

CROATIAN HIGHLY CITED PAPERS

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ABSTRACT

Highly cited papers are among the most commonly used indicators for measuring scientific excellence. The primary purpose of this study is to determine characteristics of highly cited papers authored or co-authored by Croatian researchers and to identify patterns of their national and cross-national collaboration. The Clarivate Analytics Web of Science Core Collection was used for collecting data. Data were filtered for the highly cited papers published in the 2008-2018 period. Half of 428 identified highly cited papers were published in only 18 journals. The distribution across subject areas showed a strong domination of the fields of physics and clinical medicine. The median number of authors per average paper was 30,5, while the same value in the case of Croatian authors was 2. Only 4% of the analysed papers were authored by Croatian researchers only. The national inter-institutional collaboration was marginal and mainly visible through joined collaboration with foreign institutions. European institutions are most frequently found among the authors' addresses. For a small country on the scientific periphery, international cooperation is a prerequisite not only for the publication of highly cited papers but also for acquiring additional research experience in mainstream scientific teams.

KEY WORDS

highly cited papers, scientifically peripheral countries

CLASSIFICATION

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INTRODUCTION

Science is a gift economy [1] which relies on intangible rewards like recognized contributions to knowledge and impact on ideas of other scientists. Scholarly publications allow their readers to identify this background information. A citation is basically an acknowledgment indicating which publication influenced someone's research and published work. Bornmann and Daniel [2] argue that citations are not only an indication of the (superficial) relevance of research but are also an indicator for the relevance of an investigation or a study for scientific activity in a research field.

Despite a number of controversial technical questions [3], the citation count is nowadays a standard method of research evaluation and comparison of research performance between individual researchers, departments, and research institutions [4]. The method is also used for the country and/or cross-country evaluation of research performance.

According to Aksnes [5] a large majority of scientific papers are never or seldom cited in subsequent scientific literature. However, some papers do receive an extremely large number of citations. Zitt et al. [6] emphasize that highly cited articles are among the most commonly used indicators for measuring "excellence". Their importance in research assessment has been recently growing as they became a component in some global university and institution rankings, such as the Leiden or Shanghai rankings. Aksnes and Sivertsen [7] found that the average citation by countries in different fields of science depended on a few highly cited papers to a large extent.

The term "highly cited paper" may be defined in a number of ways [8-10]. Many recently published studies used Clarivate Analytics Essential Science Indicators (ESI) according to which highly cited papers (HCPs) are papers that received enough citations to be placed in the top 1% papers in the academic field of each 22 subject areas based on a highly cited threshold for the field and publication year [11].

The main characteristics of HCPs were determined by Aksnes [5], and among them are a large number of affiliated authors, international collaboration, publishing in high-impact journals and over-representation of review articles. These findings were confirmed in the analysis of the research impact in countries with high scientific productivity as well as in small scientific communities. In their comprehensive assessment of Chinese HCPs, Fu et al. [12] confirmed international collaboration and multiple authorship of HCPs as well as a high share of articles belonging to hard sciences. Pisyakov and Shukshina [13] found that about 92% of Russian highly cited papers involved international collaboration, which is a several times higher share in comparison with the share in the overall Russian output (35%). Elango and Ho [14] analysed HCPs from India and they also identified patterns of international collaboration and high-impact journals in the HCP production and publishing.

The share and characteristics of HCPs in the overall production of scholarly articles in small or/and peripheral scientific communities have not been sufficiently analysed. However, the studies of Malaysian [15] and Slovenian HCPs [16] showed that these papers generally share the same characteristics: they are internationally collaborative, multiauthored, published in highly influential journals and belong to hard science disciplines. Goldfinch et al. [17] stated that scientists on the periphery and their institutions "should look to tie their research as strongly as they can to the international community if they wish to increase the impact of their research and the benefits this might entail".

Croatia is a small scientific community with 0,86% gross domestic expenditure on research and development (GERD) in 2016. The country joined the European Union in 2013 and it increased both the funding from the European resources and the level of research collaboration.

The EU Research and Innovation Observatory (RIO) monitors and analyses the research and innovation development in the EU countries producing RIO Country Reports every year [18]. One of the indicators employed is the highly cited publication indicator defined as a country's number of scientific publications among the top 10% most cited publications in fractional counting. The analysis is based on the Web of Science data with the citation window of publication year plus two years. Looking at the 2015 data for all 28 EU countries, Bulgaria, Lithuania, and Croatia have the lowest shares in the top 10% most cited publications in the total scientific publication of the country.

