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Analysis of quantitative and qualitative indicators of SEE countries scientific output

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Abstract This paper provides a comprehensive comparative analysis of the South East European countries scientific output and impact by Frascati fields of science in the period of 2005–2010. The aim is to determine the volume of scientific output in the mentioned period, level of development of certain scientific fields in selected countries and quality of scientific publication production. SEE countries' scientific performance is examined on several indicators including total number of country publications per full time equivalent researcher, revealed publication advantage, the *h* index and top cited articles. Results of the study could be especially significant to the planners and policy-makers because they provide facts important for the long term S&T planning of the country.

Keywords Scientific productivity · Scientific publication impact · The *h* index · Revealed publication advantage

Introduction

Development of modern society largely depends on the application of scientific and technological research. It is particularly important to note that the economic power of a country depends on its success in the implementation of new scientific knowledge. There is

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a growing interest both in developed and some developing countries for reaching the important role of scientific research and development.

However, much of the available literature concentrates on measuring scientific output in order to give an overview of the global trends in the quantity and quality of scientific production. To eliminate the risk of poor assessment of scientific sector, it is necessary to use both qualitative and quantitative approach. Quantitative and qualitative approaches in scientometrics should be complementary in order to achieve a correct research evaluation (Coccia 2008).

Guapta and Dhawan (2009) compared the similarity of Indian research profile with top 20 productive countries. The study examined country performance on several measures including country publication share in the world research output, country publication share in various subjects in the national context and in the global context, share of international collaborative papers at the national level as well as across subjects and characteristics of high productivity institutions, scientists and cited papers etc. Horta and Veloso (2007) provided a comprehensive comparative analysis of the evolution of the EU15 and US scientific output and impact throughout the 1990s, looking at publications and impact trends by scientific field. Main conclusion was that the EU15 overcame the US in paper production and is catching up in visibility and impact, as measured by citations. EU15 improved their production in most scientific areas as well as their relative quality compared to the world average.

Crespi and Geuna (2008) using a sample of 14 countries investigated the profile of the time lag between investment in HERD (higher education research and development), research output and returns to national investment in science for a period of 21 years (1981–2002). The main conclusion was that there is a strongly positive long-run elasticity between Higher Education R&D and the research output.

There are numerous studies that measure scientific output of countries in specific areas of science. The aim of study written by Sanz-Casado et al. (2007) was to analyse and map the trends in research on prion diseases and determine the volume of scientific output in the period of 1973–2002. Significant growth is observed in scientific production since 1991 and particularly in the period 1996–2001. Moscone et al. (2013) tried to measure the impact of scientific research on health care from OECD countries. Data were gathered from the Scopus database. Main suggestion was that medical research plays an important role in explaining health care productivity although various countries are characterized by different velocities in assimilating scientific knowledge.

As research becomes increasingly globalized activity, there is a growing interest in international comparisons of scientific output and impact of scientific work in different countries and regions. Science mapping based on geography of science is a relatively new method used in scientometrics in order to show the centers of excellence in a particular region, continent or world level. Bornmann and Waltman (2011) used a geographic information system to produce density maps using computer programs that are freely available. That paper reveals regions of excellence around the world based on Scopus data, identifying field-specific excellence in broader regions where highly cited papers were published. A similar method was used by Bornmann et al. (2011). They presented regions and cities where recently highly cited papers were published using Google as visualization tool.

The purpose of this paper is to reveal the status of scientific research in different fields in the region of South Eastern Europe (SEE) based on most commonly used quantitative and qualitative scientific output indicators.

Methodology

This article investigates Southeast Europe countries in terms of structure and quality of their publication output in the period of 2005–2010. Although there are different opinions regarding South East Europe boundaries, in this study are selected 13 countries that completely or partially geographically belong to SEE and could be interesting for comparation in the field of scientific productivity. This is certainly the most diverse region in Europe, made up of countries with different historical, economical and political features. Integration and cooperation among these countries is full of challenges especially because some of them are members of EU, some are candidates and some are still in transition. Important part of SEE are Western Balkan countries which suffered changes in economic patterns, political boundaries and status in the last two decades. Regardless different stages of integration of the various countries, regional cooperation in SEE is essential because it will create stability and prosperity throughout the European continent.

Most of SEE economies are facing the challenge of catching up with the enlarged EU and the constitution of the European Research Area. Transition activities and political challenges have marginalized activities in science and technology field which resulted in erosion of R&D systems in the region. Many SEE countries still did not determine priorities in national and regional S&T strategies, nor ways in which science and innovation can stimulate socio-economic development.

Development of innovative economic structure is the most promising way for tackling various problems of SEE countries. Such a structure should be tightly coupled with R&D sector. Analysing scientific performance of the region, this study gives inputs for shaping research policies and regional cooperation.

The data for the study were obtained from the ISI Web of Science (WoS) database. The search criteria in WoS database were: address—SEE countries, year published—2005–2010, publication type—articles and reviews. Web of Science database classifies scientific papers in more than 250 categories, and hence it is impractical to present different countries and different scientific fields. Therefore, this database was used to generate classification of scientific fields according to the OECD methodology (Frascati Manual).

Among other fields of science (FOS) classifications the most widely adopted certainly is the one defined by OECD and well known as Frascati classification of fields of science (OECD 2007a, b). It has been revised several times since its appearance in 1963, the last version being defined in 2006. Frascati classification is different from both Scopus and Web of Science classifications. Frascati-like classification could be generated from WoS, but not from Scopus database.

The Frascati Manual has become the internationally recognized methodology for collecting and using R&D statistics and is an indispensable tool for statistical offices around the world (OECD 2002). It includes definitions of basic concepts, data collection guidelines, and classifications for compiling statistics. The Frascati Manual (FM) 2002 deals with the FOS classification in Chapter 4.4, par. 273–276. Table 3 contains the FOS classification itself. The FM recommends that the major fields of science and technology should be adopted as the functional fields of a science classification system. This classification should be used for the R&D expenditure of the government, higher education and PNP (Private Non-Profit) sectors—and if possible of the BE (Business enterprise) sector—and for personnel data in all sectors.

Frascati classification divides science in six major scientific fields and 42 subfields, so it is more convenient for achieving the objectives of this research. Method for converting categories from one database to another is given in the Appendix and it is based on the description of scientific fields in the OECD Frascati manual.

