IOP Conf. Series: Materials Science and Engineering **724** (2020) 012012 doi:10.1088/1757-899X/724/1/012012

A bibliometric analysis of scientific research on tribology of composites in Southeastern Europe

Aleksandar Vencl[1,2], Nikolaos M Vaxevanidis[3] and Mara Kandeva[2,4]

[1] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120 Belgrade 35, Serbia
[2] South Ural State University, Lenin prospekt 76, 454080 Chelyabinsk, Russia
[3] School of Pedagogical and Technological Education, 14121 Athens, Greece
[4] Faculty of Industrial Technology, Technical University of Sofia, 8 Kliment Ohridski Blvd, 1000 Sofia, Bulgaria

E-mail: avencl@mas.bg.ac.rs

Abstract. In recent years there is a small but increasing number of articles presenting and/or analyzing the scientific production from discrete geographical regions on a certain scientific topic. These articles applied the so-called bibliometric methods in order to evaluate the contribution of different countries in a scientific research field. In the present work, the research output of all countries in Southeastern Europe on the scientific field of composites tribology is presented by using bibliometric indicators such as the total number of publications and citations, the average number of citations per publication, and the *h*-index. Analysis spans the last ten years and the required scientific data in order to calculate the bibliometric indicators were retrieved using the Scopus® scientific database.

1. Introduction

One of the definitions of bibliometrics say that it is the quantitative study of physically published units, or of bibliographic units, or of alternatives of either [1]. Bibliometric analysis uses the statistical methods to analyse books, articles, and other publications published in certain time period, and to measure the impact of the analysed subjects (research field/topic, particular paper/researcher, set of researchers, journal, institution/department, geographical region/country, etc.), through the defined bibliometric indicators. It is also a useful tool to obtain information on the state-of-the-art of research in particular topic, which helps the researchers to identify their research directions.

Composite material is a mixture of two or more materials or phases of the same material, insoluble in one another, possessing properties which are superior to any of the component materials. The use of different types of metal/ceramic/polymer matrix composites (MMCs/CMCs/PMCs) is constantly growing since they possess better physical and/or mechanical and/or tribological properties compared to the matrix materials. Better tribological properties are of great importance in all machines where parts are in contact and relative motions (tribological systems). The fact is that tribological properties define possible application of material far more than their mechanical or physical properties, since they are in better correlation with behaviour in practice [2].

This work presents the research output of all countries in Southeastern Europe (SEE) on the scientific field of composites tribology, in last ten years, by analysing bibliometric indicators such as the total number of publications and citations, the average number of citations per publication, and the

h-index. Similarly to our previous studies [3,4] the countries of SEE are defined geographically, as follows: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Montenegro, North Macedonia, Romania, Serbia, Slovenia and Turkey.

2. Methodology

Selecting the appropriate bibliometric indicators is very important for the reliable evaluation and presentation of the results in bibliometric analysis. It is also better to use a range of performance indicators than just one or two [5]. There are many different bibliometric indicators [6], but basically, there are three types: quantity indicators, which measure the productivity of a particular researcher or research group; performance indicators, which measure the quality of a publication, researcher or research group; and structural indicators, which measure connections between publications, authors and areas of research [7].

Indicators used in this study correspond to four research pillars: productivity (P: total number of publications on country level, in the given time-period); impact (C: total number of citations, excluding self-citations, on country level, in the given time-period); efficiency (C_{av}: average number of citations per publication, excluding self-citations, on country level, in the given time-period); and hybrid, i.e. productivity + impact (*h*-index, excluding self-citations, on country level, in the given time-period).

Productivity indicator, i.e. total number of publications on country level (P) is usually considered as a indicator for scientific size of a country, which of course is not the same as scientific strength of a country [8]. Total number of citations on country level (C), received by these P publications in the examined period, is another standard indicator which is considered as a indicator for scientific impact of a country. Average number of citations per publication on country level (C_{av}) is calculated as the ratio of total number of publications (P) and citations (C) in the given time-period, i.e. $C_{av} = C/P$. This indicator is used as an of efficiency indicator or as an impact index [8]. The *h*-index [9] is considered as a single indicator which combine productivity and impact indicators. The *h*-index on country level is calculated considering P and C of a country as the outcome of a single researcher. Characterization of certain number of publications (P) or citations per publication (C_{av}) as low or high, was performed with the field-based normalization method [8].