The primary purpose of this study is to determine characteristics of Croatian HCPs as they are defined by the Clarivate Analytics ESI and to identify the most important national institutions producing HCPs as well as patterns of their national and cross-national collaboration. At the same time, the field distribution of HCPs will be identified as well as their JCR quartile distribution. The second goal of the study is to examine whether the Croatian HCP sample confirms the characteristics of previous research and displays some features that might be typical of small and peripheral scientific communities.

MATERIALS AND METHODS

The web interface of Clarivate Analytics Web of Science Core Collection (WoS CC) was used to collect data. Databases were first searched by the terms Croatia or Hrvatska in the address field. The result was then refined by applying the "highly cited in field" filter.

The highly cited papers included in our study were published in the 2008-2018 period because a 10-year interval is the cumulative time period used for the ESI to calculate which papers are highly cited. All 22 subject areas were included in the analysis.

The data were collected in April 2019 and were partially analysed by using the InCite tools. The crosstab analysis was done by using the SPSS package.

RESULTS AND DISCUSSION

The search of the WoS CC resulted in the identification of 428 HCPs with at least one Croatian address. This is 0,008 % of a total of 52 077 WoS CC indexed documents of the article and review types in the 11 years. The growth in the number of HCPs has exceeded the growth in the total number of published articles and reviews since 2013, Figure 1.

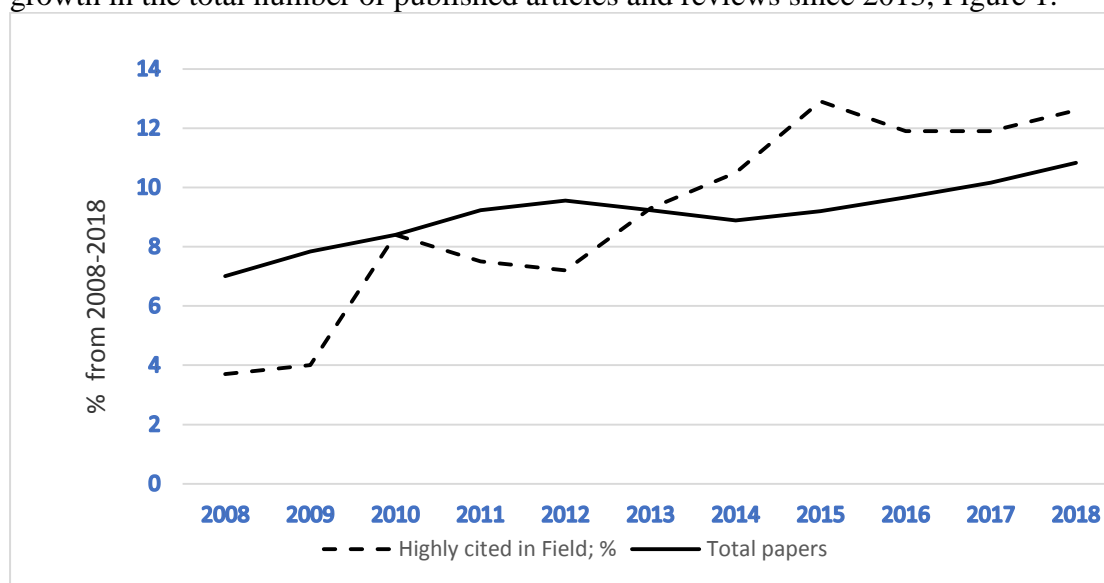


Figure 1. Yearly distribution of total number of papers (articles and reviews) and number of HCPs.

TYPE OF PAPERS AND THEIR CITATION RATE

Our sample consisted only of articles (84,6%) and reviews (15,4%). The shares do not fully correspond to the total number of published documents of these types (93,8% vs 6,2%) in the analysed period. The share of the highly cited review articles is 2,5 times higher. This confirmed Aksnes's findings [5] on the over-representation of review articles compared to the country's average. The citation share of the review articles in the total citation score is 13,3%, Table 1.

Table 1. Type of HCPs and their citation rate.