Quantitative and qualitative analysis were utilized to illustrate the patterns of scientific productivity in SEE countries. Various indicators were used in order to represent publications of the countries: (1) number of publications per full time equivalent researchers, (2) revealed publication advantage (RPA), (3) the *h* index, (4) top cited articles in 4 fields of science.

Analysis of quantitative indicators

Number and share of publications

Data in Table 1 show that in the 2005–2010 period total number of scientific papers in SEE countries (without country overlapping) incremented in all areas, and it increased from 51,427 in 2005 to 79,843 in 2010. The highest annual growth rate was in the fields Humanities (34.39 %) and Social Sciences (23.95 %). However, annual growth rate should be interpreted with caution because it does not take into account the absolute data. For example, number of publications in *Natural Sciences* for 5 years increased for about 10,000 and growth rate is 7.28 %, while in *Humanities* number of papers increased for about 1,500, and the growth rate is 34.39 %. On the other hand, annual growth rate in this limited set of data for the selected SEE countries could also be the result of the expansion of journal titles covered by the database. The largest number of papers was published in the fields *Natural Sciences*, *Engineering and Technology* and *Medical and Health Sciences* (these three fields together cover almost 90 % of the total productivity in all fields).

It is clear that the volume of the scientific output of a country is primarily influenced by the size of the country, i.e. by its population and number of employees dealing with research activities. On the other hand, higher scientific output certainly makes sound ground for the scientific impact which could be properly taken into account only by determining the quality of scientific performance.

In order to get measurable indicator for comparing the SEE countries, data on number of publications per country are normalized in relation to the number of researchers. Table 2 presents the number of publications per full-time equivalent (FTE) number of researchers. The second column shows the average number of researchers in the period 2005–2010. Eurostat statistics is used as a source of the data. Having in mind that Bosnia and Herzegovina and Albania do not have complete data for this period, for these two countries data are taken from the National Bureau of Statistics. According to normalized values, Greece has the largest number of papers per FTE researcher in this period with 4.05, followed by Slovenia with 3.49, Croatia 3.31 and Bosnia and Herzegovina 3.2.

If we look at the scientific productivity of the Frascati fields of sciences (Fig. 1), it can be concluded that the fields: *Natural Sciences*, *Engineering and Technologies* and *Medical and Health sciences* are more represented compared to the other fields of sciences in the SEE region. Greece and Slovenia have the highest number of publications per FTE researcher in the field of *Natural sciences*, with nearly 1.6 publications per FTE researcher. Slovenia has the highest number of publications per FTE researcher in the field of *Engineering and Technologies* with values over 0.8, and right after is Croatia with 0.72. Field of *Medical and Health Sciences* is the most productive in Bosnia and Herzegovina with over 1.4 papers per FTE researcher, followed by Greece and Turkey with the values of 1.27 and 1.05 respectively. The other three areas are less productive, but it is important to highlight

Table 1 Scientific publications in SEE countries from 2005–2010

Scientific fields	2005	2006	2007	2008	2009	2010	Annual growth rate %	Percentage share %
Natural sciences	2,1960	23,820	26,857	28,124	30,595	31,206	7.28	40.40
Engineering and technology	10,488	11,444	14,515	15,416	17,232	17,263	10.48	21.46
Medical and health sciences	14,627	15,709	17,978	20,075	20,708	21,426	7.93	27.47
Agricultural sciences	2,504	2,588	2,997	3,743	4,245	4,093	10.33	5.01
Social sciences	1,540	1,809	2,586	3,385	4,061	4,505	23.95	4.44
Humanities	308	341	687	1,076	1,149	1,350	34.39	1.22
Total	51,427	55,711	65,620	71,819	77,990	79,843	9.20	100

Table 2 Number of publications per FTE number of researchers

Country	Average number of researchers (FTE) from 2005–2010	Num. of papers from 2005–2010	Number of articles per FTE researcher from 2005–2010
Austria	32,458.33	83,934	2.59
Turkey	51,063.50	149,597	2.93
Hungary	18,454.33	43,406	2.35
Greece	20,171.33	81,673	4.05
Slovenia	6,590.17	22,982	3.49
Serbia	9,652.79	20,800	2.15
Croatia	6,394.33	21,186	3.31
Bulgaria	10,987.17	17,384	1.58
Romania	19,872.00	39,490	1.99
Macedonia	1,013.80	1,513	1.49
B&H	577.30	1,848	3.20
Montenegro	406.00	643	1.58
Albania	467.00	447	0.96

that Bosnia and Herzegovina and Croatia have slightly higher productivity compared to other countries in the field of *Social sciences*, while Slovenia has the highest number of papers per FTE researcher in the field of *Humanities* with the value of 0.1.

Revealed publication advantage

As a parameter to determine relative publication productivity profile, the RPA in analogy with Balassa's (1965) formula for the RPA has the following definition:

$$\mathrm{RPA}_{k,i} = 100 \times \tanh \ln \left(P_{k,i}/\Sigma i P_{k,i}\right)/\left(\Sigma k P_{k,i}/\Sigma k, i P_{k,i}\right)$$

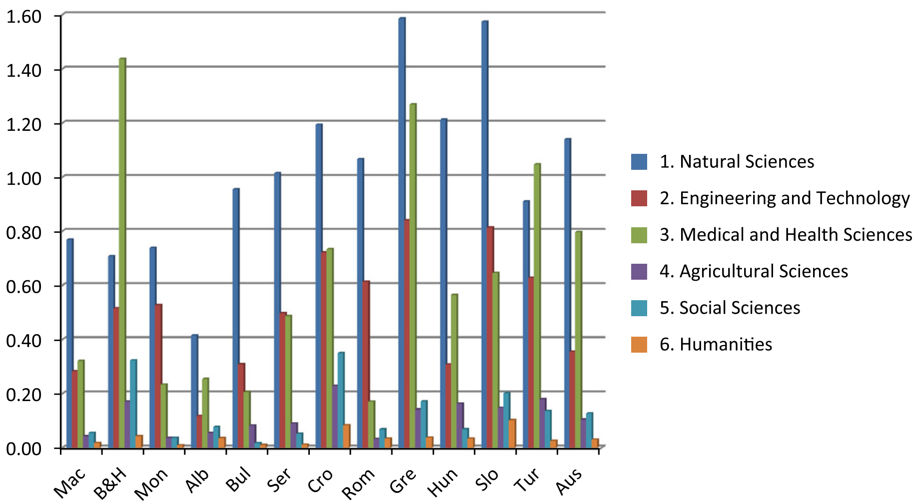

Fig. 1 Number of publications per FTE researcher in Frascati fields of sciences

with $P_{k,i}$ indicating the amount of publications of country k in the S&T field i. The logarithmic transformation centres the data around zero and the hyperbolic tangent multiplied by 100, limits the RPA values to a range of $+100$ to -100.

