Institute for Scientific Information

Global Research Report
Central Europe: A profile of the region and its place in the European research network

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Cover image: Aerial view of Budapest by night

Budapest is the capital and most populous city of Hungary. It is the ninth-largest city in the European Union by population. The city straddles the Danube, the second longest European river, which passes through three other capital cities and nine other countries in central Europe.

Executive summary

- This analysis focusses on 11 countries that have, since 2000, acceded to the European Union (EU) and gained direct access to the EU Framework Programmes of research funding. We describe this group as 'Central' Europe, while acknowledging that national and regional boundaries are rarely simple to define. (Table 1)

- Central European regional trends are comparable to that of Western Europe, when we examine research publications in journals indexed in the Web of Science (a Clarivate product) since 1990. For this report we define 'Western' Europe as the countries which were part of the EU pre-2000. (Figure 1)

- Central Europe's researchers (co)authored ~4% of global papers between 2016 and 2020, a doubling of world share since 1990. The greatest volume is in multidisciplinary materials science (5,545 papers), capturing 4.4% of world share. A greater share but smaller volume is in mathematics (2,654 papers, 8.6%) and particle physics (1,178 papers, 8.9% of world). (Table 3)

- Both Poland and the Czech Republic publish more than 10,000 papers per year, while Hungary and Romania publish over 8,000, but no other Central European country exceeds 5,000 papers per year. (Figure 2)

- International research collaboration increased globally in the early 1990s and in Central Europe for all countries except Croatia. There is variation: Poland and Romania's internationally collaborative output is 40% of total papers, while Estonia and Latvia's is around 70%. (Figures 3 and 4)

- Mainland China is a rapidly increasing research partner: co-authorship increased from <1,000 papers per year in 2010 to over 4,000 per year by 2020. Latvia leads with a 25% share of its papers listing co-authors based in Mainland China. (Figure 5)

- Regional networking is growing. Co-authors based in all 11 countries are listed on 65 papers (1990-2020) while the four biggest research economies (Poland, Czech Republic, Hungary and Romania) jointly co-authored 2,421 papers since 1990, of which ~95% were published after 2010.

- Citation impact is rising. The average Category Normalized Citation Impact (CNCI) for Estonia now approaches twice world average. However, Poland, despite its significant output, is the only country with average CNCI below that global benchmark in all years, due to its comparatively low levels of international collaboration and high domestic output. (Figure 6).

- Impact Profiles show that a substantial share of national activity in these countries is cited more frequently than the world benchmark, irrespective of the average CNCI. (Figure 7)

- Poland has good volume and share in metallurgy and condensed matter but only modest CNCI. The Czech Republic is strong in ecology and plant sciences where it has volume, share and CNCI above world average. Overall, physical sciences are a core regional research area. (Table 4)

- Central European universities' research output has increased but national academies (e.g., Polish Academy of Sciences) had a constant or reduced share of output. Changing institutional balance may reflect a cultural shift from mission-led institutes towards a more open and dynamic researcher-led environment. (Table 5)

- Splitting country and institutional publication types by national and international collaboration, using the innovative Collab-CNCI indicator described in our report *Making it Count: Research credit management in a collaborative world* (Adams et al., 2022), gives insight on research portfolios that usually remains hidden in traditional research indicators. Central European national citation counts are heavily influenced by multi-national papers. The number of these types of articles is low but the associated volume of citations is likely to skew CNCI values. (Figures 8 and 9)

Introduction

Much has been written and said about the research economies and landscapes of western European nations but, for the first ISI report on Europe, we have chosen to examine the rapidly maturing research networks in countries which have acceded to the European Union (EU) since 2000. Accession provides these countries with direct access to the EU Framework Programmes of research funding (see Csomos, 2019; Makkonen and Mitze, 2016). We describe this group of countries as 'Central' Europe. We note, however, that the concepts of Eastern, Central and Western Europe are flexible and inconsistent with no definition of the precise area that any of these sub-regions might cover because they have a wide range of geopolitical, geographical, ethnic, cultural and socioeconomic connotations. Our definition of 'central,' therefore places these countries between the previously established Western European collaborative Framework Programmes and the post-Soviet part of Eastern Europe that extends to the borders of Asia.

There are three groups of European countries that we will use in this report:

Western Europe: the pre-existing EU group prior to 2000 (Austria, Belgium, Denmark, Finland, France, Greece, Germany, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom)

Central Europe: 11 accession countries listed in Tables 1 and 2, which are the focus of this report

Eastern Europe: European countries that have not joined the EU (Albania, Belarus, Bosnia and Herzegovina, Moldova, Montenegro, North Macedonia, Russia, Serbia, Ukraine)

Chankseliani et al. (2021) note that the former Soviet "area of influence" is creating new research that builds on rich scientific traditions in selected disciplines but productivity and the post-Soviet contribution to global research remains small; such a situation is also true for some of the former states of Yugoslavia (Kutlača et al., 2015). Chankseliani et al. (2021) found these countries have publications of lower relative global quality and impact and that the proportion of international co-authorship is high. The national academies, often founded in the 19th century, built a legacy of achievement that promoted their international reputation prior to retrenchment in the 1940s. They have played an important role in the research structure of Central and Eastern Europe and continue to have a major influence on research funding, manage their own institutes and have oversight of national journals. They are influential in national research policy, including evaluation and assessment, often setting a template for institutional priorities and polices. There is some conflict of interest in these cross-cutting roles: researchers may be steered to publish in local journals accessed less often by researchers elsewhere (Hladchenko and Moed, 2021); and templated institutional assessment is not always beneficial (Good et al., 2015; Kulczycki et al., 2021). Nevertheless, the national academies' networks of research institutes, sometimes but not always in collaboration with the universities (see Table 5), remain responsible for much of Central Europe's research output.

The national academies founded in the 19th century built a legacy of achievement.

The countries in Central Europe

Our analysis starts in 1990 and takes a view over the three decades to 2020. We omit the most recent year, for which citation data will inevitably be sparse, and exclude the period prior to the fall of the Berlin Wall in 1989, which was described in part by an earlier ISI study that gave an overview of the German Democratic Republic ('East Germany'), Poland, Czechoslovakia, Hungary, Romania and Bulgaria (Vladutz and Pendlebury, 1989). The period from 1990 to 2015 has also been analyzed by Kozak et al. (2015) who reported slow change.

The 11 countries and their EU accession dates are shown in Table 1 with summary economic and population data. Their recent research productivity, based on academic articles and reviews published in journals indexed in the Web of Science between 2015 and 2019, is shown in Table 2.

Central Europe's countries vary considerably in size but have a similar ratio of GDP to population. The EU has set an aspirational target for Gross Expenditure on Research and Development (GERD) of 3% of GDP against which the expenditure on research and development (R&D) in this group varies: from 0.47% in Romania up to 1.86% in the Czech Republic and 2.08% in Slovenia, both above the United Kingdom (1.7% of GDP) and close to the recent EU average (2.1%). Investment has consequences for the relative numbers of researchers in the workforce, which is again lowest in Romania and highest in Slovenia, where the ratio approaches that of Western EU economies.

Table 1. National data for EU countries in Central Europe

	EU accession	Population	GDP [1]	GERD [2]	Researchers [3]
Bulgaria	2007	7,264,252	69.89	0.80	2,343
Croatia	2013	4,249,172	57.20	0.86	1,921
Czech Republic	2004	10,518,510	245.35	1.86	3,863
Estonia	2004	1,319,617	30.65	1.36	3,755
Hungary	2004	9,898,933	155.81	1.35	3,238
Latvia	2004	2,015,597	33.71	0.58	1,792
Lithuania	2004	2,962,171	56.55	0.95	3,191
Poland	2004	38,032,952	596.62	1.03	3,106
Romania	2007	19,982,770	248.72	0.47	882
Slovakia	2004	5,412,361	105.17	0.91	2,996
Slovenia	2004	2,059,093	53.59	2.08	4,855

1. Gross Domestic Product (GDP), = Current US$Bn, World Bank data, 2020
2. Gross Expenditure on Research & Development (GERD) = % GDP, UNESCO, recent average
3. Researchers/million population, UNESCO data, 2018

Research output

Table 2. Publication output and productivity

	Papers	Papers/GERD	Papers/researcher
Bulgaria	2,657	0.46	0.16
Croatia	4,237	1.17	0.52
Czech Republic	14,825	0.76	0.36
Estonia	2,358	1.32	0.48
Hungary	8,264	0.62	0.26
Latvia	1,014	0.88	0.28
Lithuania	2,802	1.01	0.30
Poland	31,664	0.81	0.27
Romania	8,917	0.96	0.51
Slovakia	4,274	0.86	0.26
Slovenia	4,560	1.06	0.46

Papers = annual average count of articles and reviews indexed in Web of Science, 2015-2019

The Web of Science is structured into more than 250 research categories based on journal subject similarity and this enables more granular analyses of research strengths.

The numbers of original academic papers (articles and reviews) that were published in the selective index of 20,000 or so journals covered by Web of Science is an index of research productivity (Table 2). This gives us excellent, in-depth coverage across the period covered by this report, and it also provides access to a highly curated database of references and citation links between papers. For each indexed paper we analyze the author addresses and thus collate affiliations at institutional as well as national level. The Web of Science is structured into more than 250 research categories based on journal subject similarity and this enables more granular analyses of research strengths.

Both the Czech Republic and Poland publish more than 10,000 papers per year, while Hungary and Romania publish over 8,000. This set includes three of the four members of the Visegrad Group, formed in 1991 as a Central European cultural alliance (Szuflita-Zurawska and Basinska, 2021). No other Central Europe country exceeds 5,000 papers per year on average, though numbers are rising across the region. By comparison, the larger economies of Western Europe publish as many as 100,000 papers per year.

