Global Green Computing Research: A Scientometric Assessment of Publications Output during 2009-18

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Abstract

The paper examines green computing global research output on a series of quantitative and qualitative indicators, deriving publication data from Scopus international database. The global output on green computing consisted of 7335 publications during 10 years from 2009 to 2018, registering fastest 108.06% growth and low citation impact of 4.10 citations per paper. The paper presents a profile of top 10 most productive countries, 15 most productive organizations and 15 most productive authors on a series of indicators, including publications output, citations, citation impact, h-index, international collaborative papers and relative citation index in green computing research. The paper also identifies top 15 most productive journals and presents the bibliographical characteristics of top 27 highly cited papers in this area.

Keywords: Global green computing research, Scientometrics, Green computing, Citation impact, Relative citation index

1 Introduction

Green computing or IT is a synonym to environmentally sound Information Technology (Murugesan, 2008). It includes multiple aspects like environmental sustainability, energy efficiency economics, cost of disposal/recycling etc. When computing originated, some of the basic inputs like power, energy and other resources were considered infinite. However, with the issues of sustainability and climate change in the recent past, the effective usage of computers with limited resources is the need of the hour. Particularly, the concern of carbon emissions from the data servers is being raised worldwide as it is proportional to the energy usage (Weiss, 2007).

"Green" is not an entirely new concept in case of computing. Energy management always remained an important concern for laptop manufactures (Williams and Curtis, 2008) with regular issue of weight versus battery life. Green computing is the study and practice of using computing resources efficiently and that the main objective is to minimize the negative impact on environment. Green computing has a significant impact in green environment because modern societies are dependent on IT for works and operations, and that the production and disposal of computer wastes would directly poison our green environment (Chow and Chen, 2009). Two important perspectives of Green computing have been brought up by Hasbrouck and Woodruf (2008) namely, Minimize and Enable. The former deals with minimizing the operation cost, while latter enables reduced carbon footprints of technology.

It can be concluded that Green computing is utilizing computing resources more efficiently to decrease power consumption and reduce environmental impact. It transcends recycling and printing and covers technologies and methods like virtualization, power optimization and even telecommuting (Smallwood, 2008)

Over the years the environmental impact of IT got associated with sustainability and the term "Green" got associated with Computing/IT. The metrics changed from profitability to carbon emissions, footprints etc. Over the last two-three years Sustainability issues mostly deal with environmental impact and the "Green" word has become ubiquitous in IT Industry. However, an important concern here is that the issue of Green IT is getting deeper and complicated with plethora of Green Technologies and eco-friendly solutions (Krishnadas and Pillai, 2014).

2 Literature Review

Very few bibliometric studies are available on green computing and green IT. Amongst such studies, (Hemavathy, 2019) attempts to analyses the performance of Indian researcher working in the field of green computing (596 papers) during 1968-2012, with the objective of examining the growth, the bibliographic form-wise distribution of publications, subject-wise breakup of publications, authorship pattern and determine the degree of collaboration, country-wise collaboration research and institution wise research productivity. Tushi et. al (2019) reviewed of 98 papers published on green IT between 2007−2013 to facilitate future research and to provide a retrospective analysis of existing knowledge and gaps thereof. It provides an assessment of the status of information systems literature on green IT and also provides taxonomy of segments of green IT publications. Future research opportunities are identified based on the review. Sahu and Srivastava (2011) presented a literature review and classification scheme of green computing research. The results show that an increasing volume of green computing research has been conducted for a diverse range of areas. The papers or articles are classified and results of these

are presented, based on a scheme that consists of five main categories: techno logical issues, energy conservation strategies and practices, initiatives, e-waste and infrastructure. Nanth and Pillai (2014) tried to explain the concept of green IT and IS sustainability and broadly look at these two concepts from three dimensions: Business value (profitability, optimization, efficiency, etc.), negative impacts (power, energy, e-waste, etc) and a tool for permeating environment awareness (strategic alignment, motivations, blogs, etc). These dimensions reflect the various contexts where researchers have used green IT. The interconnections among these dimensions are reviewed and gaps identified to build upon future research directions.