Positive values for S&T field i point to the fact that the field has a higher weight in the portfolio of the country than field's weight in the world (all publications from all countries taken together). Negative values indicate publication productivity of P below the average, respectively. Values around zero—negative as well as positive—are distinguished from a positive or negative productivity and labelled 'as expected' or 'world average' (Kutlaca et al. 2012).

The RPA indicator allows the assessment of the relative position of S&T field in a specific country, while eliminating size effects. The size of the field and the size of the country are standardized in this indicator, as relative shares are used. Therefore, it is possible to directly compare countries and fields. However, the standardization itself is highly affected by low absolute numbers, which means by random effects. Therefore, the profiles of countries with low absolute totals require careful interpretation.

RPA reflects the established research priorities of the SEE countries in science and technology. In order to show the similarities between the research profiles of individual countries, fields and subfields of the SEE countries are categorized into three groups depending on the RPA index:

- Most represented fields—RPA value is 0.3 or more,
- Least represented fields—RPA value in field is -0.3 or less,
- Commonly represented fields—RPA value between -0.3 and 0.3.

These groups are introduced using heat map coding in the Table 3 to mark "hot" and "cold" entries. RPA values for most represented fields are marked in green (four shades of this color), RPA values for least represented fields are marked in red (four shades of red) and RPA values for commonly represented fields are marked in light

Table 3 Subfields in which the SEE countries are most and least specialized

	Ser	Cro	B&H	Mac	Mon	Alb	Bul	Rom	Gre	Hun	Slo	Tur	Aus	SEE
1. Natural Sciences	0.13	-0.14	-0.56	0.21	0.12	0.05	0.36	0.25	-0.06	0.21	0.09	-0.28	0.06	-0.01
Mathematics	0.7	0.19	0.02	0.16	0.57	-0.34	0.34	0.79	0.05	0.52	0.5	-0.01	0.19	0.32
Computer and inf. sciences	0	-0.62	-0.62	-0.52	-0.24	-0.68	-0.31	0.11	0.5	0	0.32	-0.08	0.16	0.11
Physical sciences	0.11	-0.16	-0.58	0.19	0.42	-0.5	0.52	0.52	-0.1	0.23	0.14	-0.44	0.11	0.01
Chemical sciences	0.31	-0.08	-0.83	0.49	-0.54	-0.67	0.47	0.5	-0.23	0.25	0.17	-0.17	-0.23	0.01
Earth and rel env. sciences	-0.28	0	-0.28	0.47	-0.15	0.91	0.18	0.02	0.32	-0.14	-0.06	0.13	0.17	0.12
NS Biological sciences	-0.17	-0.17	-0.55	-0.08	0.21	-0.08	-0.08	-0.83	-0.26	0.23	-0.18	-0.53	0.13	-0.23
Other natural sciences	-0.16	-0.79	-0.5	0.14			0.96	-0.27	-0.54	-0.09	-0.68	-0.34	-0.1	-0.07
2. Engineering and Technology	0.25	0.2	-0.1	0.06	0.55	-0.35	0.09	0.5	0.15	-0.3	0.26	0.18	-0.25	0.12
Civil engineering	-0.43	0.65	-0.16	-0.38	0.05	0.22	-0.85	-0.39	0.45	-0.65	0.15	0.58	-0.42	0.24
Electrical, electronic, inf.	-0.11	-0.61	-0.5	0.4	0.92	-0.84	-0.54	0.02	0.37	-0.65	0	-0.21	-0.42	-0.14
Mechanical engineering	0.45	0.61	0.33	-0.56	0.82	-0.34	0	0.23	0.04	0.06	0.57	0.08	-0.17	0.14
Chemical engineering	0.68	-0.34	0.1	0.75	-0.3	-0.56	0.37	0.88	0.17	-0.18	-0.01	0.53	-0.74	0.36
Materials engineering	0.5	0.9	-0.43	0.44	-0.96	-0.91	0.59	0.52	-0.12	-0.16	0.73	0.36	-0.14	0.35
Medical engineering	0.64	0.8	0.37	0.35	-0.16	0.71	-0.17	-0.86	0.28	-0.19	-0.05	0.34	0.46	0.29
Environmental eng	-0.19	-0.3	-0.75	-0.07	-0.65	-0.57	-0.04	-0.65	0.47	-0.72	-0.07	0.61	-0.29	0.23
Industrial Biotechnology	-0.07	-0.9	-0.32	-0.49	-0.36	0.59	0.32	-0.09	-0.47	-0.81	-0.67	0.08	-0.45	-0.25
Nano-technology	-0.46	-0.93	-0.99	-0.64	-0.63		-0.22	-0.22	-0.1	-0.37	-0.44	-0.71	-0.04	-0.39
Other engineering & tech.	0.34	0.02	0.15	-0.21	0.22	-0.03	0.31	0.73	-0.04	-0.15	0.31	0.08	-0.16	0.14
3. Medical and Health Sciences	-0.19	-0.21	0.46	-0.23	-0.55	-0.03	-0.63	-0.82	0.14	-0.13	-0.37	0.26	0.16	0.03
Basic medicine	-0.23	-0.28	-0.59	-0.36	-0.82	-0.49	-0.29	-0.86	-0.22	0.32	-0.45	-0.2	0.04	-0.17
Clinical medicine	-0.08	-0.13	0.53	-0.18	-0.46	-0.07	-0.78	-0.83	0.29	-0.28	-0.35	0.5	0.31	0.2
Health sciences	-0.59	-0.34	-0.34	-0.36	-0.34	0.59	-0.67	-0.88	0	-0.56	-0.46	-0.43	-0.43	-0.41
Medical biotechnology	-0.4	-0.87	-0.74	-0.19	-0.53	-0.22	-0.32	-0.6	0.02	-0.77	0.2	-0.24	0.26	-0.17
Other medical sciences	-0.12	-0.03	0.98	0.09	-0.55	-0.24	-0.66	-0.21	0.13	-0.19	-0.14	0.21	0.11	0.09
4. Agricultural Sciences	0.04	0.49	0.27	-0.32	-0.5	0.35	0.25	-0.73	-0.14	0.5	0.05	0.4	0	0.18
Agricult, forestry, fisheries	0.21	0.71	0.65	0.01	-0.51	0.68	0.22	-0.86	0,15	0.72	0.14	0.29	-0.09	0.25
Animal and dairy science	-0.67	0.72	0.31	-0.59	-0.73	0.78	-0.8	-1	-0.26	0.23	0.07	0.27	-0.27	-0.02
Veterinary science	0.42	0.54	0.17	-0.27	0.34	0.25	-0.1	-0.97	-0.46	0.68	-0.05	0.77	0.32	0.46
Agricultural biotechnology	-0.33	-0.26	-0.48	-0.69	-0.97		0.55	-0.21	-0.24	-0.29	0.01	0	-0.07	-0.09
Other agricultural sciences	-0.97	-0.88		0.52		0.99	-0.83	-0.99	-0.31	-0.37	-0.34	-0.73	-0.85	-0.68
5. Social Sciences	-0.78	0.4	0.37	-0.54	-0.79	0.15	-0.94	-0.6	-0.45	-0.69	-0.17	-0.37	-0.32	-0.4
Psychology	-0.67	-0.68	-0.71	-0.35		-0.24	-0.95	-0.92	-0.65	-0.75	-0.88	-0.73	-0.36	-069
Economics and business	-0.76	-0.69	-0.5	-0.67	-0.78	-0.6	-0.89	0.06	-0.05	-0.52	-0.08	-0.11	-0.02	-0.18
Educational sciences	-0.58	-0.27	-0.3	0.01	-0.87	0.39	-0.98	-0.96	-0.34	-0.85	0.55	0.49	-0.92	-0.14
Sociology	-0.66	0,98	0.97	-0.69	0.01	0.69	-0.93	-0.78	-0.79	-0.72	0.31	-0.8	-0.63	-0.11
Law	-0.9	-0.95	0.26		-0.64		-1	-0.99	-0.95	-0.97	-0.06	-0.98	-0.81	-0.92
Political Science	-0.96	-0.97	-0.53	-0.37	-0.04	0.31	-0.98	-0.47	-0.85	-0.25	-0.56	-0.57	-0.25	-0.59
Social and economic geo	-0.94	-0.96	-0.59	-0.44		0.63	-0.98	-0.97	-0.19	-0.88	0.38	-0.54	-0.19	-0.5
Media & communications		0.68						-0.98	-1		-0.99	-0.97	-0.96	-0.94
Other social sciences	-0.91	-0.9	-0.76	-0.77	-0.91	0.65	-0.9	-0.38	-0.28	-0.75	-0.63	-0.18	-0.08	-0.36
6. Humanities	-0.91	0.01	-0.54	-0.59	-0.88	0.4	-0.86	-0.35	-0.75	-0.49	0.16	-0.78	-0.64	-0.62
History and archaeology	-0.91	-0.19	-0.97	-0.66	-0.33	0.89	-0.24	0.03	-0.34	-0.31	0.08	-0.6	-0.56	-0.41
Languages and literature	-0.9	-0.01	-0.29	-0.6		-0.17	-0.97	-0.82	-0.86	-0.3	0.31	-0.93	-0.72	-0.73
Philosophy, ethics, religion	-0.85	0.47	-0.3	-0.8	-0.57	-0.27	-0.84	0.46	-0.89	-0.72	-0.19	-0.91	-0.68	-0.61
Art (arts, performing, music)	-0.88	-0.07	-0.6	-0.72		0.62	-0.98	-0.99	-0.78	-0.66	-0.12	-0.45	-0.18	-0.55
Other humanities	-0.99	-0.87	-0.81	-0.02		-0.39	-0.95	-0.98	-0.66	-0.61	0.48	-0.54	-0.85	-0.66

