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शिक्षा मंत्रालय
MINISTRY OF EDUCATION
सत्यमेव जयते

IISER PUNE

4th G20 EDUCATION WORKING GROUP MEETING

Ministry of Education, Government of India

Special Report Release | IISER Pune | 16th June 2023

Fostering collaboration: a study of scientific publications with authors in G20 countries

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Abstract

The report analyzes the scientific publications with authors in G20 countries, focusing on the main collaboration trends. In 2021, researchers in G20 countries co-authored 75% of the total scientific publications in the World, according to the SCOPUS bibliometric database.

In the last 30 years, some of the G20 countries saw enormous growth in their scientific capacity. In 2021, the number of publications with authors in China was 67 times larger than in 1991. The multiplier was 37 for South Korea, 23 for Brazil, 16 for India.

International co-authorship ranged from 18% to 73%, for the period 2017-2021. Saudi Arabia, Australia, France, and the UK have the highest international collaboration percentages. Different collaboration strategies can be identified. For example, India's main collaborators are the U.S. the UK, and China. China favors collaborating with the U.S., the UK and Australia, the same as South Africa, while Argentina works more with the U.S., Brazil and Germany. The main collaborator for all G20 countries is the U.S., except for Indonesia that favors Japan.

The share of publications in each country targeting each one of the U.N. Sustainable Development Goals varies according to the country's challenges and interests. For the case of India, comparing the periods 2011-2013 and 2020-2022, the data evidences a strong progress in research results related to SDG 07 (Affordable and Clean Energy), SDG 09 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption) and SDG 13 (Climate Action) and a continuing strong showing in SDG 02 (Zero Hunger).

India has increased its international research collaboration in themes related to SDG 07 (Affordable and clean energy). In 2018, 16% of the publications related to SDG 07 had international co-authorship, and in 2022 the percentage grew to 26%.

The report also finds that, in another key type of collaboration, the one between academic and corporate sectors, the countries in the Global South have opportunities to advance. The average share of publications with Academic-Corporate co-authorship for the G20 countries in the Global North was, in 2022, 5.14% of the total number of publications in the country. For those in the Global South the share was, in the same year, 1.89%. Interaction in the G20 might lead to learning useful to help reduce this disparity.

Executive Summary

This report was prepared in the context of the G20 ministerial meeting that took place in India from June 16 to June 22, 2023[1].

The Group of Twenty comprises 19 countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Türkiye, United Kingdom, and United States) and European Union. The report analyses the scientific production of the 19 national entities.

The 19 countries have a wide range of socio-economic characteristics. For example, their GDPs spans a range of 30x, their populations a range of 56. Their Gross Expenditure in Research and Development spans a range of 138.

Nevertheless, they all have vigorous R&D efforts and use science and technology, created by them or learned from others, to benefit their society and their economies.

In 2021, researchers in G20 countries co-authored 75% of the total scientific publications in the World, according to the SCOPUS bibliometric database. The data covers, in the period 2012 to 2021, 24,746,950 scientific publications, with authors distributed in 19,743 research institutions in the 19 countries covered.

In the last 30 years, some of the G20 countries saw enormous growth in their scientific capacity, especially the ones that belong to the Global South. In the period 1999 to 2022, the number of scientific publications with authors in India grew at a CAGR of 11.2% per year. For China the rate was 14.7% per year, for Saudi Arabia 16.0% per year, and for Indonesia 20.1% per year.

The fast growth in the scientific output seen for countries in the Global South points to a fundamental observation apparent from the data shown here: there is a change happening in a visible way in the world research system, in that the capacity to create new science is becoming less concentrated in a small number of nations than it used to be a few decades ago.

For the countries in the Global South a key challenge is to create the conditions for the business sector to increase their in-house R&D.

International co-authorship, for the five years from 2017-2021, ranged from 18% to 73%. Saudi Arabia, Australia, France, and the UK have the highest international collaboration percentages.

Argentina, China, India, Saudi Arabia, South Africa and Turkey saw the Field Weighted Citation Impact of their publications above the world average in 2021.

1. For this reason, in some examples, the report uses some examples and cases that refer to the India science system, while still maintaining a broad vision of the G20 research landscape. We also chose to consider, in many instances, the categorization of countries according to their belonging to what is generally defined as Global North and Global South, following the Finance Center for South-South Cooperation (FCSSC), a non-profit international organization registered and founded in Hong Kong in April 2014. Since 2017, FCSSC has been in Special Consultative Status with ECOSOC of the United Nations. (see http://www.fc-ssc.org/en/partnership_program/south_south_countries)

The United States was the main collaborator for 17 of the 18 G20 partnering countries, in the period 2017-2021. Indonesia had Japan as its larger collaborator.

China was the second most important partner to two countries in 2012-2016 (Japan and South Korea) and turned out to be second larger collaborator to four G20 countries in 2017-2021 (Japan, South Korea, Australia, and Canada).

The other country from the Global South that appeared as second most important collaborator in at least one case is Brazil: in both periods it was the second main collaborator to Argentina.

The share of publications in each country targeting each one of the U.N. Sustainable Development Goals varies according to the country's challenges and interests.

For the case of India, comparing the periods 2011-2013 and 2020-2022, the data evidences a strong progress in research results related to SDG 07 (Affordable and Clean Energy), SDG 09 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption) and SDG 13 (Climate Action) and a continuing strong showing in SDG 02 (Zero Hunger).

For the case of SDG 07 (Affordable and Clean Energy) an analysis of the publications with authors in India show that there has been an increase in the international collaboration since 2018: in 2018, 16% of the publications related to SDG 07 had international co-authorship, and in 2022 the percentage grew to 26%.

The United States and the United Kingdom show similar profiles across the SDGs, showing special strength in SDG 01 (No Poverty), SDG 05 (Gender Equality), SDG 10 (Reduced Inequality), as well as in SDG 16 (Peace, Justice, and Strong Institutions).

Academic-Corporate research collaboration, as measured by the co-authorship in research publications, shows strong differences between countries in the Global North and Global South. The average share of publications with Academic-Corporate co-authorship for the G20 countries in the Global North was, in 2022, 5.14% of the total number of publications in the country. For those in the Global South the share was, in the same year, 1.89%. Interaction in the G20 might lead to learning useful to help reduce this disparity.

Contents

The Group of Twenty (G20) was created in 1999 after the Asian financial crisis of 1997-98 as an informal forum for the Finance Ministers and Central Bank Governors of the most important industrialized and developing economies to discuss international economic and financial stability.

The group was upgraded to the level of Heads of State/Government in the wake of the global economic and financial crisis of 2007, and in 2009, when it became apparent that the necessary crisis coordination would only be possible at the highest political level. Since then, the G20 Leaders have met regularly, and the G20 has become the premier forum for international economic cooperation, but other topics such as education, research and development collaboration, global health challenges, have been part of the agenda for discussions.

The G20 has 19 countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, and United States) and European Union. The members represent around 85% of the global GDP, over 75% of global trade, and about two-thirds of the world population. G20 is the premier forum for international economic cooperation, and it plays an important role in shaping and strengthening global architecture and governance on all major international economic issues. Table 1 shows the GDP, population, GDP per capita, and the Gross Expenditure in R&D (GERD) for each of the 19 countries in G20.

Table 1. GDP, Population, GDP per capita and Gross Expenditure on R&D for each of the 19 countries in G20.

	GDP 2019 ($PPP million)	Population (million)	GDP p. capita 2019 ($PPP)	Gross Expenditure on R&D, 2019 ($PPP million)
Argentina	1,033,737.6	44.9	23,003.28	4,886.1
Australia	1,315,385.7	25.3	51,909.02	24,057.3
Brazil	3,241,317.4	211.8	15,304.91	39,251.0
Canada	1,871,922.1	37.6	49,783.53	32,898.2
China	23,441,908.8	1,407.7	16,652.10	525,693.4
France	3,403,158.8	67.4	50,500.96	74,589.7
Germany	4,769,453.9	83.1	57,399.01	151,081.4
India	9,526,237.3	1,383.1	6,887.54	58,721.4
Indonesia	3,331,570.5	269.6	12,358.24	7,051.4
Italy	2,735,555.9	59.7	45,799.40	39,982.8
Japan	5,358,467.5	126.6	42,314.94	172,245.5
South Korea	2,247,126.6	51.8	43,410.30	103,975.2
Mexico	2,529,761.7	125.1	20,224.29	7,182.9
Russian Federation	4,412,881.4	144.4	30,558.80	45,687.0
Saudi Arabia	1,678,594.2	35.8	46,852.30	8,728.7

	GDP 2019 ($PPP million)	Population (million)	GDP p. capita 2019 ($PPP)	Gross Expenditure on R&D, 2019 ($PPP million)
South Africa	838,593.1	58.1	14,436.83	5,147.9
Turkey	2,313,146.5	83.5	27,708.43	24,653.0
United Kingdom	3,319,199.2	66.8	49,661.60	87,808.3
United States	21,372,572.4	328.3	65,094.80	677,881.0

Sources: GDP, Population: World Bank; GERD: OECD MSTI, NSF Science and Engineering Indicators, 2022; Brazil: MCTI: Indicadores Nacionais de Ciência e Tecnologia 2022, UNESCO IS

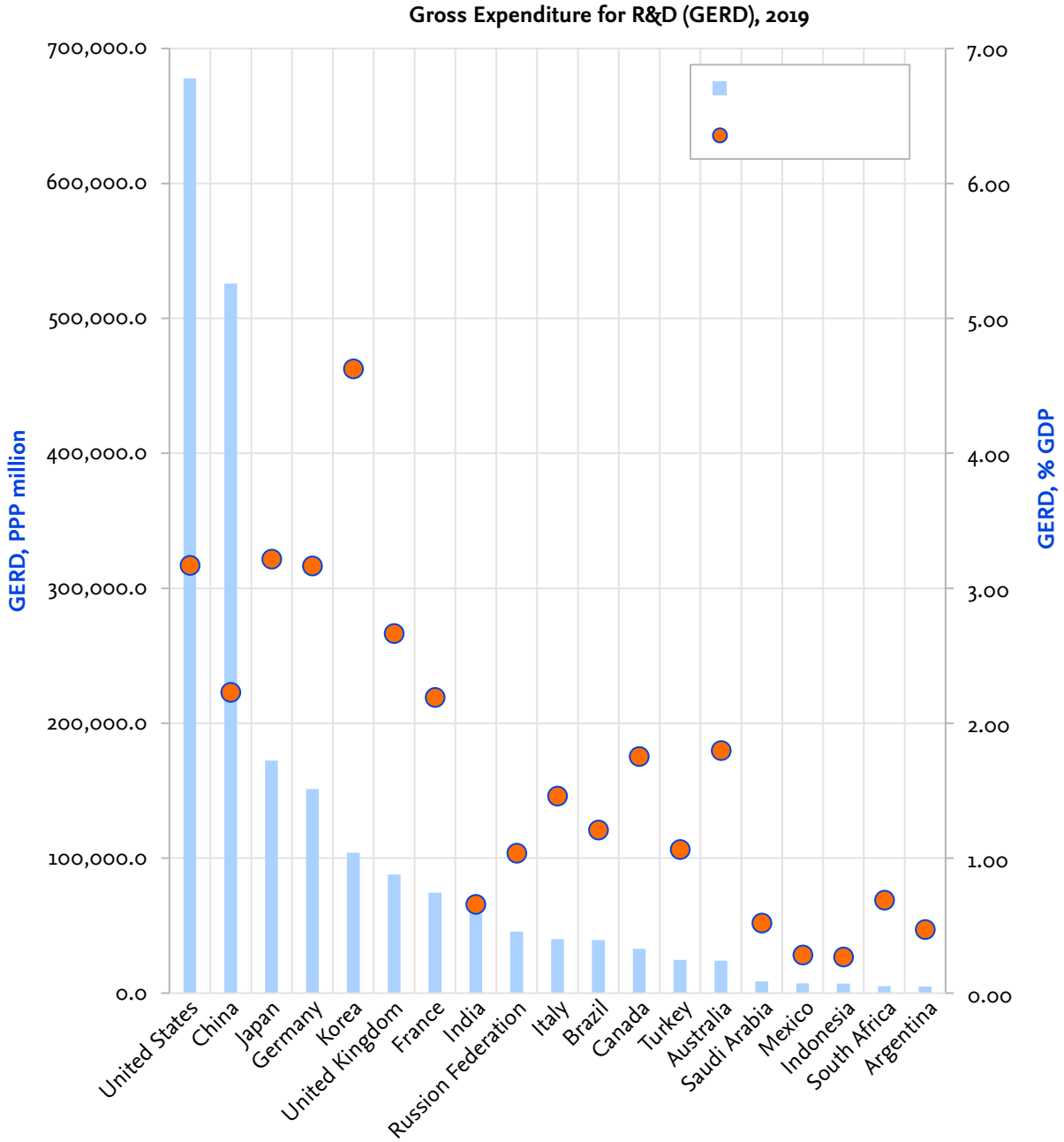


Figure 1. Gross Expenditure on Research and Development (GERD) for each of the G20 countries. The values are shown using Purchase Power Parity (PPP) exchange rate (blue columns) and as a percentage of the country's GDP (yellow circles). (Sources are the same as for Table 1

Figure 1 uses the data from Table 1 to compare the GERD for each of the G20 countries, for 2019, using units of Purchase Parity Power converted from Local Currency Units and in percentage of the country GDP.

This report analyses key aspects of the scientific publications with authors in the 19 G20 countries, such as quantity, collaboration patterns, and connection to the U.N. Sustainable Development Goals (SDGs). The data covers, in the period 2012 to 2021, 19,743 research institutions to which the authors are affiliated.

Figure 2, where the countries were grouped according to being part of the Global North (the first nine countries to the left) or Global South (the last ten countries, to the right of the graph), shows that, for those in the Global South, there is a dominance of Academic-type entities, and a deficit of Corporate-type entities. This points to one of the main challenges for countries in the Global South: that of advancing the R&D capacity in the business sector. In each country there are some companies that have strong and competitive R&D, but the challenge is to have R&D well distributed over the corporate sector, in order to gain the best benefit from the research capacity and training offered by the academic sector.

Table 2. Breakdown of the number of research entities covered by the data used in the report. (Source: Elsevier SciVal).

Country/Region	All types	Govt	Academic	Medical	Corporate	Other
All G20 countries	16,743	1,989	6,226	1,823	5,601	1,104
Argentina	93	11	58	14	9	1
Australia	443	65	113	79	141	45
Brazil	476	54	302	65	38	17
Canada	436	61	116	41	181	37
China	1,345	94	927	106	214	4
France	578	55	242	101	173	7
Germany	1,297	312	232	50	689	14
India	1,158	205	809	69	63	12
Indonesia	160	6	148	0	4	2
Italy	421	49	87	156	111	18
Japan	2,014	203	621	381	693	116
Mexico	163	28	110	15	5	5
Russian Federation	566	252	286	2	25	1
Saudi Arabia	81	5	50	21	5	0
South Africa	98	19	41	11	10	17
South Korea	336	61	148	6	118	3
Turkey	292	13	231	29	18	1
United Kingdom	1,914	183	222	257	977	275
United States	4,872	313	1,483	420	2,127	529

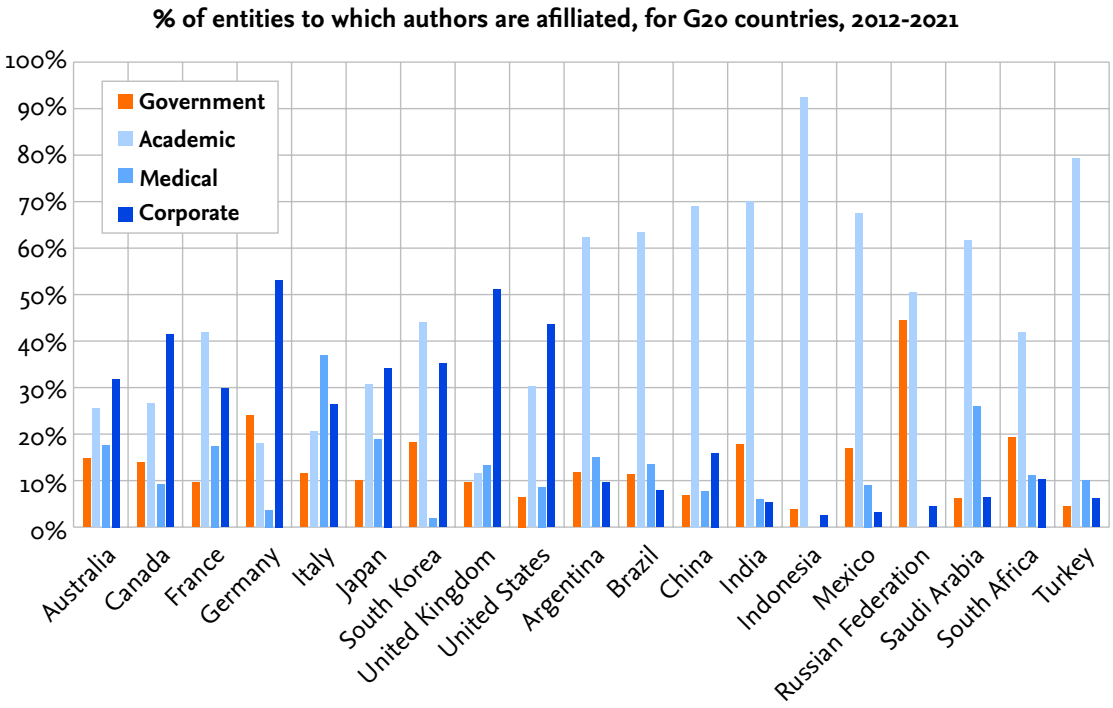


Figure 2. Share of research entities by type, for the G20 countries and the period 2012-2021. The nine countries to the left are the ones from the Global North, the ten ones to the right are the ones from the Global South. (Source: Elsevier SciVal).

For the G20 countries in the Global North, the average share of publications with authors in the corporate sector is 2.8%, from 2012 to 2021. For the G20 countries from the Global South this percentage is 0.8%. The share for each country is shown in Figure 3. This fundamental difference between research systems in the North and in the South is frequently overseen, especially in the Global South.

