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Global Tribology Research Output (1998 - 2012): A Macro Level Scientometric Study

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ABSTRACT

The aim of this study is to compare country output and citation impact as well as to assess the level of interdisciplinarity in the field of tribology research during the period 1998-2012, based on the SCOPUS database. Macro-level scientometric indicators such as growth rate, share of international collaborative papers, citation per paper, share of un-cited papers, and publication efficiency index were employed. Further, the Simpson Index of Diversity was used to measure the level of interdisciplinarity. The performance of top countries contributing more than 1000 papers during the study period was discussed. Contributions and share of continents and countries by income groups were examined. Further research contributions and citation impact of selected country groups were analyzed. This study reveals that high levels of interdisciplinarity exist in tribology research. Asia outperforms the other world regions and China contributes most of the papers (25%), while the United States receives most of the citations (22%).

Keywords: Bibliometrics, Tribology, Macro Level Study, Interdisciplinarity

1. INTRODUCTION

The word “tribology” was coined by Jost (1966) in a report as a composition of two Greek words, *tribos* and *logos*. Tribology is defined as the science and engineering of surface phenomena such as friction,

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wear, lubrication, adhesion, surface fatigue, and erosion (www.engineeringmaterials.org/tribology). It is multidisciplinary in nature, and includes mechanical engineering (especially machine elements such as journal and roller bearings and gears), materials science surface technology with surface topography analysis and coatings, and the chemistry of lubricants and additives (Mang, Bobzin, & Bartel, 2011). Tribological applications include improving car engines, hip joints and cosmetics, shrinking devices to micrometer and nanometer scales, and expanding the range of temperatures, speeds, and chemical environments where devices operate (http://www.grc.org/conferences.aspx?id=0000277). Apart from engineering applications, tribology can also be applied to products such as hair conditioners, lipsticks, and powders (http://www.jytra.com/blog/technical/what-is-industrial-tribology.html). Tribology remains as important today as it was in ancient times in the fields of physics, chemistry, mechanics, geology, biology, and engineering (Tocha, 2006). According to a report of the South African Institute of Tribology, tribology is the second most important property of matter after gravity. It is estimated that 20% of the power consumed in automobiles is used in overcoming friction while friction accounts for 10% of the power consumption in airplane piston engines and 1.5-2% in modern turbojets (Farris, 1997). The relatively younger sub-disciplines of tribology are: nanotribology (tribological phenomena occurring at sub-micron or smaller scales), biotribology (the tribology of the human body and other organisms), green tribology (science and technology of the tribological aspects of ecological balance and of environmental and biological impacts), and tribochemistry (the interaction of lubricants and lubricant additives with surfaces under tribological stress).

Scientometrics is referred to as a science about science; it is a distinct, recognized, and well-established scholarly field with its own identity, history, theories, and methodologies (Sorenko et al., 2009). Scientometric analysis is used very frequently for evaluating R&D activity and its impact on regions, countries, and institutions up to the level of individual scientists as well as the mapping of growths of scientific disciplines (UNESCO, 2001). According to Ivancheva (2008), worldwide scientometrics is becoming a more powerful instrument of science policy, determining to a great extent the way of a project and institutional funding by assessment of priorities, perspectives, and capacity.

1.1. Research Background

According to van Raan (2005), scientometric methods have been used in many disciplines of science and engineering to measure scientific progress. Scientometric indicators are useful to help scientists and decision makers to obtain valuable information (Jin & Rousseau, 2004). Bibliometric (or scientometric) studies can be classified into three levels: macro (countries, scientific disciplines), meso (research centers, university departments, scientific sub-disciplines), and micro (single papers, individual researchers) (Vinkler, 1988; Glänzel & Moed, 2002; Fiala, 2013). Macro-indicators, especially national science indicators, are standard tools in bibliometrics and provide a comprehensive picture of national research output in scientific fields (Moed, Glänzel, & Schmoch, 2004). Scientometric analyses performed at the macro-level (e.g. countries) yield at best general assessments of fields as a whole, for instance, the quality of a country's performance in physics, chemistry, psychology, or immunology (van Raan, 2003). Several macro level scientometric studies have been carried out in the past in various research fields (see a selection in Table 1).