Legend: RPA level of specialisation

-1 to -0.8	-0.79 to -0.6	-0.59 to -0.45	-0.44 to -0.3	-0.29 to -0.11	-0.1 to 0	0 to 0.1	0.11 to 0.29	0.3 to 0.44	0.45 to 0.59	0.6 to 0.79	0.8 to 1
extremely low specialized	very low specialised	highly low specialised	low specialised	below world average	world average	world average	above world average	specialised	highly specialised	very specialised	extremely specialised

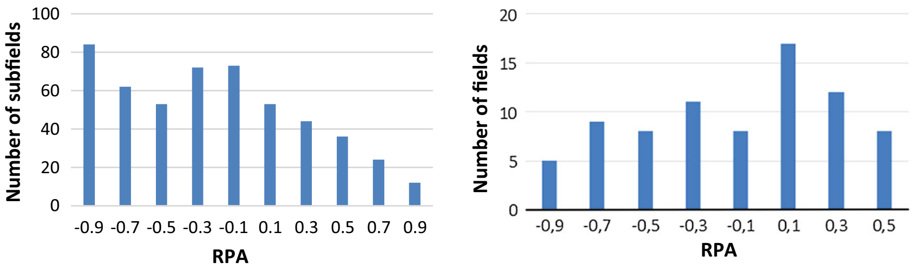

Fig. 2 Distribution of RPA values in scientific subfields (*left*) and fields (*right*)

green (two shades) and light red (two shades). Detailed scale for each color is given in the table legend.

From the Table 3, we conclude that the fields mostly represented in particular countries are *Engineering and Technology* (Montenegro, Romania), *Agricultural Sciences* (Croatia, Albania, Hungary and Turkey), *Natural Sciences* (Bulgaria), *Medical and Health Sciences* (Bosnia and Herzegovina), *Social Sciences* (Croatia and Bosnia and Herzegovina) and *Humanities* (Albania).

Fields of science that are least represented in South East Europe (in almost all countries) are *Social Sciences* and *Humanities*, while *Medical and Health Sciences* are least represented in four countries (Montenegro, Bulgaria, Romania and Slovenia).