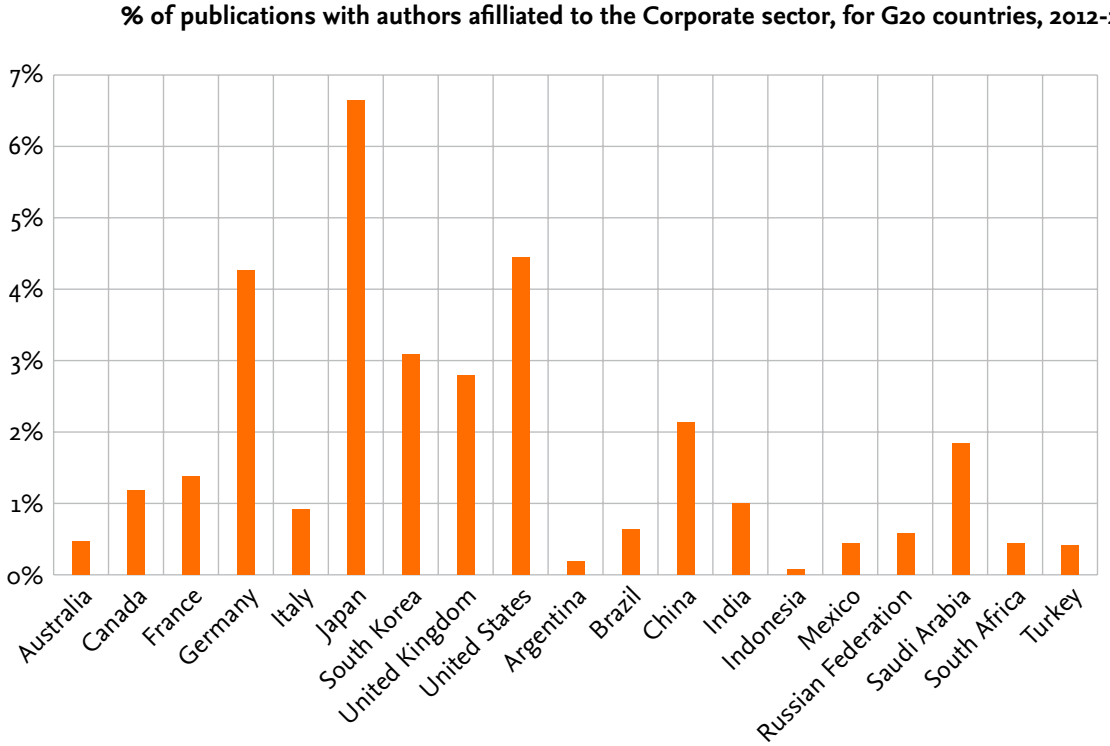


Figure 3. Share of the publications in each G20 country with authors affiliated to entities in the corporate sector, for the period 2012-2021. The nine countries to the left are the ones from the Global North, the ten ones to the right are the ones from the Global South. (Source: Elsevier SciVal).

1 The scientific publications with authors in G20 countries

1.1 The number of publications

In 1999, authors in the G20 published 894,723 scientific publications, 72% of the World total. By 2022, this number grew to 3,140,584 publications, 79% of the World total in the same year (Figure 4).

The countries with the largest number of publications in 2022 are China, United States, and India (Table 3), a marked change in comparison to 1999 when the larger publishers were the United States, Japan and the United Kingdom. China took the first position since 2020, and India overcame the United Kingdom in 2022.

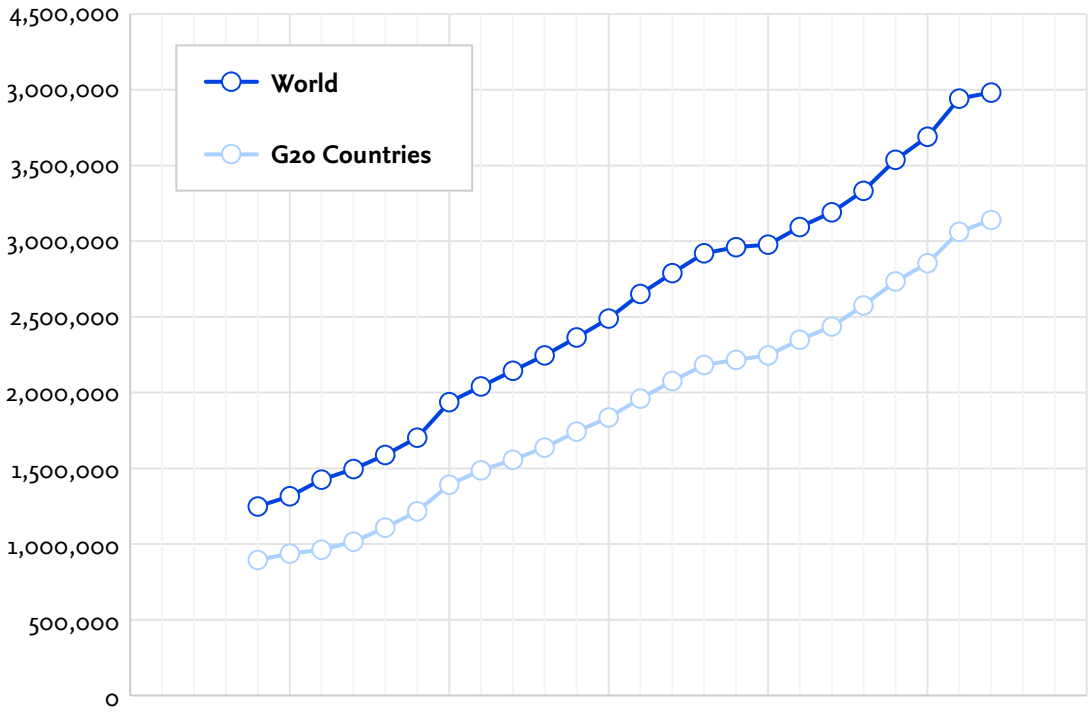


Figure 4. World publications, G20 countries publications and G20 percentage, from 1999 to 2022 (Source: Elsevier SCOPUS).

Table 3. Number of publications for G20 countries in 1999 (when the G20 was formed) and in 2022, and the CAGR in the period, for each case. (Source: Elsevier SciVal).

	1999	2022	CAGR
Argentina	5,157	16,530	5.2%
Australia	29,009	125,915	6.6%
Brazil	13,518	93,766	8.8%
Canada	42,818	132,057	5.0%
China	43,786	1,022,322	14.7%
France	62,458	124,689	3.1%
Germany	85,673	201,735	3.8%
India	24,110	278,496	11.2%
Indonesia	641	43,538	20.1%
Italy	41,806	153,603	5.8%
Japan	102,608	142,114	1.4%
Mexico	6,279	32,618	7.4%
Russian Federation	33,243	109,712	5.3%
Saudi Arabia	1,931	59,215	16.0%
South Africa	5,249	34,425	8.5%
South Korea	17,137	103,690	8.1%
Turkey	7,850	72,015	10.1%
United Kingdom	99,388	237,842	3.9%
United States	358,767	721,251	3.1%
G20	894,723	3,140,584	5.6%
World	1,248,097	3,982,475	5.2%

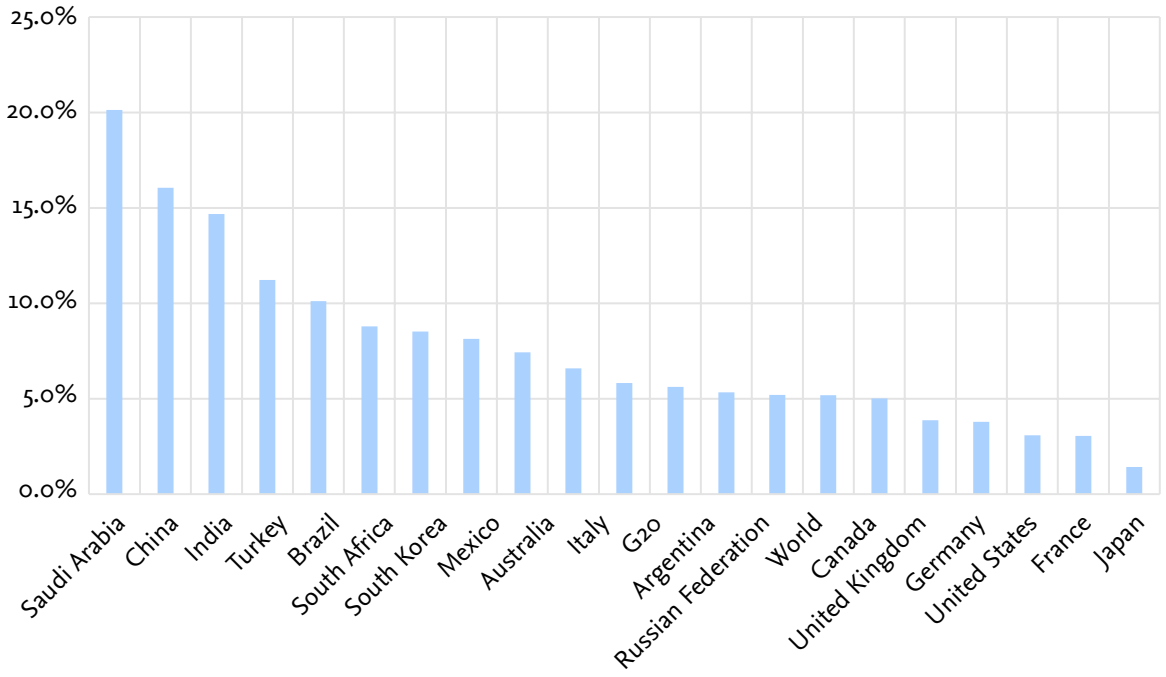


Figure 5. CAGR for the number of scientific publications with authors in each of the G20 countries, from 1999 to 2022. (Source: Elsevier, SciVal).

Since the creation of the G20 group of countries, in 1999, the number of scientific publications with authors in G20 countries grew steadily, at a CAGR of 5.6% per year. The seven with the larger CAGR are countries in the Global South, four of those with double digit values for the CAGR: Indonesia (20.1%), Saudi Arabia (16.0%), China (14.7%), India (11.2%), and Turkey (10.1%). Brazil (8.8%) and South Africa (8.5%) were slightly below 10%, still with a strong CAGR. Among countries in the Global North, South Korea had the highest CAGR, at 8.1%, followed by Australia at 6.6%. Figure 5 shows the data for all the G20 countries.

1.2 The citation impact of the publications

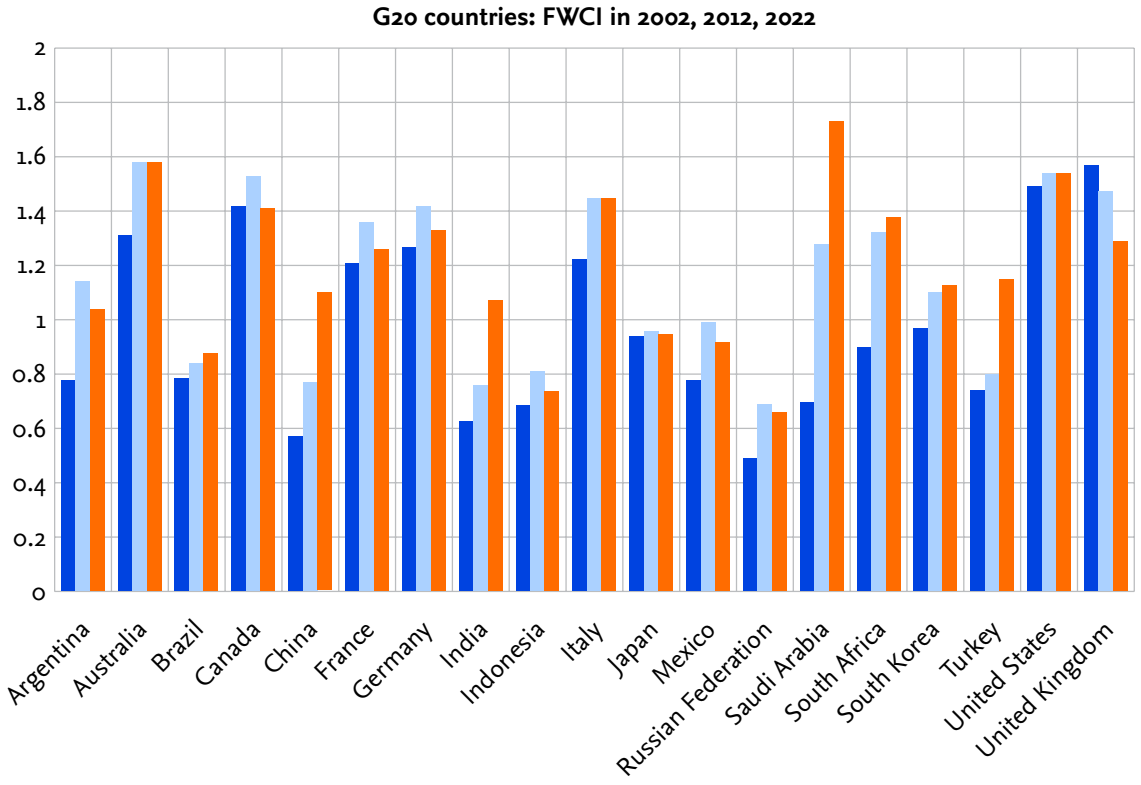


Figure 6. Field Weighted Citation Impact for each of the G20 countries in the years 2002, 2012, and 2022 (Source: Elsevier SciVal).

The citations to the publications with authors in each country offer a window (with limitations, but still useful) to estimate the influence of the publications in the scientific literature in the field. Figure 6 shows the evolution, over 20 years, of the Field Weighted Citation Impact of the publications in each of the G20 countries. South Africa, Turkey, India, China, and Saudi Arabia had the larger advances in this indicator. Among countries in the Global South, Russia, Argentina, and Mexico had increases above 20%, while Brazil and Indonesia rose by 10%. On the other hand, the United States had a decrease of 20%, from a FWCI of 1.57 in 2002 to 1.29 in 2022, a result that may be affected by the increase in the number of publications in other countries, especially in the Global South (in 2002 the United States had authors in 27% of the World total publications, while in 2022 this percentage fell to 18%, as a result of increases elsewhere).

1.3 Publications among the Top 10% cited in the World

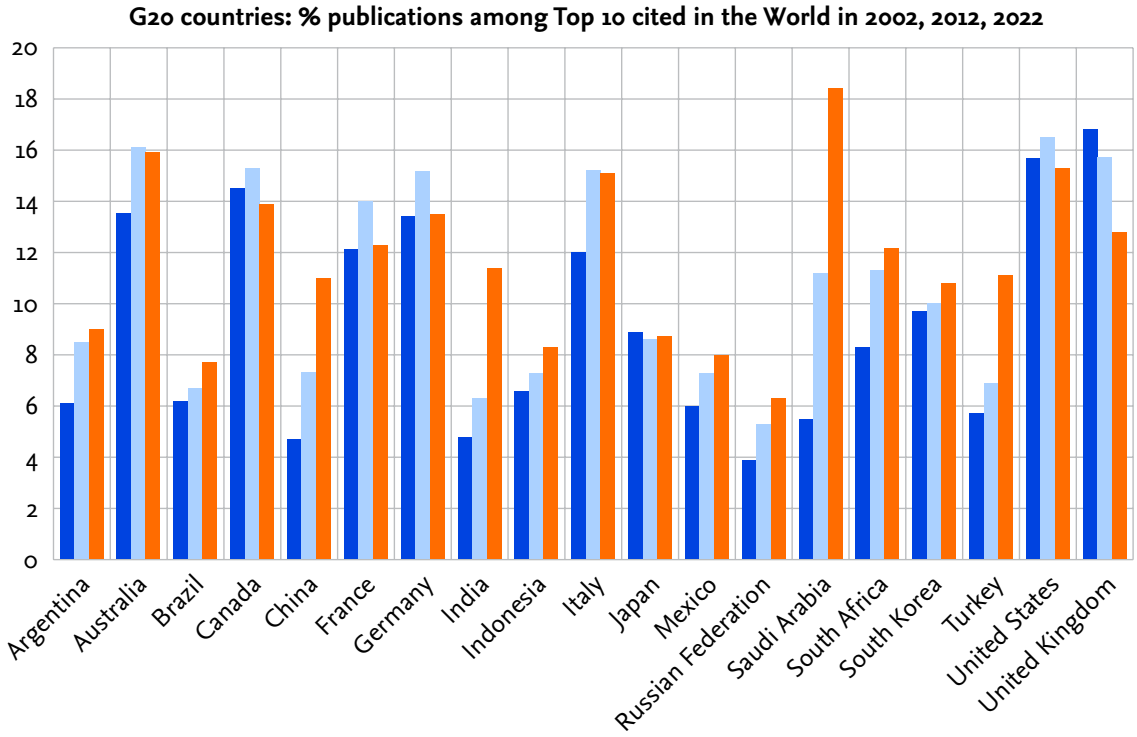


Figure 7. Percentage of publications among the 10% most cited in the World, for each of the G20 countries for the years 2002, 2012, and 2022. (Source: Elsevier SciVal).

Figure 7 shows how the percentage of the publications among the 10% most cited in the World changed, for each of the G20 countries, considering the years 2002, 2012, and 2022. For the countries in the Global North, an increase from 2002 to 2022 is seen for South Korea, Australia, and Italy. France, Germany, Japan, United Kingdom, and Canada had no changes, while for the United States there was a decrease from 16.8% to 12.8% in the same period.

For the G20 countries in the Global South, all had increases in the percentage of their publications among the 10% most cited. For Saudi Arabia, India, China, Turkey and South Africa the percentage went above 10%. Saudi Arabia, India and China had the largest increases: Saudi Arabia more than tripled the percentage among the 10% most cited, India multiplied it by 2.4, while China had a multiplication factor of 2.3. The overall tendency seen in the G20 shows a convergence in this indicator.

2 International research collaboration patterns for G20 countries

In the period 2017-2021 the percentage of publications with international collaboration[2] in G20 countries ranged from 17.9% (Indonesia) to 73.2% (Saudi Arabia).