The required scientific data for each country, for the last ten years, necessary to calculate the bibliometric indicators were retrieved using the Scopus® scientific database. During search, document type was limited, i.e. only following types was counted: Article; Conference Paper; Book; Book Chapter; Review, while types such as: Erratum; Editorial; Conference Review; Retracted; etc. were not counted. For the co-authored publications the "whole counting" method was applied, i.e. every country gets full credit for internationally co-authored publications, and every co-author gets full credit for co-authored papers. There were no special corrections of the results except from some obvious errors, as well as more detail check-up of the most cited publications in the field of composites tribology (Table 3). The used keywords, as well as the hierarchical order in which they should be inserted in the searching machine in order to get the search results were as follows:

(TITLE (tribo***) OR KEY (tribo***) OR TITLE (friction) OR KEY (friction) OR TITLE (wear) OR KEY (wear) OR TITLE (lubrication) OR KEY (lubrication) AND TITLE (***composite*) OR KEY (***composite*) OR TITLE (*mc*) OR KEY (*mc*) AND AFFILCOUNTRY (each of SEE country)) AND PUBYEAR > 2008 AND PUBYEAR < 2019 AND (LIMIT-TO (PUBSTAGE, "final"))

where term: TITLE refer to the classification "Article title", KEY refer to the classification "Keywords", AFFILCOUNTRY refer to the classification "Affiliation country", PUBYEAR refer to the limit "Published year", and PUBSTAGE refer to the classification "Publication stage (final or article in press)".

The asterisk/s at the end or the beginning of some terms is used to overcome the underestimation resulting in by the use of different but equivalent terms, i.e. "tribology" or "tribological" or "tribocorrosion" or "tribosystem", etc.; "composite" or "composites" or "nanocomposite", etc.; "MMC" or "MMCs" or "CMC" or "PMCs", etc. The keywords selection used in study is actually the result of an optimization, based on large number of trials. All data presented in this work were collected on 20th June 2019 and involved scientific work and citations published until the end of 2018.

3. Results and discussion

3.1. Trends in publications

Results of the basic search for all countries in SEE on the scientific field of composites tribology is presented in Table 1. They are presented through the selected bibliometric indicators for the last decade (2009 – 2018). For comparison purposes, search for all countries in the World was also performed. First thing that can be noticed is that for Albania, Bosnia and Herzegovina, and Montenegro searches return zero results, whilst for North Macedonia output is one. For this reason, these countries are omitted from further analysis.

Table 1. Selected bibliometric indicators for the last decade.

Country	Number of publications (P)	Number of citations (C)	Number of citations per publication (C_{av})	*h*-index
Albania	0	0	–	0
Bosnia and Herzegovina	0	0	–	0
Bulgaria	42	223	5.31	6
Croatia	14	23	1.64	2
Greece	83	857	10.33	15
Montenegro	0	0	–	0
North Macedonia	1	0	0	0
Romania	183	505	2.76	12
Serbia	37	301	8.14	10
Slovenia	35	295	8.43	9
Turkey	508	3596	7.08	31
Word	18151	n/a	n/a	n/a

n/a – not available

By comparing the number of publications (P) in Table 1, it is evident that SEE countries account only 5 % of the literature on tribology of composites published worldwide. Turkey has the largest publication output of the SEE countries, i.e., 56.3 % of total publications, followed by Romania (20.3 %) and Greece (9.2 %). These three countries contribute more than 85 % of the total SEE production on the topic. The variation of publications with year for SEE countries is not discussed in details, due to space restrictions. In general, a non-monotonic increase was identified with the annual total of publications increasing from 50 (2009) to 111 (2018).

Total number of citations (C) which is obtained by the P publications is usually used as a indicator of the cited research impact, while the number of citations per publication (C_{av}) is considered as an index of the scientific research efficiency. From Table 1 it is clear that Turkey holds the highest C which is expectable since more than half of all SEE countries publications come from Turkey. Similarly to the number of publications distribution, Turkey (62.0 %), Greece (14.8 %) and Romania (8.7 %) contribute more than 85 % of the total SEE production on the topic. On the other hand, order of SEE countries is completely different when considering the number of citations per publication (C_{av}). Greece holds the highest index (C_{av} = 10.3) followed by Slovenia (C_{av} = 8.4), Serbia (C_{av} = 8.1) and Turkey (C_{av} = 7.1). Only these four countries are above the average value of 6.2 calculated for the whole region. It is also interesting that Romania have very low C_{av} value of 2.8, the second lowest of all analysed SEE countries, although it has relatively high production of the publications.