Reviewing Frascati subfields within each field, we can conclude that in the field of *Natural Sciences*, *Mathematics* is area of particular competence and scientific interest of South East European countries with positive values of RPA in all countries except Albania and Turkey, the least productive subfield is *Biological sciences*. In the field of *Engineering and Technology*, the subfield with most common positive RPA values is the *Mechanical Engineering*; the least represented area is *Environmental Engineering*. *Medical and Health sciences* is a bit sporadically present in most SEE countries and the least represented subfield is *Medical Biotechnology*. In *Agricultural sciences*, *Agriculture, forestry and fisheries*, is the most represented subfield. The field of *Humanities* and *Social Sciences* is not represented in most countries except Croatia and Bosnia and Herzegovina, which have a very large number of publications in the field of *Sociology*. The distribution of RPA according to its value is presented in Fig. 2 for the scientific subfields and fields. The distribution shows that the productivity in majority of subfields (two-thirds) is below world average, while only one-third is above. The distribution of the RPA for the scientific fields has more likely visual distribution shape with 47 % values above and 53 % values below world average. The obvious reason for such performance is under average productivity in many subfields with low publication output which to much lesser extent contribute to the RPA of the fields compared to the subfields with higher publication output.

Previous two sections are based on two indicators: the number of publications per FTE researcher and RPA which present the scientific productivity of SEE countries. These indicators are quantitative and do not measure importance or impact of papers, so the following section will focus on the qualitative indicators in order to get a clear picture of the scientific production of the SEE countries.

Analysis of qualitative indicators

The *h* index

In order to obtain a quantitative analysis of papers published by authors from SEE countries, we used the *h* index instead of the total number of citations. The *h* index usually has advantage over total number of citations because the total number of citations does not give a clear picture of the impact, since it is ambiguously influenced by a small number of papers with a high number of citations or by high number of papers with no citations.

The *h* index is an indicator that simultaneously takes into account both the scientific productivity of researchers, fields of science, institutions, countries measured by the number of published papers, and impact effects measured by number of citations of papers.

A scientist has index *h* if *h* of his/her Np papers have at least *h* citations each, and the other (Np − h) papers have no more than *h* citations each (Hirsch 2005). Since its introduction it many times proved to be an effective and sometimes irreplaceable indicator for measuring not only the scientific impact of scientist but also of research groups, institutes, journals, countries etc.

Considering that the *h* index gives more objective results than other indicators (impact factor, the total number of documents, the total number of citations, number of highly cited papers), it has a significant role in the decision making process. Calculating the *h* index is relatively easy and can be obtained by anyone with access to the Thomson ISI Web of Science.

The *h* index cannot be used for comparing different fields, so in this paper we are comparing SEE countries by field of science. The *h* index is time-dependent; it is incorrect to compare publications published in different time periods.

One of the disadvantages of the *h* index is that it does not take into account the highly cited papers, once it meets the number required for the *h* index, it is no longer taken into account. This deficiency is solved by the *g* index (Egghe 2006), but in this paper another additional analysis has been used to measure a number of highly cited papers for each country.

Self-citations can increase the *h* index and there are different opinions among researchers if it should be removed or not, but their effect on the *h* index is much smaller than on the total citation count since only self-citations within a number of citations just above the *h* index are relevant (Hirsch, 2005).

Figure 3 shows the value of the *h* index for the SEE countries for Frascati scientific fields of science and its subfields. The main goal is to see which countries in the region are the leaders in publishing papers in scientific fields according to the criteria of the *h* index. On the graph representing *Natural sciences* we can see that Austria is leading country in all subfields, followed by Greece, Hungary and Turkey. Serbia has the largest *h* index in mathematics although it has up to three times fewer published papers in this subfield comparing to Turkey, Greece and Hungary. In the field of *Engineering and Technology*, Turkey and Greece have distinctly higher value of the *h* index in comparison to other countries. Austria has highest *h* index in *Nanotechnology*, *Medical engineering* and *other engineering and technologies* subfields. Slovenia is ranked the best in comparison to rest of the countries with high values of the *h* index in the field of *Materials Engineering*. In the field of *Medical and Health Sciences*, *Clinical Medicine* subfield is the most interesting for the analysis since it has the highest values of the *h* index in relation to other subfields. Austria with the *h* index of 146 is the leading country in this field, followed by Greece with the *h* index of 115, Hungary 92 and Turkey 85. In the field of *Agricultural Sciences*,

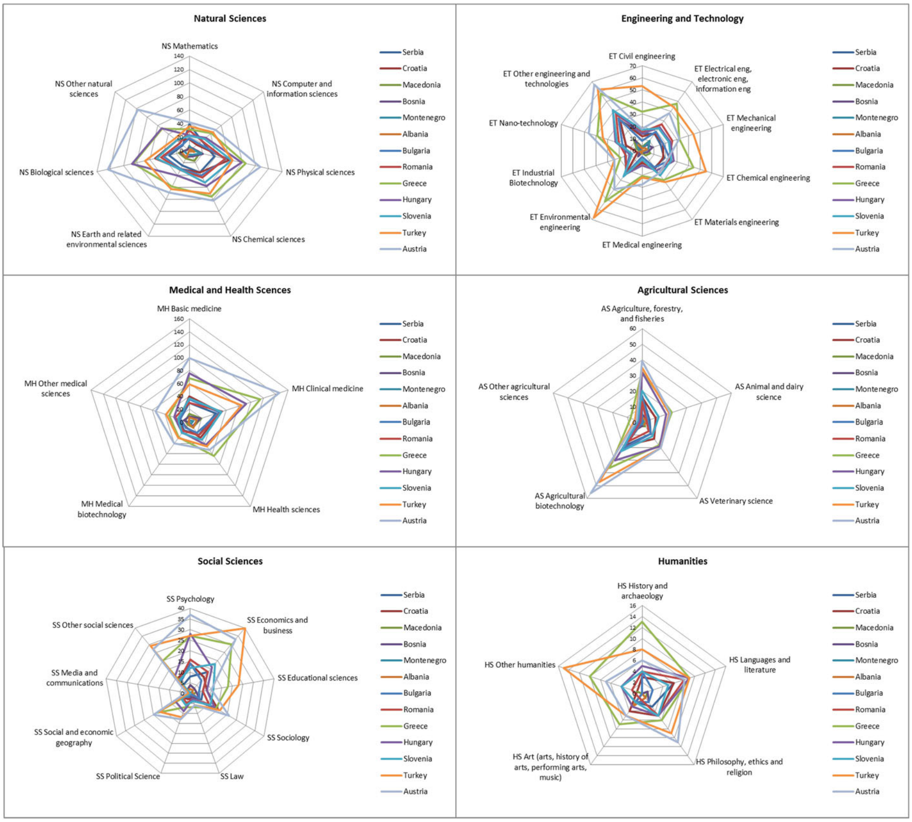

Fig. 3 The h index of SEE countries for Frascati scientific fields and subfields

Austria is the leading country in the subfield *Agricultural Biotechnology* with the *h* index of 56. In other subfields, Austria, Turkey, Greece and Hungary have approximately equal the *h* index, which is significantly higher than the other SEE countries. In the field of *Social Sciences* and *Humanities* the *h* index values in many subfields are too small and therefore not relevant for further analysis. However, Turkey has the *h* index of 40 in *Economics and Business* subfield which is valuable result if the values of the *h* index of other countries in this field are taken into account.