Overall, the average share of publications with international collaboration for G20 countries grew from 20.1% (2012-2016) to 24.3% (2017-2021) (Table 4). For all G20 countries the percentage of international co-authorship increased in comparison to the period 2012-2016, except for Indonesia where there was a decrease from 36.6% to 17.9%, and Russia, where the decrease was from 25.6% to 22.2%.

Table 4. Number of publications, number of publications with international co-authors and percentage of international co-authorship, for each of the G20 countries, 2012-2016 and 2017-2021. (Source: Elsevier SciVal).

Total and internationally co-authored publications for each G20 country						
	Total publications		# publications w. int collab		% of publications that have international collaboration	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	66,463	81,164	27,883	36,614	42.0%	45.1%
Australia	472,627	578,697	217,078	324,976	45.9%	56.2%
Brazil	342,882	457,217	95,481	152,365	27.8%	33.3%
Canada	532,707	609,159	246,178	324,997	46.2%	53.4%
China	2,332,128	3,521,761	431,053	787,907	18.5%	22.4%
France	610,913	642,213	301,255	360,210	49.3%	56.1%
Germany	873,062	983,271	398,839	496,277	45.7%	50.5%
India	661,912	1,012,624	104,983	191,017	15.9%	18.9%
Indonesia	38,002	210,283	13,927	37,744	36.6%	17.9%
Italy	546,640	691,004	229,313	319,800	41.9%	46.3%
Japan	673,541	705,614	169,740	211,749	25.2%	30.0%
Mexico	105,826	148,395	41,134	61,971	38.9%	41.8%
Russian Federation	308,726	586,710	79,113	130,201	25.6%	22.2%
Saudi Arabia	87,695	161,340	61,220	118,083	69.8%	73.2%

2. *A publication is considered to have international collaboration if there are at least two authors from different countries.*

South Africa	100,035	148,952	44,229	74,639	44.2%	50.1%
South Korea	394,396	465,224	104,229	136,508	26.4%	29.3%
Turkey	210,439	269,402	41,635	67,201	19.8%	24.9%
United Kingdom	1,031,944	1,168,949	467,939	644,844	45.3%	55.2%
United States	3,415,712	3,663,795	1,022,972	1,299,157	29.9%	35.5%
G20 Total	**11,073,929**	**13,673,021**	**2,380,547**	**3,321,688**	**20.1%**	**24.3%**

The four G20 countries with the highest share of publications with international collaboration were Saudi Arabia (73.2%), Australia (56.2%), France (56.1%), and the United Kingdom (55.2%).

Considering the G20 countries that are part of the Global South, Saudi Arabia, South Africa, Argentina, Mexico, and Brazil show international collaboration above 30% in the period 2017-2021. Comparing the period 2017-2021 to 2012-2016, Turkey, Australia, United Kingdom, and China had relative increments in the percentage of publications with international collaborators above 20%.

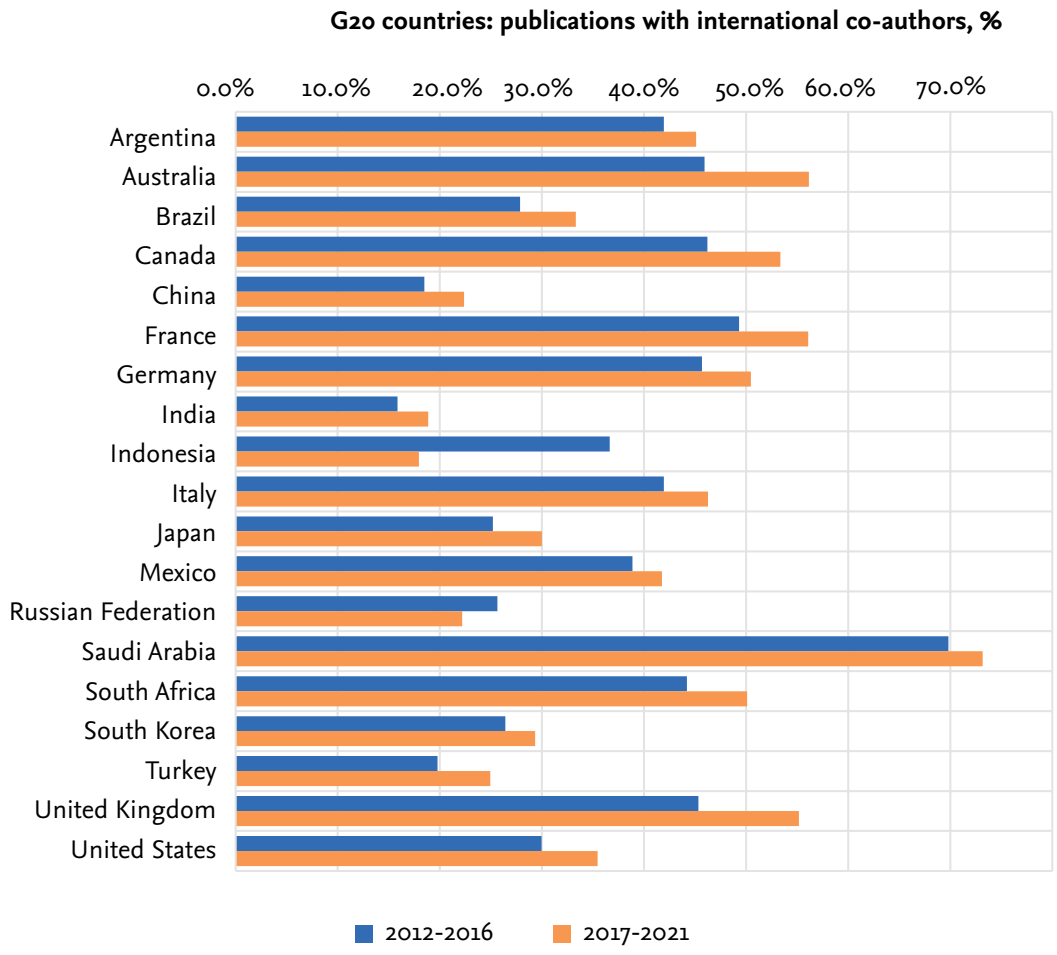


Figure 8. International co-authorship in publications with authors in each of the G20 countries, 2012-2016 and 2017-2021. (Source: Elsevier SciVal).

2.1 Argentina

Table 5. Argentina: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Argentina								
International collaboration by Argentina occurring with each G20 country								
	# of collaborative publications between Argentina and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Argentina's publications		% of publications with collaboration with each G20 country as a share of Argentina's publications with international collaboration		Rank of each country based on share of collaborative publications with Argentina	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Australia	2,035	3,096	3.1%	3.8%	7.3%	8.5%	8	8
Brazil	5,079	6,994	7.6%	8.6%	18.2%	19.1%	2	2
Canada	2,514	3,505	3.8%	4.3%	9.0%	9.6%	7	7
China	1,305	2,173	2.0%	2.7%	4.7%	5.9%	11	10
France	3,594	4,922	5.4%	6.1%	12.9%	13.4%	4	4
Germany	3,826	5,391	5.8%	6.6%	13.7%	14.7%	3	3
India	883	1,344	1.3%	1.7%	3.2%	3.7%	15	14
Indonesia	76	207	0.1%	0.3%	0.3%	0.6%	18	18
Italy	3,074	4,441	4.6%	5.5%	11.0%	12.1%	6	6
Japan	1,370	1,926	2.1%	2.4%	4.9%	5.3%	10	11
Mexico	1,855	3,000	2.8%	3.7%	6.7%	8.2%	9	9
Russian Federation	970	1,409	1.5%	1.7%	3.5%	3.8%	13	13
Saudi Arabia	184	405	0.3%	0.5%	0.7%	1.1%	17	17
South Africa	1,128	1,650	1.7%	2.0%	4.0%	4.5%	12	12
South Korea	369	634	0.6%	0.8%	1.3%	1.7%	16	16
Turkey	900	1,199	1.4%	1.5%	3.2%	3.3%	14	15
United Kingdom	3,227	4,888	4.9%	6.0%	11.6%	13.4%	5	5
United States	9,233	12,104	13.9%	14.9%	33.1%	33.1%	1	1

2.2 Australia

Table 6. Australia: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Australia								
International collaboration by Australia occurring with each G20 country								
	# of collaborative publications between Australia and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Australia's publications		% of publications with collaboration with each G20 country as a share of Australia's publications with international collaboration		Rank of each country based on share of collaborative publications with Australia	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	2,035	3,096	0.4%	0.5%	0.9%	1.0%	16	18
Australia	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Brazil	5,832	10,939	1.2%	1.9%	2.7%	3.4%	10	10
Canada	19,276	29,311	4.1%	5.1%	8.9%	9.0%	5	5
China	35,737	75,811	7.6%	13.1%	16.5%	23.3%	3	2
France	15,129	22,208	3.2%	3.8%	7.0%	6.8%	6	6
Germany	22,135	32,609	4.7%	5.6%	10.2%	10.0%	4	4
India	6,762	14,397	1.4%	2.5%	3.1%	4.4%	9	9
Indonesia	2,123	4,438	0.4%	0.8%	1.0%	1.4%	15	15
Italy	11,439	19,002	2.4%	3.3%	5.3%	5.8%	7	7
Japan	10,077	15,574	2.1%	2.7%	4.6%	4.8%	8	8
Mexico	1,857	3,177	0.4%	0.5%	0.9%	1.0%	18	17
Russian Federation	3,424	5,913	0.7%	1.0%	1.6%	1.8%	13	13
Saudi Arabia	2,803	5,903	0.6%	1.0%	1.3%	1.8%	14	14
South Africa	5,285	8,674	1.1%	1.5%	2.4%	2.7%	11	11
South Korea	4,701	8,218	1.0%	1.4%	2.2%	2.5%	12	12
Turkey	1,998	3,595	0.4%	0.6%	0.9%	1.1%	17	16
United Kingdom	44,982	66,691	9.5%	11.5%	20.7%	20.5%	2	3
United States	63,029	88,456	13.3%	15.3%	29.0%	27.2%	1	1

2.3 Brazil

Table 7. Brazil: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Brazil								
International collaboration by Brazil occurring with each G20 country								
	# of collaborative publications between Brazil and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Brazil's publications		% of publications with collaboration with each G20 country as a share of Brazil's publications with international collaboration		Rank of each country based on share of collaborative publications with Brazil	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	5,079	6,994	1.5%	1.5%	5.3%	4.6%	8	9
Australia	5,832	10,939	1.7%	2.4%	6.1%	7.2%	7	7
Brazil	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Canada	7,868	13,942	2.3%	3.0%	8.2%	9.2%	6	6
China	4,474	8,392	1.3%	1.8%	4.7%	5.5%	9	8
France	11,932	16,865	3.5%	3.7%	12.5%	11.1%	3	4
Germany	11,037	17,488	3.2%	3.8%	11.6%	11.5%	4	3
India	3,303	6,378	1.0%	1.4%	3.5%	4.2%	12	10
Indonesia	231	788	0.1%	0.2%	0.2%	0.5%	18	18
Italy	8,913	14,858	2.6%	3.2%	9.3%	9.8%	5	5
Japan	3,380	5,839	1.0%	1.3%	3.5%	3.8%	11	12
Mexico	3,657	6,107	1.1%	1.3%	3.8%	4.0%	10	11
Russian Federation	3,186	4,744	0.9%	1.0%	3.3%	3.1%	13	13
Saudi Arabia	817	1,618	0.2%	0.4%	0.9%	1.1%	17	17
South Africa	2,144	3,708	0.6%	0.8%	2.2%	2.4%	14	14
South Korea	1,837	3,097	0.5%	0.7%	1.9%	2.0%	16	15
Turkey	2,004	2,965	0.6%	0.6%	2.1%	1.9%	15	16
United Kingdom	13,060	22,870	3.8%	5.0%	13.7%	15.0%	2	2
United States	34,089	52,690	9.9%	11.5%	35.7%	34.6%	1	1

2.4 Canada

Table 8. Canada: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Canada								
International collaboration by Canada occurring with each G20 country								
	# of collaborative publications between Canada and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Canada's publications		% of publications with collaboration with each G20 country as a share of Canada's publications with international collaboration		Rank of each country based on share of collaborative publications with Canada	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	2,514	3,505	0.5%	0.6%	1.0%	1.1%	17	17
Australia	19,276	29,311	3.6%	4.8%	7.8%	9.0%	6	6
Brazil	7,868	13,942	1.5%	2.3%	3.2%	4.3%	9	8
Canada	0	0	0.0%	0.0%	0.0%	0.0%	19	19
China	29,888	54,016	5.6%	8.9%	12.1%	16.6%	3	2
France	23,650	31,318	4.4%	5.1%	9.6%	9.6%	4	5
Germany	23,327	32,513	4.4%	5.3%	9.5%	10.0%	5	4
India	6,252	10,281	1.2%	1.7%	2.5%	3.2%	10	10
Indonesia	334	825	0.1%	0.1%	0.1%	0.3%	18	18
Italy	13,494	20,291	2.5%	3.3%	5.5%	6.2%	7	7
Japan	9,506	13,164	1.8%	2.2%	3.9%	4.1%	8	9
Mexico	3,122	5,061	0.6%	0.8%	1.3%	1.6%	15	15
Russian Federation	3,857	6,096	0.7%	1.0%	1.6%	1.9%	14	12
Saudi Arabia	3,947	5,746	0.7%	0.9%	1.6%	1.8%	13	14
South Africa	3,978	6,071	0.7%	1.0%	1.6%	1.9%	12	13
South Korea	5,043	7,149	0.9%	1.2%	2.0%	2.2%	11	11
Turkey	2,749	4,182	0.5%	0.7%	1.1%	1.3%	16	16
United Kingdom	34,558	49,511	6.5%	8.1%	14.0%	15.2%	2	3
United States	109,869	139,474	20.6%	22.9%	44.6%	42.9%	1	1

2.5 China

Table 9. China: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

China								
International collaboration by China occurring with each G20 country								
	# of collaborative publications between China and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all China's publications		% of publications with collaboration with each G20 country as a share of China's publications with international collaboration		Rank of each country based on share of collaborative publications with China	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	1,305	2,173	0.1%	0.1%	0.3%	0.3%	17	18
Australia	35,737	75,811	1.5%	2.2%	8.3%	9.6%	3	3
Brazil	4,474	8,392	0.2%	0.2%	1.0%	1.1%	13	13
Canada	29,888	54,016	1.3%	1.5%	6.9%	6.9%	5	4
China	0	0	0.0%	0.0%	0.0%	0.0%	19	19
France	17,780	31,230	0.8%	0.9%	4.1%	4.0%	7	7
Germany	27,174	49,807	1.2%	1.4%	6.3%	6.3%	6	5
India	6,125	17,707	0.3%	0.5%	1.4%	2.2%	11	10
Indonesia	608	2,245	0.0%	0.1%	0.1%	0.3%	18	17
Italy	9,896	21,060	0.4%	0.6%	2.3%	2.7%	9	9
Japan	32,099	46,272	1.4%	1.3%	7.4%	5.9%	4	6
Mexico	2,155	4,349	0.1%	0.1%	0.5%	0.6%	16	16
Russian Federation	6,469	15,238	0.3%	0.4%	1.5%	1.9%	10	11
Saudi Arabia	5,329	14,011	0.2%	0.4%	1.2%	1.8%	12	12
South Africa	2,706	5,899	0.1%	0.2%	0.6%	0.7%	15	15
South Korea	14,839	26,111	0.6%	0.7%	3.4%	3.3%	8	8
Turkey	2,929	6,414	0.1%	0.2%	0.7%	0.8%	14	14
United Kingdom	41,752	89,358	1.8%	2.5%	9.7%	11.3%	2	2
United States	184,602	301,428	7.9%	8.6%	42.8%	38.3%	1	1

2.6 France

Table 10. quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

France								
International collaboration by France occurring with each G20 country								
	# of collaborative publications between France and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all France's publications		% of publications with collaboration with each G20 country as a share of France's publications with international collaboration		Rank of each country based on share of collaborative publications with France	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	3,594	4,922	0.6%	0.8%	1.2%	1.4%	16	16
Australia	15,129	22,208	2.5%	3.5%	5.0%	6.2%	7	7
Brazil	11,932	16,865	2.0%	2.6%	4.0%	4.7%	9	9
Canada	23,650	31,318	3.9%	4.9%	7.9%	8.7%	5	5
China	17,780	31,230	2.9%	4.9%	5.9%	8.7%	6	6
France	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Germany	50,264	62,532	8.2%	9.7%	16.7%	17.4%	3	3
India	7,161	10,581	1.2%	1.6%	2.4%	2.9%	11	11
Indonesia	761	1,592	0.1%	0.2%	0.3%	0.4%	18	18
Italy	40,545	54,315	6.6%	8.5%	13.5%	15.1%	4	4
Japan	13,755	18,736	2.3%	2.9%	4.6%	5.2%	8	8
Mexico	4,794	6,496	0.8%	1.0%	1.6%	1.8%	13	13
Russian Federation	11,256	15,651	1.8%	2.4%	3.7%	4.3%	10	10
Saudi Arabia	2,952	4,761	0.5%	0.7%	1.0%	1.3%	17	17
South Africa	4,707	6,375	0.8%	1.0%	1.6%	1.8%	14	14
South Korea	4,883	6,938	0.8%	1.1%	1.6%	1.9%	12	12
Turkey	4,263	6,251	0.7%	1.0%	1.4%	1.7%	15	15
United Kingdom	50,357	65,881	8.2%	10.3%	16.7%	18.3%	2	2
United States	74,937	90,960	12.3%	14.2%	24.9%	25.3%	1	1