Figure 1 summarizes the growth profiles of the three European groups. The Central group has a similar growth rate to that of the established Western EU economies. The Western EU includes four large G7 nations with very substantial output so, for comparison of growth rates, the data are plotted on different scales. Nonetheless, the Central group has accelerated somewhat compared to the Western group. The Eastern group, however, suffered a stasis in research output from 1992 until around 2005, after which its growth rose at a rate like that of Central Europe.

The national totals that make up the Central Europe group pool are summarized in Figure 2. The annual numbers of papers in the journals indexed in Web of Science varies across the accession countries by an order of magnitude (see Table 2) so the publication data are shown as a log plot which allows easier comparison and tells us that the growth rates are in fact very similar and generally stable despite the size differences. There are some evident 'steps' in output, potentially due to beneficial effects from gaining access to the EU research network and funding. Lithuania joined the EU in 2004 and has a step-up in indexed research productivity around this time; Romania joined the EU in 2007 and a step-up in its output is seen a few years later.

We see a sharp increase in recorded output for several countries in the very early 1990s. This is almost certainly a consequence not of sudden additional academic activity but of a post-Soviet and post-Yugoslavia shift in publication patterns from primarily regional journals to more globally accessible, international literature. It is thus a growth in output in quality, indexed journals rather than actual productivity.

Figure 1. The regional growth of research publications in journals indexed in the Web of Science. The lines show the 11 countries in Central Europe that have acceded to the European Union since 2000, the older Western EU countries established prior to 2000 and the other Eastern Europe countries that are not part of the EU. Note that the data are plotted on a log scale to accommodate the differences in volume.

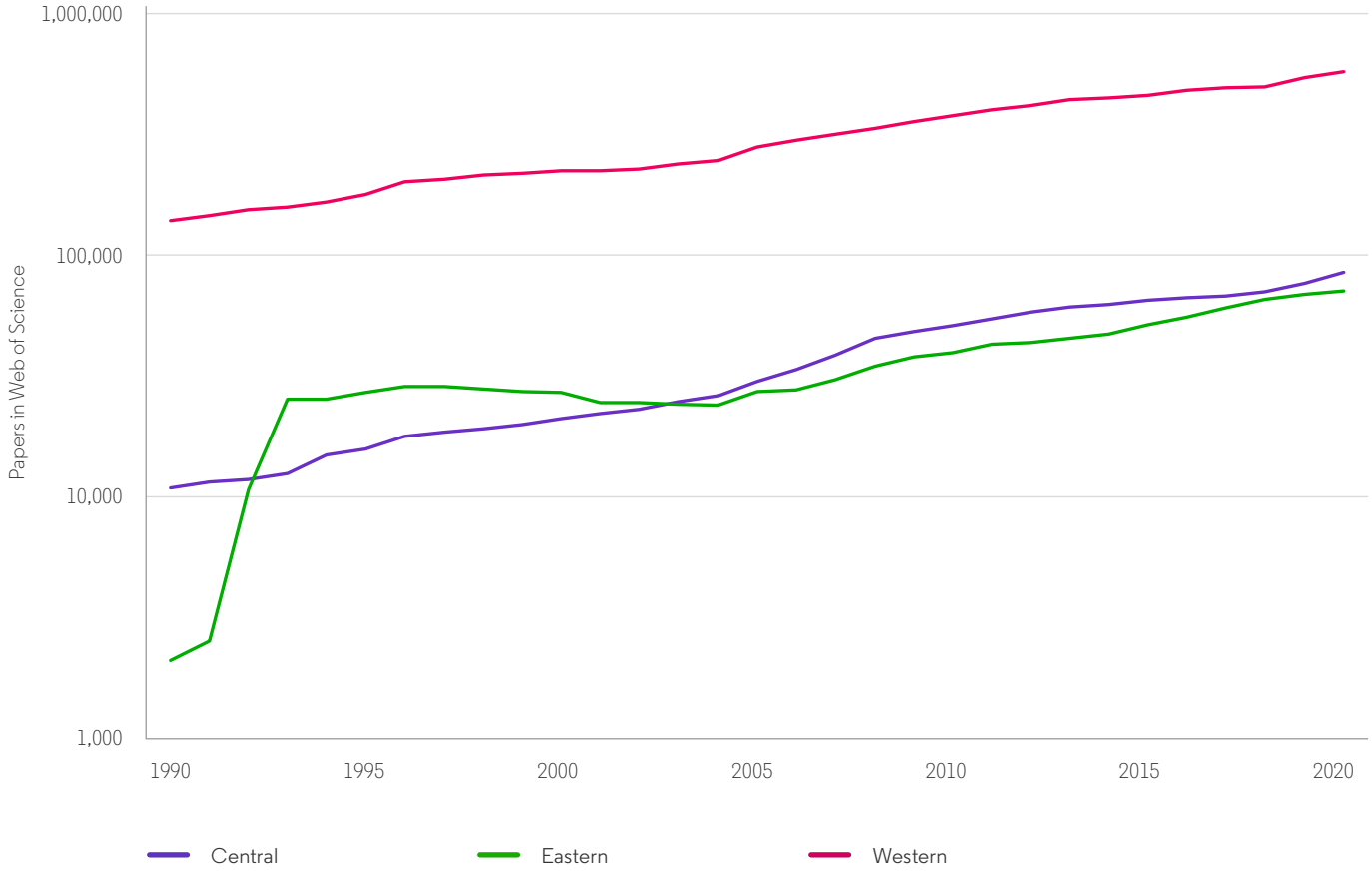
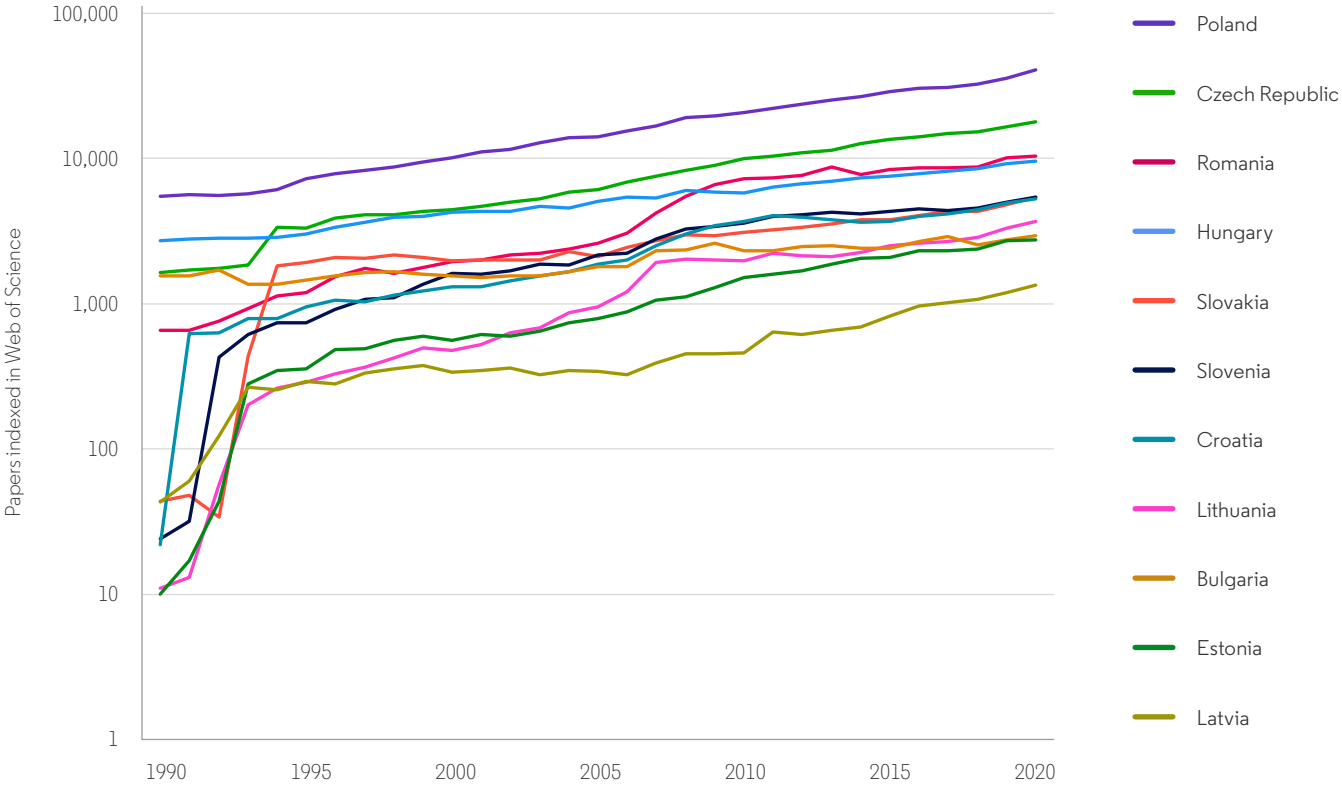


Figure 2. The national publication output of the 11 Central European countries that have acceded to the EU since 2000. Note that the vertical axis is a logarithmic plot. Parallel lines indicate that growth rates in these countries are similar. The legend lists the countries in order of descending annual output in 2020.