The *h*-index [9] was originally intended to combine in a single, hybrid, indicator a metric for quantity and impact of a researcher's scientific output, i.e. it was originally to evaluate individual researchers. Nevertheless, it may also be applied to research teams, faculties and faculty/university departments, journals, countries, etc. According to the obtained results (Table 1), the order of SEE countries according to the *h*-index is similar as the order according to the total number of citations (C), i.e. Turkey holds the highest *h*-index of 31 followed in descending order by Greece (15) and Romania (12).

Since there are no data available to reliably compare publication outputs to inputs in terms of number of researchers, publication output is usually compared to the size of the population in the different countries – although differences in population do not necessarily reflect differences in research efforts [10]. Much of the difference among SEE countries in publication output shown in Table 1 can be attributed to differences in country size, number and quality of researchers and investments in research, as well as to social-economic indicators.

3.2. Authorship characteristics

As it can be noticed from Table 1, the analysis is based on research output of approximately 900 publications (articles; conference papers, books and books chapters) indexed in Scopus® during the period 2009 – 2018. All these publications include at least one author listing an affiliation in one of the SEE countries. During search it was observed that the majority of publications are written by the authors employed at the universities and public research institutions associated with higher education organizations. Private research centers and industry seem to have very small contribution and participation. Moreover, as it is expected for a multi-disciplinary scientific topic such as tribology of composites, the vast majority of published articles have been co-authored. The most productive authors (with a threshold of $P \geq 5$) in the field of composites tribology, from each SEE country and worldwide (for compassion), are presented in Table 2. It should be noted that the P, C and *h*-index values for authors in Table 2 refer only to publications concerning "tribology of composites", so the overall output of an author might be much greater.

By comparing the number of publications of different authors (P) in Table 2, it is evident that the authors from SEE countries are much less productive that the most productive authors worldwide. The most productive authors in the field of composites tribology publish approximately 9 publications per year, which is quite impressive if they write all the publications. On the other hand, the difference between worldwide authors and SEE authors are not so obvious when considering the total number of citations per publication (C). The diversity of institutions of the most productive SEE authors is questionable, since in some cases all of the authors are from the same institution, e.g. Sakarya University in Turkey, or in other cases, there are not enough authors that pass the threshold ($P \geq 5$), e.g. Bulgaria and Croatia. It is also interesting that some authors have more publications than citations. This could be either due to the fact that the publications are published in the last year (2018) of the analysed period, and is not recognised as relevant literature yet, or that the publications do not have the potential to impact other researches.

The most cited publications in the field of composites tribology, from each SEE country and worldwide (for compassion), are presented in Table 3. Three publications at maximum from each country were included, with a limit that the publication received at least 10 citations ($C \geq 10$). It is very hard to compare different publications according to the citations they obtain, since they were not the same period of time available for citations, i.e. some of them was published in 2009 (or even in 2008 as on-line first) and some at the end of 2008. More appropriate criteria would be citation per year, but this data was not available for this analysis. As expected review papers usually get more citations. Another interesting aspect that was investigated is the "journal preference" [3,4], but due to space restrictions it was omitted from the final version of this paper.

3.3. International scientific collaborations

Nowadays there is an increasing international scientific collaboration in many disciplines [8]. Table 4 shows the international collaboration within the SEE counties and with other countries. For each SEE country the three countries with the highest number of common papers are presented. First thing that can be noticed is that the percentage of international publications is for all countries moderate, and mostly with non SEE countries. This can be observed when total number of publications obtained as a sum of each country publications (903) is compared with total number of publications without overlapping (889), since for the co-authored publications the "whole counting" method was applied, i.e. every country gets full credit for internationally co-authored publications. This means that 14 or less publications have co-authors from 2 or more SEE countries, i.e. less than 2 %. During search, it was also noticed that almost all (881) publications are written in English.

Table 2. The most productive authors in the field of composites tribology for the last decade.