2.7 Germany

Table 11. Germany: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Germany								
International collaboration by Germany occurring with each G20 country								
	# of collaborative publications between Germany and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Germany's publications		% of publications with collaboration with each G20 country as a share of Germany's publications with international collaboration		Rank of each country based on share of collaborative publications with Germany	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	3,826	5,391	0.4%	0.5%	1.0%	1.1%	16	16
Australia	22,135	32,609	2.5%	3.3%	5.5%	6.6%	7	6
Brazil	11,037	17,488	1.3%	1.8%	2.8%	3.5%	10	10
Canada	23,327	32,513	2.7%	3.3%	5.8%	6.6%	6	7
China	27,174	49,807	3.1%	5.1%	6.8%	10.0%	5	5
France	50,264	62,532	5.8%	6.4%	12.6%	12.6%	3	3
Germany	0	0	0.0%	0.0%	0.0%	0.0%	19	19
India	10,142	14,300	1.2%	1.5%	2.5%	2.9%	11	11
Indonesia	992	2,429	0.1%	0.2%	0.2%	0.5%	18	18
Italy	42,828	58,812	4.9%	6.0%	10.7%	11.9%	4	4
Japan	18,696	25,146	2.1%	2.6%	4.7%	5.1%	9	9
Mexico	4,168	6,061	0.5%	0.6%	1.0%	1.2%	15	15
Russian Federation	18,749	26,056	2.1%	2.6%	4.7%	5.3%	8	8
Saudi Arabia	3,624	4,969	0.4%	0.5%	0.9%	1.0%	17	17
South Africa	5,634	8,622	0.6%	0.9%	1.4%	1.7%	14	14
South Korea	7,830	10,811	0.9%	1.1%	2.0%	2.2%	12	12
Turkey	6,073	8,667	0.7%	0.9%	1.5%	1.7%	13	13
United Kingdom	71,000	94,090	8.1%	9.6%	17.8%	19.0%	2	2
United States	113,872	139,375	13.0%	14.2%	28.6%	28.1%	1	1

2.8 India

Table 12. India: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

India								
International collaboration by India occurring with each G20 country								
	# of collaborative publications between India and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all India's publications		% of publications with collaboration with each G20 country as a share of India's publications with international collaboration		Rank of each country based on share of collaborative publications with India	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	883	1,344	0.1%	0.1%	0.8%	0.7%	17	18
Australia	6,762	14,397	1.0%	1.4%	6.4%	7.5%	6	6
Brazil	3,303	6,378	0.5%	0.6%	3.1%	3.3%	13	14
Canada	6,252	10,281	0.9%	1.0%	6.0%	5.4%	8	9
China	6,125	17,707	0.9%	1.7%	5.8%	9.3%	9	3
France	7,161	10,581	1.1%	1.0%	6.8%	5.5%	5	8
Germany	10,142	14,300	1.5%	1.4%	9.7%	7.5%	3	7
India	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Indonesia	494	2,051	0.1%	0.2%	0.5%	1.1%	18	17
Italy	5,805	10,190	0.9%	1.0%	5.5%	5.3%	11	10
Japan	6,534	9,874	1.0%	1.0%	6.2%	5.2%	7	11
Mexico	1,917	3,563	0.3%	0.4%	1.8%	1.9%	16	16
Russian Federation	3,072	6,913	0.5%	0.7%	2.9%	3.6%	14	12
Saudi Arabia	5,992	17,158	0.9%	1.7%	5.7%	9.0%	10	4
South Africa	3,489	6,487	0.5%	0.6%	3.3%	3.4%	12	13
South Korea	8,385	14,416	1.3%	1.4%	8.0%	7.5%	4	5
Turkey	2,103	4,969	0.3%	0.5%	2.0%	2.6%	15	15
United Kingdom	12,431	23,117	1.9%	2.3%	11.8%	12.1%	2	2
United States	34,545	52,966	5.2%	5.2%	32.9%	27.7%	1	1

2.9 Indonesia

Table 13. Indonesia: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Indonesia								
International collaboration by Indonesia occurring with each G20 country								
	# of collaborative publications between Indonesia and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Indonesia's publications		% of publications with collaboration with each G20 country as a share of Indonesia's publications with international collaboration		Rank of each country based on share of collaborative publications with Indonesia	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	76	207	0.2%	0.1%	0.5%	0.5%	18	18
Australia	2,123	4,438	5.6%	2.1%	15.2%	11.8%	2	2
Brazil	231	788	0.6%	0.4%	1.7%	2.1%	12	13
Canada	334	825	0.9%	0.4%	2.4%	2.2%	10	12
China	608	2,245	1.6%	1.1%	4.4%	5.9%	8	6
France	761	1,592	2.0%	0.8%	5.5%	4.2%	6	9
Germany	992	2,429	2.6%	1.2%	7.1%	6.4%	5	5
India	494	2,051	1.3%	1.0%	3.5%	5.4%	9	8
Indonesia	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Italy	293	972	0.8%	0.5%	2.1%	2.6%	11	10
Japan	3,348	7,581	8.8%	3.6%	24.0%	20.1%	1	1
Mexico	122	527	0.3%	0.3%	0.9%	1.4%	15	17
Russian Federation	98	729	0.3%	0.3%	0.7%	1.9%	17	14
Saudi Arabia	214	896	0.6%	0.4%	1.5%	2.4%	13	11
South Africa	162	716	0.4%	0.3%	1.2%	1.9%	14	15
South Korea	733	2,105	1.9%	1.0%	5.3%	5.6%	7	7
Turkey	121	628	0.3%	0.3%	0.9%	1.7%	16	16
United Kingdom	1,246	3,547	3.3%	1.7%	8.9%	9.4%	4	4
United States	1,830	4,112	4.8%	2.0%	13.1%	10.9%	3	3

2.10 Italy

Table 14. Italy: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Italy								
International collaboration by Italy occurring with each G20 country								
	# of collaborative publications between Italy and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Italy's publications		% of publications with collaboration with each G20 country as a share of Italy's publications with international collaboration		Rank of each country based on share of collaborative publications with Italy	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	3,074	4,441	0.6%	0.6%	1.3%	1.4%	16	16
Australia	11,439	19,002	2.1%	2.7%	5.0%	5.9%	6	7
Brazil	8,913	14,858	1.6%	2.2%	3.9%	4.6%	9	8
Canada	13,494	20,291	2.5%	2.9%	5.9%	6.3%	5	6
China	9,896	21,060	1.8%	3.0%	4.3%	6.6%	7	5
France	40,545	54,315	7.4%	7.9%	17.7%	17.0%	4	4
Germany	42,828	58,812	7.8%	8.5%	18.7%	18.4%	3	3
India	5,805	10,190	1.1%	1.5%	2.5%	3.2%	11	11
Indonesia	293	972	0.1%	0.1%	0.1%	0.3%	18	18
Italy	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Japan	9,359	13,323	1.7%	1.9%	4.1%	4.2%	8	9
Mexico	3,420	5,460	0.6%	0.8%	1.5%	1.7%	14	14
Russian Federation	7,904	13,110	1.4%	1.9%	3.4%	4.1%	10	10
Saudi Arabia	2,367	4,090	0.4%	0.6%	1.0%	1.3%	17	17
South Africa	3,178	5,113	0.6%	0.7%	1.4%	1.6%	15	15
South Korea	4,092	6,784	0.7%	1.0%	1.8%	2.1%	13	13
Turkey	4,987	8,324	0.9%	1.2%	2.2%	2.6%	12	12
United Kingdom	47,697	70,821	8.7%	10.2%	20.8%	22.1%	2	2
United States	66,849	86,782	12.2%	12.6%	29.2%	27.1%	1	1

2.11 Japan

Table 15. Japan: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Japan								
International collaboration by Japan occurring with each G20 country								
	# of collaborative publications between Japan and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Japan's publications		% of publications with collaboration with each G20 country as a share of Japan's publications with international collaboration		Rank of each country based on share of collaborative publications with Japan	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	1,370	1,926	0.2%	0.3%	0.8%	0.9%	18	18
Australia	10,077	15,574	1.5%	2.2%	5.9%	7.4%	7	6
Brazil	3,380	5,839	0.5%	0.8%	2.0%	2.8%	12	13
Canada	9,506	13,164	1.4%	1.9%	5.6%	6.2%	8	9
China	32,099	46,272	4.8%	6.6%	18.9%	21.9%	2	2
France	13,755	18,736	2.0%	2.7%	8.1%	8.8%	5	5
Germany	18,696	25,146	2.8%	3.6%	11.0%	11.9%	3	3
India	6,534	9,874	1.0%	1.4%	3.8%	4.7%	10	10
Indonesia	3,348	7,581	0.5%	1.1%	2.0%	3.6%	13	11
Italy	9,359	13,323	1.4%	1.9%	5.5%	6.3%	9	8
Japan	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Mexico	1,574	2,358	0.2%	0.3%	0.9%	1.1%	17	17
Russian Federation	5,538	7,438	0.8%	1.1%	3.3%	3.5%	11	12
Saudi Arabia	1,652	2,763	0.2%	0.4%	1.0%	1.3%	16	16
South Africa	1,918	3,012	0.3%	0.4%	1.1%	1.4%	15	14
South Korea	12,896	14,368	1.9%	2.0%	7.6%	6.8%	6	7
Turkey	2,135	2,895	0.3%	0.4%	1.3%	1.4%	14	15
United Kingdom	18,132	24,808	2.7%	3.5%	10.7%	11.7%	4	4
United States	56,212	66,796	8.3%	9.5%	33.1%	31.5%	1	1

2.12 Mexico

Table 16. Mexico: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Mexico								
International collaboration by Mexico occurring with each G20 country								
	# of collaborative publications between Mexico and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Mexico's publications		% of publications with collaboration with each G20 country as a share of Mexico's publications with international collaboration		Rank of each country based on share of collaborative publications with Mexico	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	1,855	3,000	1.8%	2.0%	4.5%	4.8%	12	11
Australia	1,857	3,177	1.8%	2.1%	4.5%	5.1%	11	10
Brazil	3,657	6,107	3.5%	4.1%	8.9%	9.9%	5	4
Canada	3,122	5,061	3.0%	3.4%	7.6%	8.2%	7	7
China	2,155	4,349	2.0%	2.9%	5.2%	7.0%	8	8
France	4,794	6,496	4.5%	4.4%	11.7%	10.5%	2	3
Germany	4,168	6,061	3.9%	4.1%	10.1%	9.8%	4	5
India	1,917	3,563	1.8%	2.4%	4.7%	5.7%	9	9
Indonesia	122	527	0.1%	0.4%	0.3%	0.9%	18	18
Italy	3,420	5,460	3.2%	3.7%	8.3%	8.8%	6	6
Japan	1,574	2,358	1.5%	1.6%	3.8%	3.8%	13	13
Mexico	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Russian Federation	1,902	2,947	1.8%	2.0%	4.6%	4.8%	10	12
Saudi Arabia	560	896	0.5%	0.6%	1.4%	1.4%	17	17
South Africa	850	1,408	0.8%	0.9%	2.1%	2.3%	16	16
South Korea	1,412	2,063	1.3%	1.4%	3.4%	3.3%	14	14
Turkey	1,092	1,773	1.0%	1.2%	2.7%	2.9%	15	15
United Kingdom	4,556	7,390	4.3%	5.0%	11.1%	11.9%	3	2
United States	16,270	23,646	15.4%	15.9%	39.6%	38.2%	1	1

2.13 Russian Federation

Table 17. Russian Federation: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Russian Federation								
International collaboration by Russian Federation occurring with each G20 country								
	# of collaborative publications between Russian Federation and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Russian Federation's publications		% of publications with collaboration with each G20 country as a share of Russian Federation's publications with international collaboration		Rank of each country based on share of collaborative publications with Russian Federation	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	970	1,409	0.3%	0.2%	1.2%	1.1%	16	17
Australia	3,424	5,913	1.1%	1.0%	4.3%	4.5%	9	10
Brazil	3,186	4,744	1.0%	0.8%	4.0%	3.6%	10	11
Canada	3,857	6,096	1.2%	1.0%	4.9%	4.7%	8	9
China	6,469	15,238	2.1%	2.6%	8.2%	11.7%	6	5
France	11,256	15,651	3.6%	2.7%	14.2%	12.0%	3	3
Germany	18,749	26,056	6.1%	4.4%	23.7%	20.0%	2	2
India	3,072	6,913	1.0%	1.2%	3.9%	5.3%	12	8
Indonesia	98	729	0.0%	0.1%	0.1%	0.6%	18	18
Italy	7,904	13,110	2.6%	2.2%	10.0%	10.1%	5	6
Japan	5,538	7,438	1.8%	1.3%	7.0%	5.7%	7	7
Mexico	1,902	2,947	0.6%	0.5%	2.4%	2.3%	14	14
Russian Federation	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Saudi Arabia	854	2,351	0.3%	0.4%	1.1%	1.8%	17	16
South Africa	1,640	2,605	0.5%	0.4%	2.1%	2.0%	15	15
South Korea	3,084	4,598	1.0%	0.8%	3.9%	3.5%	11	12
Turkey	2,336	4,097	0.8%	0.7%	3.0%	3.1%	13	13
United Kingdom	10,199	15,566	3.3%	2.7%	12.9%	12.0%	4	4
United States	20,003	27,247	6.5%	4.6%	25.3%	20.9%	1	1

2.14 Saudi Arabia

Table 18. Saudi Arabia: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Saudi Arabia								
International collaboration by Saudi Arabia occurring with each G20 country								
	# of collaborative publications between Saudi Arabia and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Saudi Arabia's publications		% of publications with collaboration with each G20 country as a share of Saudi Arabia's publications with international collaboration		Rank of each country based on share of collaborative publications with Saudi Arabia	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	184	405	0.2%	0.3%	0.3%	0.3%	18	18
Australia	2,803	5,903	3.2%	3.7%	4.6%	5.0%	8	5
Brazil	817	1,618	0.9%	1.0%	1.3%	1.4%	14	15
Canada	3,947	5,746	4.5%	3.6%	6.4%	4.9%	5	6
China	5,329	14,011	6.1%	8.7%	8.7%	11.9%	3	3
France	2,952	4,761	3.4%	3.0%	4.8%	4.0%	7	8
Germany	3,624	4,969	4.1%	3.1%	5.9%	4.2%	6	7
India	5,992	17,158	6.8%	10.6%	9.8%	14.5%	2	2
Indonesia	214	896	0.2%	0.6%	0.3%	0.8%	17	16
Italy	2,367	4,090	2.7%	2.5%	3.9%	3.5%	9	11
Japan	1,652	2,763	1.9%	1.7%	2.7%	2.3%	12	12
Mexico	560	896	0.6%	0.6%	0.9%	0.8%	16	16
Russian Federation	854	2,351	1.0%	1.5%	1.4%	2.0%	13	13
Saudi Arabia	0	0	0.0%	0.0%	0.0%	0.0%	19	19
South Africa	690	2,037	0.8%	1.3%	1.1%	1.7%	15	14
South Korea	2,102	4,469	2.4%	2.8%	3.4%	3.8%	10	9
Turkey	1,971	4,297	2.2%	2.7%	3.2%	3.6%	11	10
United Kingdom	5,327	10,270	6.1%	6.4%	8.7%	8.7%	4	4
United States	12,332	18,773	14.1%	11.6%	20.1%	15.9%	1	1

2.15 South Africa

Table 19. South Africa: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

South Africa								
International collaboration by South Africa occurring with each G20 country								
	# of collaborative publications between South Africa and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all South Africa's publications		% of publications with collaboration with each G20 country as a share of South Africa's publications with international collaboration		Rank of each country based on share of collaborative publications with South Africa	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	1,128	1,650	1.1%	1.1%	2.6%	2.2%	14	15
Australia	5,285	8,674	5.3%	5.8%	11.9%	11.6%	4	3
Brazil	2,144	3,708	2.1%	2.5%	4.8%	5.0%	10	10
Canada	3,978	6,071	4.0%	4.1%	9.0%	8.1%	6	7
China	2,706	5,899	2.7%	4.0%	6.1%	7.9%	9	8
France	4,707	6,375	4.7%	4.3%	10.6%	8.5%	5	6
Germany	5,634	8,622	5.6%	5.8%	12.7%	11.6%	3	4
India	3,489	6,487	3.5%	4.4%	7.9%	8.7%	7	5
Indonesia	162	716	0.2%	0.5%	0.4%	1.0%	18	18
Italy	3,178	5,113	3.2%	3.4%	7.2%	6.9%	8	9
Japan	1,918	3,012	1.9%	2.0%	4.3%	4.0%	11	11
Mexico	850	1,408	0.8%	0.9%	1.9%	1.9%	15	17
Russian Federation	1,640	2,605	1.6%	1.7%	3.7%	3.5%	12	12
Saudi Arabia	690	2,037	0.7%	1.4%	1.6%	2.7%	17	14
South Africa	0	0	0.0%	0.0%	0.0%	0.0%	19	19
South Korea	696	1,425	0.7%	1.0%	1.6%	1.9%	16	16
Turkey	1,258	2,097	1.3%	1.4%	2.8%	2.8%	13	13
United Kingdom	10,260	16,781	10.3%	11.3%	23.2%	22.5%	2	2
United States	14,414	21,686	14.4%	14.6%	32.6%	29.1%	1	1

2.16 South Korea

Table 20. South Korea: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

South Korea								
International collaboration by South Korea occurring with each G20 country								
	# of collaborative publications between South Korea and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all South Korea's publications		% of publications with collaboration with each G20 country as a share of South Korea's publications with international collaboration		Rank of each country based on share of collaborative publications with South Korea	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	369	634	0.1%	0.1%	0.4%	0.5%	18	18
Australia	4,701	8,218	1.2%	1.8%	4.5%	6.0%	9	7
Brazil	1,837	3,097	0.5%	0.7%	1.8%	2.3%	13	13
Canada	5,043	7,149	1.3%	1.5%	4.8%	5.2%	7	8
China	14,839	26,111	3.8%	5.6%	14.2%	19.1%	2	2
France	4,883	6,938	1.2%	1.5%	4.7%	5.1%	8	9
Germany	7,830	10,811	2.0%	2.3%	7.5%	7.9%	5	6
India	8,385	14,416	2.1%	3.1%	8.0%	10.6%	4	3
Indonesia	733	2,105	0.2%	0.5%	0.7%	1.5%	16	15
Italy	4,092	6,784	1.0%	1.5%	3.9%	5.0%	10	10
Japan	12,896	14,368	3.3%	3.1%	12.4%	10.5%	3	4
Mexico	1,412	2,063	0.4%	0.4%	1.4%	1.5%	15	16
Russian Federation	3,084	4,598	0.8%	1.0%	3.0%	3.4%	11	11
Saudi Arabia	2,102	4,469	0.5%	1.0%	2.0%	3.3%	12	12
South Africa	696	1,425	0.2%	0.3%	0.7%	1.0%	17	17
South Korea	0	0	0.0%	0.0%	0.0%	0.0%	19	19
Turkey	1,503	2,728	0.4%	0.6%	1.4%	2.0%	14	14
United Kingdom	7,564	12,096	1.9%	2.6%	7.3%	8.9%	6	5
United States	51,721	56,407	13.1%	12.1%	49.6%	41.3%	1	1