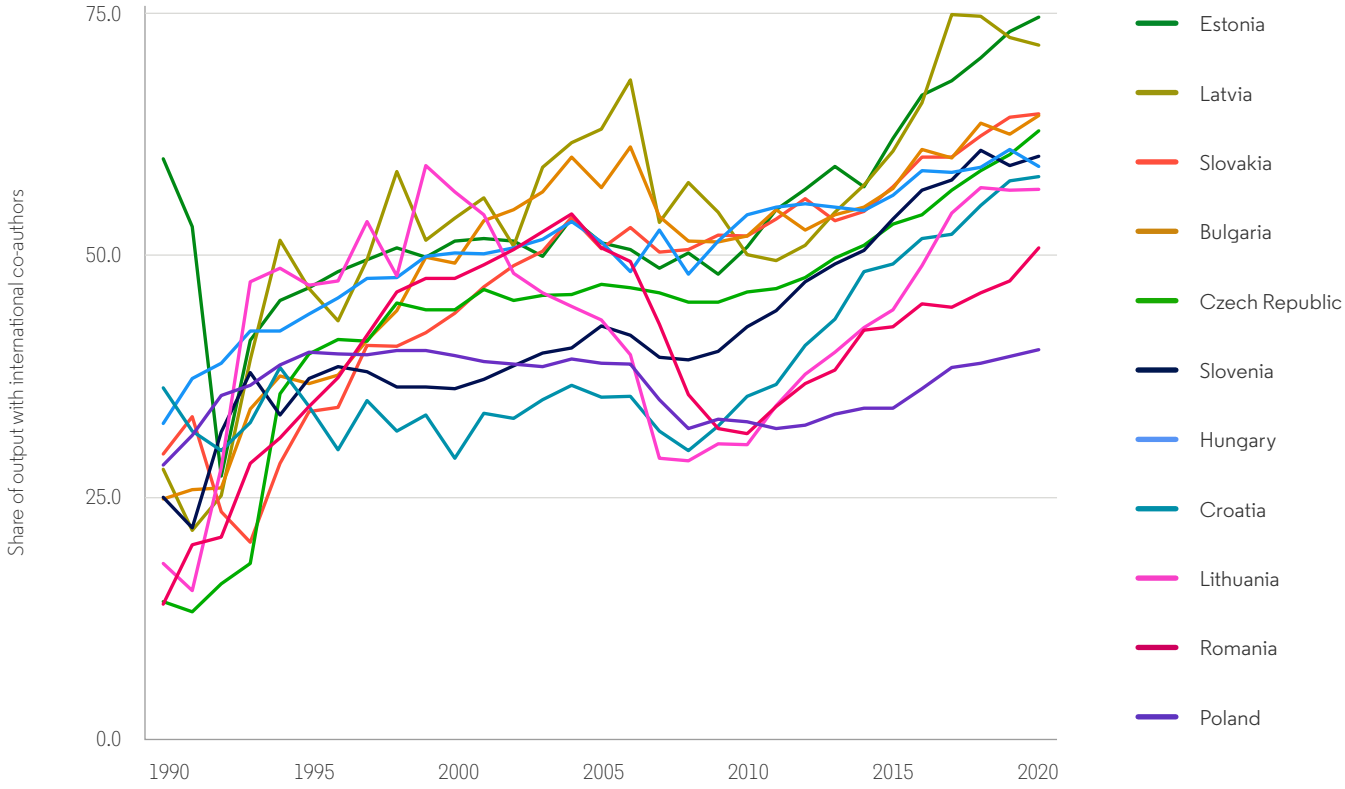
International collaboration

Growth in international collaboration and co-authorship has been a predominant feature of the global research environment over the last few decades. For many countries in Western Europe this has been boosted by the Framework Programmes and has stimulated an increase in international co-authorship from less than 10% of national output in the early 1980s to over two-thirds of output in recent years.

For the accession countries, key questions are how much of their output growth has been mediated through international collaboration, how much collaboration has been with the rest of the EU and how much with Eastern Europe?

The data in Figure 3 show a marked rise in international collaboration in the early 1990s, for all countries except Croatia. Unlike many countries outside this group (Adams, 2013), this does not show a continuous increase but instead plateaus, and then dips for some countries in the mid-2000s, before beginning a more sustained rise from around 2010. Most of these countries joined the EU in 2004 but accession was later for Bulgaria and Romania (Table 1). The stimulus to co-authorship in each country may be linked to these dates, but that argument would not apply to Croatia where growth picks up from 2008 as it did not join the EU until 2013.

Figure 3. International co-authorship. For 11 countries in Central Europe that acceded to the EU since 2000, the percentage of papers published in journals indexed the Web of Science that had international co-authorship. The legend lists the countries in order of descending share of national output (2020) that is internationally co-authored.



There is considerable variation in the national share of output that is internationally collaborative. For Poland and Romania, which have the largest output (Figure 2), it is around 40% but for Estonia and Latvia, which have the smallest output, it is around 70%. This is an important factor to bear in mind in any policy analysis. Internationally co-authored papers tend to receive more attention – often because international collaboration is associated with more challenging research – and consequently are cited more frequently by later research. A high proportion of international co-authorship may boost national average citation impact, but this would not then be a sound reflection of activity in the domestic research base.

European regional collaboration is deconstructed in Figure 4. The total is the complete output for the 11 countries in Central Europe and matches the relevant curve in Figure 1. Within the total area under the curve are stacked the 'bilateral' components that show the co-authored papers with Western Europe and Eastern Europe. There is also a small, but growing, slice of 'trilateral' papers that benefit from at least one author from each of the three European groups.

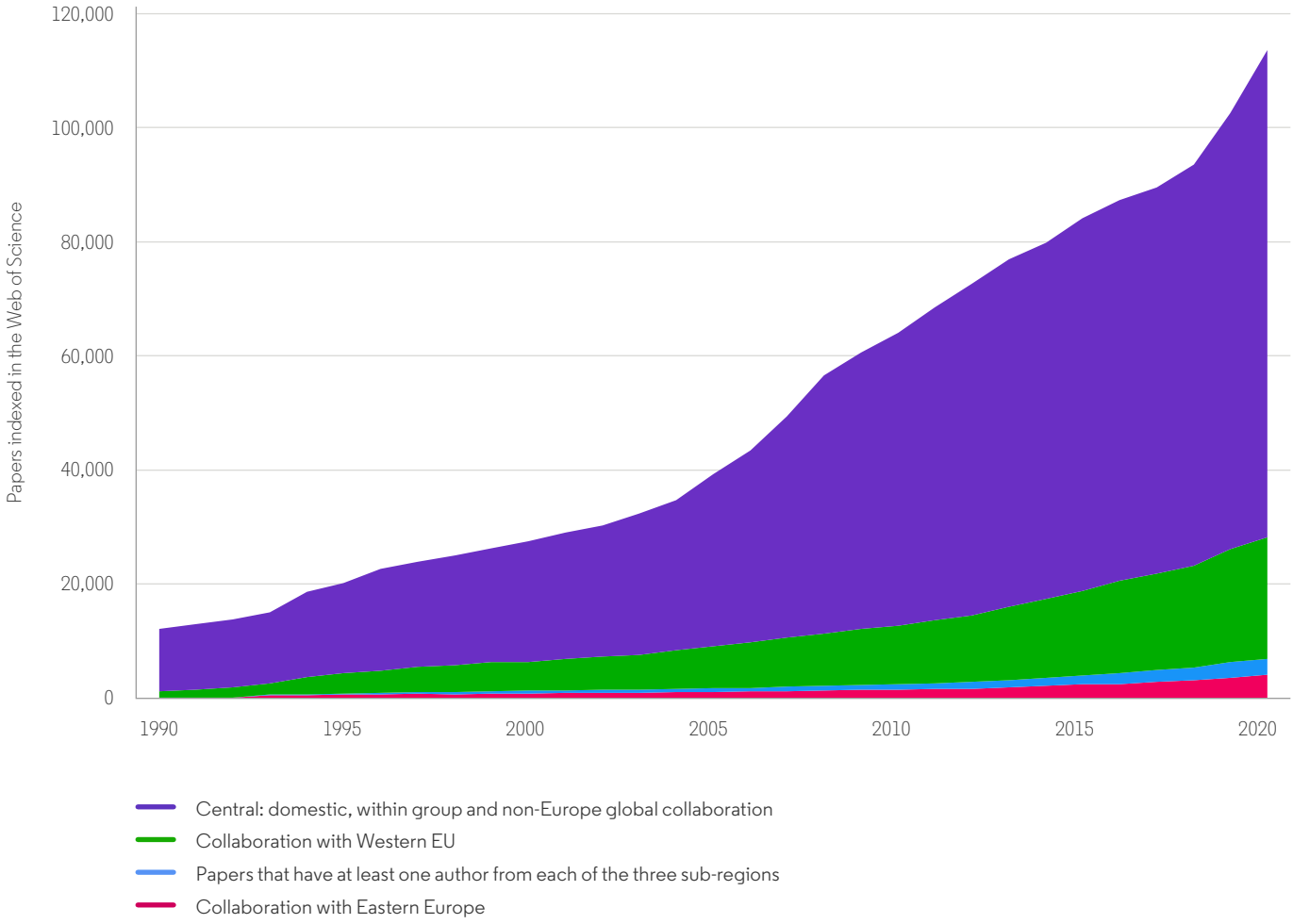
The proportion of activity, within the rising overall volume, that overlaps between regions has changed surprisingly little as a proportion of total Central European research. Output co-authored with Western Europe grew from about 18% in 1990-94 to about 20% of total output in 2015-19, while that with Eastern Europe has grown from 4% to 5%. Thus, although joining the EU research network may have enabled more rapid underlying growth (Figure 1), it does not seem to have influenced the direction of collaboration which evidently always favored Western Europe.

The largest segment in the graph is clearly the part of regional output that is either purely domestic (authors from only one country) or collaborative with another country outside Europe. This reflects not only the strong domestic research base noted in e.g., Poland, Romania and other countries but also the wider global network that Central Europe has established over a relatively short period.

Networking within the group is growing. There are 65 papers published in the period that have co-authors from all 11 countries. If we reduce our focus down to the four largest economies publishing more than 8,000 papers per year (Table 2: Poland, Czech Republic, Hungary and Romania) then we find 2,421 papers since 1990 that have co-authors from all four, of which 2,294 (~95%) were published in the last 10 years. This is important information because these papers appear in each of the country totals, but only once in the regional total, and analysts may want to bear this in mind in interpreting relative collaboration rates.

A key international policy question that is likely to arise in any contemporary research context is the emergence of partnerships with Mainland China, which has been seen to have exceptionally rapid collaborative growth with many G7 nations (Johnson et al., 2021).

