences considering all kinds of publications as shown in Figure 2. It shows that only 6 review paper means 1.8% of contribution in the form of review publications. Therefore, this bibliometric review on outdoor performance characterization of SPV is written.

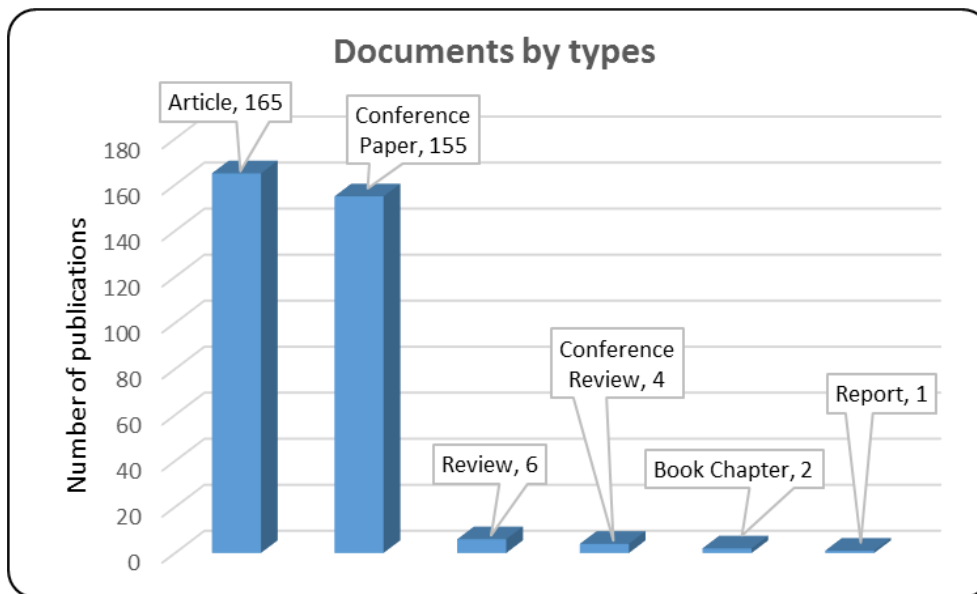


Figure 2. The Publication types wise trend of SPV outdoor performance characterization accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Year-wise trend

The year-wise overview of academic publications for the duration of significance (1984–2020) as displayed in a tabular manner in Table 2. The number of publications increases steadily. For the span of thirty-six years from 1984 to 2020, the related documents were collected as journal papers, conference papers, articles, book chapter etc. From the table, it is apparent that the increase in publications in this region only started in 2011. Figure 3 measures the extent of publications released each year over the last 10 years. During this time, the publishing pattern in the field of SPV characterization shows that 252

publications with the most 41 papers in 2018 were published in Scopus.

Table 2. Year-wise trends of publications of SPV outdoor performance characterization accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Year	No. of Publications	Year	No. of Publications	Year	No. of Publications
1984	2	1998	4	2010	7
1985	1	2000	2	2011	15
1987	2	2001	1	2012	23
1988	2	2002	6	2013	23
1989	2	2003	3	2014	25
1990	2	2004	5	2015	28
1993	1	2005	5	2016	27
1994	3	2006	7	2017	34
1995	2	2007	2	2018	41
1996	3	2008	12	2019	25
1997	2	2009	5	2020	11

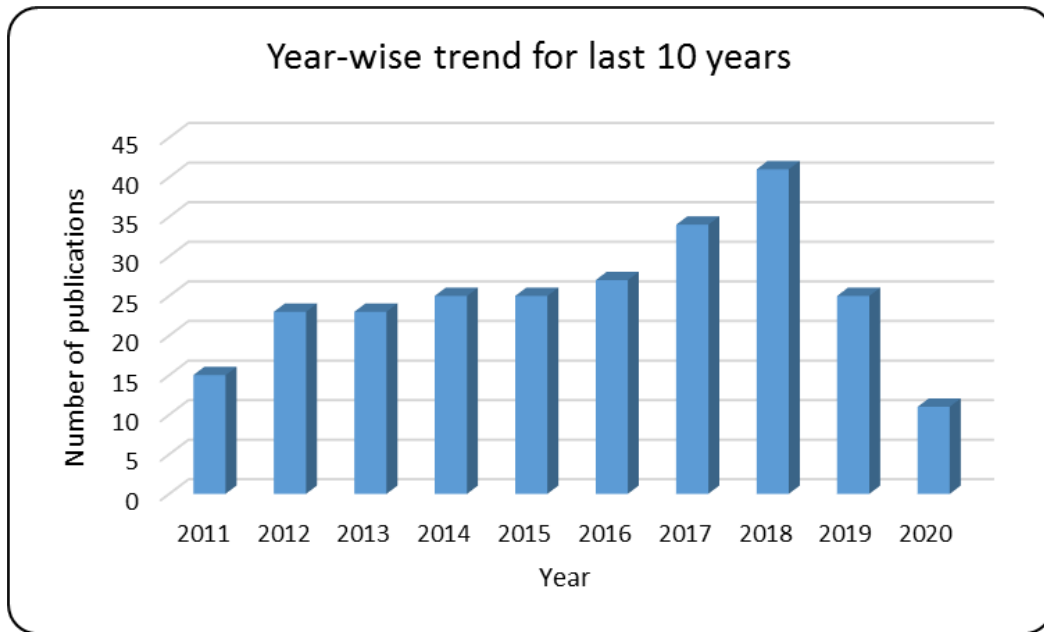


Figure 3. Year-wise publication trend SPV Publication, fetched from Scopus database accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Country-wise trend analysis