Country (P/C)	Author	P*	C*	Affiliation
Bulgaria (42/223)	M. Kandeva	11	10	Technical University of Sofia, Faculty of Industrial Technology, Sofia
Greece (83/857)	C.A. Charitidis	10	228	National Technical University of Athens, School of Chemical Engineering, Athens
	G.D. Papadimitriou	8	89	National Technical University of Athens, School of Mining and Metallurgical Engineering, Athens
	E.P. Koumoulos	8	64	National Technical University of Athens, School of Chemical Engineering, Athens
	A.G. Lekatou	8	62	University of Ioannina, School of Engineering, Ioannina
	A.E. Karantzalis	8	61	University of Ioannina, School of Engineering, Ioannina
Romania (183/505)	M. Buciumeanu	16	93	"Dunărea de Jos" University of Galaţi, Faculty of Engineering, Galaţi
	G. Andrei	13	5	"Dunărea de Jos" University of Galaţi, Faculty of Engineering, Galaţi
	R. Căliman	11	1	Vasile Alecsandri University of Bacău, Faculty of Engineering, Bacău
Serbia (37/301)	B. Stojanović	15	94	University of Kragujevac, Faculty of Engineering, Kragujevac
	M. Babić	14	192	University of Kragujevac, Faculty of Engineering, Kragujevac
	A. Vencl	11	123	University of Belgrade, Faculty of Mechanical Engineering, Belgrade
Slovenia (35/295)	M. Kalin	7	130	University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana
	B. Podgornik	6	16	Institute of Metals and Technology Ljubljana, Ljubljana
	P. Panjan	5	49	Jožef Stefan Institute, Ljubljana
Turkey (508/3596)	H. Akbulut	26	405	Sakarya University, Faculty of Engineering, Adapazarı
	A. Mimaroğlu	22	98	Sakarya University, Faculty of Engineering, Adapazarı
	M. Uysal	18	224	Sakarya University, Faculty of Engineering, Adapazarı
	H. Ünal	18	91	Sakarya University, Faculty of Technology, Adapazarı
World (18151)	X. Shi	89	465	Wuhan University of Technology, School of Mechanical and Electronic Engineering, Wuhan, China
	W.M. Liu	87	779	Chinese Academy of Sciences, Lanzhou Institute of Chemical Physics, Lanzhou, China
	A. Patnaik	83	675	Malaviya National Institute of Technology Jaipur, Department of Mechanical Engineering, Jaipur, India

* P and C values for authors refer only to papers concerning "tribology of composites", so the overall output of an author might be much greater

Table 3. The most cited publications in the field of composites tribology for the last decade.