Recently, Elango, Rajendran, and Manickaraj (2013) analyzed the tribology research output in BRIC countries (Brazil, Russia, India, and China), Elango, Rajendran, and Bornmann (2013) examined global nanotribology research output, and Rajendran, Elango, and Manickaraj (2014) analyzed India's contribution to world tribology research. As a final step in analyzing tribology research, publication output of countries and regions, and degree of interdisciplinarity, are analyzed in this study.

2. OBJECTIVES

The objective of this paper is to analyze scientific productivity and its citation impact in the field of tribology research as reflected in SCOPUS (Elsevier) during 1998-2012 using macro-level indicators by world region, level of income, and various country groups such as the Developing Eight Countries (D8), the Association of Southeast Asian Nations (ASEAN),

Table 1. Recent Macro Level Scientometric Studies

Author(s)	Research Area	Geographical Area
Patra & Chand (2009)	Library and Information Science	SAARC (South Asian Association for Regional Cooperation) and ASEAN (Association of Southeast Asian Nations)
Karpagam, Gopalakrishnan, & Ramesh Babu (2011)	Nanotechnology	G15 (Group of 15)*
Leta, Thijs, & Glänzel (2013)	Science	Brazil and Latin America
Sombatsompap et al. (2011)	Energy and Fuel	ASEAN (Association of Southeast Asian Nations)
Borsi & Schubert (2011)	Agricultural and Food Science	Europe
Wiysonge C. S. et al. (2013)	Childhood Immunization	Africa
Soterades et al. (2005)	Biomedical	World regions
Clarke et al. (2007)	Public Health	Europe
Tan, Goudarzlou, & Chakrabarty (2010)	Service Research	Asia
Asplund, Eriksson, & Persson (2012)	Human Stroke	World wide
Chinchilla-Rodriguez et al. (2012)	Medical research	Latin America and Caribbean
Plotnikova & Rake (2014)	Pharmaceutical research	Worldwide

*Composed of countries from Latin America, Asia, and Africa. Comprises 17 countries, although the name has not changed: Algeria, Argentina, Brazil, Chile, Egypt, India, Indonesia, Iran, Jamaica, Kenya, Malaysia, Mexico, Nigeria, Senegal, Sri Lanka, Venezuela, and Zimbabwe.

the Union of South American Nations (UNASUR), and the Emerging and Growth-Leading Economies (EAGLEs). Further, this study is designed to address the following questions: What are the top countries in this research field? What is the level of interdisciplinarity in this research field?

3. METHODOLOGY

3.1. Data Set

SCOPUS was used to retrieve the bibliographic records related to tribology research for the period of 15 years from 1998 to 2012. The following keywords were used in the combined fields of title, abstract, and keywords: **tribolog* OR "tribosyst*" OR "tribo-syst*" OR "tribo-chem*" OR "tribochem*" OR "tribotechn*" OR "tribo-physi*" OR "tribophysi*"* (Elango, Rajendran, & Bornmann, 2015). The search was carried out on 19 December 2013 and was refined to restrict the literature to articles, conference papers, and reviews (Carg et al., 2010). Self-citations have been included in the analyses, because self-citations are seen as an essential part of the scientific communication process (Glänzel, 2003; Leta, Thijs, & Glänzel, 2013). After removal of duplicate records, 27,952 articles were considered for the present study. The following procedures were adapted to count the author's country of origin: (i) only primary affiliation is considered, (ii) authors' professional associations are discarded, and (iii) the country of origin is verified with Google where it is not available. The fractional counting method was applied to give credit to all the contributing countries (Borsi & Schubert, 2011; Elango, Rajendran, & Bornmann, 2013).

3.2. Scientometric Indicators and Tools Employed

Growth Rate

Compound Annual Growth Rate (CAGR) is used to give an indication of yearly growth (Choi, Lee, & Sung, 2011):

$$CAGR = \left(\frac{End\ Value}{Beginning\ Value}\right)^{\frac{1}{n-1}} - 1$$

where n = number of years

Share of International Collaborative Papers

The Share of International Collaborative Papers (SICP) measures internationally co-authored publications in the national total as well as the strength of co-publication links between countries (Glänzel, 2000).