It is very interesting to see that many research publications come from the USA. Out of the 333 publications, USA has contributed to 58 of them with the most related articles

and the most-visit accomplice among all the global community articles. Algeria comes next with 30 publications, followed by Italy and Spain at 29 publications each. This is shown in Figure 4. Articles of Algeria, India, Japan, Spain and China developed a lot quicker than other countries in the most recent 5 years.

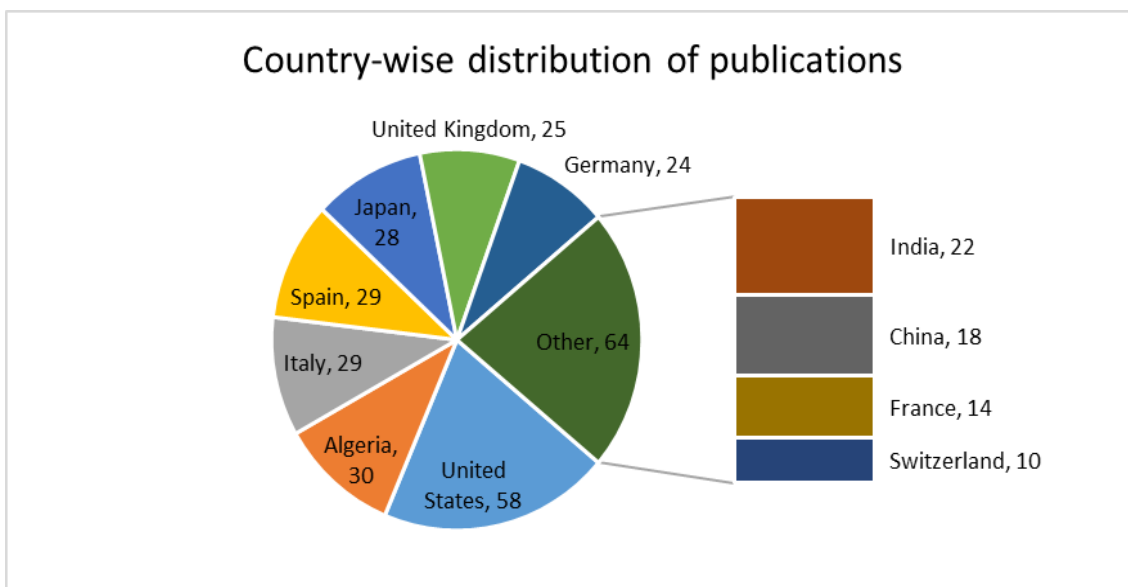


Figure 4. Countries leading in publishing SPV research from data retrieved accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Geographical regional-wise trend analysis

In Figure 5, a world map that includes the subtleties of nations aligned with SPV performance characterization shared discovery that is produced using iMapBuilder.com. It is evident from Figure 5 that detailed work is being performed in the characterization of SPV. From the chart, it is obvious that the overwhelming majority of authors come from the European nations.

Subject area-wise trend analysis

Figures 6, give a view of the subject or research areas which have largely contributed to the research. As is seen from Figure 6, Engineering, Energy and material science have contributed more than 70% (74.16%) of the research publications and gradually turned

into the mainstream of the SPV characterization research. In terms of the number of publications, Engineering has 194 publications, followed by Energy with 159 and Material science with 112. It is additionally seen that less measure of research been completed in the area of Economics, Econometrics and Finance, Agricultural and Psychology.



Figure 5. World map with details of countries involved in these collaborative research, accessed on 25th September 2020 (Source: <http://www.scopus.com>)