2.17 Turkey

Table 21. Turkey: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

Turkey								
International collaboration by Turkey occurring with each G20 country								
	# of collaborative publications between Turkey and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all Turkey's publications		% of publications with collaboration with each G20 country as a share of Turkey's publications with international collaboration		Rank of each country based on share of collaborative publications with Turkey	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	900	1,199	0.4%	0.4%	2.2%	1.8%	17	17
Australia	1,998	3,595	0.9%	1.3%	4.8%	5.3%	12	11
Brazil	2,004	2,965	1.0%	1.1%	4.8%	4.4%	11	12
Canada	2,749	4,182	1.3%	1.6%	6.6%	6.2%	7	9
China	2,929	6,414	1.4%	2.4%	7.0%	9.5%	6	5
France	4,263	6,251	2.0%	2.3%	10.2%	9.3%	5	6
Germany	6,073	8,667	2.9%	3.2%	14.6%	12.9%	3	3
India	2,103	4,969	1.0%	1.8%	5.1%	7.4%	10	7
Indonesia	121	628	0.1%	0.2%	0.3%	0.9%	18	18
Italy	4,987	8,324	2.4%	3.1%	12.0%	12.4%	4	4
Japan	2,135	2,895	1.0%	1.1%	5.1%	4.3%	9	13
Mexico	1,092	1,773	0.5%	0.7%	2.6%	2.6%	16	16
Russian Federation	2,336	4,097	1.1%	1.5%	5.6%	6.1%	8	10
Saudi Arabia	1,971	4,297	0.9%	1.6%	4.7%	6.4%	13	8
South Africa	1,258	2,097	0.6%	0.8%	3.0%	3.1%	15	15
South Korea	1,503	2,728	0.7%	1.0%	3.6%	4.1%	14	14
Turkey	0	0	0.0%	0.0%	0.0%	0.0%	19	19
United Kingdom	6,271	10,287	3.0%	3.8%	15.1%	15.3%	2	2
United States	15,313	19,070	7.3%	7.1%	36.8%	28.4%	1	1

2.18 United Kingdom

Table 22. United Kingdom: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

United Kingdom								
International collaboration by United Kingdom occurring with each G20 country								
	# of collaborative publications between United Kingdom and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all United Kingdom's publications		% of publications with collaboration with each G20 country as a share of United Kingdom's publications with international collaboration		Rank of each country based on share of collaborative publications with United Kingdom	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	3,227	4,888	0.3%	0.4%	0.7%	0.8%	17	17
Australia	44,982	66,691	4.4%	5.7%	9.6%	10.3%	5	5
Brazil	13,060	22,870	1.3%	2.0%	2.8%	3.5%	9	10
Canada	34,558	49,511	3.3%	4.2%	7.4%	7.7%	7	7
China	41,752	89,358	4.0%	7.6%	8.9%	13.9%	6	3
France	50,357	65,881	4.9%	5.6%	10.8%	10.2%	3	6
Germany	71,000	94,090	6.9%	8.0%	15.2%	14.6%	2	2
India	12,431	23,117	1.2%	2.0%	2.7%	3.6%	10	9
Indonesia	1,246	3,547	0.1%	0.3%	0.3%	0.6%	18	18
Italy	47,697	70,821	4.6%	6.1%	10.2%	11.0%	4	4
Japan	18,132	24,808	1.8%	2.1%	3.9%	3.8%	8	8
Mexico	4,556	7,390	0.4%	0.6%	1.0%	1.1%	16	16
Russian Federation	10,199	15,566	1.0%	1.3%	2.2%	2.4%	12	12
Saudi Arabia	5,327	10,270	0.5%	0.9%	1.1%	1.6%	15	15
South Africa	10,260	16,781	1.0%	1.4%	2.2%	2.6%	11	11
South Korea	7,564	12,096	0.7%	1.0%	1.6%	1.9%	13	13
Turkey	6,271	10,287	0.6%	0.9%	1.3%	1.6%	14	14
United Kingdom	0	0	0.0%	0.0%	0.0%	0.0%	19	19
United States	136,480	180,718	13.2%	15.5%	29.2%	28.0%	1	1

2.19 United States

Table 23. United States: quantity of publications, percentage of all publications with co-authors in each of the G20 countries, and percentage of the publications with international co-authorship having co-authors in G20 countries. (Source: Elsevier SciVal).

United State								
International collaboration by United States occurring with each G20 country								
	# of collaborative publications between United States and co-authors in each G20 country		% of publications with collaboration with each G20 country as a share of all United States's publications		% of publications with collaboration with each G20 country as a share of United States's publications with international collaboration		Rank of each country based on share of collaborative publications with United States	
	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021	2012-2016	2017-2021
Argentina	9,233	12,104	0.3%	0.3%	0.9%	0.9%	17	17
Australia	63,029	88,456	1.8%	2.4%	6.2%	6.8%	7	6
Brazil	34,089	52,690	1.0%	1.4%	3.3%	4.1%	11	11
Canada	109,869	139,474	3.2%	3.8%	10.7%	10.7%	4	3
China	184,602	301,428	5.4%	8.2%	18.0%	23.2%	1	1
France	74,937	90,960	2.2%	2.5%	7.3%	7.0%	5	5
Germany	113,872	139,375	3.3%	3.8%	11.1%	10.7%	3	4
India	34,545	52,966	1.0%	1.4%	3.4%	4.1%	10	10
Indonesia	1,830	4,112	0.1%	0.1%	0.2%	0.3%	18	18
Italy	66,849	86,782	2.0%	2.4%	6.5%	6.7%	6	7
Japan	56,212	66,796	1.6%	1.8%	5.5%	5.1%	8	8
Mexico	16,270	23,646	0.5%	0.6%	1.6%	1.8%	13	13
Russian Federation	20,003	27,247	0.6%	0.7%	2.0%	2.1%	12	12
Saudi Arabia	12,332	18,773	0.4%	0.5%	1.2%	1.4%	16	16
South Africa	14,414	21,686	0.4%	0.6%	1.4%	1.7%	15	14
South Korea	51,721	56,407	1.5%	1.5%	5.1%	4.3%	9	9
Turkey	15,313	19,070	0.4%	0.5%	1.5%	1.5%	14	15
United Kingdom	136,480	180,718	4.0%	4.9%	13.3%	13.9%	2	2
United States	0	0	0.0%	0.0%	0.0%	0.0%	19	19

2.20 Highlights on G20 research publications co-authorship

2.20.1 Main collaborating countries

The Unites States continues to be a strong attractor for research collaborations among the G20 countries. In both periods analyzed, 2012-2016 and 2017-2021, the U.S. was the main collaborator for 17 out of 18 countries. In both cases, Indonesia had as main collaborator Japan.

The United Kingdom appeared as second main collaborator in 10 cases (Brazil, China, France, Germany, India, Italy, Mexico, South Africa, Turkey, and the United States), in the period 2017-2021. Canada, who was the second main collaborator to the UK for the period 2012-2016, had China as second largest partner in 2017-2021.

Germany appeared as second largest collaborator in two cases, in the period 2017-2021: when working with the Russian Federation and with the United Kingdom. In the same period, Australia was the second most important collaborator to Indonesia and India had the same role with respect to Saudi Arabia.

China, who was the second most important partner to two countries in 2012-2016 (Japan and South Korea), turned out to be second collaborator to four G20 countries in 2017-2021 (Japan, South Korea, Australia, and Canada).

The other country from the Global South that appeared as second most important collaborator in at least one case is Brazil: in both periods it was the second main collaborator to Argentina.

2.20.2 Main themes for collaboration

Research collaboration relies on the commonality of interests of the collaborating partners. Sometimes collaboration may require access to large research facilities, common in the fields of Particle Physics and Astrophysics. On the other hand, in many cases collaboration depends on investigator-initiated interactions that lead to sharing of ideas and experimental results that help advance each partners' objectives.

As an example, let's consider the collaboration themes apparent from the publications that have authors in India and the United Kingdom published in 2018-2019 (7,880 publications), shown in Figure 9. We chose to use a shorter time period to be able to focus on themes; additionally, we chose the period to end before the pandemic years, as these might have affected the main themes of interest. In this case, most of the keyphrases relate to large collaborations in the fields of High Energy Physics or Astrophysics. These are very relevant and highlight the relevance of shared facilities or institutional initiatives that allow researchers from any region to participate in large and expensive experiments. A finer view of the themes in the India-UK collaboration can be seen by selecting only the 5,425 publications that have ten or less authors (Figure 10). In this case the set of publications will be more representative of organic collaborations which were dependent on researchers meeting each other and interacting in a less institutionalized way.

Figure 9. Main keyphrases identified in publications with authors in India and the United Kingdom, for the period 2018-2019. (Source: Elsevier SciVal).

Figure 10. Main keyphrases identified in publications with authors in India and the United Kingdom, for the period 2018-2019, considering only the publications with 10 or less authors. (Source: Elsevier SciVal).

In this case, keyphrases related to Health Science and Social Sciences are noticeable, alongside themes in the Natural Sciences. Large collaborations and small collaborations are equally relevant, and it is important to adjust the bibliometric "lenses" to be able to see both.

Keyphrases can also help to identify differences in collaboration themes when countries in the Global South interact, as opposed to South-North collaborations. This is shown in Figure 11 and Figure 12, for collaborations between India and Brazil, again considering the full set of co-authored publications from 2018-2019 (2,337 publications, Figure 11) and the set limited to the publications with 10 or less authors (1,004 publications, Figure 12). For the full set there is again a dominance of keyphrases related to large collaborations, apparently in a way that is stronger than for the case of the India-UK collaboration shown above. The set considering publications with 10 or less authors allows the identification of some other themes. Especially those related to Bioenergy and to Nanotechnology and Materials.

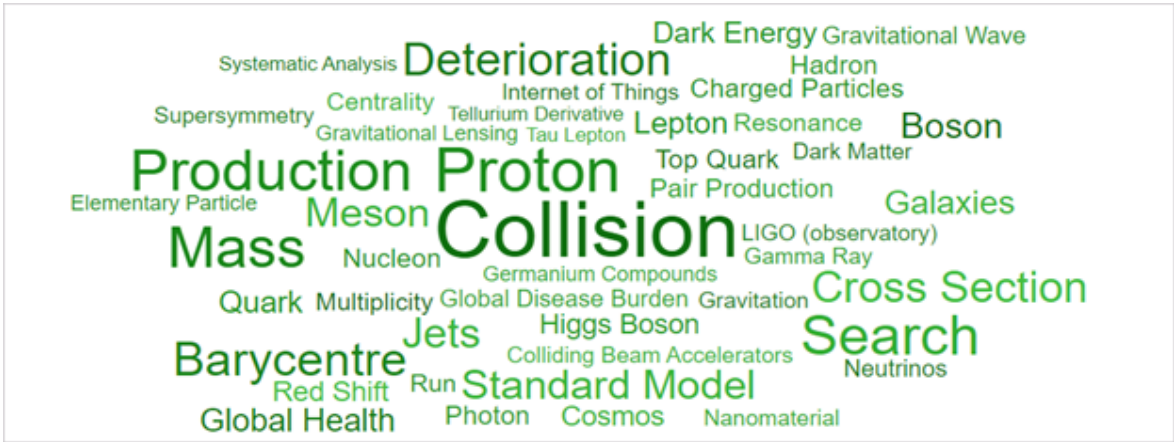


Figure 11. Main keyphrases identified in publications with authors in India and Brazil, for the period 2018-2019. (Source: Elsevier SciVal).

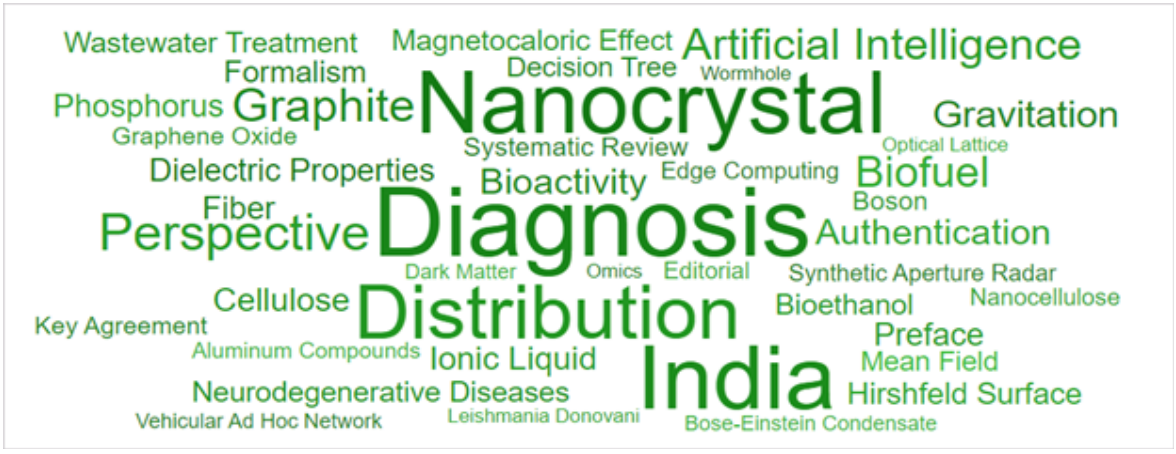


Figure 12. Main keyphrases identified in publications with authors in India and Brazil, for the period 2018-2019, considering only the publications with 10 or less authors. (Source: Elsevier SciVal).

When researchers in India collaborate with colleagues in South Africa the keyphrases descriptive of the themes are shown in Figure 13. In the set of 1,624 publications, we find themes related to nanofluidics, materials and water treatment.

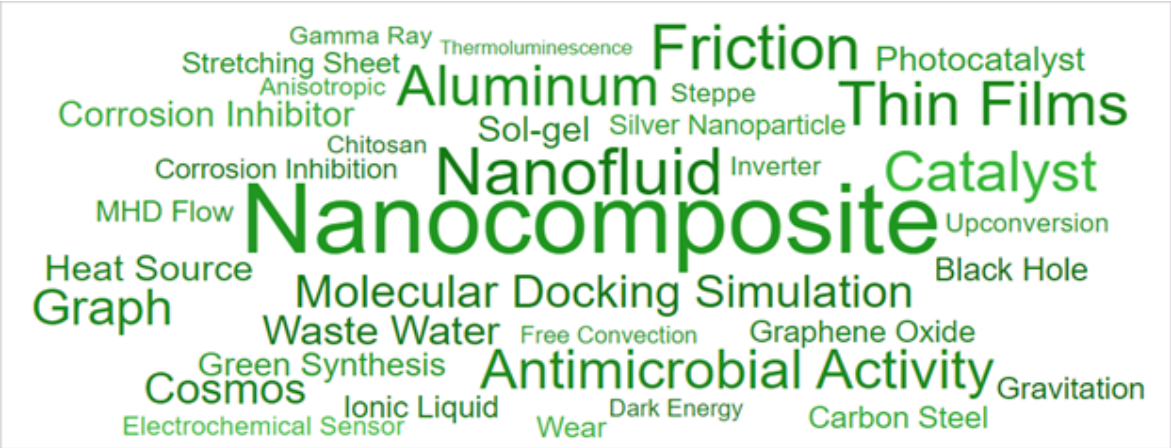


Figure 13. Main keyphrases identified in publications with authors in India and South Africa, for the period 2018-2019, considering only the publications with 10 or less authors. (Source: Elsevier SciVal).

In recent years, China has been the third larger collaborator with India and the main keyphrases in their collaborative publications (4,256 in 2018-2019) with 10 or less authors are shown in Figure 14, showing that nanomaterials, neural networks, graphene, the internet of things, and the environment are important targets for joint study.

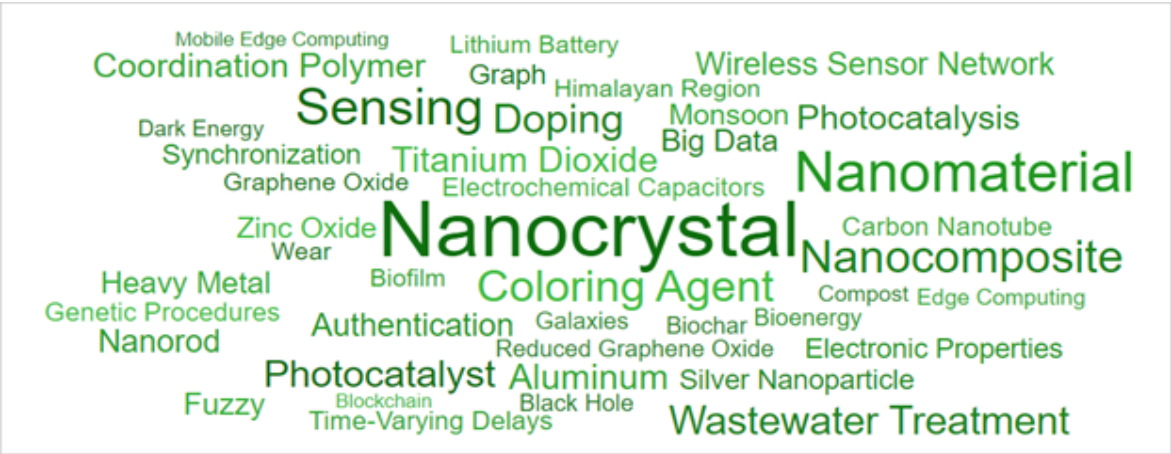


Figure 14. Main keyphrases identified in publications with authors in India and China, for the period 2018-2019, considering only the publications with 10 or less authors. (Source: Elsevier SciVal).

Moving to another side of the World, in America, the 1,558 collaborative publications from 2018-2019 with authors in the two countries have a strong emphasis in the Life Sciences, covering ecology themes, locally relevant diseases (Chagas), agriculture and several local species.

Figure 15. Main keyphrases identified in publications with authors in Brazil and Argentina, for the period 2018-2019, considering only the publications with 10 or less authors. (Source: Elsevier SciVal).