However, other bibliometric studies are available in the area of computing, such as cloud computing (Gupta et. al, 2015), grid computing (Gupta et. al, 2018), mobile computing (Dhawan et. al, 2017), mobile cloud computing Gupta et l, 2017), parallel computing (Gupta and Dhawan, 2013), pervasive and ubiquitous computing (Dhawan et. al, 2017), quantum computing (Dhawan et. al, 2018), supercomputing (Dhawan et. al, 2018) and computing research in general (Gupta et. al, 2011; Gupta and Dhawan, 2017; Gupta et. al, 2010; Gupta et. al, 2011).

3 Objectives

The study is aimed at making a quantitative and qualitative assessment of global publications on green computing and its associated fields, as covered in Scopus database during 2009-18. The specific objectives are to study: growth and distribution of world literature, the bibliometric profile of the 10 most productive countries, 15 most productive organizations and 15 most productive authors; publication output by broad subject areas and its distribution and identification of important keywords, the medium of communications and the bibliographic characteristics of its highly cited publications.

4 Methodology

The world publications and publications of top 10 most productive countries in green computing derived were derived from Scopus database (http://www.scopus.com) using a keyword for the years 2009-2018. The “keyword” or “Article Title or “Source Title” tags (as shown in the search string below) were searched for the keywords “green computing” restricting the hit to the period 2009-18 in date range tag. The search string was then restricted to select individual countries by name in “country tag” to find top ten most productive countries output (including India) in green computing research. On further restricting main search string by “subject area tag”, “country tag”, “source title tag”, “journal title name” and “affiliation tag”, statistics on distribution of publications by subject, collaborating countries, author-wise,

organization-wise and journal-wise etc. were obtained. Citations data was obtained from the date of publication till 2 February 2019.

(KEY("Green computing") OR TITLE("Green computing")OR SRCTITLE("Green computing")) AND PUBYEAR > 2008 AND PUBYEAR < 2019

5 Data Analysis and Results

The green computing research output cumulated to a total of "7335 publications respectively in 10 years during 2009-18. The global annual output on green computing grew in volume from 42 in 2009 to 2290 publications respectively in 2018, registering 108.06% annual growth. The 5-years cumulative publication output in green computing grew from 1929 during 2009-13 to 5406 during 2014-18, registering 180.25% growth. The 10-year average citation impact of global research output in green computing was 4.10 citations per publication (CPP) during 2009-18, which decreased from 9.09 CPP during 2009-13 to 2.32 during 2014-18.Of the total global output in the field, 70.10% (5142) has appeared as conference papers, 21.12% (1549) as articles, 3.22% (236) as articles in press, 2.17% (159) as book chapters, 1.64% (120) as editorials, 0.94% (69) as reviews, 0.42% (31) as books and others including conference reviews (0.29%), notes and short surveys (0.04% each) and letters (0.03%) .

Table 1

Annual and cumulative world publication output on Green Computing research during 2010-18

Publication Period	World		
	TP	TC	CPP
2009	42	1640	39.05
2010	291	4496	15.45
2011	217	2556	11.78
2012	464	4135	8.91
2013	915	4714	5.15
2014	573	2472	4.31
2015	353	2107	5.97
2016	649	2450	3.78
2017	1541	3747	2.43
2018	2290	1791	0.78
2009-13	1929	17541	9.09
2014-18	5406	12567	2.32
2010-18	7335	30108	4.10
TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper			

5.1 Most Productive Countries in Green Computing Research

Although green computing research had originated in as many as 121 countries during 2009-18, but publication productivity by country of origin remained highly skewed. Fourteen countries alone

contributed 101 to 1743 papers each, compared to 14 others contributing 51 to 100 papers and 93 others publishing 1 to 50 papers each.