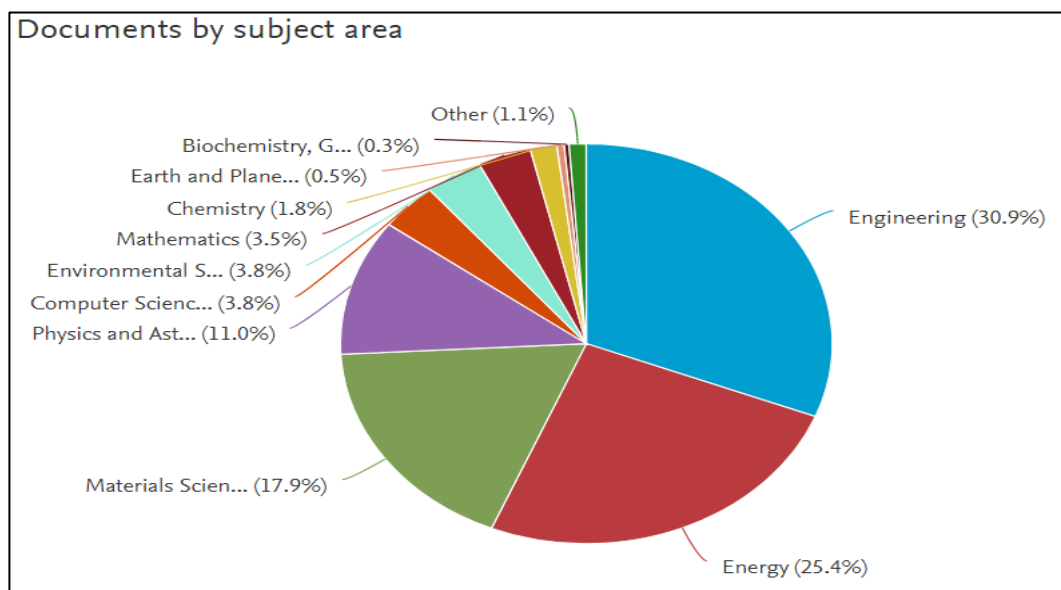


Figure 6. The subject area-wise percentage spread of the publications accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Affiliation statistics

Figure 7 shows the top ten universities / organizational affiliations which contribute. It is astounding that nation like Algeria concentrates more in the research in renewable energies. Center for Renewable Energies Development (CRED) from Algeria driving the table with 22 affiliations followed by National Institute of Advanced Industrial Science and Technology (AIST) from Japan with 21 and National Renewable Energy Laboratory (NREL) from the USA with 18 affiliations.

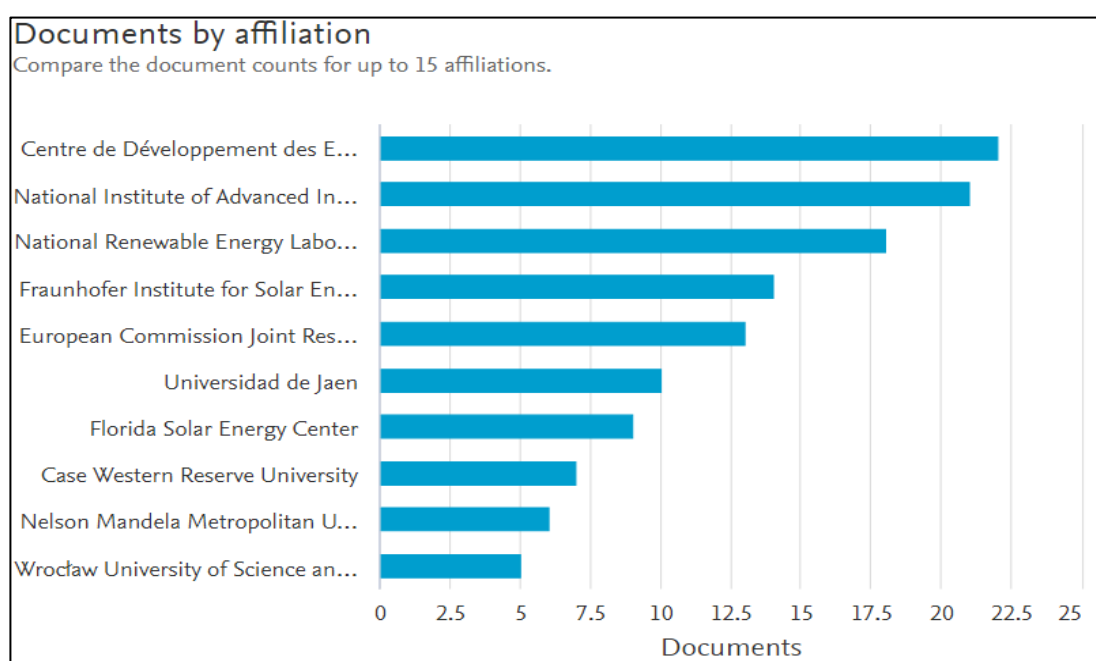


Figure 7. Top 10 Affiliation-wise institutes or research centres accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Author-wise Trend

In Figure 8, the number of publications of the top 10 most prolific researchers is given as a bar chart. Hishikawa Yoshihiro from National Institute of Advanced Industrial Science and Technology, Japan leads the pack with 15 publications in the period under review.