Top cited articles: the 1 % most highly cited papers

One of the disadvantages of the *h* index is that it does not take into account highly cited papers, once it meets the number required for the *h* index. As a consequence, there is no direct comparison between the impact of papers from different countries encompassed by their individual *h* indices. Therefore, in this section, the focus is on the most influential papers published by the authors from the SEE countries in the period 2005–2010. The main objective is to overcome the lack of the *h* index and gain a complete picture of the quality of published papers by authors from SEE countries.

In the scientific literature there is a debate about which percentage of the papers should be considered as a highly cited among one field. According to National Science Board (2010) highly cited papers are those that are included in the top 1 %.

Four fields of science were examined. *Social Sciences* and *Humanities* were not included in the analysis because of a very low productivity of SEE countries in these fields.

The procedure starts with a search for all papers published by the authors from the SEE countries within one field (4 fields based on Frascati FOS). After sorting the search results by citation counts in decreasing order, the 1 % of papers at the top of such sorted WoS list were marked and downloaded. Using the procedure described we got the following number of papers:

- Agricultural sciences: 416 papers which received at least 52 citations.
- Medical and health sciences: 3,431 papers, >50 citations.
- Engineering and technology: 1,113 papers, >79 citations.
- Natural sciences: 3,280 papers, >76 citations.

Based on the number of citations that are selected as highly cited, it could be concluded that this is proper selection according to the fact that the least cited paper has more than 50 citations.

In order to make comparison between countries normalization of data is used according to following formula:

$$X_{i,j} = \frac{Y_{i,j}}{Z_i} \times 1000$$

where $X_{i,j}$ is the number of highly cited papers from country i and field j per 1,000 FTE researcher in the period of 2005–2010, Y is the number of highly cited papers from country i and field j in the period of 2005–2010 and Z_i number of FTE researchers in the country i in the period of 2005–2010.

Figure 4 shows countries of South East Europe by number of the papers per 1,000 FTE researchers among the top cited papers published in the period 2005–2010. In the field of *Natural Sciences*, Greece and Austria have the highest production of highly cited papers per 1,000 FTE researchers. Slovenia, Hungary and Croatia are slightly lower but also have remarkable number of highly cited papers per 1,000 FTE researchers. In the field of *Engineering and Technology*, Greece with 16.46 highly cited papers per 1,000 FTE researchers is most productive country followed by Turkey and Slovenia with 8.89 and 8.19 respectively.

In the field of *Agricultural Sciences*, Austria has 3.54 highly cited papers per 1,000 FTE researchers, followed by Hungary, Slovenia, Turkey and Greece that have around 2.8.

In the field of *Medical and Health Sciences*, variation between countries is much higher. Austria with 57 published highly cited papers per 1,000 FTE researchers is the most productive, Greece has 33.66 and Hungary around 20.

Main conclusions

The scientific performance of the 13 countries of the region of South East Europe has been analyzed based on two quantitative (number of publications per FTE researcher and RPA) and two qualitative indicators (the *h* index and top 1 % cited publications).

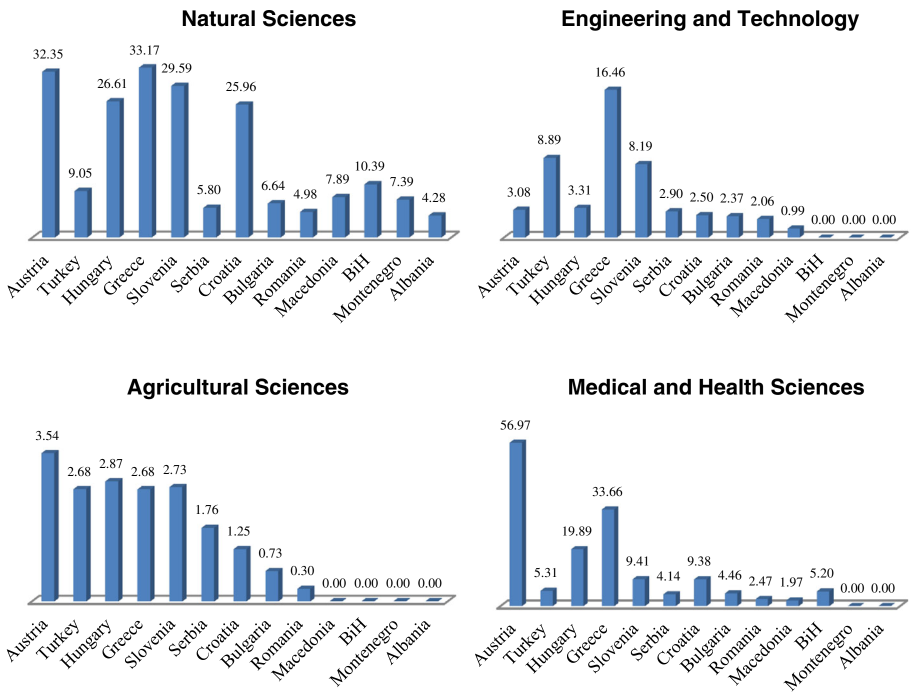

Fig. 4 Distribution of top cited articles between countries for the four most productive Frascati fields of science (number of top cited papers per 1,000 FTE researchers)

Research presented in this paper gives information for making significant decisions regarding R&D in specific country or region. This is particularly important for developing countries which should choose priorities in science and technology, but also for developed countries that should maintain their positions or find new ones. Indices introduced here are necessary for strategic decision making and also for creating strategic documents such as national strategies of S&T development, smart specialization strategies and other. Publication productivity indicators can also be used for making decisions about financing scientific institutions and projects, as well as for staff recruitment.

Countries with high productivity usually have good impact but countries with medium productivity in certain subfields also show noticeable impact performance. Countries with low productivity usually have low impact, rarely reaching the impact performance of other more productive countries. The country dominance in particular fields and subfields varies from field to field.