Citation Per Paper

Citation Per Paper (CPP) is obtained by dividing the total number of citations by the total number of papers.

Non-Citation Relative Rate

The Non-Citation Relative Rate (NCRR) is the quotient of the percentage of a country's non-cited papers and of all the countries. NCRR = 1 indicates that a country's uncitedness is equal to the world average; NCRR > 1 (NCRR < 1) indicates that a country's uncitedness is greater (lower) than the world average. NCRR = 0 indicates that a country's uncitedness is 0.

Publication Efficiency Index

Publication Efficiency Index (PEI) (Guan & Ma, 2007) is a measure of research quality and indicates whether the impact of publications in a country within a research field is compatible with the research efforts. The value of PEI>1 (PEI<1) for a country indicates that the impact of publications is more (less) than the research effort devoted to it by that particular country, and vice versa.

$$PEI = \frac{TNC_i / TNC_t}{TNP_i / TNP_t}$$

where TNC_i denotes the total number of citations of country i, TNC_t denotes the total number of citations of all countries, TNP_i denotes the total number of papers of country i, and TNP_t denotes the total number of papers of all countries

Simpson Index of Diversity

The multidisciplinary character of tribology can be measured on the basis of SCOPUS subject areas (Igami & Saka, 2007). SCOPUS classifies journal titles into 27 major subject areas, where a journal may belong to more than one subject area. The multidisciplinary nature of tribology research can be assessed by the distribution of the papers across different subject areas. We use the Simpson Index of Diversity to characterize this:

$$SID = 1 - \frac{\Sigma n\ (n-1)}{N\ (N-1)}$$

where n is the number of papers attributed to the i^{th} subject area and N is the total number of papers attributed to all subject areas. The value ranges between 0 and 1; the greater the SID, the greater the sample diversity.

4. DATA ANALYSIS

Table 2 provides a general overview over tribology research output for the period of 15 years from 1998 to 2012. 97.5% of the tribology research papers have country affiliation information for the authors (in SCOPUS). 7.94% annual publication growth was observed over the period.

General characteristics of tribology research from 1998 to 2012 are presented in Table 3: yearly output, CPP, and share of cited papers. A threefold increase was observed over the study period, (from 951 in 1998 to 2773 in 2012). The highest number of papers was published in the year 2011 with 3645, and the lowest in 1999 with 946.

Table 4 shows the comparison between international collaboration and national output. International collaborative papers received higher CPP than nationally collaborative papers. This result is in agreement with the result of many other studies (Glänzel, 2001).

Classification of countries by world regions is adopted from SCImago (www.scimagojr.com). Table 5 presents the contribution and share of the world regions.

Table 2. Summary Of Tribology Research Output During 1998-2012

Number of Papers	27952
CAGR	7.94%
Countries involved	108
Information about country of origin of authors available	27252 (97.5%)
International collaborative papers (%)	3789 (13.9%)
Citations received by all papers from time of publication to 19.12.2013	238563
Cited papers (%)	20684 (74%)
CPP	8.53
Citation per paper per year (CPPY)	1.45

Table 3. Yearly Output And Citation Impact 1998-2012

Year	TP	TC	CPP	%cited
1998	951	12580	13.23	68.24
1999	946	16026	16.94	81.18
2000	1017	16796	16.52	76.50
2001	1087	17190	15.81	75.53
2002	1144	13735	12.01	73.16
2003	1197	17642	14.74	79.78
2004	1467	19031	12.97	77.10
2005	1466	18627	12.71	79.81
2006	1502	17426	11.60	78.83
2007	1365	15082	11.05	80.88
2008	2223	16857	7.58	78.81
2009	3574	24236	6.78	78.76
2010	3595	17579	4.89	76.72
2011	3645	11484	3.15	69.79
2012	2773	4272	1.54	51.14

TP = Total Papers, TC = Total Citations, CPP = Citation Per Paper

Table 4. International vs. National Output

Type of Collaboration	TP	TC	CPP	%cited
International Collaboration	3789	44340	11.70	85.14
Single Country	23463	192598	8.21	73.38

TP = Total Papers, TC = Total Citations, CPP = Citation Per Paper

Almost 46% of world tribology research output was contributed by authors located in the Asiatic region followed by Western Europe, North America, and Eastern Europe. Africa had the lowest contribution among the world region even though the number of contributing countries is higher than for the Middle East. Publications from North America received the highest citations per paper (14.5) followed by Western Europe with 11.8 and the Middle East with 9.6.