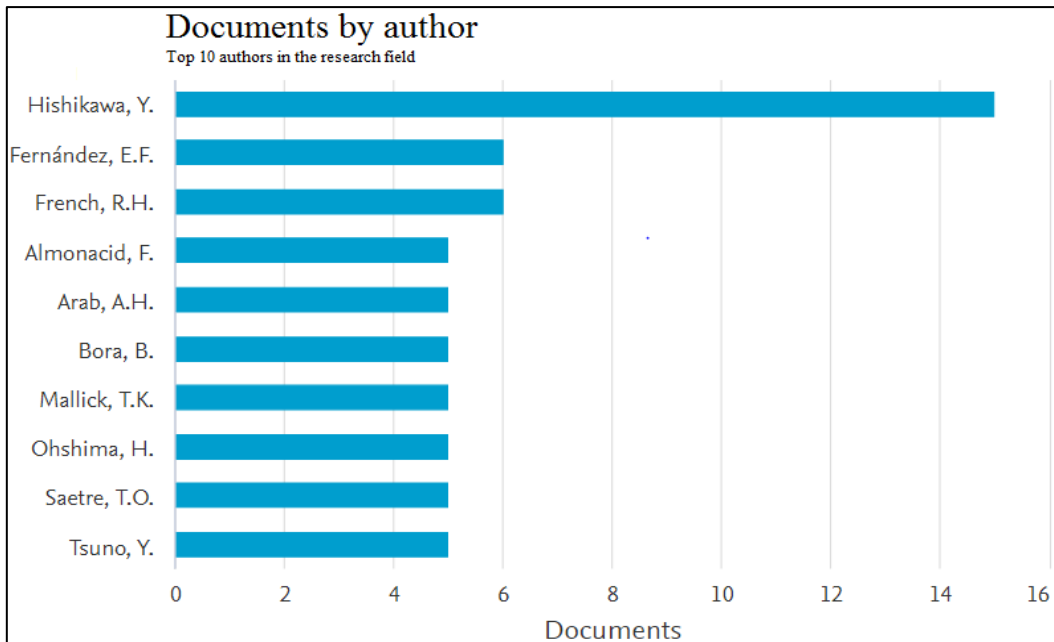


Figure 8. Top ten authors who have published and contributed their expertise, data accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Funding sponsor-wise

Figure 9 shows the top ten funding sponsors for the research in the field of SPV and RE. Consequently, it is not surprising that the majority of the research funding sponsorship comes from the USA which is acknowledged by 10 publications. The funding for Research and Development (R&D) from the European Commission (EC) of Belgium, The New Energy & Industrial Technology Development Organization (NEDO) of Japan and Office of Energy Efficiency & Renewable Energy (EERE) of USA jointly secured second place with 7 publications each. Now a day many countries providing economical support by assigning budget for R&D to become self-sufficient in terms of increasing future requirement energy. Countries like Algeria and India surprising become major contributors in the last 5 years.

Citation-wise trend analysis

Table 3 reveals annual citations collected from publications taken from the Scopus

database for the SPV field of research. The all-out reference check of 333 distributions is 4991 till date. Citation analysis shows this research area pulls in light of a legitimate concern for specialist more in the past 10 years. Table 4 displays the list of the extraordinarily referred top ten publications/books along with references obtained for this work before the date of the data collection. The publication from Solar Energy journal with the highest number of citations is 196, is the first paper that has the maximum number of citations since it was published in September 2012.

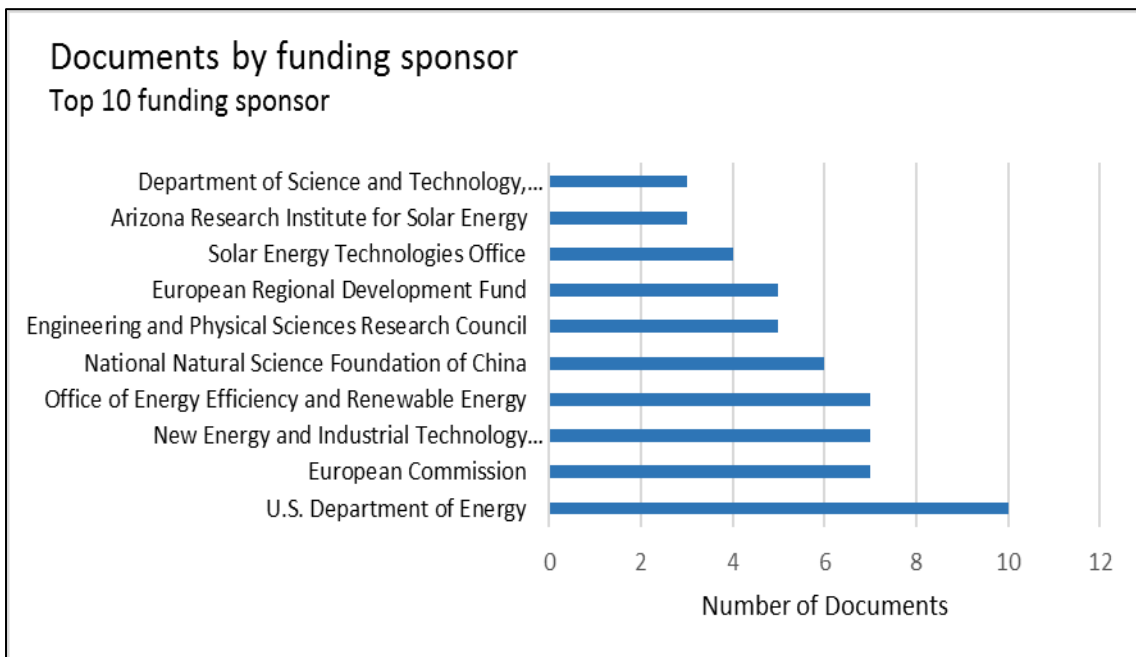


Figure 9. Leading top ten funding sponsors in SPV research domains as data accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Table 3. Citation analysis of publications of SPV outdoor performance characterization as per data accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Year	Cited By	Year	Cited By	Year	Cited By
<2011	454	2014	371	2018	722
2011	132	2015	448	2019	798
2012	154	2016	496	2020	453
2013	301	2017	662	Total	4991