	No. of documents	%	No. of citations	%
Articles	362	84,6	93 108	86,7
Reviews	66	15,4	14 298	13,3
Total	428	100,0	107 406	100,0

The WoS definition of the article as a document type primarily relates to the "reports of research on original works". However, it should be noted that these databases classify also recommendations, consensus papers, position papers and guidelines into the article category although such papers present only statements aimed at supporting particular decision-making [19]. Their citation rate is usually very high and their impact on the total citation score may be significant. In our sample we found 32 papers (9%) of that type and all of them were classified as articles. Their total citation score was 10,117, almost 11% of the total citation score for all HCPs classified as articles.

SOURCE TITLES

The HCPs from our sample were published in 178 different journals; half of them were published in only 18 journals (Table 2). In the group of the top 18 journals, six journals

Table 2. Journals with most HCPs published.

Journal Titles	Frequency	Percent	Cumulative Percent
Physics Letters B	34	7,9	7,9
Physical Review Letters	26	6,1	14,0
Nature	22	5,1	19,1
Nature Genetics	16	3,7	22,9
Lancet	14	3,3	26,1
Food Chemistry	12	2,8	28,9
European Physical Journal C	11	2,6	31,5
Journal of Instrumentation	11	2,6	34,1
Journal of High Energy Physics	9	2,1	36,2
Proceedings of The National Academy of Sciences of The United States of America	9	2,1	38,3
Physical Review C	8	1,9	40,1
European Heart Journal	7	1,6	41,8
Science	7	1,6	43,4
Journal of Crohns & Colitis	6	1,4	44,8
Journal of Pediatric Gastroenterology and Nutrition	6	1,4	46,2
Lancet Oncology	6	1,4	47,6
New England Journal of Medicine	5	1,2	48,8
Physical Review D	5	1,2	50,0

belong to the field of physics and six to the field of clinical medicine, while four journals belong to the multidisciplinary category.

Aksnes [5] emphasised that “highly cited papers tend to be published in high impact journals”. The JCR quartile distribution showed that 86,4% of journals were ranked as Q1 in their subject categories, Table 3. This percentage is higher or similar to the results of other studies [15, 16].

Table 3. Journals’ publishing year JCR Qs.

Publishing year Q	Frequency	Percent
None	5	1,2
Q1	370	86,4
Q2	42	9,8
Q3	10	2,3
Q4	1	0,2
Total	428	100,0

SUBJECT AREAS

The distribution of the Croatian HCPs across subject areas (Table 4) showed a strong domination of the fields of physics and clinical medicine. A Croatian affiliation was found in 113 analysed documents (26,4%) in the field of physics and in 95 analysed documents in the field of clinical medicine (22,2%). The area of molecular biology and genetics is the third top field (10,1%). A similar pattern can be found in other studies too [13, 16].

Table 4. HCPs distribution across 20 ESI subject areas.

Highly cited field	Frequency	Percent	Cumulative Percent
Physics	113	26,40	26,40
Clinical Medicine	95	22,20	48,60
Molecular biology & genetics	43	10,05	58,64
Chemistry	19	4,44	63,08
Engineering	19	4,44	67,52
Social Sciences	15	3,50	71,03
Agricultural sciences	25	3,50	74,53
Biology & Biochemistry	15	3,50	78,04
Space science	13	3,04	81,07
Neuroscience & Behavior	12	2,80	83,88
Plant & Animal Science	12	2,80	86,68
Environment/Ecology	11	2,57	89,25
Geosciences	11	2,57	91,82
Materials Science	6	1,40	95,56
Immunology	6	1,40	96,96
Psychiatry/Psychology	4	0,93	97,66
Multidisciplinary	3	0,70	98,36
Pharmacology & Toxicology	3	0,70	99,06
Mathematics	2	0,47	99,53
Microbiology	1	0,23	100,00
Total	428	100,00	

Previous studies of the Croatian scientific productivity and impact also showed that physics and clinical medicine have been leading research areas [20; pp.114-116, 21], and that their share was about 50%. Croatian authors in both preclinical and clinical medicine have traditionally a prominent international output. If the HCPs in the fields of clinical medicine, immunology, neuroscience and psychiatry are combined into one broad category of biomedicine, this category takes the first place.

The HCPs are mainly present in “hard sciences”. With the exception of 15 papers (3%) classified into the subject area of social sciences, all other papers belong to “hard” scientific fields. The HCPs classified into the social sciences area are also borderline papers of anthropological, epidemiological or public health content orientation.