The following paragraphs will present the most important results of the SEE countries in Frascati field of sciences and the scientific potential of these countries.

In the field of *Natural Sciences*, Greece and Slovenia have the highest number of publications per FTE researcher, with nearly 1.6 publications per researcher. If we look at quality of published papers Greece and Austria have the highest production of highly cited papers per FTE researcher. Slovenia, Hungary and Croatia are slightly lower but also have remarkable number of highly cited papers per FTE researcher. According to the *h* index for individual subfields, we can see that Austria is leading country in almost all subfields.

In the field of *Engineering and Technology* 4 countries (Serbia, Montenegro, Romania and Slovenia) are highly specialized according to RPA indicator. Slovenia has the highest number of publications per FTE researcher in the field of Engineering and Technologies with the value over 0.8, while immediately behind is Croatia with 0.72. As for the quality of work in this area according to top cited articles we can conclude that the Greece is significantly ahead of other countries.

Field of *Medical and Health Sciences* is the most productive in Bosnia and Herzegovina with over 1.4 papers per FTE researcher, followed by Greece and Turkey with the values of 1.27 and 1.05 respectively. Quality of papers shows much greater variation between countries. Austria with 57 published highly cited papers per 1,000 FTE researchers is the most productive. RPA indicator shows that Montenegro, Bulgaria, Romania and Slovenia are countries that have a lower share of the total number of publications in the field of *Medical Sciences and Health* compared to the world average.

Hungary is the most specialized SEE country in the field of *Agricultural Sciences* with RPA indicator of 0.5, followed by Croatia with 0.49. Other countries do not have a large share of papers in this area and the least specialized country is Romania with RPA indicator of −0.73. Based on the *h* index, we conclude that Austria, Turkey, Hungary and Greece are at approximately the same level in all subfields except the *Agricultural Biotechnology* where Austria is well ahead of the other SEE countries with the *h* index of 56. Austria has 3.54 highly cited paper per 1,000 FTE researchers, followed by Hungary. Slovenia, Turkey and Greece that have about 2.8 highly cited papers.

Based on the RPA indicator we can conclude that the degree of specialization in most SEE countries in the field of *Social Sciences* and *Humanities* is at very low level. All countries have a negative value RPA in Social Sciences except Croatia, Albania and Bosnia and Herzegovina. In Humanities, Albania, Croatia and Slovenia have positive values of RPA indicator.

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Appendix

WoS categories-Frascati fields of science	WoS categories-Frascati fields of science	WoS categories-Frascati fields of science
Biotechnology applied microbiology: agricultural biotechnology	Engineering chemical: chemical engineering	Business: economics and business
Agriculture multidisciplinary: Agriculture, forestry, and fisheries	Architecture: civil engineering	Business finance: Economics and business

WoS categories-Frascati fields of science	WoS categories-Frascati fields of science	WoS categories-Frascati fields of science
Agronomy: agriculture, forestry, and fisheries	Construction building technology: civil engineering	Economics: economics and business
Fisheries: agriculture, forestry, and fisheries	Engineering civil: civil engineering	Industrial relations labor: economics and business
Forestry: agriculture, forestry, and fisheries	Transportation science technology: civil engineering	Management: economics and business
Horticulture: agriculture, forestry, and fisheries	Automation control systems: Electrical engineering, electronic engineering, information engineering	Operations research management science: economics and business
Soil science: agriculture, forestry, and fisheries	Communication: electrical Engineering, electronic engineering, information engineering	Education educational research: educational sciences
Agriculture dairy animal science: animal and dairy science	Computer science hardware architecture: electrical engineering, electronic engineering, information engineering	Education scientific disciplines: educational sciences
Agricultural economics policy: other agricultural sciences	Engineering electrical electronic: electrical engineering, electronic engineering, information engineering	Education special: educational sciences
Veterinary sciences: veterinary science	Robotics: electrical engineering, electronic engineering, information engineering	Criminology penology: law
	Telecommunications: electrical engineering, electronic engineering, information engineering	Law: law
	Energy fuels: environmental engineering	Area studies: other social sciences
	Engineering environmental: environmental engineering	Cultural studies: other social sciences
	Engineering geological: environmental engineering	Social sciences Interdisciplinary: other social sciences
	Engineering marine: environmental engineering	Social sciences mathematical methods: Other social sciences
	Engineering ocean: environmental engineering	Environmental studies: other social sciences
	Engineering petroleum: environmental engineering	International relations: political science
	Mining mineral processing: environmental engineering	Political science: political science
	Remote sensing: environmental engineering	Public administration: political science
	Materials science biomaterials: industrial biotechnology	Psychology: psychology
	Materials science ceramics: materials engineering	Psychology applied: psychology
	Materials science coatings films: materials engineering	Psychology biological: psychology
	Materials science composites: materials engineering	Psychology clinical: psychology

WoS categories-Frascati fields of science	WoS categories-Frascati fields of science	WoS categories-Frascati fields of science
	Materials science paper wood: materials engineering	Psychology developmental: psychology
	Materials science textiles: materials engineering	Psychology educational: Psychology
	Engineering aerospace: mechanical engineering	Psychology experimental: Psychology
	Engineering mechanical: mechanical engineering	Psychology mathematical: Psychology
	Mechanics: mechanical engineering	Psychology multidisciplinary: Psychology
	Nuclear science technology: mechanical engineering	Psychology psychoanalysis: Psychology
	Thermodynamics: mechanical engineering	Psychology social: psychology
	Medical laboratory technology: medical engineering	Geography: Social and economic geography
	Nanoscience nanotechnology: nano-technology	Planning development: Social and economic geography
	Agricultural engineering: other engineering and technologies	Transportation (social aspects): Social and economic geography
	Engineering industrial: other engineering and technologies	Urban studies: Social and economic geography
	Engineering manufacturing: other engineering and technologies	Anthropology: sociology
	Engineering multidisciplinary: other engineering and technologies	Demography: sociology
	Imaging science photographic technology: other engineering and technologies	Ethnic studies: sociology
	Instruments instrumentation: other engineering and technologies	Family studies: sociology
	Materials science characterization testing: other engineering and technologies	Social issues: sociology
	Materials science multidisciplinary: other engineering and technologies	Social work: sociology
	Metallurgy metallurgical engineering: other engineering and technologies	Sociology: sociology
	Food science technology: other engineering and technologies	Womens studies: sociology
Anatomy morphology: basic medicine	Behavioral sciences: biological sciences	Art: art (arts, history of arts, performing arts, music)
Chemistry medicinal: basic medicine	Biochemical research methods: biological sciences	Dance: art (arts, history of arts, performing arts, music)
Immunology: basic medicine	Biochemistry molecular biology: biological sciences	Film radio television: art (arts, history of arts, performing arts, music)
Neurosciences: basic medicine	Biodiversity conservation: biological sciences	Folklore: art (arts, history of arts, performing arts, music)