3 Scientific publications from G20 countries and the U.N. Sustainable Development Goals

The Sustainable Development Goals (SDGs), defined by the United Nations in 2015[3], form a useful classification to assess the relation between research publications and sustainability.

Elsevier started, since 2018, the SDG Mapping Initiative, in partnership with the University of Southern Denmark, Aurora (represented by Vrije Universiteit Amsterdam), and the University of Auckland to gather extensive experience and share best practices. Working with partners to build consensus on mapped publications, the Elsevier Data Science team established a collaborative system to build a knowledge base of SDG-related publications in conjunction with the research community. As a result, a set of search terms was developed to be used with the SCOPUS database to identify the publications in each SDG[4]. In addition, after applying the search for terms, an algorithm was developed using machine learning to improve the search in terms of accuracy and recall. This classification system is now part of the Elsevier SciVal tool. All searches and the algorithm description are documented and publicly accessible[5] .

The tool allows one to count in a collection of publications how many are related to each of the SDGs[6]. To understand the specialisation patterns between different countries, we utilise the relative activity index.

The RAI for SDGs compares the share of a country's publications in each SDG with the share of the respective SDG globally. A RAI equal to 1 for an SDG N indicates that the entity in question has a percentage of its publications dedicated to SDG N equal to the percentage of the complete SCOPUS base (i.e., the total of all countries added together).

Figure 16 shows the RAI for each SDG, for publications with authors in India in the periods 2011-2013 and 2020-2022. The data evidences a strong progress in research results related to SDG 07 (Affordable and Clean Energy), SDG 09 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption) and SDG 13 (Climate Action) and a continuing strong showing in SDG 02 (Zero Hunger).

3. *Details about the creation and the definition of each one of the Sustainable Development Goals can be found at https://sdgs.un.org/goals.*
4. *Roberge, G., Kashnitsky, Y., & James, C. (2022). Elsevier 2022 Sustainable Development Goals (SDG) Mapping. Mendeley Data, V1. https://elsevier.digitalcommonsdata.com/datasets/6bjy52jkm9.*
5. *Rivest, M., Kashnitsky, Y., Bédard-Vallée, A., Campbell, D., Khayat, P., Labrosse, I., Pinheiro, H., Provençal, S., Roberge, G., & James, C. (2021, April). DATASET: Improving the Scopus and Aurora queries to identify research that supports the United Nations Sustainable Development Goals (SDGs) 2021. Elsevier BV. https://doi.org/10.17632/9SXDYKM8S4.4.*
6. *The exception is SDG 17, for which a mapping is still underway.*

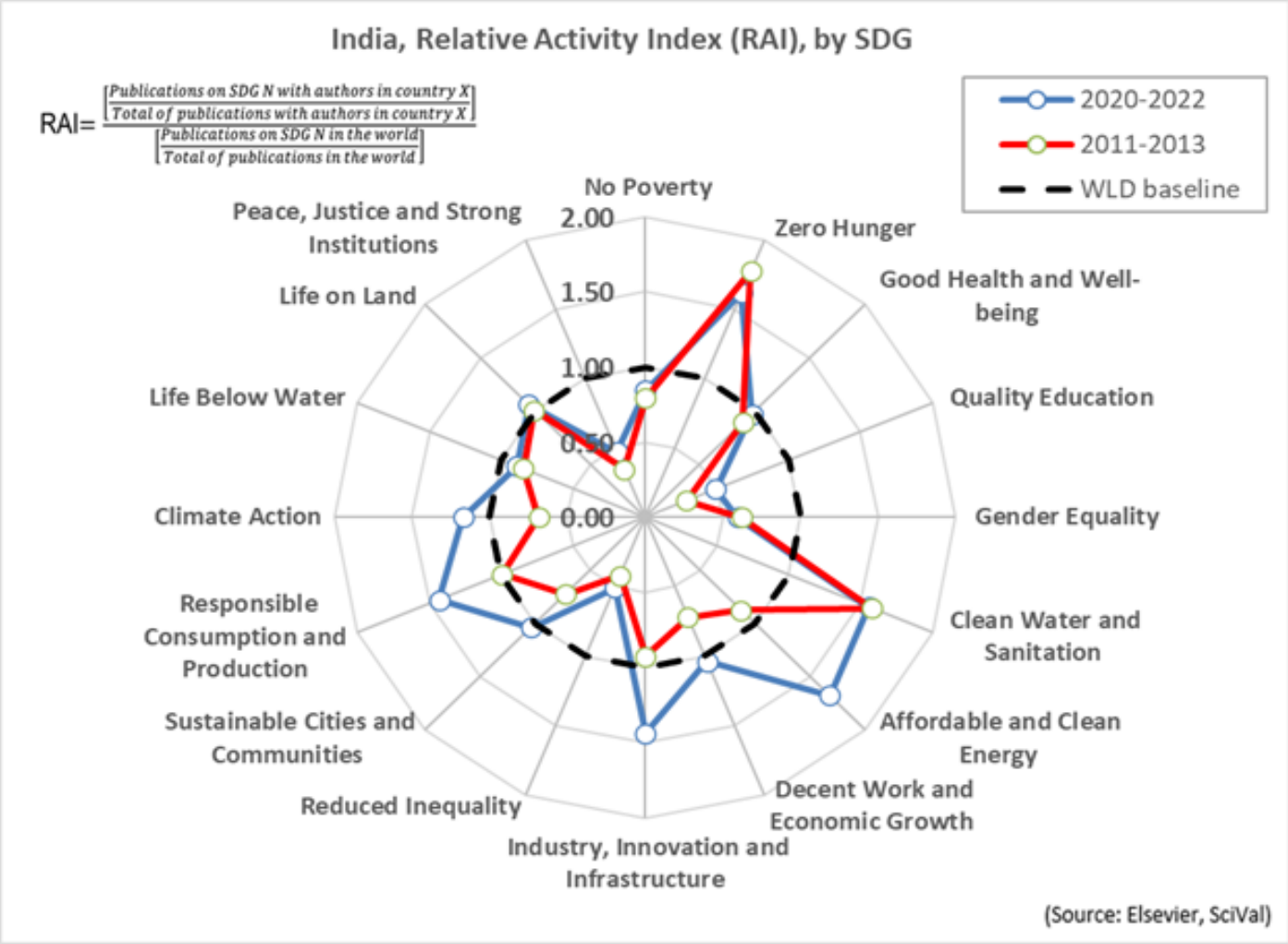


Figure 16. Relative Activity Index by SDG, for the publications with authors in India for the periods 2011-2013 and 2020-2022. (Fonte: Elsevier SciVal).

For the case of SDG 07 (Affordable and Clean Energy) an analysis of the publications with authors in India show that there has been an increase in the international collaboration since 2018 (Figure 17): in 2018, 16% of the publications related to SDG 07 had international co-authorship, and in 2022 the percentage grew to 26%. A similar behaviour is seen for the publications with authors in India related to SDG 13 (Climate Action) (Figure 18). For SDG 02 (Zero Hunger), which has the highest RAI for India, the growth in international collaboration started earlier, in 2012 (Figure 19).

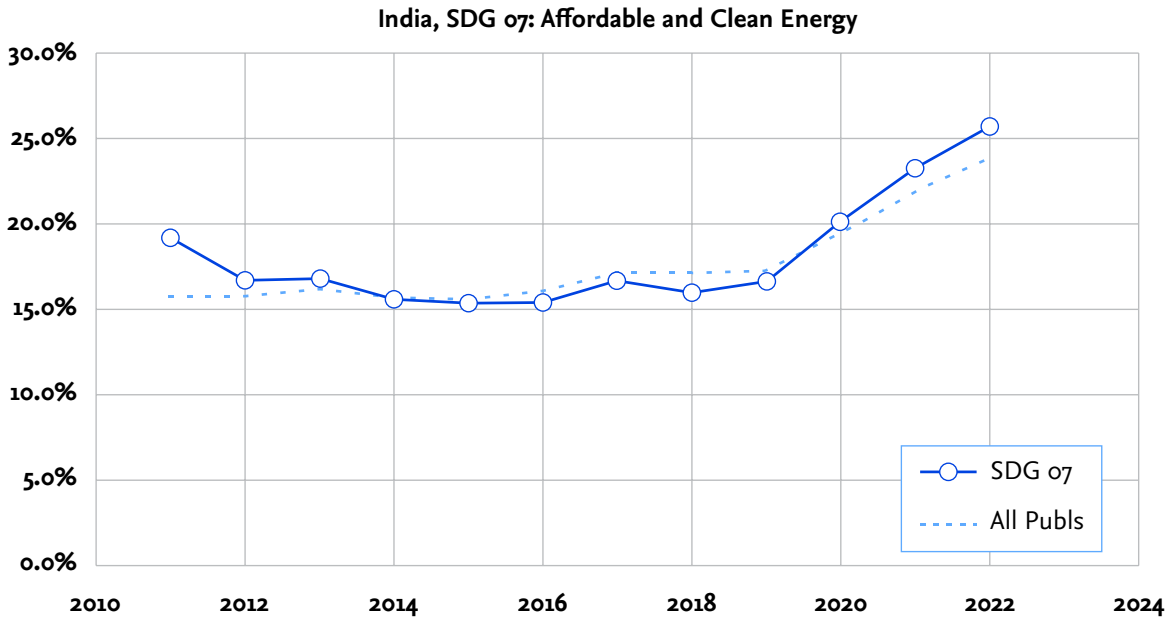


Figure 17. Percentage of publications with authors in India related to SDG 07 (Affordable and Clean Energy) that had international co-authorship, 2011-2022. (Source: Elsevier SciVal).

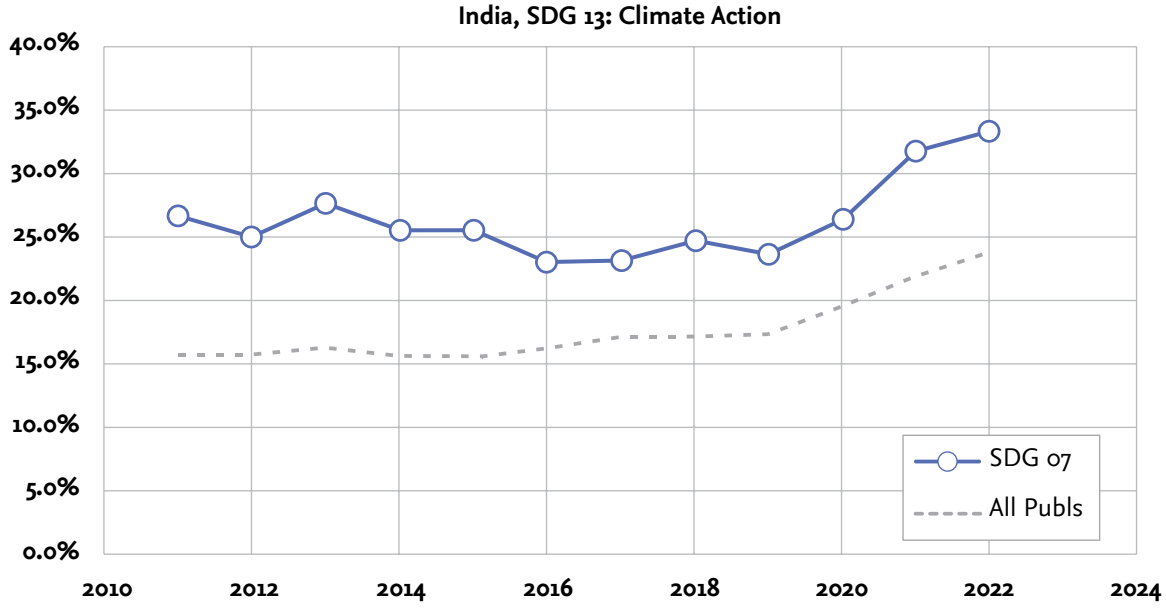


Figure 18. Percentage of publications with authors in India related to SDG 13 (Climate Action) that had international co-authorship, 2011-2022. (Source: Elsevier SciVal).

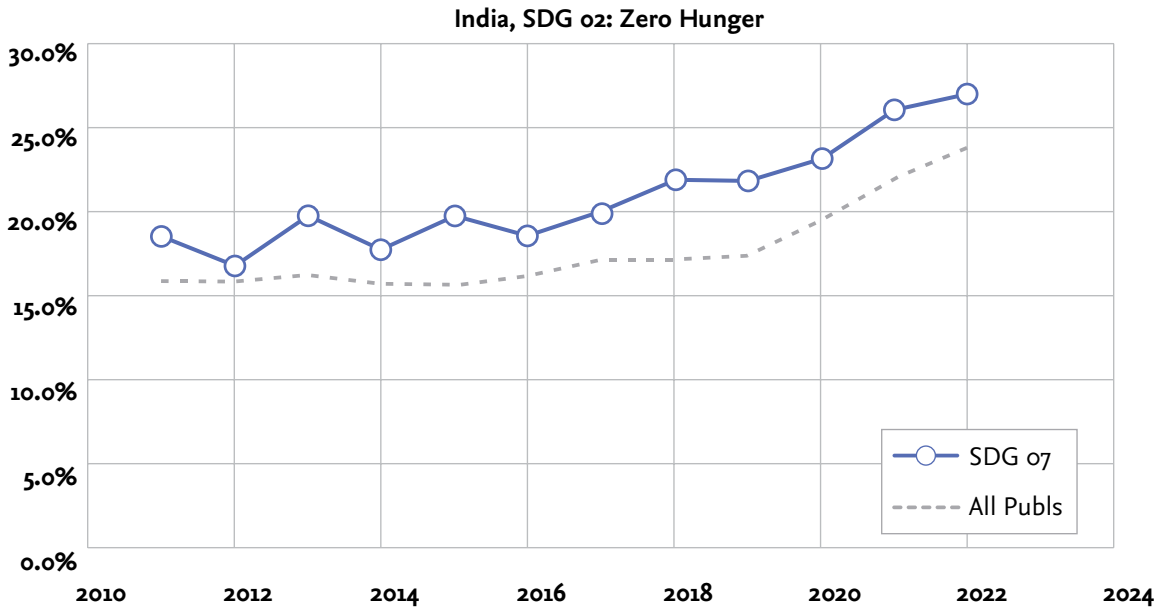


Figure 19. Percentage of publications with authors in India related to SDG 02 (Zero Hunger) that had international co-authorship, 2011-2022. (Source: Elsevier SciVal).

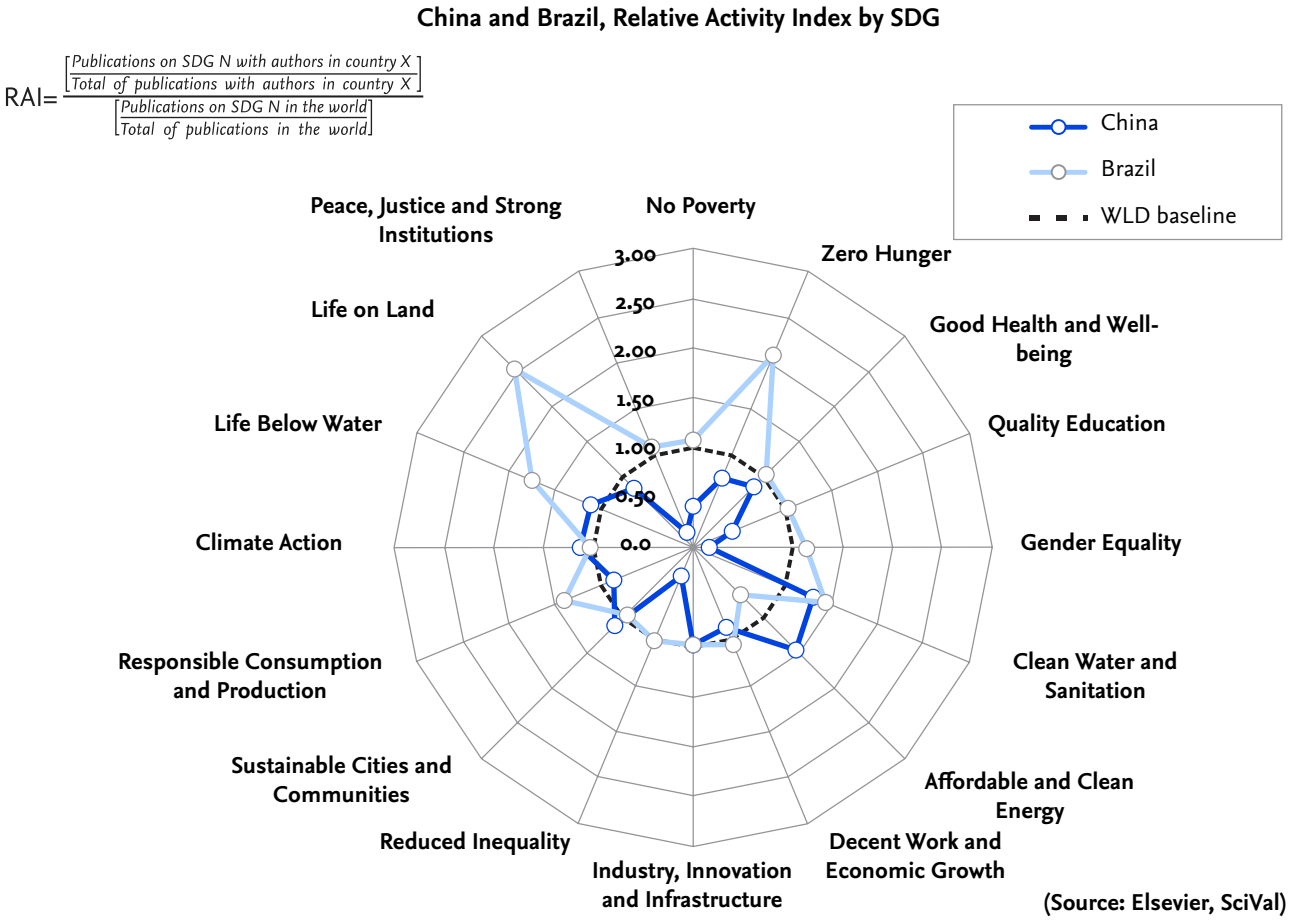


Figure 20. Relative Activity Index by SDG, for the publications with authors in Brazil and China in 2020-2022. (Fonte: Elsevier SciVal).