Two ESI subject areas have not been represented in our sample. These are computer science and economics and business areas. These two areas generally have a lower number of HCPs, and that may be attributed to differences in citation patterns across scientific fields [22, 23].

AUTHORS AND THEIR AFFILIATIONS

Multi-authorship is one of the most important characteristics of HCPs [5]. We found the median value of 30,5 authors per average paper. Even 73 papers (17%) were authored by more than 1000 researchers. The maximum number of authors is 5 153. Two single-author papers belong to the fields of mathematics and agricultural sciences.

The papers from the field of physics have the highest average number of authors per paper, i.e. 1378,48.

The median number of Croatian authors is 2 per paper. Their number varies in range from 1 to 22. Almost 50% of papers has one Croatian author in the byline. The highest average number of Croatian authors per paper is 8,07, found in the field of physics, Table 5.

Table 5. Number of HCPs authors across the ESI subject areas.

ESI subject area	No. of HCPs	Total no. of authors	Average no. of authors per paper	No. of Croatian authors	Average no. of Croatian authors per paper
Agricultural sciences	25	184	7,36	109	4,36
Biology & Biochemistry	15	1233	82,20	44	2,93
Chemistry	19	24 701	1300,05	140	7,37
Clinical Medicine	95	10 783	113,50	202	2,13
Engineering	19	93	4,90	30	1,58
Environment/Ecology	11	257	23,36	23	2,09
Geosciences	11	360	32,72	18	1,64
Immunology	6	390	65,00	14	2,33
Materials science	6	55	9,17	6	1,00
Mathematics	2	3	1,50	3	1,50
Microbiology	1	2	2,00	1	1,00
Molecular biology & genetics	43	8 983	208,90	102	2,37
Multidisciplinary	3	216	72,00	5	1,67
Neuroscience & Behavior	12	304	25,33	20	1,67
Pharmacology & Toxicology	3	17	5,67	3	1,00
Physics	113	155 768	1378,48	912	8,07
Plant & Animal Science	12	613	51,08	31	2,58
Psychiatry/Psychology	4	159	39,75	5	1,25
Social Sciences	15	1096	73,07	30	2,00
Space science	13	2 514	193,38	34	2,62

We found 72 papers (16,8%) with a Croatian researcher as the first or corresponding author. This is significantly less than what findings of other studies show [15, 16].

According to our results, there are three Croatian centers of scientific excellence. The majority of Croatian researchers who authored/co-authored the HCPs have been affiliated to the University of Zagreb, University of Split or the Ruđer Bošković Institute, Table 6.

INSTITUTIONAL COLLABORATION

According to many former studies, HCPs are characterised by strong international collaboration. The number of institutions participating in the production of HCPs in our sample varies from 1 to 1164 with a median of 25 per average paper. Only 17 papers (4,0%) in our sample were authored by Croatian researchers only. The national inter-institutional collaboration is marginal (Table 7) and it is mainly visible in the joined collaboration with foreign institutions. This supports one of the main characteristics of small scientific communities and scientifically peripheral countries, the so called “intellectual island effect” [24], primarily reflected in an incapacity of effective local research collaboration.

Discussing the reasons for the growing level of the international scientific collaboration, Wagner and Leydersdorff [25] mentioned an increasing specialisation within scientific fields, sharing centrally located facilities (e.g. CERN), and primarily the network organization of international collaboration. They say that “the network of international collaboration is highly dynamic, quickly changing, and very influential” and that “it feeds back into the national, regional, and local levels, influencing the organization of science”. Therefore, researchers on the periphery tend to tie strongly their research to internationally renowned institutions which enables them to gain experience and discuss their ideas.

Table 6. Croatian institutions participating in production of HCPs.

Croatian institutions	Web of Science HCPs	Times cited	HCPs in Q1 journals
University of Zagreb	171	39 206	122
University of Split	153	49 616	120
Ruđer Bošković Institute	117	30 434	93
University of Rijeka	45	9 469	30
University of JJ Strossmayer Osijek	9	839	7
Institute for Anthropological Research Zagreb	5	801	3
Croatian Academy of Sciences & Arts	4	1732	3
Croatian Forest Research Institute	3	124	2
Institute for Medical Research & Occupational Health	3	297	1
Institute of Physics Zagreb	3	682	3
Croatian Institute of Oceanography & Fisheries	2	29	1
Croatian Veterinary Institute Zagreb	2	42	1
University of Zadar	2	1764	2
University of Dubrovnik	1	70	1

Table 7. National collaboration.