Top 10 most productive countries contributed 89.53% global publications share and accounted for more than 100.0% citations share during the period. Their global publication share in green computing research varied from 2.94% to 23.76%. China contributed the highest publication share (23.76%), followed by USA (19.51%), India (17.68%) and seven other countries (from 2.94% to 5.82%) during 2009-18. The 5-year absolute global publication share of India, U.K., Italy and Australia witnessed increase ranging from 0.34% to 7.67%, whereas in the case of China, USA, Japan, France, Germany and Canada, it declined from 0.11% to 9.82% during 2009-13 to 2014-18. Of the top 10 countries, five scored relative citation index above the group average of 1.13: Australia (2.50), Germany (1.85), USA (1.73), Canada (1.40) andItaly (1.29). India registered one of the lowest relative citation index score of 0.55.

Table 2

Global research output and publication share of top 10 most productive countries in green computing research during 2009-18

S.No	Country Name	Number of Papers			Share of Papers			TC	CPP	ICP	%ICP	RCI
		2009-13	2014-18	2009-18	2009-13	2014-18	2009-18	2009-18				
1	China	598	1145	1743	31.00	21.18	23.76	6519	3.74	560	32.13	0.91
2	USA	424	1007	1431	21.98	18.63	19.51	10161	7.10	549	38.36	1.73
3	India	232	1065	1297	12.03	19.70	17.68	2906	2.24	101	7.79	0.55
4	U.K.	83	344	427	4.30	6.36	5.82	1790	4.19	233	54.57	1.02
5	France	106	220	326	5.50	4.07	4.44	1083	3.32	158	48.47	0.81
6	Italy	69	250	319	3.58	4.62	4.35	1682	5.27	135	42.32	1.29
7	Japan	96	175	271	4.98	3.24	3.69	584	2.15	78	28.78	0.53
8	Germany	89	180	269	4.61	3.33	3.67	2041	7.59	101	37.55	1.85
9	Canada	72	196	268	3.73	3.63	3.65	1537	5.74	159	59.33	1.40
10	Australia	52	164	216	2.70	3.03	2.94	2211	10.24	138	63.89	2.50
	Total	1821	4746	6567	94.40	87.79	89.53	30514	4.65	2212	33.68	1.13
	World Total	1929	5406	7335				30108	4.10			
		598	1145	1743	31.00	21.18	23.76	6519				
*TC=Total citations; CPP=Citations Per Paper; ICP=International Collaborative Papers; RCI=Relative Citation Index												

5.2 Subject-Wise Distribution of Papers

The global research output on green computing research published during 2009-18 was classified under tenn broad subjects (as defined by Scopus). Computer science accounted for largest global publications share (84.25%) and business, accounting &management (1.45%) for the least. The research activities showed increase in publication activity in engineering, mathematics, energy, social sciences, physics & astronomy, materials science, decision science and business, accounting & management, as against decrease in computer science and environment science from 2009-13 to 2014-18 (Table 3).

Table 3

Subject-wise breakup of global publications on green computing research during 2009-18

S.No	Subject*	Number of Papers (TP)			Share of Papers		
		2009-13	2014-18	2009-18	2009-13	2014-18	2009-18
1	Computer Science	1778	4402	6180	92.17	81.43	84.25
2	Engineering	138	2357	2495	7.15	43.60	34.01
3	Mathematics	245	898	1143	12.70	16.61	15.58
4	Energy	28	560	588	1.45	10.36	8.02
5	Social Sciences	18	490	508	0.93	9.06	6.93
6	Physics & Astronomy	11	402	413	0.57	7.44	5.63
7	Environment Science	284	72	356	14.72	1.33	4.85
8	Materials Science	8	321	329	0.41	5.94	4.49
9	Decision Science	15	228	243	0.78	4.22	3.31
10	Business, Accounting & Management	14	92	106	0.73	1.70	1.45
	World Output	1929	5406	7335			
• There is overlapping of paper under various subjects							

5.3 Significant Keywords

In order to understand and compare the ongoing research trends in green computing and related research, top 60 most productive keywords were identified in terms of frequency of their occurrence in literature (Table 4).