Table 4. The list of top-ten highly cited publications in SPV as per data accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Sr. No.	Title	Authors	Year	Cited By	Journal Title
1	A cell-to-module-to-array detailed model for photovoltaic panels	Tian H., Mancilla-David F., Ellis K., Mujjadi E., Jenkins P.	2012	196	Solar Energy
2	Improved equivalent circuit and analytical model for amorphous silicon solar cells and modules	Merten J., Asensi J.M., Voz C., Shah A.V., Platz R.,	1998	180	IEEE Transactions on Electron Devices
3	A MATLAB-simulink-based PV module model and its application under conditions of nonuniform irradiance	Ding K., Bian X., Liu H., Peng T.	2012	174	IEEE Transactions on Energy Conversion
4	A comparison of the performance of different PV module types in temperate climates	Carr A.J., Pryor T.L.	2004	162	Solar Energy
5	Modeling and simulation of a grid connected PV system based on the evaluation of main PV module parameters	Chouder A., Silvestre S., Sadaoui N., Rahmani L.	2012	152	Simulation Modelling Practice and Theory
6	Analysis of the effect of parasitic resistances on the performance of photovoltaic modules	van Dyk E.E., Meyer E.L.	2004	112	Renewable Energy
7	The design and experimental characterisation of an asymmetric compound parabolic photovoltaic concentrator for building façade	Mallick T.K., Eames P.C., Hyde T.J., Norton B.	2004	111	Solar Energy
8	Growth, fabrication, and characterization of InGaN solar cells	Chen X., Matthews K.D., Hao D., Schaff W.J., Eastman L.F.	2008	105	Physica Status Solidi (A) Applications and Materials Science
9	Solar photovoltaic system modeling and performance prediction	Ma T., Yang H., Lu L.	2014	103	Renewable and Sustainable Energy Reviews
10	Characterization and testing of a tool for photovoltaic panel modeling	Adamo F., Attivissimo F., Di Nisio A., Spadavecchia M.	2011	98	IEEE Transactions on Instrumentation and Measurement

Patent analysis

For the SPV characterization research area as per the Scopus database, 3874 patents are filed in last the 54 years out of which 2876 patents are reported in the last 10 years as shown in Figure 10. In 2017, highest 387 patents are filed as per Scopus database. It demonstrates how quickly the production of RE and SPV is increasing in research as well. Essentially, this shows the potential of the field and the value of the energy requirement. Table 5 shows, The United States Patent & Trademark Office is driving universally with 2266 patents followed by the Japan patent office with 1150 patents.

Table 5. Patent office wise analysis of Patents published as per data accessed on 25th September 2020 (Source: <http://www.scopus.com>)

Patent Office	Number of Patents filed	%
United States Patent & Trademark Office	2266	58.49
Japan Patent Office	1150	29.69
World Intellectual Property Organization	248	6.4
European Patent Office	199	5.14
United Kingdom Intellectual Property Office	11	0.28
Total Patents	3874	

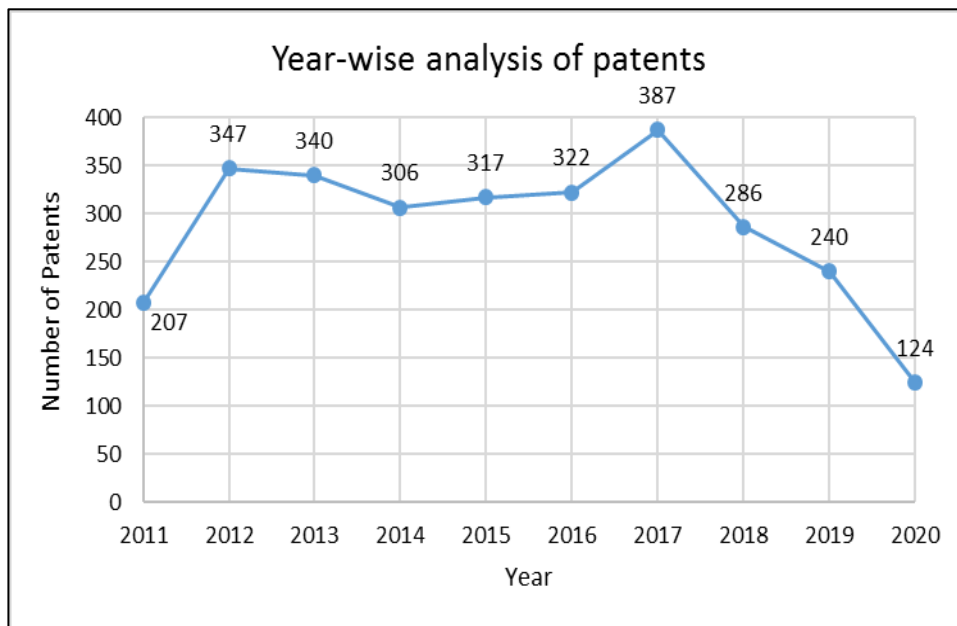


Figure 10. Year-wise break up of patents in SPV characterization, as per data accessed on 25th September 2020 (Source: <http://www.scopus.com>)

2.3 Analysis using Web of Science (WoS) database

In this section, a detailed bibliometric analysis of data which the WoS database has provided. Using the same set of keyword, the WoS database is analyzed. Similar to Scopus, when queried the database for all years (the database starts from 1980), the total number was 92 publications out of which 91 published in English and 1 is published the Korean language. on Filtering the time-span to the last 10 years (2011-2020) will show 83 publications. The year-wise distribution of them is shown in Figure 11. Therefore, based on the data from WoS, it is evident that publication in SPV characterization attracts researchers in this field more from last 10 years.