The classification of countries by income group was obtained from the World Bank (http://data.worldbank.org). The distribution of tribology contributions by income group is presented in Table 6. It can be observed that there is a relationship between the income of a specific country and its research activity. Almost 95% of world publications are from countries of the high and upper middle income categories. This result is in agreement with earlier studies (Huffman et al., 2013; Al & Taskin, 2015). As expected, publications from high and lower income countries have the highest CPP. The lower income countries profit from larger proportions of papers with international collaboration: Out of the eight countries in the lower income group, five published all their papers with international collaboration.

Table 7 provides information about the publication patterns of the top 7 countries in the dataset, which published more than 1000 papers over the study period. Countries having more than 1000 publications in a research field are termed as highly productive countries (Kademani et al., 2013). Except for China and India, five countries belong to the G7 group (USA, UK, France, Germany, Italy, Canada, and Japan). This shows that the G7 nations are the leaders in tribology research. The seven countries in Table 7 together contributed 66.5% of the world output. This list of countries replicates the top countries contributing in materials science and technology (Adams & Pendlebury, 2011). Among the top countries, China contributed 25% of the total output, followed by the United States with 13% and Japan with 10.5%. India tops the list in the papers' growth rate with 19%. With growth rate greater than 8%, only India's and China's growth rates were higher than the world average. Among the top seven countries, five belong to the high income group.

According to the Royal Society's report in 2011, China will overtake the United States in Science in two years. In case of tribology research, China surpassed the United States in 2004 itself (Fig. 1) and continues to the world leader in terms of scientific production in this research field.

The citation impact of the top countries is provided in Table 8. The papers of these top countries received 66% of world citations. Among the top countries, contributions from the United States received 22% of world citations and contributions from India only 4%. However, India has the fourth highest CPP of 9.18. Contributions from the United Kingdom have the highest CPP of 15.17, and the lowest CPP applies to contributions from China and Japan. Except for China, the NCRR of all the top countries is lower than the world average of 1. The PEI values for China and Japan are lower than the world average of 1 because these countries publish articles in their regional languages such as Chinese and Japanese, which are not easily understood by the scientific community in the rest of the world.

Table 9 presents the most productive UNASUR (Union of South American Nations) countries from 1998 to 2012. Among the countries, Brazil contributed more than 1% of world publication output during the study period, followed by Colombia and Argentina. Only Ecuador received a higher CPP value than the world average of 8.53 (see Table 2). Except for Brazil

Table 5. Contribution by World Regions

Region	# Countries	TP	World Share	CPP	Leading Country
Asiatic Region	18	12424.16	45.59	6.10	China
Western Europe	21	6576.22	24.13	11.77	Germany
North America	2	3939.46	14.46	14.51	United States
Eastern Europe	22	2465.84	9.05	4.48	Russian Federation
Middle East	14	996.78	3.66	9.59	Turkey
Latin America	12	482.77	1.77	6.64	Brazil
Pacific Region	2	240.20	0.88	8.92	Australia
Africa	17	126.07	0.46	4.95	South Africa

TP = Total Papers, CPP = Citations Per Paper

Table 6. Contribution by Income Groups

Income Group	# Countries	TP	World Share	CPP
High Income	46	16233.79	59.57	10.88
Upper Middle Income	34	9516.74	34.92	5.13
Lower Middle Income	20	1477.48	5.42	7.63
Lower Income	8	23.49	0.09	10.17

TP = Total Papers, CPP = Citations Per Paper

Table 7. Contributions of Top Countries (>1000 papers)