Country (P)	Authors and publication	C
Bulgaria (223)	Kelly P.J., Li H., Whitehead K.A., Verran J., Arnell R.D., Iordanova I., *A study of the antimicrobial and tribological properties of TiN/Ag nanocomposite coatings*, Surface and Coatings Technology, 204, 6-7, 2009, 1137-1140	83
	Kelly P.J., Li H., Benson P.S., Whitehead K.A., Verran J., Arnell R.D., Iordanova I., *Comparison of the tribological and antimicrobial properties of CrN/Ag, ZrN/Ag, TiN/Ag, and TiN/Cu nanocomposite coatings*, Surface and Coatings Technology, 205, 5, 2010, 1606-1610	83
	Xu D., Karger-Kocsis J., Apostolov A.A., *Hybrids from HNBR and in situ polymerizable cyclic butylene terephthalate (CBT): Structure and rolling wear properties*, European Polymer Journal, 45, 4, 2009, 1270-1281	14
Greece (857)	Charitidis C.A., *Nanomechanical and nanotribological properties of carbon-based thin films: A review*, International Journal of Refractory Metals and Hard Materials, 28, 1, 2010, 51-70	164
	Patnaik A., Satapathy A., Chand N., Barkoula N.M., Biswas S., *Solid particle erosion wear characteristics of fiber and particulate filled polymer composites: A review*, Wear, 268, 1-2, 2010, 249-263	85
	Lekatou A., Karantzalis A.E., Evangelou A., Gousia V., Kaptay G., Gácsi Z., Baumli P., Simon A., *Aluminium reinforced by WC and TiC nanoparticles (ex-situ) and aluminide particles (in-situ): Microstructure, wear and corrosion behaviour*, Materials & Design, 65, 2015, 1121-1135	45
Romania (505)	Benea L., Wenger F., Ponthiaux P., Celis J.P., *Tribocorrosion behaviour of Ni-SiC nano-structured composite coatings obtained by electrodeposition*, Wear, 266, 3-4, 2009, 398-405	41
	Benea L., Başaa S.-B., Dănăilă E., Caron N., Raquet O., Ponthiauxd P., Celis J.-P., *Fretting and wear behaviors of Ni/nano-WC composite coatings in dry and wet conditions*, Materials & Design, 65, 2015, 550-558	39
	Benea L., *Electrodeposition and tribocorrosion behaviour of ZrO_2-Ni composite coatings*, Journal of Applied Electrochemistry, 39, 10, 2009, 1671-1681	36
Serbia (301)	Vencl A., Bobic I., Arostegui S., Bobic B., Marinković A., Babić M., *Structural, mechanical and tribological properties of A356 aluminium alloy reinforced with Al_2O_3, SiC and SiC + graphite particles*, Journal of Alloys and Compounds, 506, 2, 2010, 631-639	68
	Mitrović S., Babić M., Stojanović B., Miloradović N., Pantić M., Džunić D., *Tribological potential of hybrid composites based on zinc and aluminium alloys reinforced with SiC and graphite particles*, Tribology in Industry, 34, 4, 2012, 177-185	27
	Babic M., Slobodan M., Džunic D., Jeremic B., Ilija B., *Tribological behavior of composites based on ZA-27 alloy reinforced with graphite particles*, Tribology Letters, 37, 2, 2010, 401-410	21
Slovenia (295)	Kalin M., Zalaznik M., Novak S., *Wear and friction behaviour of poly-ether-ether-ketone (PEEK) filled with graphene, WS_2 and CNT nanoparticles*, Wear, 332-333, 2015, 855-862	48
	Basu B., Kalin M., *Tribology of Ceramics and Composites: A Materials Science Perspective*, John Wiley & Sons, Hoboken, 2011	48
	Çalışkan H., Kurbanoğlu C., Panjan P., Čekada M., Kramar D., *Wear behavior and cutting performance of nanostructured hard coatings on cemented carbide cutting tools in hard milling*, Tribology International, 62, 2013, 215-222	37

Table 3. *Continued*.

Turkey (3596)	Gül H., Kılıç F., Aslan S., Alp A., Akbulut H., *Characteristics of electro-co-deposited Ni-Al_2O_3 nano-particle reinforced metal matrix composite (MMC) coatings*, Wear, 267, 5-8, 2009, 976-990	120
	Kurt A., Uygur I., Cete E., *Surface modification of aluminium by friction stir processing*, Journal of Materials Processing Technology, 211, 3, 2011, 313-317	72
	Gül H., Kılıç F., Uysal M., Aslan S., Alp A., Akbulut H., *Effect of particle concentration on the structure and tribological properties of submicron particle SiC reinforced Ni metal matrix composite (MMC) coatings produced by electrodeposition*, Applied Surface Science, 258, 10, 2012, 4260-4267	67
World (n/a)	Geetha M., Singh A.K., Asokamani R., Gogia A.K., *Ti based biomaterials, the ultimate choice for orthopaedic implants – A review*, Progress in Materials Science, 54, 3, 2009, 397-425	2081
	Ferracane J.L., Resin composite – State of the art, Dental Materials, 27, 1, 2011, 29-38	617
	Liu D., Tang Y., Cong W.L., *A review of mechanical drilling for composite laminates*, Composite Structures, 94, 4, 2012, 1265-1279	292

Table 4. Collaborations of SEE countries with other countries in the field of composites tribology.

Country (P)	Collaboration country* (P)		
Bulgaria (42)	United Kingdom (5)	Poland (4)	CZE (3) FRA (3) DEU (3) USA (3)
Croatia (14)	Slovenia (4)	CHN (1) CZE (1) FRA (1) USA (1)	
Greece (83)	Hungary (6)	United Kingdom (6)	DEU (5) ITA (5) USA (5)
Romania (183)	Portugal (17)	Germany (9)	BRA (8)
Serbia (37)	France (2)	Slovakia (2)	CHE (2)
Slovenia (35)	Croatia (5)	Turkey (3)	IND (2) ESP (2)
Turkey (508)	United States (20)	Iran (11)	GBR (10) DEU (10)

* name of the countries in the last column was abbreviated by the three letters UN codes

The share of internationally collaborative publications in the overall scientific output of a country can be considered as first indication of the extent to which researchers in a country cooperate with colleagues outside their own country. This indicator can be seen as a measure of the international orientation of a country. On the other hand, the share of non-internationally collaborative publications, is an indicator of the size of a country's own scientific basis and of its "scientific independence" [8].