Figure 20 shows the Relative activity Index by SDG for China and Brazil, the Global South Countries that, together with India, have the larger number of publications. China demonstrates strength in SDG 07 (Affordable and Clean Energy) and in SDG 06 (Clean Water and Sanitation), while Brazil demonstrates especially good performance in SDG 02 (No Hunger), SDG 14 (Life under Water), and SDG 15 (Life on Land).

United States and United Kingdom, Relative Activity Index by SDG

$$RAI = \frac{\left[\frac{Publications\ on\ SDG\ N\ with\ authors\ in\ country\ X}{Total\ of\ publications\ with\ authors\ in\ country\ X}\right]}{\left[\frac{Publications\ on\ SDG\ N\ in\ the\ world}{Total\ of\ publications\ in\ the\ world}\right]}$$

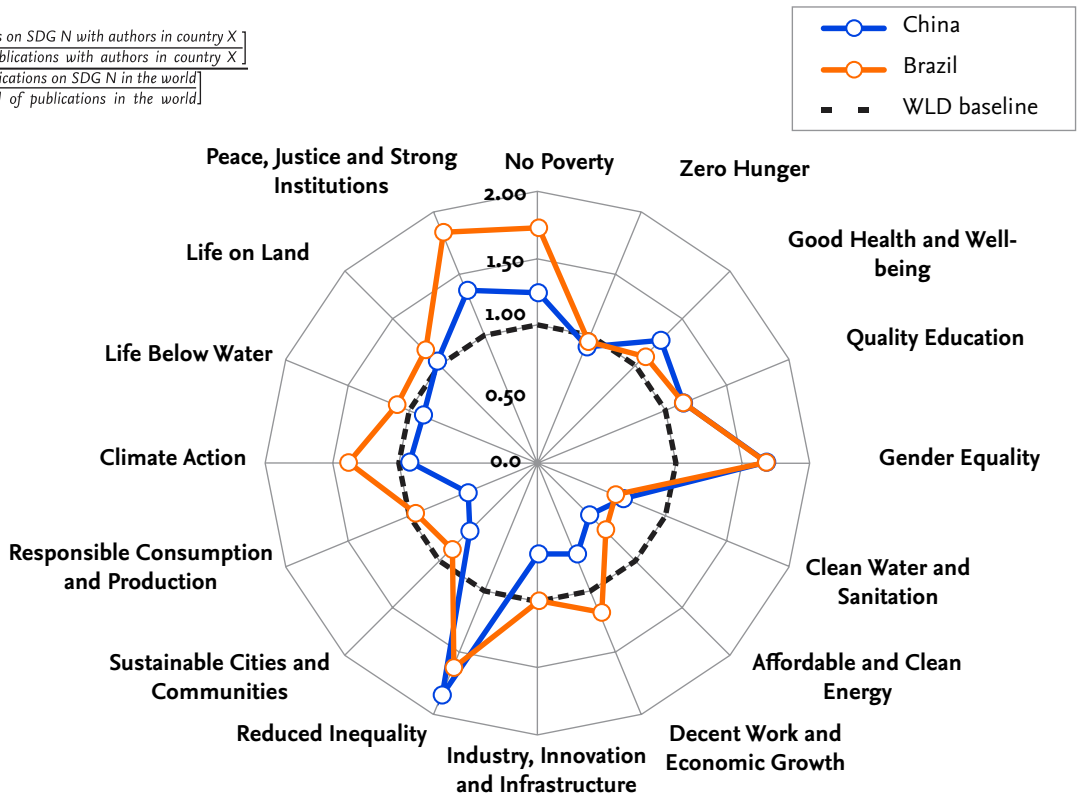


Figure 21. Relative Activity Index by SDG, for the publications with authors in the United States and the United Kingdom in 2020-2022. (Fonte: Elsevier SciVal).

In the Global North, the two countries in G20 with the highest number of publications are the United States and the United Kingdom. Their Relative Activity Index by SDG is shown in Figure 21. Both countries show strength in SDG 01 (No Poverty), SDG 05 (Gender Equality), SDG 10 (Reduced Inequality), as well as in SDG 16 (Peace, Justice, and Strong Institutions).

Collaboration in research related to SDGs is very important to obtain faster advances in knowledge. Figure 22 shows how the international co-authorship changed from 2011 to 2022 for each of the G20 countries, for their publications related to SDG 13 (Climate Action). Russian Federation and Indonesia show a decrease in international co-authorship for the publications related to SDG 13. On the other hand, Turkey, Japan, Australia, and the United States show strong increases in international collaboration for this SDG.

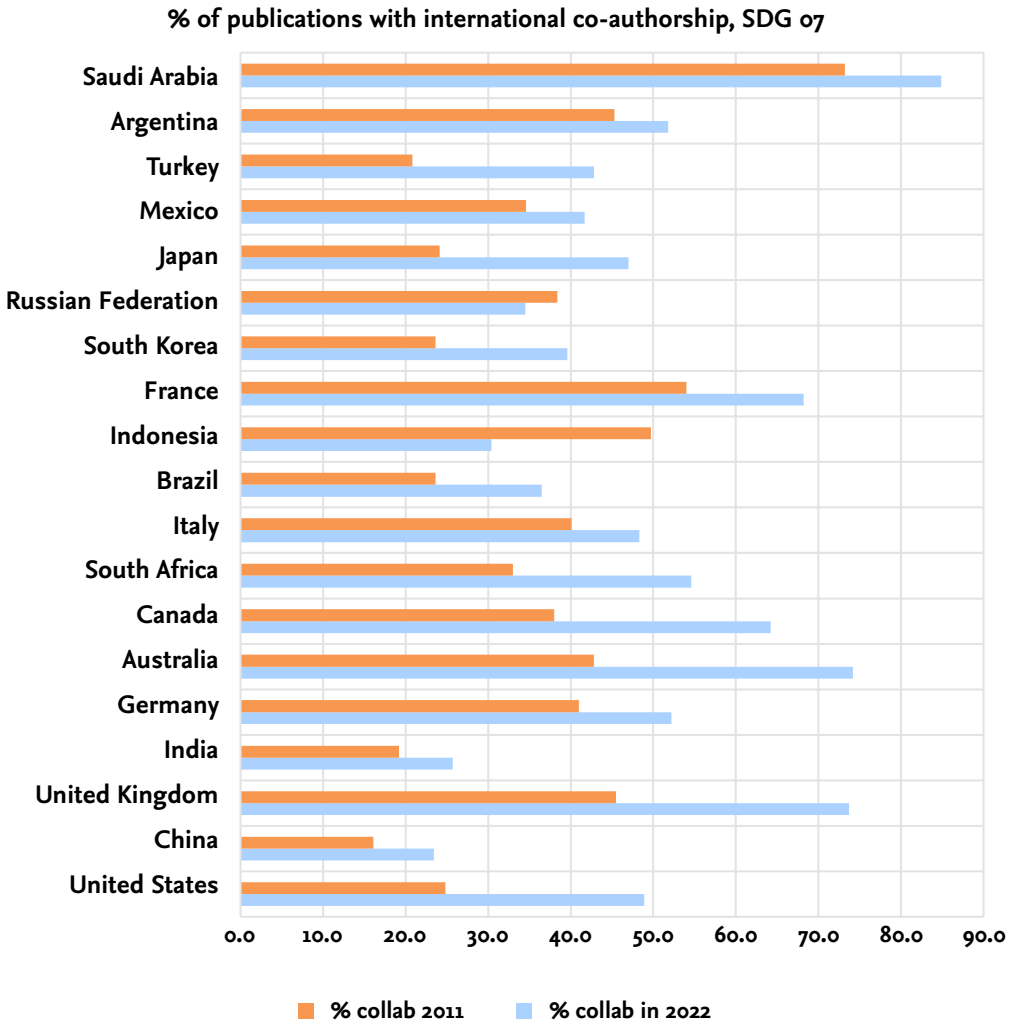


Figure 22. Percentage of research publications with international co-authorship and related to SDG 13 (Climate Action) for each of the G20 countries. (Source: Elsevier SciVal).

4 Two relevant themes: publications related to Eliminating Hunger in the World and to Artificial Intelligence

4.1 Publications related to SDG 2: No Hunger

Among the U.N. approved Sustainable Development Goals, SDG 2 holds a prominent spot, aiming at ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture. As with all the SDGs, the target date is 2030, which makes the challenge enormous. There are tremendous resources in the planet, but unequal access and inefficient handling leaves millions of people malnourished. Previous experience demonstrated that sound scientific research has an especially relevant role to assist the achievement of this goal.

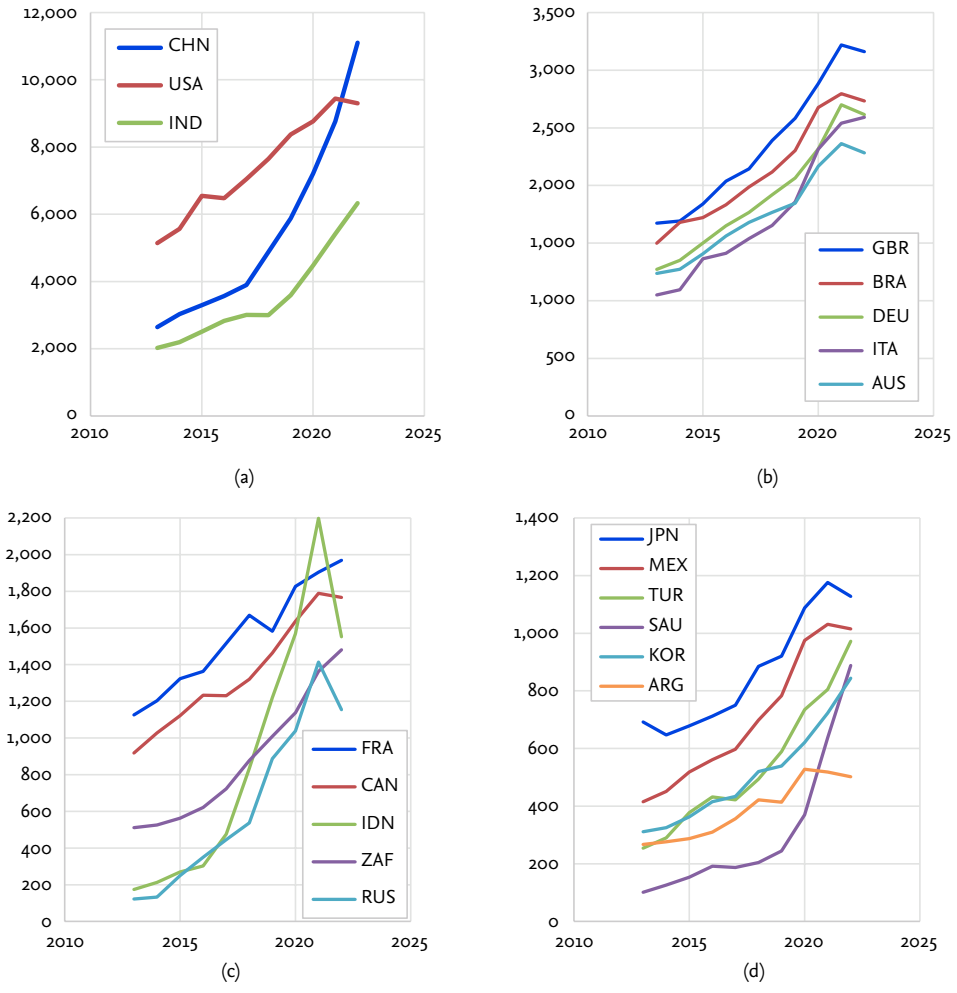


Figure 23. Publications with authors in G20 countries and related to SDG 2 (No Hunger). In (a) China, United States, and India; in (b) United Kingdom, Brazil, Germany, Italy, Australia; in (c) France, Canada, Indonesia, South Africa, Russia; in (d) Japan, Mexico, Turkey, Saudi Arabia, South Korea, and Argentina. Please note the different vertical scales in each plot. (Source: Elsevier SciVal).

Figure 23 shows the evolution, between 20130 and 2022, of the number of scientific publications related to SDG 2 and with authors in the G20 countries. The methodology for the classification in the SCOPUS database is described in Section 3.

China, India, Indonesia, Russia, South Africa, Saudi Arabia and Turkey show strong growth in the period, even though for the cases of Indonesia and Russia a decrease can be seen from 2021 to 2022. The CAGR for the period 2013-2022 is shown in Figure 24 to facilitate the comparison. In this theme, the strong growth seen for most of the G20 countries that are part of the Global South catches the eye.

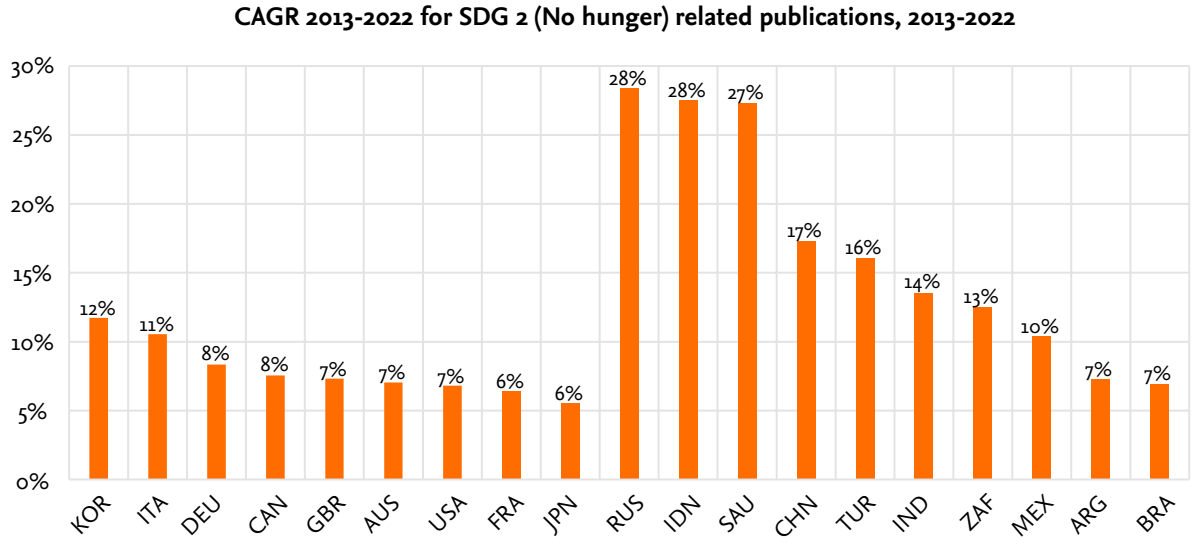


Figure 24. CAGR between 2013 and 2022 for the number of SDG 2 (No Hunger) related publications in G20 countries. The countries are grouped according to their belonging to the Global North (nine ones to the left) or Global South (ten ones to the right). (Source: Elsevier SciVal).

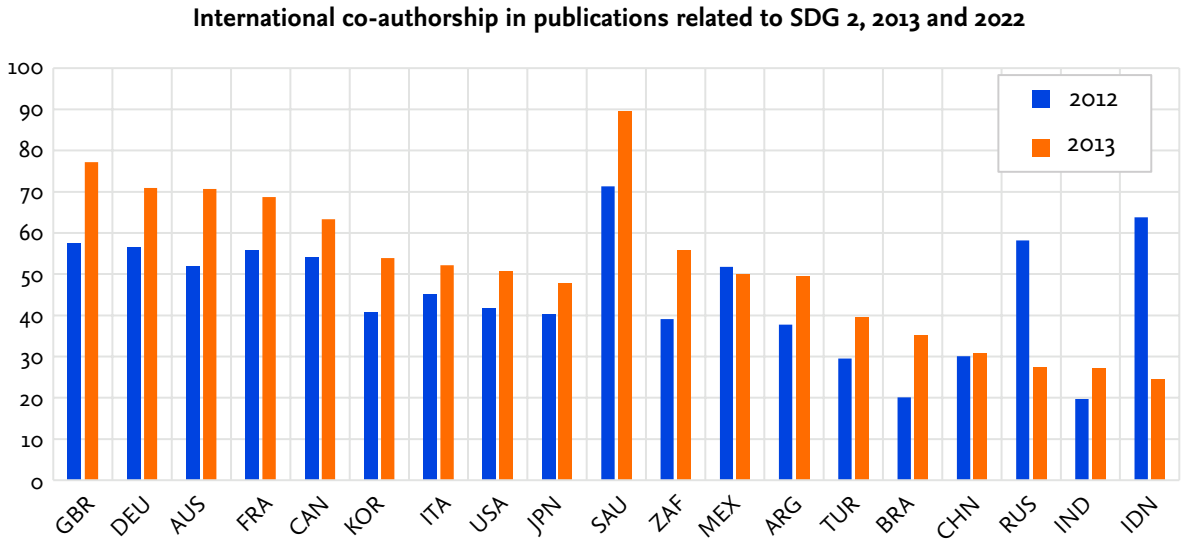


Figure 25. International co-authorship in SDG 2 related publications for G20 countries in 2013 and in 2022. The countries are grouped according to their belonging to the Global North (the nine ones to the left) or Global South (the ten ones to the right). (Source: Elsevier SciVal).

The cases of India and China are noteworthy here, as they form, together with the United States, the "power trio" in publications related to SDG 2. On top of this, China and India show a growth rate substantially higher than that of the United States.

International collaboration is strong for G20 countries in fields related to SDG 2. As shown in Figure 25, countries in the Global South have room to grow their international connections and most of them have been doing this.

4.2 Publications in Artificial Intelligence (AI) topics

As a second example analysing the scientific capacity among the G20 countries, we look at research related to Artificial Intelligence. Artificial Intelligence is an expanding field, especially in recent years when applications to several other domains (health, Biology, Physics, Engineering, Social Sciences) have been an increasing focus of interest. Here we chose to approach the classification of publications using a method that opens the door to publications dealing with applications of AI in various domains. This is described in the Annex. Basically, we used a search composed of 118 text strings describing terms related to AI. These terms were searched in the Title, Abstract or Keywords of each article in the Scopus database.