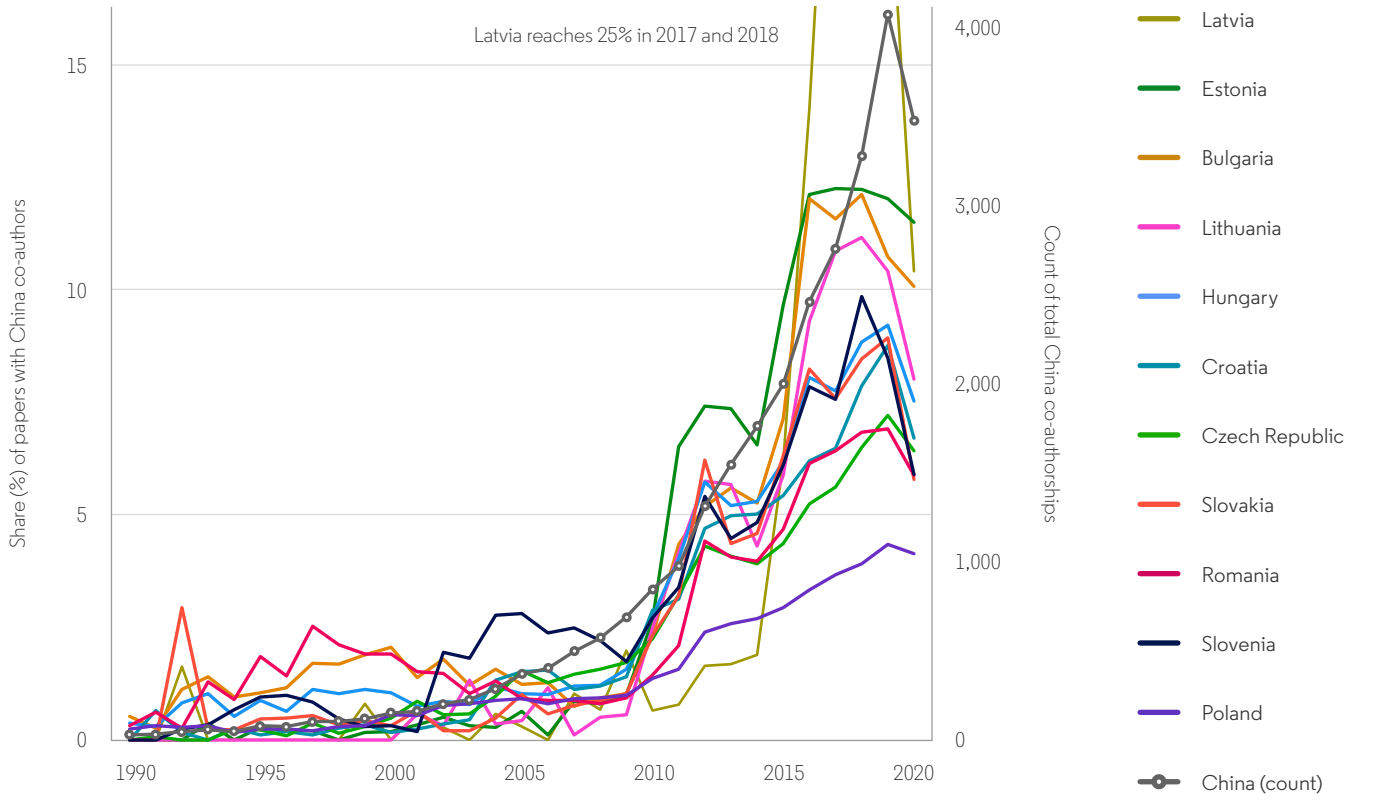
Figure 4. Regional output for 11 countries in Central Europe that acceded to the EU since 2000, disaggregated by collaboration with other sub-regions of Europe.



Such a growth pattern is also seen in Central Europe. In 1997 the number of papers with a Mainland China co-author reached 100, and by 2010 there were still fewer than 1,000 co-authored papers for the 11 countries but by 2020 this had grown to over 4,000 per year. This total accounted for at least 9% of annual output in recent years in every country except Poland, Czech Republic and Romania and exceeds 25% for Latvia in 2018. (Figure 5)

Mainland China is, of course, keen to place and financially support its research students in European research universities with an established culture and diverse research programs (Johnson et al., 2021). Nevertheless, one might note that, whereas the volume of Central Europe's collaboration with Western Europe was 10 times the volume of collaborative output with Mainland China in 2010, it is now the case that it is only four times greater despite an expanded output and despite all Central countries now having access to and full partnership of the EU Framework Programmes.

Figure 5. Co-authorship of research papers with Mainland China (some papers may have authors from additional countries). Data shown are the total regional count of papers published with at least one author from a country in Central Europe that also have a co-author from Mainland China and the percentage of annual output from each of the 11 countries. The legend lists the countries in order of descending share (%) of their papers co-authored with Mainland China.

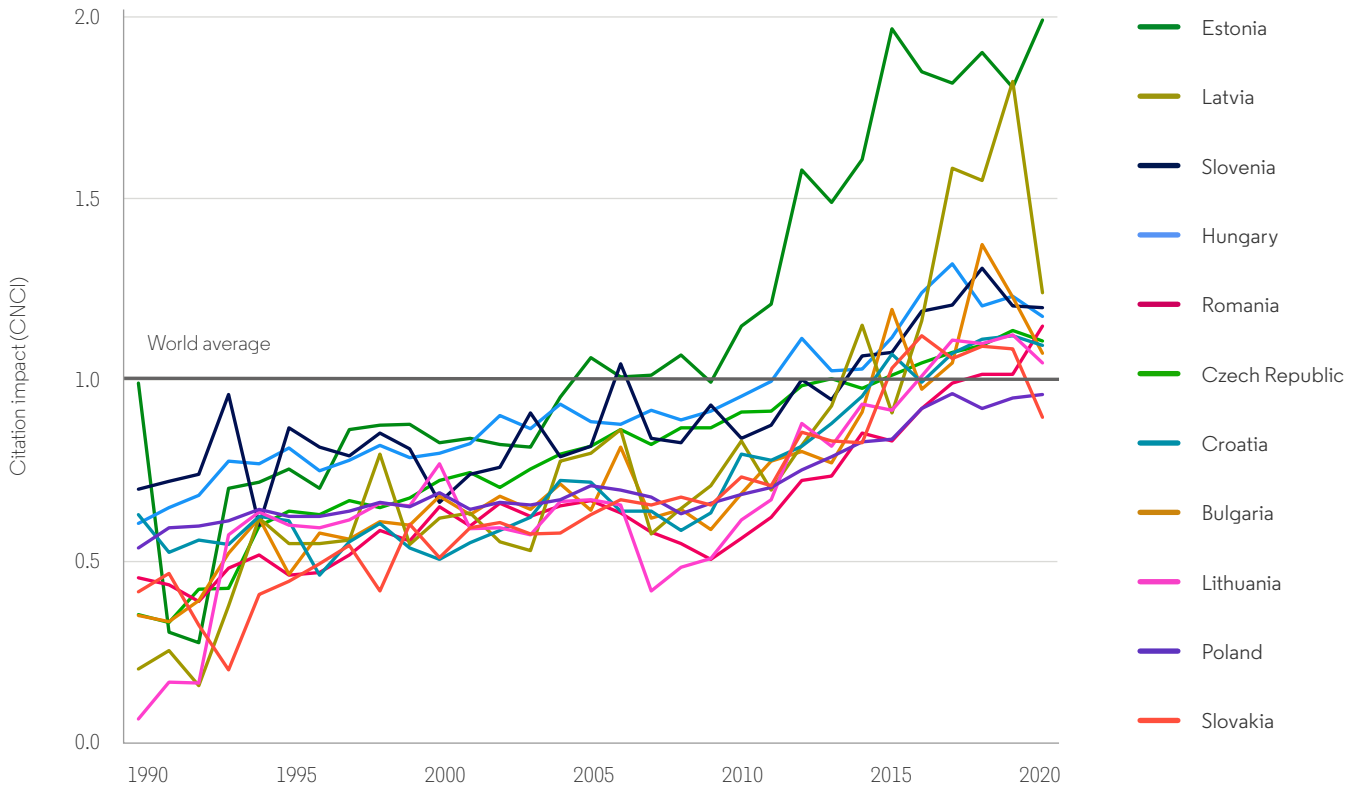


Research impact

As output and collaboration grows, the influence of national research papers evolves, usually also in an upwards direction as the research output draws more attention. The quality of research cannot be measured directly but the academic impact of research is now normally indexed by evaluating the numbers of citations (references) that a paper receives from later literature (Szomszor et al., 2021). Because citations accumulate over time at a rate that is dependent on the research field, it is conventional to 'normalize' the citation count for any one paper against the global average for its year of publication and the subject category of the journal in which it was published. This is referred to as Category Normalized Citation Impact (CNCI: e.g., Potter et al., 2020)

The average annual CNCI for the Central Europe countries was below world average (which is always 1.0 for CNCI) prior to 2000 and for some years thereafter, but the general pattern was for improvement after accession and therefore presumably after joining the Framework Programmes (although there may have been some previous engagement). By 2016, 10 of the countries had passed the world average benchmark and Estonia and Latvia evidenced a quite remarkable climb to near or above twice world average. The exception was Poland, while Slovakia passed 1.0 and then fell back.

Figure 6. Average annual Category Normalized Citation Impact (CNCI) for papers published in journals indexed in the Web of Science and with at least one co-author from one of the 11 Central European countries that gained accession to the EU since 2000. The legend lists the countries in order of descending CNCI.