4. Conclusions

Bibliometric indicators were used to describe the scientific activity in the field of composites tribology of in the 11 Southeastern Europe countries during the last decade. Based on the authors' knowledge,

this is the first article that analyse the quantity and quality of scientific research on this topic from this region. The research output is presented through bibliometric indicators such as the total number of publications and citations, the average number of citations per publication, and the *h*-index.

The total number of publications found in Scopus® between 2009 and 2018 is approximately 900, which is only 5 % of the literature on tribology of composites published worldwide. Turkey has the largest publication output of the SEE countries, i.e., 56.3 %, followed by Romania (20.3 %) and Greece (9.2 %). On the other hand, order of SEE countries is completely different when considering the scientific research efficiency i.e. the average number of citations per publication. Greece holds the highest number of citations per publication (10.3) followed by Slovenia (8.4), Serbia (8.1) and Turkey (7.1). Romania have very low number of citations per publication value (2.8), the second lowest of all analysed SEE countries, although it has relatively high production of the publications.

The majority of publications are written in English, and by the authors employed at the universities and public research institutions associated with higher education organizations. The diversity of institutions of the most productive SEE authors is questionable, since in some cases all of the authors are from the same institution. In addition, some authors have more publications than citations, which can be due to several reasons among which is that the publications do not have the potential to impact other researches. The percentage of international publications is for all SEE countries moderate, and mostly with non SEE countries (more than 98 %).

Acknowledgments
Aleksandar Vencl acknowledges the project TR 35021, supported by the Republic of Serbia, Ministry of Education, Science and Technological Development. Nikolaos M. Vaxevanidis acknowledges the funding program "Strengthening research of ASPETE faculty members", supported by the "Special Account for Research of ASPETE", Greece. Mara Kandeva acknowledges the project ДН 07/28-15.12.2016, funded by the National Science Fund at the Ministry of Education and Science, Bulgaria. Collaboration through the CEEPUS network CIII-BG-0703 is also acknowledged.

References

[1] Broadus R N 1987 Toward a definition of "Bibliometrics", *Scientometrics* **12** 373–9
[2] Vencl A 2012 Tribology of the Al-Si alloy based MMCs and their application in automotive industry, in: Magagnin L (Ed.) *Engineered Metal Matrix Composites: Forming Methods, Material Properties and Industrial Applications* (New York; Nova Science Publishers) pp 127–66
[3] Vaxevanidis N M, Vencl A and Psyllaki P 2015, Research on tribology in Southeastern Europe: A bibliometric study, *FME Transactions* **43** 259–68
[4] Vaxevanidis N M, Vencl A, Assenova E, Kandeva M and Psyllaki P 2019 Scientific literature on thermal spray coatings from Southeastern Europe: A ten years bibliometric analysis, *FME Transactions* **47** 649–57
[5] Martin B R 1996 The use of multiple indicators in the assessment of basic research, *Scientometrics* **36** 343–62
[6] Todeschini R and Baccini A 2016 *Handbook of Bibliometric Indicators: Quantitative Tools for Studying and Evaluating Research* (Weinheim; Wiley-VCH)
[7] Durieux V and Gevenois P A 2010 Bibliometric indicators: Quality measurements of sientific publication, *Radiology* **255** 342–51
[8] van Raan A F J, van Leeuwen T N and Calero-Medina C 2009 Performance of European science: research networks and profiles of EU countries in a global perspective, in: Delanghe H, Muldur U and Soete L (Eds.) *European Science and Technology Policy: Towards Integration or Fragmentation?* (Cheltenham: Edward Elgar Publishing) pp 256–90
[9] Hirsch J E 2005 An index to quantify an individual's scientific research output, *Proc. Natl. Acad. Sci. U.S.A.* **102** 16569–72
[10] dos Santos Rubem A P, de Moura A L and Soares de Mello J.C.C.B 2015 Comparative analysis of some individual bibliometric indices when applied to groups of researchers, *Scientometrics* **102** 1019–35