Figure 12 shows the Tree map given by WoS, showing the top 10 categories, in which the papers are published between 1980 to 2020. It is evident that Energy fuels with 73 publications and Physics applied with 26 publications is the subject area with maximum publications followed by Material science with 24 publication and Engineering with 16 publications.

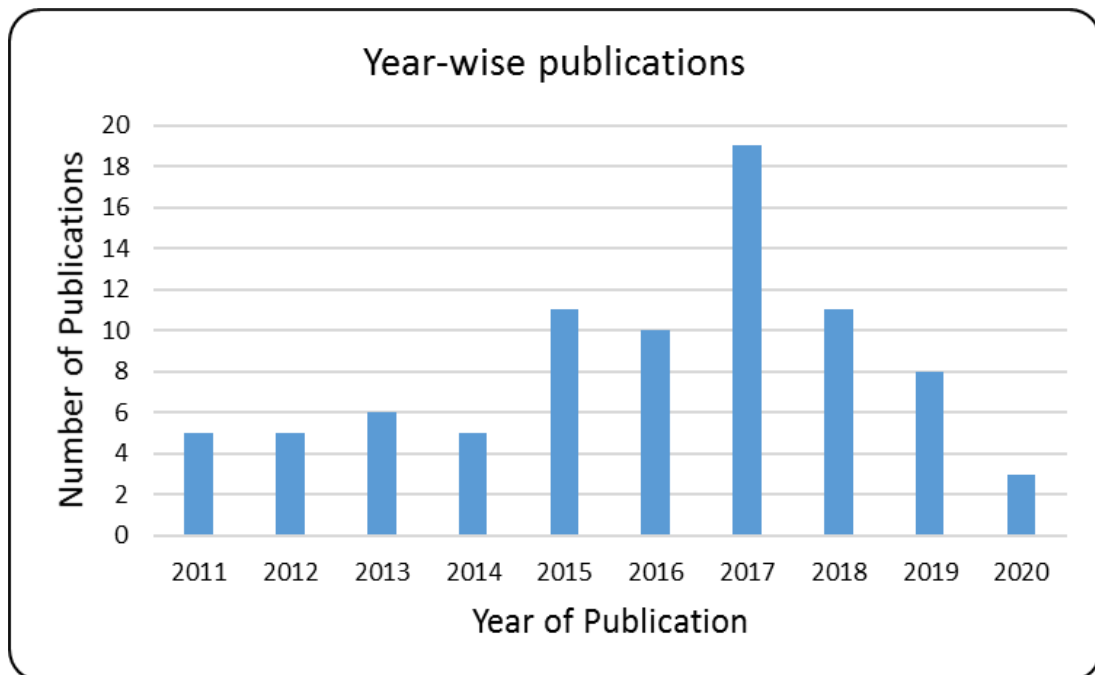


Figure 11. Year-wise publication from 2011 to 2020 as per data accessed on 25th September 2020 (Source: <http://access.webofknowledge.com>).