Country	TP	World Share	#ICP	Growth Rate in %	Income Group
China	6759.27	24.80	719	15	Upper Middle
United States	3524.08	12.93	1098	3	High Income
Japan	2870.33	10.53	431	2	High Income
Germany	1631.28	5.99	594	6	High Income
United Kingdom	1195.58	4.39	578	7	High Income
India	1073.88	3.94	201	19	Lower Middle
France	1070.00	3.93	522	5	High Income

TP = Total Papers, ICP = International Collaborative Papers

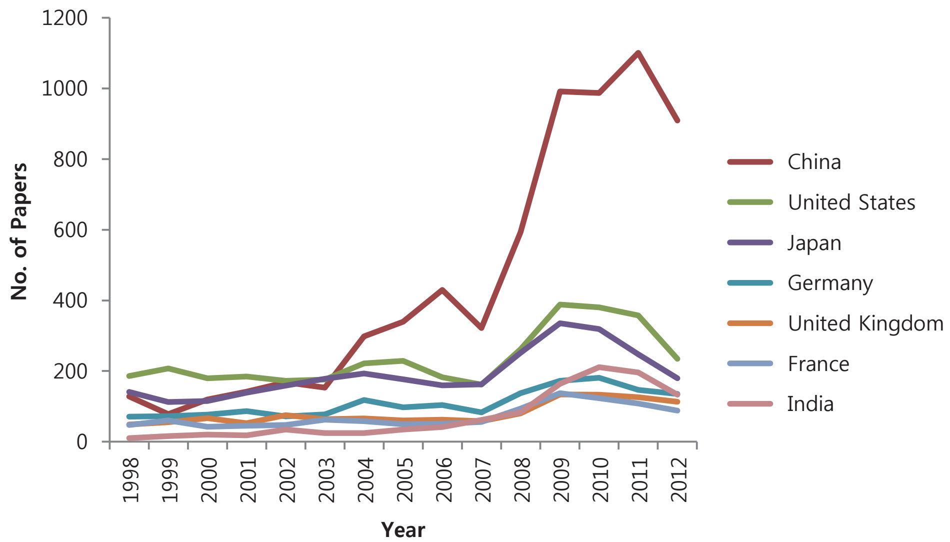

Fig. 1 Annual growth of publications of top seven countries

Table 8. Citation Impact of Top Countries (>1000 papers)

Country	TC	%TC	CPP	NCRR	PEI
China	34351.88	14.50	5.08	1.19	0.58
United States	52160.60	22.01	14.80	0.29	1.69
Japan	15174.52	6.40	5.29	0.66	0.60
Germany	14112.97	5.96	8.65	0.28	0.99
United Kingdom	18134.37	7.65	15.17	0.11	1.73
India	9854.38	4.16	9.18	0.11	1.05
France	12976.65	5.48	12.13	0.10	1.39

TC = Total Citations, CPP = Citation Per Paper, NCRR = Non Citation Relative Rate, PEI = Publication Efficiency Index

and Colombia, the NCRR of all this group of countries is lower than the world average of 1. PEI value is below the world average of 1 for all these countries except Ecuador, which published its article with international collaboration.

Table 10 shows the publication pattern of ASEAN (Association of Southeast Asian Nations) countries. Out of 10 ASEAN countries, only five countries engaged in the research field of tribology during the study period, and these five countries together contributed 1.56% of total world output. Singapore is the top ASEAN country with the highest publication share, and Thailand received the highest CPP. Among the ASEAN countries, Singapore and Thailand received a higher CPP than the world average of 8.53 (see Table 3). Vietnam contributed all its share of papers with

Table 9. Contribution and Impact of UNASUR Countries

Country	TP	World Share	CPP	%ICP	NCRR	PEI
Brazil	283.33	1.04	6.89	33.43	6.27	0.79
Colombia	42.67	0.16	6.17	60.94	1.14	0.70
Argentina	39.50	0.14	6.21	48.15	0.85	0.71
Venezuela	26.92	0.10	7.70	71.00	0.85	0.88
Chile	12.75	0.05	1.84	47.06	0.64	0.21
Ecuador	0.50	0.002	9.00	100.00	0.00	1.03
Total	405.67	1.49	6.65			