Institution	HCPc	Times cited
University of Zagreb – University of Split	19	8 584
University of Zagreb – Ruđer Bošković Institute	7	1004
Ruđer Bošković Institute – University of Split	77	20 449

Table 8. International collaboration resulting in ≥ 100 HCPs.

Collaborative institution	Web of Science HCPs	Times cited
Helmholtz Association, Helmholtz Assoc MDC, Max Delbruck Ctr Mol Med, Mol Epidemiol Res Grp, Berlin, Germany	150	43 913
Univ California System	147	48 758
Universite Paris-Est Marne-la-Vallee, Centre National de la Recherche Scientifique (CNRS), National Institute for Mathematical Sciences	135	38 082
Universite Paris Saclay (ComUE), Paris Saclay Univ, L2S, 3 Rue Joliot Curie, Gif Sur Yvette, France	127	36 515
Univ Helsinki	126	37 060
Imperial College London	124	36 391
Massachusetts Institute of Technology (MIT)	118	38 643
Univ Padua	111	29 628
CEA, Inst Crustal Dynam, Beijing 100085, Peoples R China	110	30 094
United States Department of Energy (DOE)	109	27 355
Boston University	108	34 101
Univ Athens	108	27 842
Ohio State University	106	28 178
Universite de Strasbourg	102	27 963
Univ Turin	102	28 411
Univ Cantabria, Consejo Superior de Investigaciones Cientificas (CSIC), E-39005 Santander, Spain.	101	26 148
Sapienza University Rome	101	26 335
Chinese Academy of Sciences	100	27 074

European scientific institutions are most frequently found among the authors' addresses of the HCPs making our sample, Table 8. This is possibly so because of the EU extensive programmes for research and innovations in which Croatia has been participating more actively in the last five years.

RESEARCH FUNDING

According to the data available in the WoS CC databases, 274 funding agencies participated in the research projects which resulted in HCPs authored or co-authored by Croatian scientists. The projects which resulted in ≥ 50 HCPs were financed by 31 agencies with the US National Science Foundation and German Research Foundation (DFG) leading the list, Table 9. The Croatian Ministry of Science and Education, the main Croatian research funding body, participated in funding projects which resulted in the production of 53 HCPs (12%). As already mentioned, according to the Eurostat data for 2017 [26], the Croatian R&D expenditure is among the lowest in the European Union (0,86% of GDP).

TOP 10 HCPs

The 10 most frequently cited HCPs were published in journals classified by the ESI in five subject areas. According to the overall results, physics was the most frequently cited field with 26,4% of HCPs (Table 4). However, there was only one paper dealing with a topic belonging to physics among the most frequently cited ten HCPs, the first paper on the list, with

Table 9. Source of funds.

Funding Agency	Rank	Web of Science HCPs	Times cited
US National Science Foundation (NSF)	1	100	25 589
German Research Foundation (DFG)	2	97	20 564
German Federal Ministry of Education & Research (BMBF)	3	90	18 000
National Natural Science Foundation of China	4	89	20 599
United States Department of Energy (DOE)	5	81	20 358
Brazilian National Council for Scientific and Technological Development (CNPq)	6	81	18 292
European Union (EU)	7	80	17 833
Istituto Nazionale di Fisica Nucleare	8	79	18 299
UK Science & Technology Facilities Council (STFC)	9	78	18 192
Fundacao de Amparo a Pesquisa do Estado de Sao Paulo (FAPESP)	10	74	17 617
Academy of Finland	11	74	15 452
Mexican Consejo Nacional de Ciencia y Tecnologia (CONACyT)	12	72	17 150
Department of Atomic Energy (DAE)	13	72	17 143
Greek Ministry of Development-GSRT	14	71	16 162
Chinese Academy of Sciences	15	67	14 958
European Research Council (ERC)	16	64	14 797
Centre National de la Recherche Scientifique (CNRS)	17	64	14 733
CAPES, Tecnologia e Inovacion Colciencias (Brasil)	18	63	14 584
Portuguese Foundation for Science and Technology	19	62	15 022
Departamento Administrativo de Ciencia	20	62	14 580
Science Foundation Ireland	21	61	14 452
Scientific & Technological Research Council of Turkey (TUBITAK)	22	60	14 233
Fundacao Carlos Chagas Filho de Amparo a Pesquisa do Estado do Rio de Janeiro (FAPERJ)	23	59	14 028
Russian Academy of Sciences	24	59	9 253
Russian Foundation for Basic Research	25	58	13 198
FWO – Research Foundation Flanders	26	57	13 385
Turkish Enerji ve Tabii Kaynaklar Bakanligi	27	55	13 193
Ministry of Science and Education, Republic of Croatia	28	53	13 051
Fonds de la Recherche Scientifique (FNRS)	29	52	11 963
Alexander von Humboldt Foundation	30	51	12 689
French Atomic Energy Commission	31	50	12 968