Table 4

Significant keywords in global computing research during 2009-18

S.No	Keyword	Frequency	S.No	Keyword	Frequency
1	Green Computing	4941	31	Virtualization	214
2	Energy Efficiency	2277	32	Mobile Telecommunication System	207
3	Energy Utilization	2272	33	Energy Management	204
4	Cloud Computing	1145	34	Wireless Telecommunication Systems	197
5	Internet	1007	35	Virtual Reality	193
6	Electric Power Utilization	557	36	Data Handling	189
7	Energy Conservation	555	37	Learning Systems	170
8	Data Centers	553	38	Mobile Devices	168
9	Optimization	537	39	Resource Management	165
10	Distributed Computer Systems	479	40	Edge Computing	163
11	Scheduling	445	41	Neural Networks	152
12	Power Management	441	42	Small Power Grids	150
13	Network Security	385	43	Field Programming Gate Arrays	148
14	Digital Storage	382	44	High Performance Computing	142
15	Energy Consumption	371	45	Social Networks Online	142
16	Virtual Machines	366	46	Cloud Data Centers	133
17	Algorithms	315	47	Artificial Intelligence	131
18	Resource Allocation	307	48	Web Services	129
19	Computational Theory	299	49	Carbon Footprints	124

20	Computer Architecture	277	50	Cooling	124
21	Big Data	275	51	Application Programs	123
22	Network Architecture	263	52	Smart City	115
23	Information Management	263	53	Power Electronics	114
24	Scheduling Algorithms	256	54	Cluster Computing	113
25	Sustainable Development	254	55	Genetic Algorithms	112
26	Costs	242	56	Energy Policy	106
27	Embedded Systems	237	57	Fog	106
28	Wireless Sensor Networks	233	58	Cluster Algorithms	103
29	Hardware	232	59	Renewable Energy	120
30	Economic & Social Effects	213	60	Green IT	92

5.3 Contribution and Impact of Top 15 most Productive Global Organizations

Four Hundred Sixty Four organizations participated in global green computing research during 2009-18, but the level of their participation remained skewed. Of the 465 organizations, 176 contributed 1-5 papers each, 125 organizations 6-10 papers each, 70 organizations 11-20 papers each, 81 organizations 21-50, 11 organizations 51-100 paperseach and 1 organizations 109 papers each.

The 15 most productive organizations contributed 962 papers (13.12% share) and received 3653 citations (12.13% share) during 2009-18.

- Only five organizations registered productivity rate above the group average of 64.13: Beihang University, China (109 papers), Beijing University of Posts and Telecommunications, China (96 papers), Tsinghua University, China(82 papers), CNRS Centre National de la recherché Scientifique, France and andHuazhong University of Science & Technology, China (69 papers each):
- Seven organizations registered citation impact and relative citation index above the group average of 3.80 citations per paper and 0.93: Zhejiang University, China(7.17 and 1.75), University of Electronic Science & Technology of China, China (6.10 and 1.49), Tsinghua University, China (5.66 and 1.38), Huazhong University of Science & Technology, China (5.41and 1.32), INRIA Institut National de Recherche en Informatique et en Automatique, France (4.92 and 1.20), Beihang University, China (4.45 and 1.09) and Dalian University of Technology, China (4.44 and 1.08);
- Nine organizations registered international collaborative papers above the group average of 36.69%: Huazhong University of Science & Technology, China (52.17%0, Zhejiang University, China (48.94%), Tsinghua University, China (46.34%), Hosei university, Japan (44.90%), Dalian University of Technology, China (44.44%), University of Electronic Science & Technology of China, China (43.75%), Beijing University of Posts and Telecommunications, China (40.63%), Shanghai Jiao Tong University, China (39.29%) and CNRS Centre National de la recherché Scientifique, France (37.68%). (Table 5).