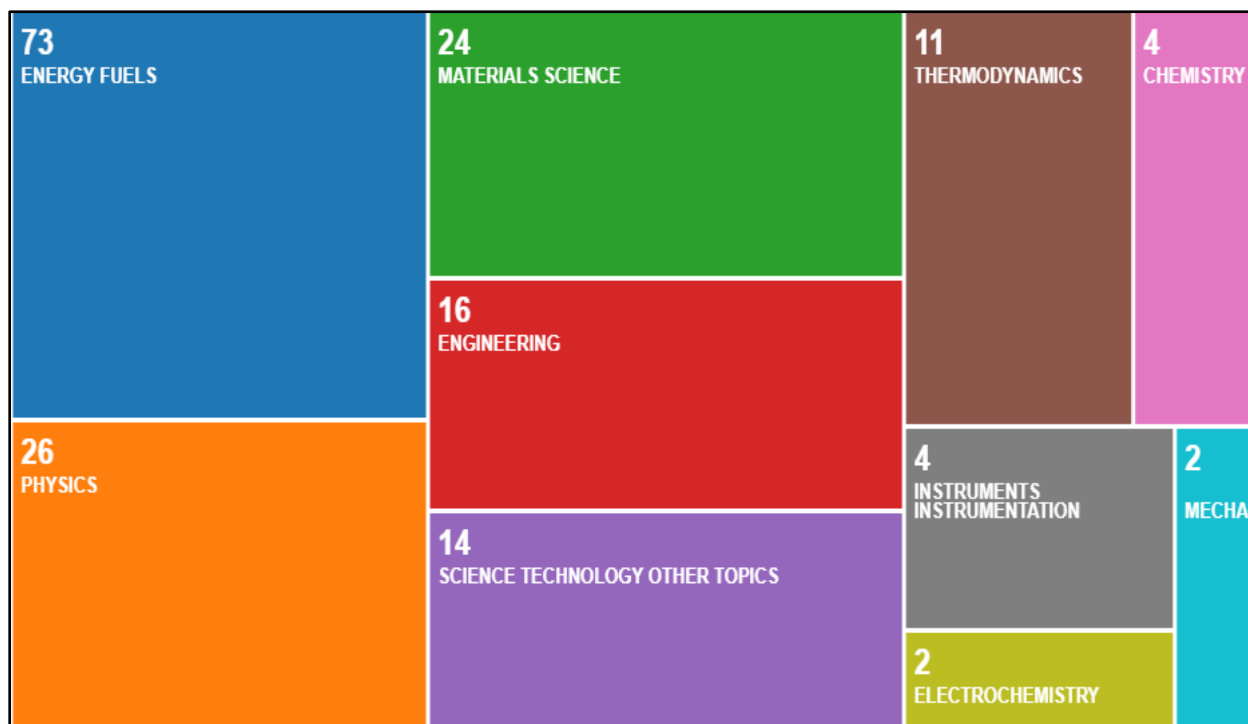


Figure 12. Tree-map of papers published in various subject categories from 1980 to 2020 as per data accessed on 25th September 2020 (Source: <http://access.webofknowledge.com>)

For the WoS database, majority of the research funding sponsorship comes from the European Union (EU) which acknowledged by 8 publications followed by The National Natural Science Foundation of China (NSEC) and The Regional Government of Andalusia (Spanish: Junta de Andalucía) of Spain secured a second and third place which is acknowledged by 5 and 4 publications respectively. The Top ten funding sponsor is as shown in Figure 13.

Table 6 shows top-ten leading and most cited journals titles with their Impact factor, CiteScore and Publisher. Solar energy is the Official Journal of the International Solar Energy Society with an impact factor of 4.608 and CiteScore of 8.1 which is published by Elsevier. Similarly, Energy journal publishes the multidisciplinary publications in energy engineering and research with an impact factor of 6.082 and CiteScore of 9.9 which is published by Elsevier.

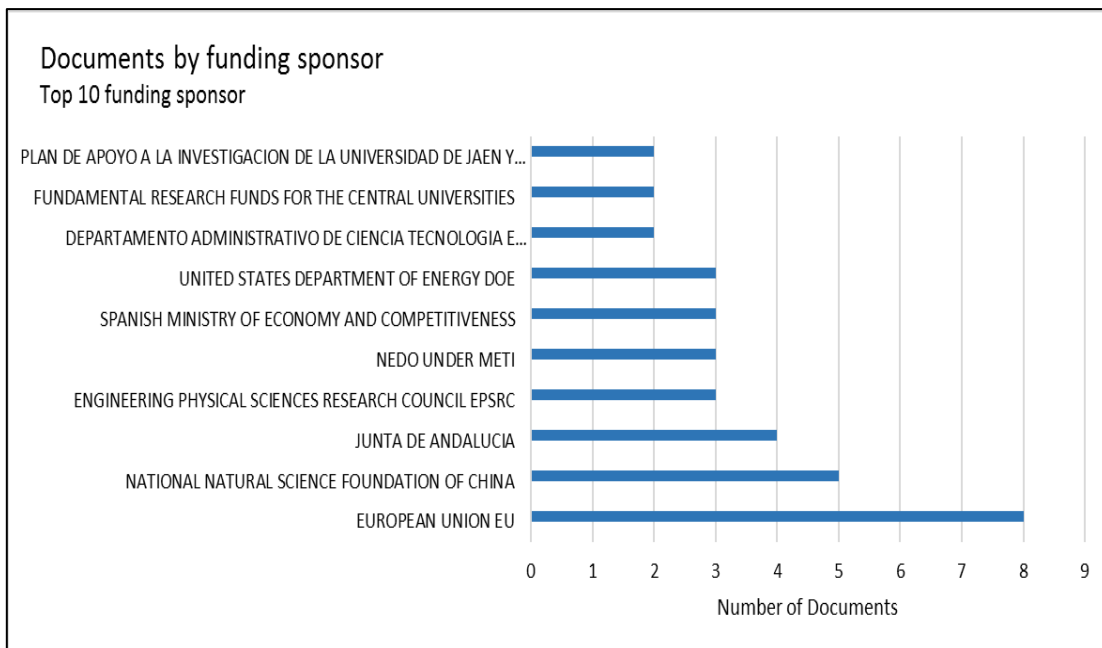


Figure 13. The top ten funding sponsor with numbers of documents by them from 1980 to 2020 as per data accessed on 25th September 2020 (Source: <http://access.webofknowledge.com>)

Table 6. List of leading scientific research journals where research work has been published, obtained as per data accessed on 25th September 2020 (Source: <http://access.webofknowledge.com>).