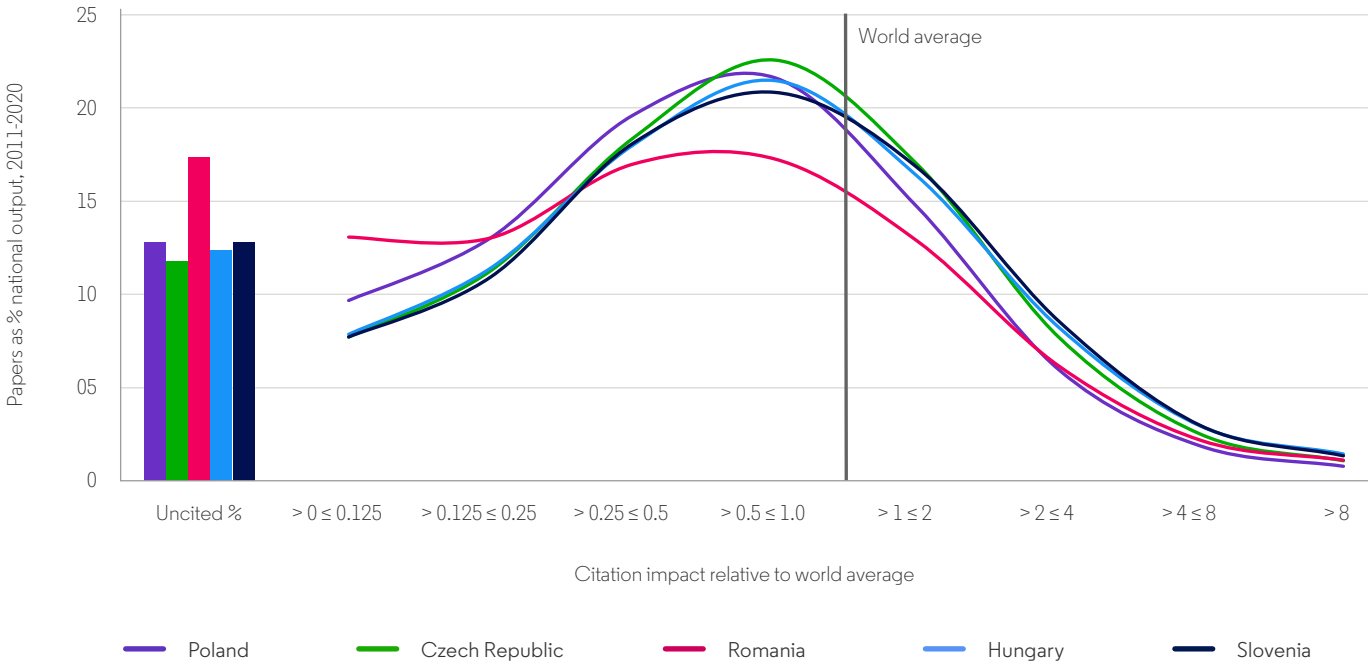


Poland is the most prolific of the 11 countries (Table 2) and has the lowest percentage of international co-authorships (Figure 2: 40% average for the last five years). Estonia and Latvia are the smallest producers of research papers and have the highest level of international collaboration (70% average for the last five years). It is generally true that international co-authorships lead to higher citation rates (Adams et al., 2019; Potter et al., 2020) so the high level of collaboration boosts the average citation count for the smaller portfolios of the Baltic states and the citation counts to these papers are balanced (or diluted) less by their domestic output. Poland's substantial domestic output is a much greater fraction of its overall portfolio and is a dominant factor in its research status and profile.

These annual averages helpfully describe trends but tell us little about the balance of better and poorer activity within each national portfolio. That information comes from shifting the focus of analysis from summary indicators and averages towards visualization of the underlying distribution of weaker, good and excellent activity in Impact Profiles. This is achieved through an Impact Profile (Adams et al., 2007) which allocates the papers by CNCI to a series of nine pots: one uncited, and four above and below world average. This reveals the spread of excellence so that we can compare the percentage of activity in these different impact categories between countries, or indeed between years or institutions.

The Impact Profiles of the five Central Europe countries with the greatest volume of papers demonstrates that though the largest category of output may be below world average, there can still be a substantial share of activity above that benchmark (Figure 7). In fact, more than 10% of the output from the Czech Republic, Hungary and Slovenia is cited more than twice the world average for subject and year. The figure also reveals why the average CNCI for Romania (the fourth largest by volume) is less than that of Slovenia (the fifth largest). Although Romania publishes a similar percentage of papers in high impact categories (above 4 x world) it clearly has fewer papers in the categories around world average but a much higher percentage in the very low impact categories and uncited. Poland also has a higher percentage of papers below world average than the other three but many more than Romania. Slovenia has a particularly strong performance with the greatest percentage of papers in the categories just above world average.

Figure 7. Impact Profile of papers published by researchers in five Central Europe countries between 2011 and 2020. Curves show the percentage of national total in each impact category.



Strengths and specialisms

Analysis of research specialisms and strengths is made complex by the variable scale of research subject categories and a complex relationship between capacity and quality.

Because research categories vary in size, we look not only at absolute volume of publications but also at what they represent in terms of world share of that field. Central Europe's researchers (co)authored some 4.18% of global papers published in journals indexed in the Web of Science between 2016 and 2020. This is an increase from less than 2% of global share in 1990. Table 3 shows that the category with the greatest volume is multidisciplinary materials science (5,545 papers) which captures 4.43% of world share: around the overall average for the region. A greater world share is found in mathematics (2,654 papers, 8.57%) and particle physics (1,178 papers: too few to make the list but 8.87% of world). Interpretation of 'specialism' must therefore be cautious. Looking across countries, it is apparent that the core physical sciences make up a significant part of Central Europe's research strength: share is high in mathematics, physics and materials, and volume is high in Chemistry. Poland appears strong in metallurgy and condensed matter where it has both volume and share but its CNCI is only modest. The Czech Republic appears strong in ecology and plant sciences where it has volume, share and CNCI above world average.

An alternative perspective is obtained by considering the 'top 10' categories not by activity but by impact, where the country's average CNCI is highest. Table 4 lists the 27 subject categories that cover the 'top 10' for the region and the same four countries as Table 3. The subject balance is quite different. Physical sciences are less well represented and biomedical sciences better represented on impact and the arts and humanities have a very substantial presence. However, in none of these high impact areas is there any great volume (meaning average CNCI is more likely to be influenced by outlier values) and all are well below the relevant world share (which has therefore been omitted).

A full analysis requires more attention to detail than we have space for so this can only be a brief introduction to Central Europe as a whole and to the four largest countries. It confirms the impression that the physical sciences remain a lead area for activity, which may prove an interesting complement to the focus on life sciences in Western Europe (Johnson et al., 2021). Priority areas such as climate change and innovative energy technologies are likely to require such competency and capacity.

The assumption that CNCI is always a reliable guide to strengths is challenged by Table 4. An area with only a few specialist groups may be a beacon of quality. Growth of a successful research area may later result in an increased number of more generalist groups, diversity of activity and a beneficial expansion from pure research to its application. Problematically for the analyst, this results in publications of lower average citation impact but greater socio-economic impact. As shown in Figure 7, Impact Profiles help to unpack and interpret these factors.

Central Europe's researchers (co)authored some 4.18% of global papers published in journals indexed in the Web of Science between 2016 and 2020. This is an increase from less than 2% of global share in 1990.

Table 3. Papers authored by Central Europe researchers. Web of Science categories (WoSCats) by greatest volume (2016-2020) for the group as a whole and for the four largest countries by annual publication count: the 18 WoSCats that cover these five 'top tens' are grouped by major disciplines. Data also show world share (%) for all 18 categories and Category Normalized Citation Impact (CNCI). Average world share shown at top of each share column; magenta numbers where share > 1.5 x national average.

Categories of greatest output	Central Europe			Poland			Czech Republic			Romania			Hungary		
% world		4.18			1.74			0.80			0.48			0.44	
	Output	Share	CNCI	Output	Share	CNCI	Output	Share	CNCI	Output	Share	CNCI	Output	Share	CNCI
Mathematics	2,654	**8.57**	1.09	941	**3.04**	0.94	–	**1.30**	–	529	**1.71**	1.83	344	**1.11**	0.86
Mathematics, applied	2,293	**7.78**	0.90	–	**2.71**	–	–	**1.28**	–	520	**1.76**	1.50	–	**0.66**	–
Engineering, electrical/electronic	2,016	2.51	0.77	–	1.03	–	–	0.47	–	–	0.30	–	–	0.14	–
Chemistry, multidisciplinary	4,907	5.92	0.50	1,983	2.39	0.52	842	1.02	0.68	1,011	**1.22**	0.31	335	0.40	0.59
Chemistry, physical	3,904	5.14	0.59	1,909	2.51	0.57	731	0.96	0.66	346	0.46	0.55	320	0.42	0.56
Materials science, multidisciplinary	5,545	4.43	0.64	2,369	1.89	0.67	1,127	0.90	0.72	735	0.59	0.46	327	0.26	0.69
Metallurgy and metallurgical engineering	–	**6.58**	–	855	**3.73**	0.70	–	1.20	–	–	0.48	–	–	0.32	–
Physics, condensed matter	–	5.60	–	968	**2.71**	0.58	–	1.08	–	–	0.57	–	–	0.35	–
Physics, applied	3,462	4.50	0.73	1,530	1.99	0.74	698	0.91	0.81	415	0.54	0.64	–	0.29	–
Physics, multidisciplinary	–	**6.95**	–	–	**3.14**	–	–	1.07		362	**1.51**	1.09	–	**0.66**	–
Astronomy and astrophysics	–	**7.90**	–	–	**3.77**	–	493	**2.21**	1.40	361	0.68	2.15	–	**1.62**	–
Physics, particles and fields	–	**8.87**	–	–	**4.87**	–	434	**3.26**	1.58	–	**1.93**	–	320	**2.41**	1.78
Biochemistry and molecular biology	3,612	4.96	0.88	1,692	2.32	0.79	700	0.96	0.92	–	–	–	406	0.56	1.01
Pharmacology and pharmacy	–	3.99	–	–	1.71	–	–	0.59	–	289	0.59	0.80	259	0.53	1.07
Neurosciences	–	3.28	–	–	1.18	–	–	0.69	–	–	0.16	–	319	**0.67**	0.98
Environmental sciences	4,415	5.63	0.79	2,007	2.56	0.68	753	0.96	1.05	552	0.70	0.69	306	0.39	1.05
Plant sciences	–	5.80	–	–	2.31	–	547	**1.81**	1.17	–	0.27	–	–	0.65	–
Ecology	–	4.93	–	–	1.71	–	414	**1.71**	1.45	–	0.29	–	–	**0.69**	–

Table 4. Papers authored by Central Europe researchers. Ten Web of Science categories (WoSCats) by average Category Normalized Citation Impact (2016-2020) for the group as a whole and for the four largest countries. Data also show absolute output. The 27 WoSCats that cover these five 'top 10' are grouped by major disciplines.