Table 5

Scientometric profile of top 15 most productive global organizations in green computing research during 2009-18

S.No	Name of the Organization	TP	TC	CPP	HI	ICP	%ICP	RCI
1	Beihang University, China	109	485	4.45	11	27	24.77	1.09
2	Beijing University of Posts and Telecommunications, China	96	235	2.45	7	39	40.63	0.60
3	Tsinghua University, China	82	464	5.66	11	38	46.34	1.38
4	CNRS Centre National de la recherché Scientifique, France	69	155	2.25	7	26	37.68	0.55
5	Huazhong University of Science & Technology, China	69	373	5.41	9	36	52.17	1.32
6	Dalian University of Technology, China	63	280	4.44	9	28	44.44	1.08
7	National University of Defense Technology, China	59	170	2.88	6	18	30.51	0.70
8	University of Chinese Academy of Sciences, China	59	220	3.73	6	14	23.73	0.91
9	Shanghai Jiao Tong University, China	56	178	3.18	9	22	39.29	0.78
10	Vellore Institute of technology, India	54	98	1.81	5	10	18.52	0.44
11	INRIA Institut National de Recherche en Informatique et en Automatique, France	51	251	4.92	9	18	35.29	1.20
12	Universiti Malaysia Perlis, Malaysia	51	47	0.92	3	11	21.57	0.22
13	Hosei university, Japan	49	67	1.37	5	22	44.90	0.33
14	University of Electronic Science & Technology of China, China	48	293	6.10	6	21	43.75	1.49
15	Zhejiang University, China	47	337	7.17	9	23	48.94	1.75
	Total of 15 organizations	962	3653	3.80	7.47	353	36.69	0.93
	Total of World	7335	30108	4.10				
	Share of top 15 organizations in World's total	13.12	12.13					

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; HI=h-index; ICP=International Collaborative Papers; RCI=Relative Citation Index

5.4 Contribution and Impact of top 15 most productive authors

Five Hundred Twenty One authors participated in global green computing research, but the level of their participation remained skewed. Of the 521 authors, 375 contributed 1-5 papers each, 130 authors 6-10 papers each, 27 authors 11-20 papers each and 9 authors 21-40 papers each.

The 15 most productive authors contributed 15 to 40 papers each, and together contributed 332 papers (4.53% share) and generated 2406 citations (7.99% share) during 2009-18.

- Eight authors registered productivity rate above the group average of 22.13: Yang, L.T (40 papers), Buyya, R (27 papers), Takizawa, M (26 papers), Khan, S.U. (25 papers), Ma, J. and Orgerie, A.C.(24 papers each), Enokido, T and Xia, F (23 papers each);

- Six authors registered citation impact and relative citation index above the group average of 7.25 citations per paper and 1.77: Khan, S.U (23.72 and 5.79), Zomaya, A.Y. (17.45 and 4.26), Buyya, R(13.59 and 3.32), Jin, H (11.87 and 2.89), Leung, VCM (10.06 and 2.45) and Li, K (7.53 and 1.84);
- Eight authors registered international collaborative papers (ICP) above the group average of 49.10%: Khan, S.U (92.0%), Yang, L.T. (90.0%), Ma, J. (87.50%), Leung, V.C.M. (82.35%), Zomaya, A.Y. (68.18%), Li, K. (63.16%), Buyya, R. (59.26%) and Xia, F. (52.17%).

Table 6

Scientific profile of top 15 most productive authors in global green computing research during 2009-18

S.No	Name of the Author	Affiliation of the Author	TP	TC	CPP	HI	ICP	%ICP	RCI
1	Yang, L.T	Saint Francis Xavier University, Canada	40	176	4.40	7	36	92.00	1.07
2	Buyya, R	University of Melbourne, Australia	27	367	13.59	8	16	90.00	3.32
3	Takizawa, M	Hosei university, Japan	26	64	2.46	4	0	87.50	0.60
4	Khan, S.U	North Dakota State University, USA	25	593	23.72	10	23	82.35	5.79
5	Ma,J	Hosei university, Japan	24	26	1.08	3	21	68.18	0.26
6	Orgerie, A.C.	Institut de Recherche en Informatique et Systemes, France	24	116	4.83	6	6	63.16	1.18
7	Enokido, T	Rissho University, Japan	23	41	1.78	3	0	59.26	0.43
8	Xia, F	Dalian University of Technology, China	23	138	6.00	7	12	52.17	1.46
9	Zomaya, A.Y	The University of Sydney, Australia	22	384	17.45	5	15	40.00	4.26
10	Li, K	State University of New York at New Paltz	19	143	7.53	7	12	25.00	1.84
11	Leung, VCM	The University of British Columbia, Canada	17	171	10.06	6	14	6.67	2.45
12	Syed, Idrus S.Z.	Universiti Malaysia Perlis, Malaysia	17	3	0.18	1	1	5.88	0.04
13	Dahham, O.S.	Universiti Malaysia Perlis, Malaysia	15	3	0.20	1	1	0.00	0.05
14	Hamzah, R	Universiti Malaysia Perlis, Malaysia	15	3	0.20	1	0	0.00	0.05
15	Jin, H	Huazhong University of Science & Technology, China	15	178	11.87	6	6	0.00	2.89
	Total		332	2406	7.25	5.0	163	49.10	1.77
	Total of the World		7335	30108	4.10				
	Share of 15 authors in World output		13.12	12.13					