2,3 times more citations than the next paper, Table 10. Among 228 participating institutions and 2 891 authors, there were two Croatian institutions (University of Split and Ruder Bošković Institute) with 12 affiliated scientists.

Seven papers from the list were published in the fields of molecular biology and genetics (4) and clinical medicine (3). All three clinical medicine papers belong to the group of guidelines and systematic reviews and they are regularly very influential and highly cited.

On the list of top 10 papers there is a paper authored exclusively by Croatian researchers and produced by the Croatian leading research institution. This paper gives a description of a free accessible web application for summarizing and visualizing the gene ontology categories. Methods papers, particularly those focused on computational methods, are generally among the most frequently cited papers [27, 28].

Nine out of ten papers on the list were published between 2010 and 2015. Some authors argue that the papers published earlier have an advantage over the papers published later as more citations can be accumulated [29]. The time factor obviously does not have a critical influence on the citation ranking of the analysed HCPs.

Table 10. Most frequently cited HCPs.

Total no. of authors	No. of Croatian authors	Croatian first or corresponding author	Croatian affiliations	Citations	ESI subject area	Journal	Document type	Croatian funding	Published
2891	12	No	University of Split; Ruđer Bošković Institute	5099	Physics	Physics Letters B	Article	Yes	2012
1268	1	No	University of Split	2177	Molecular biology & genetics	Autophagy	Review	No	2012
18	1	Yes	University of Zagreb	1851	Clinical medicine	European Heart Journal	Article	No	2011
2834	22	No	University of Zagreb; University of Zadar; 9 hospitals	1733	Clinical medicine	New England Journal of Medicine	Article	No	2013
375	5	No	University of Zagreb; University of Split	1650	Molecular biology & genetics	Nature Genetics	Article	Yes	2010
3100	9	No	Ruđer Bošković Institute	1650	Chemistry	Journal of Instrumentation	Review	No	2008
56	1	No	Croatian Academy of Sciences & Arts	1565	Molecular biology & genetics	Science	Article	No	2010
95	1	No	University of Zagreb	1337	Molecular biology & genetics	Nature	Article	No	2015
4	3	Yes	Ruđer Bošković Institute	1325	Biology & Biochemistry	PLOS ONE	Article	Yes	2011
21	1	No	University of Split	1241	Clinical Medicine	Lancet	Article	No	2010

CONCLUSIONS

The main characteristics of the HCPs authored/co-authored by Croatian researchers are similar to those described in the previous studies. The Croatian HCPs are multi-authored, internationally collaborative, published predominantly in the field of hard sciences and in highly cited journals. Almost half of the HCPs belong to the fields of physics and clinical medicine, and half are published in 18 journals, all ranked as JCR Q1. European scientific institutions are most frequently found among the authors' affiliations and the median value of authors per average HCP is 30,5.

The HCPs characteristics that can be attributed to small and/or scientifically peripheral countries relate to the low participation of local funds, a lack of local research co-operation and few local authors being the first or corresponding authors.

Not more than 4,0% of all analysed HCPs were authored by Croatian authors exclusively, and 16,8% had a Croatian researcher as the first or corresponding author.

The Croatian Ministry of Science and Education participated in funding projects which resulted in the production of 12% of the analysed HCPs.

The majority of the Croatian researchers who authored/co-authored the HCPs have been affiliated to the University of Zagreb, the University of Split or the Ruđer Bošković Institute.

The national inter-institutional collaboration has been minimal and mainly visible in the joined collaboration with foreign institutions.

Discussing the 63% of the Norwegian highly cited papers involving international collaboration, Aksnes said that the concept of "Norwegian papers" appears rather problematic [5]. It seems that this could be said for our results as well. However, cross-border links in science, with resources being diffused in international networks, were considered to be the extension of national systems finding opportunities to complement each others' capabilities [30].

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