Categories of greatest output	Central Europe		Poland		Czech Republic		Romania		Hungary	
	Output	CNCI	Output	CNCI	Output	CNCI	Output	CNCI	Output	CNCI
Physics, multidisciplinary	–	–	–	–	–	–	–	–	159	3.69
Quantum science & tech	–	–	–	–	–	–	–	–	14	2.94
Allergy	–	–	–	–	20	3.01	26	3.21	–	–
Anesthesiology	–	–	–	–	–	–	7	2.81	–	–
Cardiac & cardiovascular	–	–	–	–	191	2.60	114	2.94	173	2.73
Critical care medicine	102	1.76	36	2.29	27	2.45	12	3.39	–	–
Emergency medicine	–	–	21	2.70	10	3.74	11	3.89	7	4.13
Geriatrics & gerontology	–	–	–	–	34	3.09	–	–	–	–
Medicine, general/internal	140	3.16	41	8.66	10	12.90	18	17.23	–	–
Oncology	–	–	–	–	–	–	–	–	240	2.42
Rheumatology	205	1.80	–	–	42	2.76	–	–	45	2.63
Substance abuse	–	–	–	–	–	–	9	2.91	–	–
Urology & nephrology	–	–	–	–	84	2.58	–	–	–	–
Mycology	179	1.60	–	–	–	–	–	–	29	2.46
Psychology	–	–	–	–	–	–	11	2.90	–	–
Psychology, biological	70	1.73	21	3.78	–	–	–	–	–	–
Psychology, mathematical	11	1.98	–	–	2	4.37	–	–	–	–
Humanities, multidiscipl	–	–	42	2.33	–	–	–	–	–	–
Medieval & Renaissance	35	1.82	–	–	–	–	–	–	4	4.11
Poetry	7	1.77	–	–	2	3.09	–	–	2	2.41
Art	119	2.08	21	4.76	–	–	5	4.78	–	–
Classics	–	–	14	2.09	–	–	–	–	–	–
Religion	–	–	56	2.44	–	–	–	–	–	–
Architecture	68	2.11	5	3.18	–	–	–	–	–	–
Demography	–	–	–	–	–	–	4	3.03	–	–
Film, radio, television	–	–	–	–	–	–	–	–	3	2.53
Ethnic studies	–	–	13	2.15	–	–	–	–	–	–

The impact of institutions

It is challenging, in a regional report, to give a proper appreciation of the range of research institutions across 11 countries. Table 5 provides a summary of the more recent output and citation impact of some of the larger institutions in each country, including the national academies. It is apparent that output has increased markedly for the universities. While the academies have largely maintained their status, comparison with the national data behind Figure 2 shows a reduced contribution in all countries. The Polish Academy of Sciences (PAN) continues to publish about one-sixth of Poland's papers but the Czech (CAS) and Hungarian (MTA) academies are down from about 37% to 30% of their country's output and the Bulgarian academy's (BAS) share is down from about two-thirds to less than half. This change in institutional balance reflects a cultural shift away from research in mission-led institutes towards a more open and dynamic researcher-led environment. Such a shift was also seen in the United Kingdom in the 1990s and later in Germany and France.

Table 5. Publication output and citation impact of the larger academies and universities for each of the 11 countries in Central Europe. Data shown are the annual figures for 2011 and 2020, the total number of papers indexed in Web of Science during that 10-year period and the average Category Normalized Citation Impact for the last five years. Institutions are ordered by type (academies, universities) and total output.

Country	Institution	2011		2020		Total (10 yr)	CNCI (5 yr)
		Papers	CNCI	Papers	CNCI		
Poland	Polish Academy of Sciences	3632	0.93	6247	1.04	49626	1.09
Czech Rep	Czech Academy of Sciences	3775	1.00	5369	1.08	45198	1.10
Hungary	Hungarian Academy of Sciences	2300	1.11	2931	1.22	26887	1.35
Bulgaria	Bulgarian Academy of Sciences	1388	0.79	1442	0.86	13937	0.99
Romania	Romanian Academy of Sciences	932	0.64	1024	0.89	9842	0.75
Czech Rep	Charles University Prague	2973	1.09	4962	1.12	38655	1.26
Poland	Jagiellonian University	1734	0.85	3247	1.03	24694	1.33
Slovenia	University of Ljubljana	1973	0.88	2883	1.10	22535	1.22
Poland	University of Warsaw	1326	1.16	2477	1.33	18755	1.39
Czech Rep	Masaryk University, Brno	855	0.81	1959	1.09	13981	1.08
Slovakia	Comenius University, Bratislava	827	0.98	1502	0.93	11754	1.16
Estonia	University of Tartu	835	1.16	1369	1.68	11658	1.94
Hungary	Eötvös Loránd University	817	1.13	1420	1.56	10600	1.73
Hungary	Semmelweis University	740	1.02	1340	1.31	9945	1.47
Lithuania	Vilnius University	763	0.96	1276	1.16	9434	1.17
Romania	Babeş-Bolyai University, Cluj	821	0.72	989	1.19	9103	1.02
Romania	University of Bucharest	762	0.60	906	0.95	8364	0.80
Croatia	University of Split	505	1.43	712	1.04	5832	1.37
Bulgaria	University of Sofia	494	1.15	546	0.78	5342	0.98
Latvia	University of Latvia	294	0.46	487	1.18	3874	1.34

Collaboration between academies and universities varies between countries. In Poland, PAN's 68 institutes have some but limited collaboration with universities whereas CAS, in the Czech Republic, has co-authors from Charles University on about 25% of its papers and MTA, in Hungary, has a similar overlap with Eötvös Loránd University. The trend is generally towards reduced collaboration, and this may reflect a changing status for the academy institutes.

Citation impact has improved for almost every institution, sometimes by a marked degree, and three-quarters now have an average CNCI above world average. A key driver in this growth and improvement is the expansion of international collaboration that we documented earlier.

Research portfolio insights

The recent development of the Collab-CNCI indicator (Potter et al., 2020) has provided additional insight into country and institution research output previously hidden by the standard CNCI and other indicator measures. One advantage of the Collab-CNCI method is the dissection of publications into national and international collaboration types, namely: domestic single and multi-institutional papers, and international bilateral, trilateral and quadrilateral plus papers.

Data covering articles published in the Web of Science Core Collection between 2009 and 2018 (inclusive) illustrates the differences in CNCI, as well as article and citation counts, across the five collaboration types, for four of the Central European countries (Figure 8) and four institutions (Figure 9).

The analyses for CNCI and total cites in Figures 8 and 9 are presented using boxplots. This allows the range of values for a variable to be plotted while also emphasizing the core of the distribution. The colored boxes span the range between the lower and upper quartiles of the data distribution; the bar within it is the median for the range; the white or gray square is the mean. The bar to the right of the box marks 1.5 times the interquartile range (following Tukey: see McGill et al., 1978) and the values beyond that are then high outliers. The distribution for the number of articles and total cites are presented in bar charts.

On average, citation counts and mean CNCI increases as articles become more collaborative (i.e., domestic single papers have the lowest mean CNCI; international quadrilateral plus, the highest). However, the distribution of articles and citations is inconsistent between the collaboration types.

Poland's article output (~280,000 in the period of interest) was overwhelmingly domestic, accounting for almost 70% of national output: this is corroborated by its relatively low international collaboration rates (see Figure 3). Forty-three percent of Poland's articles were domestic single author, but these accounted for only 32% of its total citations (a cites-to-article ratio of 0.74). Domestic multi-institutional articles fared slightly worse with 25% output accounting for 16% of citations (a cites-to-article ratio of 0.64). In contrast, international quadrilateral plus articles accounted for over 30% of all citations received, despite accounting for only 8% of article output (a cites-to-article ratio of 3.75).