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; HI=h-index; ICP=International Collaborative Papers; RCI=Relative Citation Index

5.5 Channels of Research Communication

Of the 73350 global publications on green computing, 66.43%(4873) appeared in conferences, 25.84% (1895) in journals, 4.83% (354) in book series, 2.45% (180) as books and 0.45% (33) as trade

publications during 209-18. The 1895 journal research papers appeared across 252 journals and found to be highly scattered across journals. For instance, 179 journals published 1-5 papers each, 41 journals 6-10 papers each, 20 journals 11-20 papers each, 11 journals 21-50 papers each and 1 journal 117 papers.The top 15 most productive journals in green computing research published 19 to 117 papers each and together contributed 554 papers (29.23% share of journals output) during 2009-18. The 5-year publication output reported in top 15 most productive journals decreased from 32.14% to 28.95% from 2009-13 to 2014-18. IEEE Access emerged as the topmost productive journal (with 117 papers), followed by Sustainable Computing Informatics & Systems(49 papers), IEEE Internet of Things Journal(46 papers), Journal of Supercomputing(39 papers), Future Generation Computer System (17 papers), IEEE Transaction on Cloud Computing(34 papers), Concurrency Computation (32 papers), etc. during 2009-18 (Table 7).

Table 7

Top 15 most productive journals reporting global output ingreen computing research during 2009-18

S.No	Name of the Journal	Number of Papers		
		2009-13	2014-18	2009-18
1	IEEE Access	0	117	117
2	Sustainable Computing Informatics & Systems	9	40	49
3	IEEE Internet of Things Journal	0	46	46
4	Journal of Supercomputing	8	33	41
5	Future Generation Computer System	5	34	39
6	IEEE Transaction on Cloud Computing	1	33	34
7	Concurrency Computation	0	32	32
8	IEEE Transactions on Parallel Distributed Systems	2	28	30
9	JisuanjiXuebao. Chinese Journal of Computers	20	10	30
10	Cluster Computing	4	25	29
11	IEEE Systems Journal	0	26	26
12	Energy	3	19	22
13	IEEE Transactions on Computer-Aided Design of Integrated Circuits & Systems	1	19	20
14	Sensors Switzerland	1	19	20
15	IEEE Transactions on Industrial Informatics	0	19	19
	Total of 15 Journals	54	500	554
	Total of World	168	1727	1895
	Share of 15 journals in World journal output	32.14	28.95	29.23

5.6 Highly Cited Papers

Of the total 7335 global publications in green computing, only 27 papers received 100 to 760 citations per paper, cumulating to 3636 citations, which averaged 134.67 citations per paper. The distribution of 27

highly cited papers by citations is skewed. Seventeen papers accumulated citations in the range 100 to 199 per paper, 7 papers in the citation range 200-399 and 3 papers in the citation range 491-760 citations.