TP = Total Papers, CPP = Citation Per Paper, ICP = International Collaborative Papers, NCRR = Non Citation Relative Rate, PEI = Publication Efficiency Index

Table 10. Contribution and Impact of ASEAN Countries

Country	TP	World Share	CPP	%ICP	PEI	NCRR
Singapore	225.25	0.83	12.68	29.96	1.45	0.46
Malaysia	125.83	0.46	7.23	28.57	0.83	0.84
Thailand	64.27	0.24	14.20	33.33	1.62	0.35
Indonesia	6.00	0.02	9.25	90.91	1.06	0.35
Vietnam	2.33	0.01	5.94	100.00	0.68	0.77
Total	423.68	1.56	11.20			

TP = Total Papers, CPP = Citation Per Paper, ICP = International Collaborative Papers, PEI = Publication Efficiency Index, NCRR = Non Citation Relative Rate

international collaboration. All ASEAN countries had higher shares of international collaborative papers than the world average. All countries received lower NCRR than the world average.

All the countries of the D8 (Developing Eight) are engaged in tribology research (see Table 11). Among the D8 countries, Turkey and Iran contributed more than 1% of total world output and all the D8 countries together contributed 4% of total world output. Publications from Bangladesh received the highest citations per paper (11.2) followed by Pakistan with 9.5 and Indonesia with 9.25. Indonesia produced most of its papers in international collaboration, as did Pakistan and Bangladesh. Among the D8 countries, Egypt, Bangladesh, and Nigeria received a higher NCRR than the world average.

EAGLEs (Emerging and Growth-Leading Economies) countries together contributed 38% of the tribology output, where China is the leader followed by India, Russia, and South Korea (see table 12). Apart from Egypt, Mexico, and Indonesia, all D8 countries contributed more than 1% of the world's total output. The share of international collaborative papers for China and Taiwan is lower than the world average. Among the D8

Table 11. Contribution and Impact of D8 Countries

Country	TP	World Share	CPP	%ICP	PEI	NCRR
Turkey	407.45	1.68	7.02	17.41	0.80	0.77
Iran	283.17	1.16	5.60	18.27	0.64	0.80
Malaysia	125.83	0.57	7.23	28.57	0.83	0.84
Egypt	78.50	0.37	4.46	30.11	0.51	1.12
Bangladesh	16.83	0.10	11.17	52.17	1.28	1.00
Pakistan	16.00	0.10	9.47	76.92	1.08	0.74
Nigeria	13.50	0.06	1.33	20.00	0.15	2.31
Indonesia	6.00	0.05	9.25	90.91	1.06	0.35
Total	947.28	3.48	6.46			

TP = Total Papers, CPP = Citation Per Paper, ICP = International Collaborative Papers, PEI = Publication Efficiency Index, NCRR = Non Citation Relative Rate

Table 12. Contribution and Impact of EAGLEs Countries

Country	TP	World Share	CPP	%ICP	PEI	NCRR
China	6759.25	24.80	5.08	10.08	0.58	1.19
India	1073.88	3.94	9.18	17.05	1.05	0.65
Russia	680.03	2.50	3.73	23.23	0.43	1.84
South Korea	644.08	2.36	8.67	27.20	0.99	0.67
Taiwan	484.67	1.78	8.54	9.43	0.97	0.46
Turkey	407.45	1.50	7.02	17.41	0.80	0.77
Brazil	283.33	1.04	6.89	33.43	0.79	0.98
Egypt	78.50	0.29	4.46	30.11	0.51	1.12
Mexico	68.00	0.25	6.20	52.13	0.71	1.10
Indonesia	6.00	0.02	9.25	90.91	1.06	0.35
Total	10485.19	38.47	5.92			

TP = Total Papers, CPP = Citation Per Paper, ICP = International Collaborative Papers, PEI = Publication Efficiency Index, NCRR = Non Citation Relative Rate

countries, the share of non-cited papers for China, Russia, Egypt, and Mexico is higher than the world average.