Source Title	Impact Factor	CiteScore	Publisher	Number of publications	%
Solar Energy	4.608	8.1	Elsevier	19	20.65
Energy	6.082	9.9	Elsevier	9	9.78
Progress in Photovoltaics	7.69	16.3	Wiley-Blackwell	8	8.7
IEEE Journal of Photovoltaics	3.052	6.9	IEEE	6	6.52
Renewable Energy	6.274	11.2	Elsevier	6	6.52
Solar Energy Materials and Solar Cells	6.984	11.6	Elsevier	5	5.43
Applied Energy	8.848	16.4	Elsevier	4	4.35
Japanese Journal of Applied Physics	1.376	2.6	Japan Society of Applied Physics	3	3.26
Energies	2.702	3.8	MDPI	2	2.17
Energy Conversion and Management	8.208	13.6	Elsevier	2	2.17

3. Summary of comparison between Scopus and WoS database

Comparison of Language-wise analysis of publication in the Scopus and WoS database is shown in Table 7. Majority publications are published in English language only. Another comparison is regarding the distribution of publications in different the research areas of Scopus and WoS database is shown in Table 8. Which shows Engineering, Energy, Material science, Energy fuels and physics are the key research areas in this field. Increase in the publication from the previous last ten year shows the impact and significance of the research in this area. EU and USA lead the tables with top funding sponsor and affiliation to their R&D centres.

Table 7. Language-wise comparative study of publication as per the data obtained from Scopus and WoS database.

Scopus		WoS	
Language	Publication	Language	Publication
English	325	English	91
Japanese	4	Korean	1
Chinese	3		
Korean	1		
Romanian	1		

Research gaps and opportunities in SPV characterization

The detailed analysis of publication and upcoming increase need for energy of every nation is being considered for the overview to find the research gaps in this field which is as follows.

- Development of Current-Voltage Current Tracer (IVCT) for high power rated SPV string needs to be explored. The various researcher developed curve tracer for SPV cell and SPV module using different loading techniques. The development of curve tracer for high power rated SPV modules which are

deployed outdoor needs to be studied. It will save the time of the technician/engineers and helps to monitor health more economically by scheduling maintenance of SPV power plant more effectively.

- An increase in complexity from SPV cell to SPV modules string (scaling) will change the behavior of power components used in IVCT which is not yet analyzed, so it is not obvious which component is dominant in actual systems
- Difference between labelled and extracted parameters from I–V and P–V curve shows the significant difference between actual and measured power plant efficiency. It is unacceptable and above tolerance level ($> 5\%$) while going upscale. This error margin will be reduced if more accurate IVCT is developed for outdoor performance characterization of SPV cell/module.
- A direct contact measurement of high power rated SPV cell/module output is not safe for an operator, and it will also add noise in the measuring system. More prominent method for isolation during characterization for on-field safety and error-free measurement is yet to be explored.
- IVCT also used to calculate the exact costing of under-performing (Degraded) solar plant. It is an important tool used for accurate power plant sizing, configuration and commissioning. Commercially available high power ($> 3\text{kWp}$) rated IVCT is expensive. Research for minimizing the cost of this device is not at the pace which limits its use.

Table 8. Comparative study distribution of publications in different the research areas of Scopus and WoS database.

Scopus		WoS	
Research Area	Count	Research Area	Count
Engineering	194	Energy Fuels	73
Energy	159	Physics	26
Materials Science	112	Materials Science	24
Physics and Astronomy	69	Engineering	16
Computer Science	24	Science technology and other topic	14
Environmental Science	24	Thermodynamics	11
Mathematics	22	Chemistry	4
Chemistry	11	Instruments Instrumentation	4
Earth and Planetary Sciences	3	Electrochemistry	2
Biochemistry, Genetics and Molecular Biology	2	Mechanics	2
Chemical Engineering	2	Automation control system	1
Social Sciences	2	Computer science	1
Agricultural and Biological Sciences	1	Operation research management science	1
Economics, Econometrics and Finance	1	Optics	1
Psychology	1		

4. Conclusions

This paper concludes a detailed analysis of all related publications extracted from the Scopus and WoS database for the particular combination of the keywords. Investigation of the information has prompted some interesting bits of information. The overview covers 333 publications from Scopus database out of which 324 distributions are reported in the English language itself from 1984 to 2020. While analyzing based on publication type, the authors in the SPV characterization research area has published 96.1% documents in journals and conferences. It shows the significance of a review paper in this research filed. By constraining the investigation time of the Scopus database to the most recent 10 years it is found that there have been 252 publications which shows a dependable advancement in the number of publications. The nation insightful

investigation appears the USA drives the best 10 nations with 13.43% of the research publications. A portion of the developing countries like Algeria and India has published 16 articles each out of a sum of 138 papers which are distributed over the most recent 5 years. The investigation domains, specifically Engineering, Energy and material science have contributed 74.16% of the research publications.

A total of 3874 patents have been documented with 3074 of these being published in the last 11 years (2010–2020). This shows the scope of patentability of the document in this research field. The WoS database, though bringing out 92 publications in the period, shows comparable patterns over the measurements. The top-ten journal's title in this research area with their impact factor, CiteScore and publisher as per data extracted from WoS is tabulated in this paper. It also listed top-ten funding sponsors for the maximum publications of WoS. This paper completed a near investigation of the metrics in Scopus and Web of Science databases. Overall, the analysis describes the language, subject area, institutions, authors, funding agencies and academic journals in which the work has been published. As a potential approach, the author of this paper plans to further analyze the publications of other repositories in order to carry out an in-depth study of the various characterization methods used for accurate outdoor SPV output measurement and to recognize the main areas of research that need to be explored. It could be concluded that the SPV cells and their characterization would be the complement of solar power research in the twenty-first century.

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