WoS categories-Frascati fields of science	WoS categories-Frascati fields of science	WoS categories-Frascati fields of science
Pathology: basic medicine	Biology: biological sciences	Music: art (arts, history of arts, performing arts, music)
Pharmacology pharmacy: basic medicine	Biophysics: biological sciences	Theater: art (arts, history of arts, performing arts, music)
Physiology: basic medicine	Cell biology: biological sciences	Archaeology: history and archaeology
Toxicology: basic medicine	Developmental biology: biological sciences	History: history and archaeology
Audiology speech Language Pathology: clinical medicine	Ecology: biological sciences	Classics: languages and literature
Allergy: clinical medicine	Entomology: biological sciences	language linguistics: languages and literature
Andrology: clinical medicine	Evolutionary biology: biological sciences	Linguistics: languages and literature
Anesthesiology: clinical medicine	Genetics heredity: biological sciences	Literary reviews: languages and literature
Cardiac cardiovascular systems: clinical medicine	Limnology: biological sciences	Literary theory criticism: languages and literature
Clinical neurology: clinical medicine	Marine freshwater biology: biological sciences	Literature: languages and literature
Critical care medicine: clinical medicine	Mathematical computational Biology: biological sciences	Literature african australian canadian: languages and literature
Dentistry oral surgery medicine: clinical medicine	Microbiology: biological sciences	Literature american: languages and literature
Dermatology: clinical medicine	Mycology: biological sciences	Literature british isles: languages and literature
Emergency medicine: clinical medicine	Ornithology: biological sciences	Literature german dutch scandinavian-languages and literature
Endocrinology metabolism: clinical medicine	Plant sciences: biological sciences	Literature romance: languages and literature
Gastroenterology hepatology: clinical medicine	Reproductive biology: biological sciences	Literature slavic: languages and literature
Geriatrics gerontology: clinical medicine	Virology: biological sciences	Poetry: languages and literature
Gerontology: clinical medicine	Zoology: biological sciences	Asian studies: other humanities
Hematology: clinical medicine	Chemistry analytical: chemical sciences	Medieval renaissance studies: other humanities
Medicine general internal: clinical medicine	Chemistry applied: chemical sciences	Hospitality leisure sport tourism: other humanities
Neuroimaging: clinical medicine	Chemistry inorganic nuclear: chemical sciences	Humanities multidisciplinary: other humanities
Obstetrics gynecology: clinical medicine	Chemistry multidisciplinary: chemical sciences	Ethics: philosophy, ethics and religion

WoS categories-Frascati fields of science	WoS categories-Frascati fields of science	WoS categories-Frascati fields of science
Oncology: clinical medicine	Chemistry organic: chemical sciences	History of social sciences: philosophy, ethics and religion
Ophthalmology: clinical medicine	Chemistry physical: chemical sciences	History philosophy of science: philosophy, ethics and religion
Orthopedics: clinical medicine	Electrochemistry: chemical sciences	Philosophy: philosophy, ethics and religion
Otorhinolaryngology: clinical medicine	Polymer science: chemical sciences	Religion: philosophy, ethics and religion
Pediatrics: clinical medicine	Computer science artificial intelligence: computer and information sciences	
Peripheral vascular disease: clinical medicine	Computer science cybernetics: computer and information sciences	
Psychiatry mh clinical medicine	Computer science information systems: computer and information sciences	
Radiology nuclear medicine medical imaging: clinical medicine	Computer science Interdisciplinary applications: computer and information sciences	
Rehabilitation: clinical medicine	Computer science software engineering: computer and information sciences	
Respiratory system: clinical medicine	Computer science theory methods: computer and information sciences	
Rheumatology: clinical medicine	Information science library Science: computer and information sciences	
Surgery: clinical medicine	Environmental sciences: earth and related environmental sciences	
Transplantation: clinical medicine	Geochemistry geophysics: earth and related environmental sciences	
Urology nephrology: clinical medicine	Geography physical: earth and related environmental sciences	
Health care sciences services: health sciences	Geology: earth and related environmental sciences	
Health policy services: health sciences	Geosciences multidisciplinary: earth and related environmental sciences	
Infectious diseases: health sciences	Meteorology atmospheric sciences: earth and related environmental sciences	
Medical ethics: health sciences	Mineralogy: earth and related environmental sciences	
Nursing: health sciences	Oceanography: earth and related Environmental sciences	
Nutrition dietetics: health sciences	Paleontology: earth and related environmental sciences	
Parasitology: health sciences	Water resources: earth and related environmental sciences	
Primary health care: health sciences	Logic: mathematics	

WoS categories-Frascati fields of science	WoS categories-Frascati fields of science	WoS categories-Frascati fields of science
Public environmental Occupational health: health sciences	Mathematics: mathematics	
Social sciences Biomedical: health sciences	Mathematics applied: mathematics	
Sport sciences: health sciences	Mathematics interdisciplinary applications: mathematics	
Substance abuse: health sciences	Statistics probability: mathematics	
Tropical medicine: health sciences	Multidisciplinary sciences: other natural sciences	
Cell tissue engineering: medical biotechnology	Acoustics: physical sciences	
Engineering biomedical: medical biotechnology	Astronomy astrophysics: physical sciences	
Ergonomics: other medical sciences	Crystallography: physical sciences	
Integrative complementary medicine: other medical sciences	Microscopy: physical sciences	
Medicine research experimental: other medical sciences	Optics: physical sciences	
Medical informatics: other medical sciences	Physics applied: physical sciences	
Medicine legal: other medical sciences	Physics atomic molecular chemical: physical sciences	
	Physics condensed matter: physical sciences	
	Physics fluids plasmas: physical sciences	
	Physics mathematical: physical sciences	
	Physics multidisciplinary: physical sciences	
	Physics nuclear: physical sciences	
	Physics particles fields: physical sciences	

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