Measurement of Interdisciplinarity

In this study, we use the Simpson Index of Diversity based on the number of SCOPUS subject areas to measure the level of interdisciplinarity in tribology research (Kalz & Specht, 2013). This index is commonly used for calculating biodiversity habitats in ecology. For example, the degree of interdisciplinarity has been assessed in the fields of forestry (Bojović et al., 2014) and cardiovascular systems (Leydesdorff & Opthof, 2013). The analyses of interdisciplinarity are based solely on those papers in the dataset of this study which are indexed under the main SCOPUS subject category Physical Sciences. Tribology research belongs to pure engineering and nearly all papers have been categorized in this main category.

The value of the Simpson Index of Diversity is calculated as 0.75, which shows the high level of interdisciplinarity in tribology research. Fig. 2 shows the different subject areas of the papers (through journals) in tribology research. It can be observed from Fig. 2 that all the papers in the dataset have been attributed to either Engineering or Materials Science along with other subject areas.

5. DISCUSSION & LIMITATIONS

We examined the world tribology research output across a 15 year period. Tribology research output has increased drastically over the 15 year period by a factor of three, from 951 in 1998 to 2773 in 2012. The number of countries engaged in tribology research also grew from 55 in 1998 to 85 in 2012. There were 108 countries involved in tribology research during this period. Tribology research work is dominated by the Asiatic region and high income countries. Similar results have been reported for related disciplines such as materials science (Kademani et al., 2013). There exists a high level of interdisciplinarity in the tribology papers. The share of international collaborative papers is 13.9%, which is lower than for other research fields such as stem cells (Luo & Matthews, 2013) with 21%. China contributed 25% of the world's total tribology research output during the study period, which is a higher share than in other research fields such as global positioning systems (Wang et al., 2013), stem cells (Luo & Matthews, 2013), and medicine (Gupta & Bala, 2011). In these fields, China's contribution was below 10%. Contributions by authors from North America had the highest impact and those from Eastern Europe the lowest.

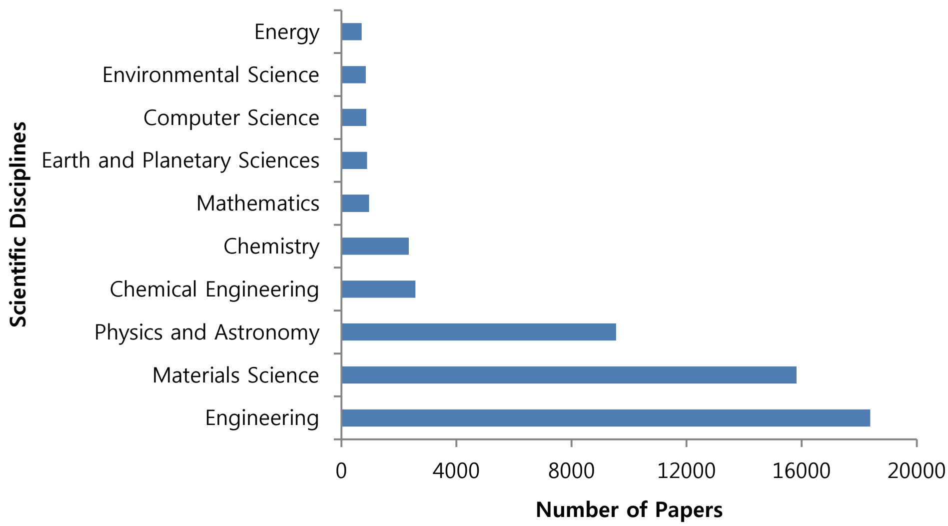

Fig. 2 SCOPUS Subject areas attributed by tribology research papers

There are two limitations of this study. First, growth rates have been calculated using CAGR, which is based entirely on the initial and final values. It takes no account of changes in-between. Second, the level of interdisciplinarity has been evaluated based on the subject classifications at journal level. Interdisciplinarity should actually be measured on the basis of individual papers.

The results of this study could provide help not only to the scientists and science policy makers in the field of tribology, but also to information managers. Future studies will be addressed the limitations of this study. Further studies such as research efforts given by countries in different sub-disciplines of tribology research and adjusted with GDP can be useful to monitor the research progress. Research collaborations of countries in this research field could be of interest which would be useful in finding research partner especially for scientists of under developed countries.

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