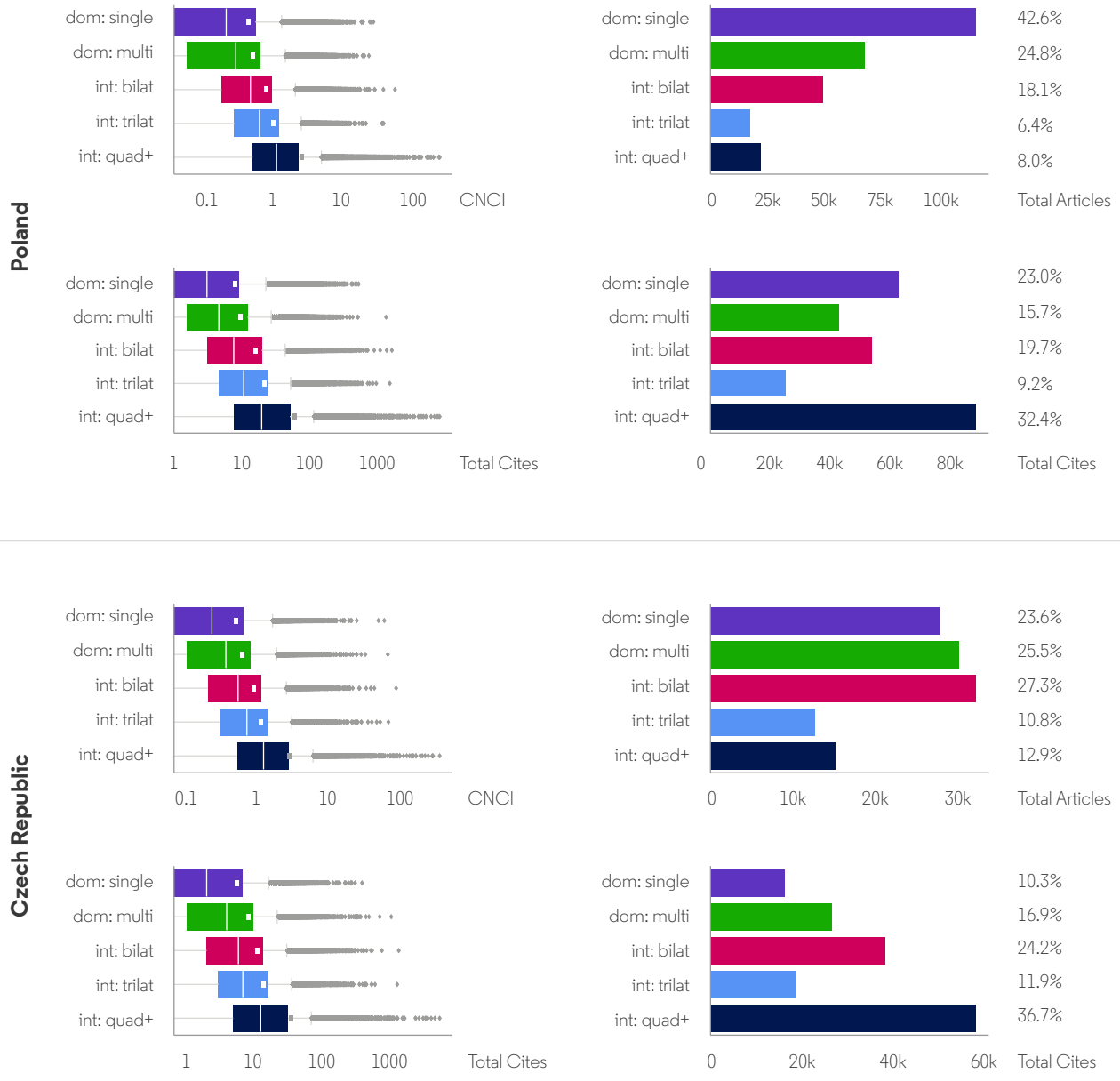
The Czech Republic, whose total article output (~120,000) is slightly less than half of Poland's, shows a more balanced distribution with the domestic groups and bilateral articles each accounting for about one quarter of output. Again, however, citation share for these groups was notably lower, though difference in international bilateral was only ~3%. As with Poland, most citations were from international quadrilateral plus articles (37% from 13% of articles). Overall, domestic and international collaborative output were roughly equal over the period, though the Czech Republic has seen a steady growth in international collaboration since 2010 (Figure 3).

Croatia's overall output (~45,000) is approximately one third of the Czech Republic. Sixty percent of its output was domestic but this only accounted for ~25% of citations. International bilateral article output and citation share were even (~21%). International quadrilateral plus accounted for more than double the citation share of trilateral (45%), though its article share was roughly half (11%). Croatia's international output has also notably increased since 2010; prior to 2010 its international share was lower than Poland's but by 2020 it had significantly exceeded it (Figure 3).

Estonia is the smallest country, of this group, by research output (~20,000), with just under half the output of Croatia and one fourteenth of Poland's. Unlike the other countries, international quadrilateral plus accounts for almost one quarter of output; domestic single and international bilateral output is also approximately one quarter. However, quadrilateral plus still dominated citation share accounting for 59%; international bilateral was the only other group to account for more than 10% of citations. Figure 3 shows that Estonia's international collaboration has increased significantly since 2010, reaching almost 75% in 2020 (though in 2010 it ranked above most of its peers). The rate of increase is comparable to that of Croatia.

These examples demonstrate that Central European national citation counts are heavily sourced from their international quadrilateral plus papers. Though the absolute output of these types of articles is low, the sheer volume of citations is likely to skew their CNCI values. This is evidenced by mean CNCI values being close to, or greater than, the upper quartile and the large spread of outlier values beyond (Figure 8). Consequently, the single CNCI value for these countries will hide many facets of their research portfolios, as shown here.

Figure 8. Article and citation distribution for four countries covering the period 2009-2018. Articles are divided into five collaboration types: domestic single (dom: single) and multi (dom: multi), and international bilateral (int: bilat), trilateral (int: trilat) and quadrilateral–plus (int: quad+). White or gray squares on boxplots represent the mean. The percentage of total articles and cites is presented to the right of the bar charts.



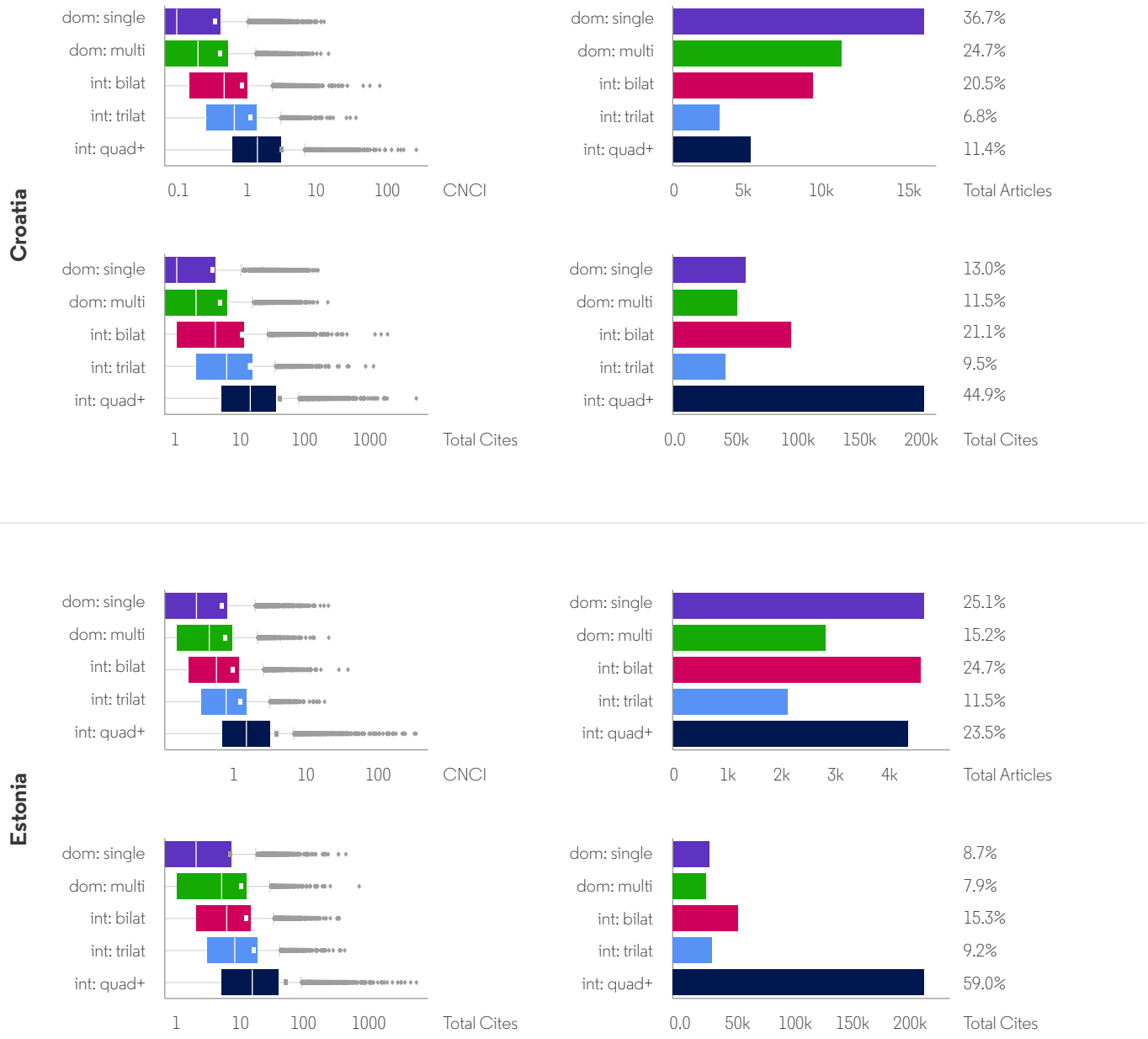


Figure 9 presents the same set of variables as Figure 8 but from the perspective of four institutions.

Eötvös Loránd University, Hungary, has a fairly even spread of article groups – domestic multi and bilateral output is comparable (~27%); international quadrilateral plus accounts for one-fifth of articles, but 52% of citations. International trilateral accounts for ~10% of articles and citations. Overall, output is internationally collaborative (~58%).

University of Ljubljana, Slovenia, unlike its peers, has domestic single articles as its most productive group (~32%), roughly 1.5 times that of domestic multi and international bilateral. Again though, international quadrilateral plus accounts for the largest share of citations (~39%) despite having only 13% of the article output. This institution has a slight majority of domestic collaborations (~53%).