- Of the 27 highly cited papers, 11 resulted from organizations participating in research in their stand-alone capacity (non-collaborative papers) and 16 from two or more organizations participating in their capacity as collaborators (7 national collaborative and 9 international collaborative papers);
- Among highly cited papers, the organizations from USA accounted for the largest participation (with 12 papers), followed by Australia and China (5 papers each), Italy (4 papers), Germany and Norway (2 papers each), Belgium, Canada, H. Kong, India, Qatar, New Zealand, Poland and U.K. (1 paper each);
- The 27 highly cited papers resulted from the participation of 103 authors from 55 organizations.
- Of the 27 highly cited papers, 18 were published as articles, 8 as conference papers and 1 as review;
- The 27 highly cited papers have been published in 17 journals, with 2 papers in Computer Networks and 1 paper each in Geophysics, Future Generation Computer Systems, IEEE Access, IEEE Network, IEEE Transactions on Computers, IEEE Communications Magazine, IEEE Communications Surveys and Tutorials, IEEE Signal Processing Magazine, IEEE Transactions on Parallel and Distributed Systems, IEEE Transactions on Signal and Information Processing over Networks, IEEE/ACM Transactions on Networking, Journal of Supercomputing, Nature Materials, Proceedings of the IEEE, Reviews of Modern Physics and Scientific Programming

6 Summary of Findings

This paper provides a scientometric assessment of global green computing research in terms of quantitative and qualitative indicators with a focus on top 10 most productive countries in the subject. The annual 10-year global output in green computing (7335 publications) during 2009-18 witnessed fastest growth 108.06%, but averaged slow citation impact of 4.10 citations per paper.

Of the 121 participating countries in global research on green computing, the top 10 most productive countries individually contributed 2.94% to 23.76% global publications share and cumulatively or jointly 89.53% and more than 100% global publications share and citations share respectively. The China is the world leader in the subject with highest publication share (23.76%), followed distantly by USA (19.51%), India(17.68%), etc. during the period. Five countries registered relative citation index above the group average of 1.13: Australia (2.50), Germany (1.85), USA (1.73), Canada (1.40) and Italy (1.29)

Computer science, among various subjects, is the most sought after subject in green computing research with its highest publications share (84.25%), followed by Engineering (34.01%), mathematics (15.58%), energy (8.02%), social sciences (8.93%), environment science (4.85%), etc. during 2009-18.

Of the 464 global organizations and 521 global authors that contributed to global green computing research, top 15 most productive global organizations and authors together contributed 13.12% and 4.53% global publication share and 12.13% and 7.99% global citation share respectively. The five leading leading organizations in terms of their research productivity wereBeihang University, China (109 papers), Beijing University of Posts and Telecommunications, China (96 papers), Tsinghua University, China (82 papers), CNRS Centre National de la recherché Scientifique, France and andHuazhong University of Science & Technology, China (69 papers each). The leading organizations in terms of citations per paper and relative citation index were: Zhejiang University, China (7.17 and 1.75), University of Electronic Science & Technology of China, China (6.10 and 1.49), Tsinghua University, China (5.66 and 1.38), Huazhong University of Science & Technology, China(5.41and 1.32), INRIA Institut National de Recherche en Informatique et en Automatique, France (4.92 and 1.20) during 2009-18.

IEEE Access was the most productive journal (with 117 papers) in globalgreen computing research, followed Sustainable Computing Informatics & Systems (49 papers), IEEE Internet of Things Journal (46 papers), Journal of Supercomputing (39 papers), Future Generation Computer System (17 papers), IEEE Transaction on Cloud Computing (34 papers), Concurrency Computation (32 papers), etc. during 2009-18. Among the 1895 journal papers (in 252 journals) in global greencoputing research, the top 15 most productive journals contributed 29.23% share of total journal publication output during 2009-18, which decreased from 32.14% to 28.95% from 2009-13 to 2014-18. Twenty Seven highly cited papers in the subject received 100 to 760 citations per paper since their publication during 2009-18. Jointly they registered 3636 citations and averaged 134.67 citations per paper.

7 Conclusion

The study reveals that though India ranks 3rdmost productive country in the world in global green computing research, it ranks at the bottom in terms of citation impact per paper (2.24) among top 10 countries. In view of the importance of green computing across various sectors of national economy, India needs to give priority to this sub-field among computer science research. It needs to focus more both in terms of quantity and quality of research in the subject.

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