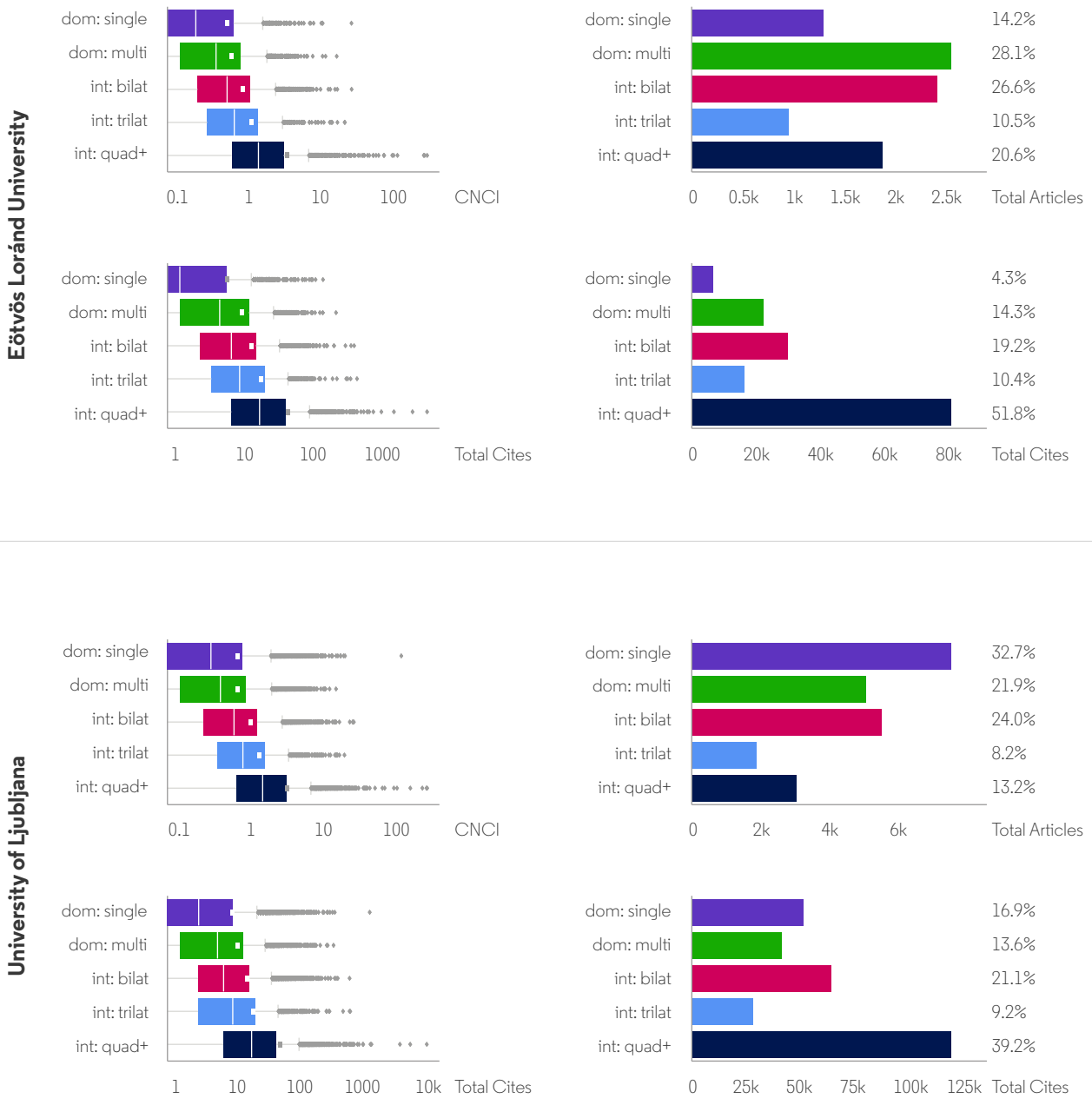
University of Split, Croatia, has a slight majority of internationally collaborative articles (~54%); most of those articles are international quadrilateral plus accounting for ~29% of all articles (though domestic multi output is comparable). This most collaborative group accounts for ~77% of all citations; no other collaboration type accounts for more than 8% of citations.

University of Tartu heavily mirrors the output of Estonia as a whole – a fairly even spread of output between the collaboration types but a high citation share for international quadrilateral plus articles (52%). Internationally collaborative output is the same as Eötvös Loránd University (~58%).

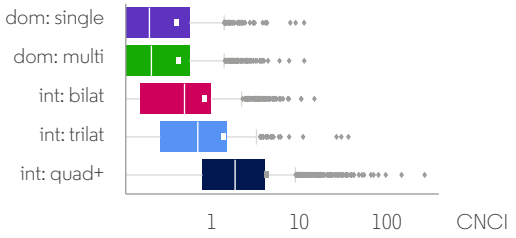
As at national level, institutional citations are also driven by highly collaborative papers – citation shares for all quadrilateral plus groups were greater than their article share. Of the other collaboration groups, only international trilateral for Eötvös Loránd University and University of Tartu (11%) had comparable article output share and citation share. Again, highly collaborative articles will skew CNCI values presenting an incomplete picture (in the context of a single CNCI value) of the institutions' research portfolio (all quadrilateral plus article CNCI means are at, or above, the upper quartile).

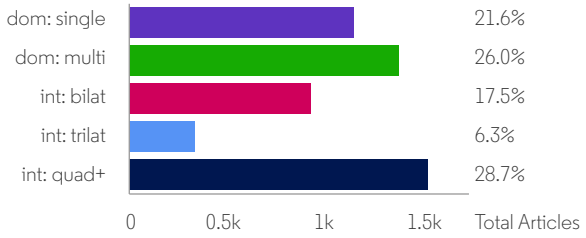
These analyses highlight the importance of differentiating collaboration types from one another. Such insights are not only valuable from a pure analysis perspective but also help research managers and funders, both at national and institutional level, to better understand output and identify areas of opportunity.

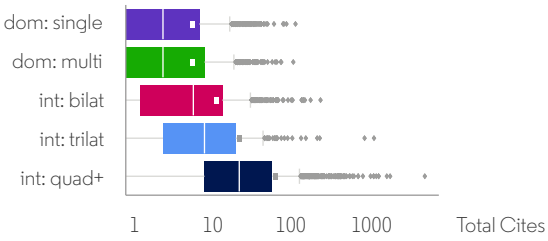
Figure 9. Article and citation distribution for four institutions covering the period 2009-2018. Articles are divided into five collaboration types: domestic single (dom: single) and multi (dom: multi), and international bilateral (int: bilat), trilateral (int: trilat) and quadrilateral–plus (int: quad+). White or gray squares on boxplots represent the mean. The percentage of total articles and cites is presented to the right of the bar charts.

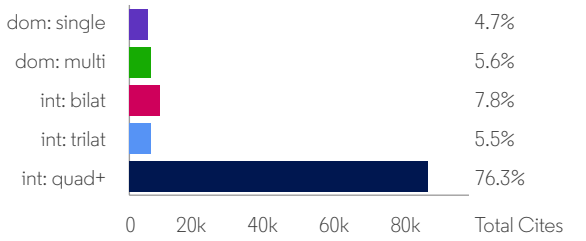


University of Split

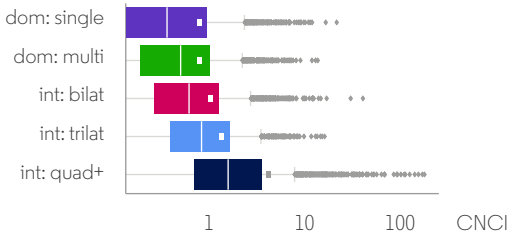


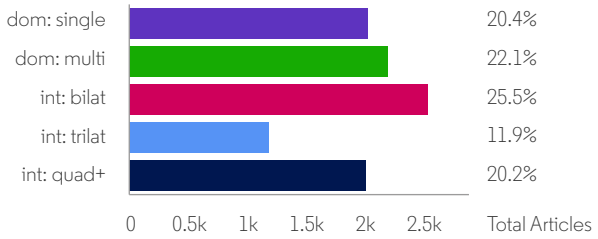


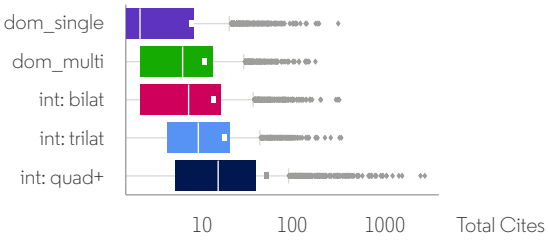


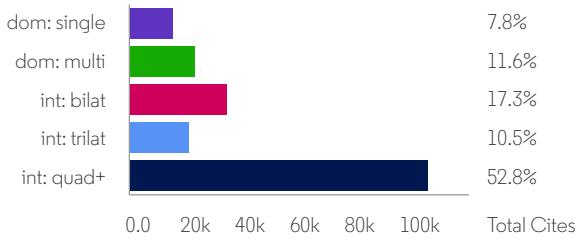


University of Tartu









Overview

Central Europe has seen a doubling of its share of global papers over the last 30 years, likely due to its increase in international collaboration.

Though this 'Central' European group of 11 countries only began joining the EU after 2000, the increase in research publications indexed in the Web of Science has matched that of the pre-2000 EU countries over the last 30 years (Figure 1).

Central Europe has seen a doubling of its share of global papers in this time, likely due to its increase in international collaboration (Figure 3). The rate of international collaboration, however, varies significantly between countries. Estonia and Latvia, two of the smallest by research output, have international collaboration rates around 70%. Conversely, Poland – considerably the largest by research output – has an international collaboration rate of around 40% which is no different to twenty years ago. The increase in international collaboration has also contributed to the region's rising citation impact. Though again there are significant differences between the countries: Estonia has remarkably reached nearly twice world average for CNCI; Poland has yet to surpass world average (Figure 6). However, dissecting collaborative output by national and international types illustrates that citation counts are heavily influenced by highly multi-national papers (Figures 8 and 9).

The physical sciences are a core research focus for the region (with some strong performance in subfields; Tables 3 and 4) which complements the life science focus in Western Europe. This expertise is likely to be crucial for involvement in globally relevant research such as climate change and innovative energy technologies.

The influence of national academies in the region appears to have stagnated or decreased (Table 5). Such a change in institutional balance may reflect a cultural shift in research from mission-led institutes towards a more open and dynamic researcher-led environment in a manner similar to its larger Western European neighbors.

Overall, the Central European region has shown strong, consistent growth in research output over the past 30 years with the increase in international collaboration clearly having a positive impact; countries with lower international collaboration rates may need to consider a change in research strategy. However, how much of the positive impact is due to a country's own researchers is unclear due to the most influential work being highly multi-national. Nevertheless, exposure to other countries' research methods and technology will likely strengthen each Central European country's core research base.

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