The number of publications related to Artificial Intelligence methods and applications and with authors in the 19 G20 countries analysed in this report is shown in Figure 26, where we divided the countries in four plots to make the features of the time-evolution more visible to the reader.

Figure 26 (a) shows the four leading countries in quantity of AI related publications. Here it is especially noticeable how the growth rate for China and India is larger than for the other three countries shown (United States, United Kingdom, and Germany). Figure 27 shows that between 2013 and 2022 the CAGR for China was 19% per year, India 23% per year, while for the United States it has been 12% per year, and Germany and the United Kingdom trailed at 12% per year.

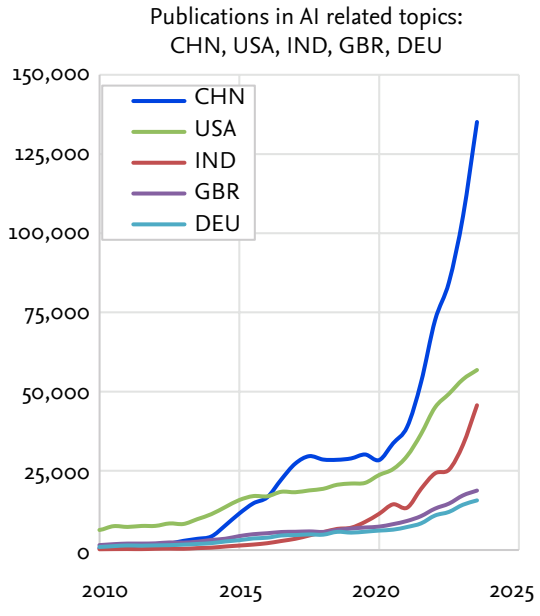
Figure 26 (b) shows how the evolution for South Korea, Canada, Italy, Australia, and Japan is similar, with South Korea and Italy having a faster growth rate (Figure 27), but still with a CAGR below that of Indonesia, Saudi Arabia, Russia, India, South Africa, and China (all above 15% per year from 2013 to 2022). It is noticeable how South Korea was behind until 2017 and then caught up and overcame the others.

Figure 26 (c) shows the strong climb in the number of AI related publications with authors in Saudi Arabia and the recent decrease in the number of publications with authors in Russia. Brazil was ahead of this pack until 2017 and ended up last in 2022.

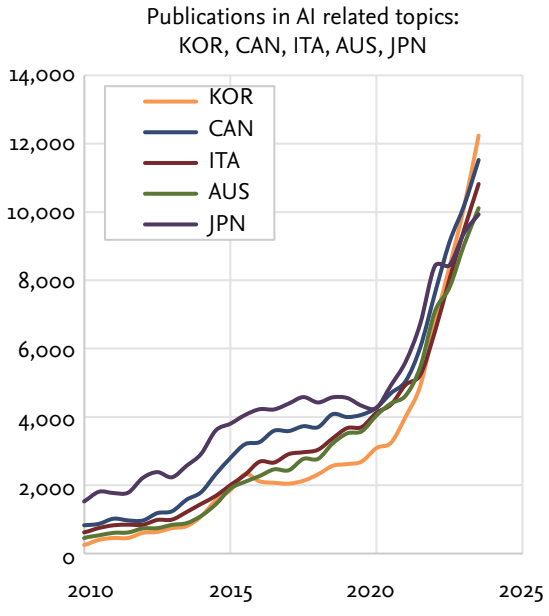
Figure 26 (d) shows a very fast growth, between 2015 and 2019, in the number of publications with authors in Indonesia.

Figure 27 shows that, of the 19 countries analysed here, only 8 have seen CAGR above the World average in the period 2013-2022.

Regarding international collaboration, Figure 28 shows that only Indonesia and Russia decreased international collaboration between 2013 and 2022. China and India have ample room to grow their international networks.



(a)



(b)

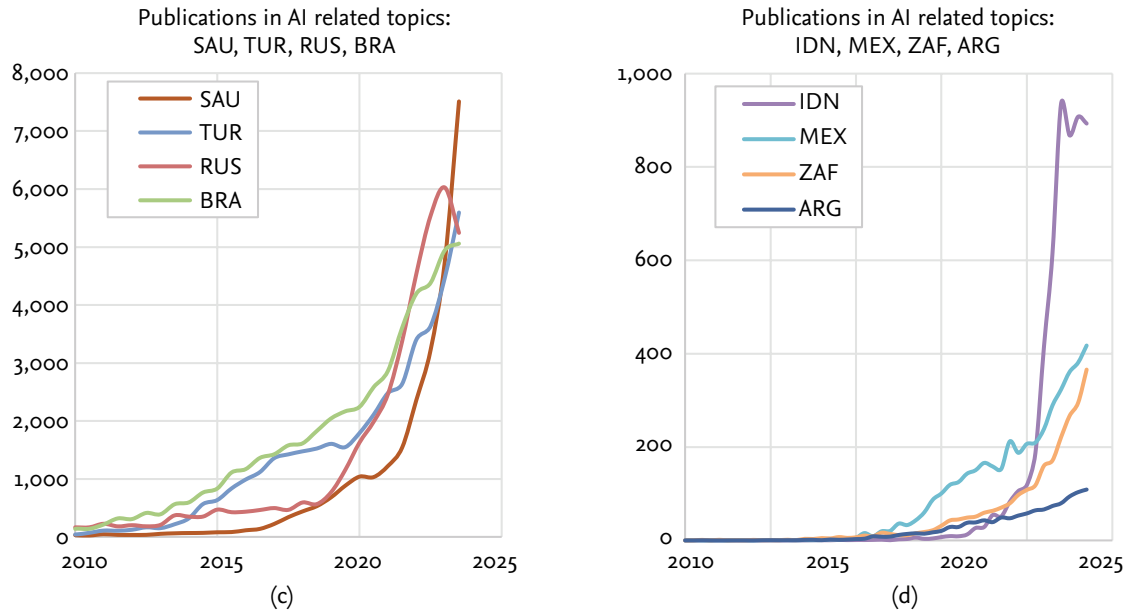


Figure 26. The race for AI. Number of AI related publications for G20 countries. In (a) China, United States, and India, United Kingdom, and Germany; in (b) South Korea, Canada, Italy, Australia, and Japan; in (c) Saudi Arabia, Turkey, Russia, Brazil; in (d) Indonesia, Mexico, South Africa, and Argentina. Please note different vertical scales in each plot. (Source: customized search on Elsevier Scopus.)

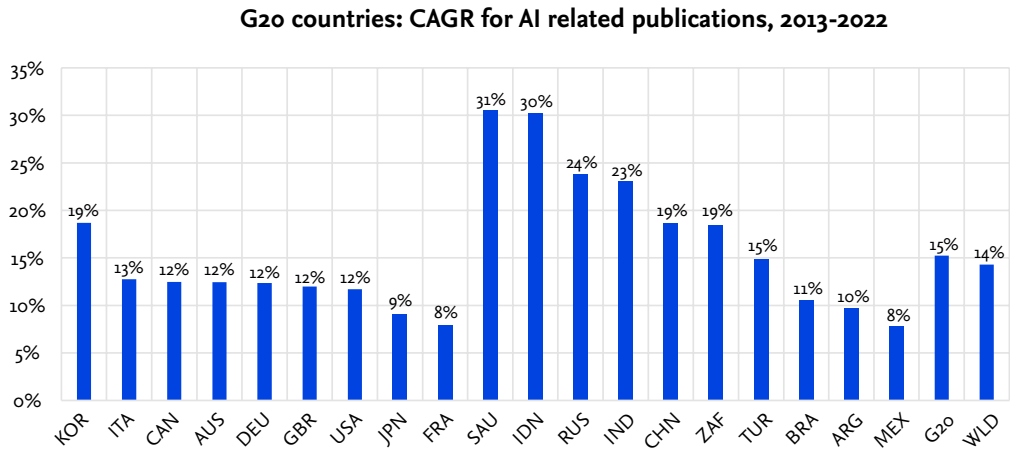


Figure 27. CAGR between 2013 and 2022 for the number of AI related publications in G20 countries. The countries are grouped according to their belonging to the Global North (nine ones to the left) or Global South (ten ones to the right). (Source: customized search on Elsevier Scopus).

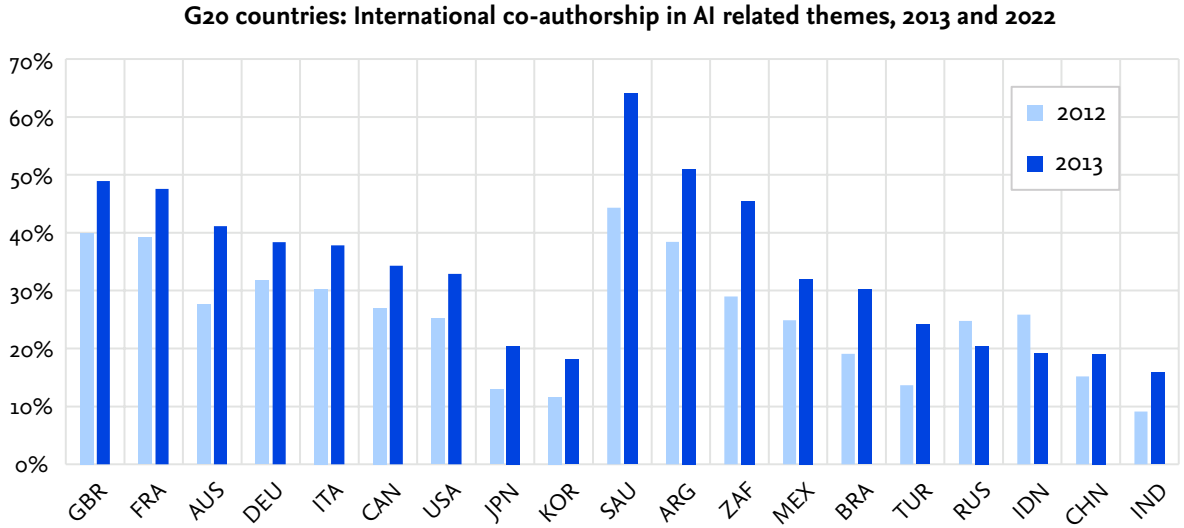


Figure 28. International co-authorship in AI related publications for G20 countries in 2012 and in 2022. The countries are grouped according to their belonging to the Global North (the nine ones to the left) or Global South (the ten ones to the right). (Source: customized search on Elsevier Scopus).

5 Academic-Corporate collaboration and interactions

An important challenge worldwide is to improve the efficacy of academic research contributing to technology and innovation development in the business sector.

The interaction between the business sector and the academic sector occurs via many channels: collaborative research, co-authorship in research publications, visits by business sector scientists to academic institutions and vice-versa, hiring of graduated students in the business sector, personal contacts in conferences and meetings, usage by business sector researchers of results published by academic-sector researchers, and many others. Enhancing these interactions is usually done with care in governmental policies, to preserve the capability of universities to pursue investigator-initiated research, since it is also well recognized that academic researchers frequently find new paths for research that have, after some years, enormous impact to the benefit of society. Classic examples of the latter would be the discovery of mRNA, which happened because scientists were trying to understand living organisms, and not to make a vaccine. Still, more than 50 years after the discovery of mRNA, that knowledge was used to make efficient vaccines to fight the COVID-19 pandemic, with huge benefit to humankind.

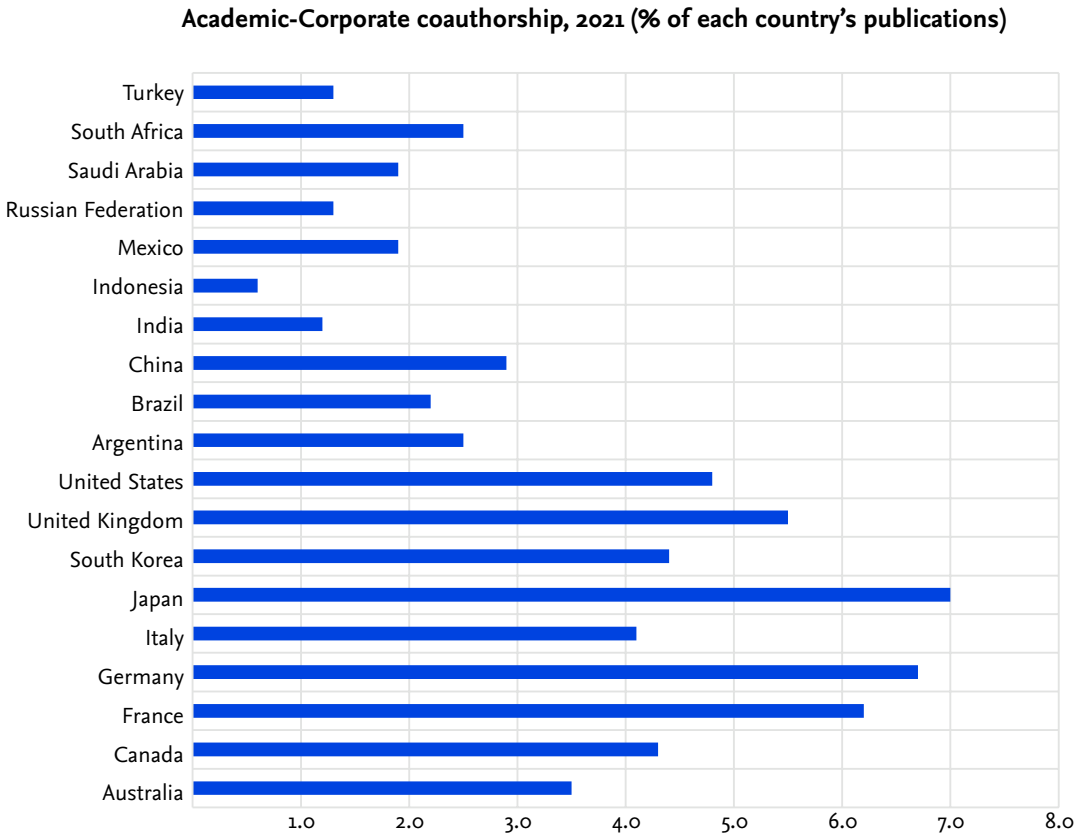


Figure 29. Share of country publications (2011 and 2021) that had co-authors in academic and corporate entities. (Source: Elsevier SciVal).

One window to observe the intensity of academic-corporate collaboration in research, is through the publications that have co-authors in an academic institution and in a corporate entity. This usually represents a highly codified type of collaboration, in which the collaborators studied together a problem, discovered a new and publishable result, wrote together an article, and got it accepted in a scientific journal. Figure 29 shows how the share of publications with co-authors in academic and corporate entities changed from 2011 to 2021, grouping the G20 countries according to their participation in the Global North (lower 9 countries in the figure) or Global South (top 10 countries in the figure). This data reinforces what was shown in Figure 2, in relation to the challenges, for countries in the Global South, of creating the conditions for the business sector to engage much more in inhouse R&D.

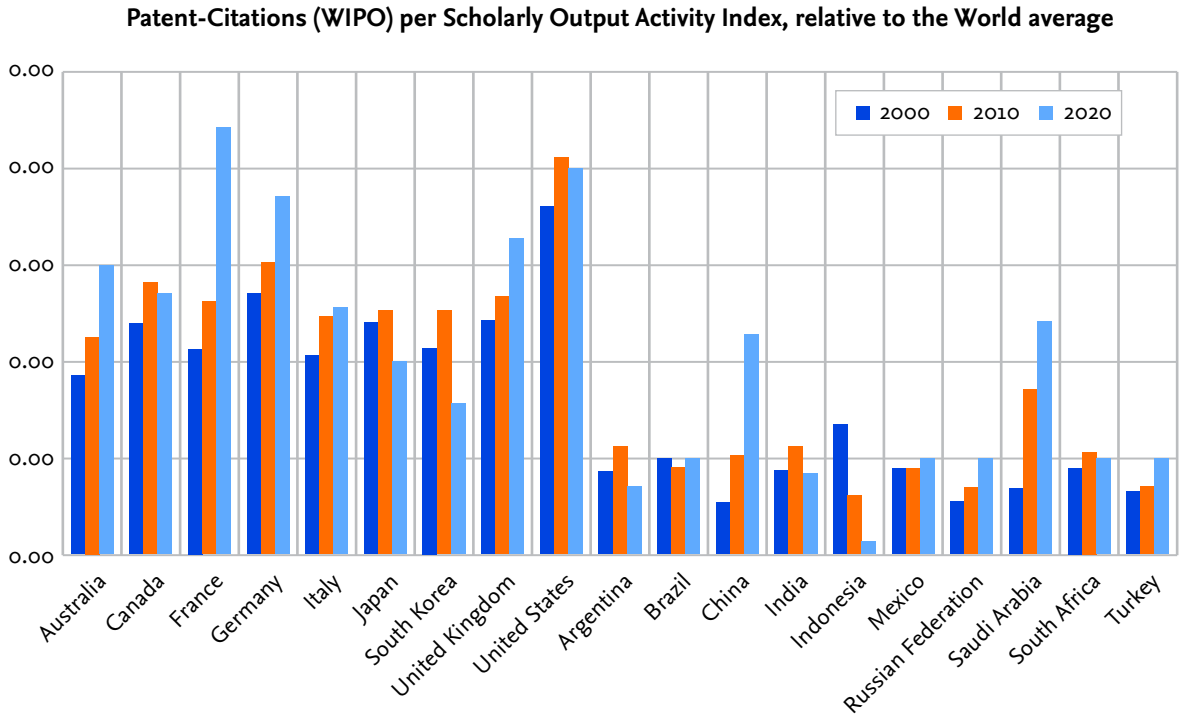


Figure 30. Patent citations per scholarly output for 200, 2010, and 2020, normalized to the World average. (Source: Elsevier SciVal).

Another view, that leads to a conclusion that is consistent with the necessity of more business sector performed R&D, is shown in Figure 30, depicting the ratio of number of citations in patents to each country's scholarly output, for the years 2000, 2010, and 2020, normalized to the World average. The patent database considered in this case is that of the World International Patent Organization (WIPO). It is evident that countries in the Global South face challenges in this indicator. The cases of China and Saudi Arabia might be illustrations that there are ways to improve the connection between patents and publications.

In addition to the number of patents citing each country's scholarly output, there are challenges related to having local organizations citing (using) the publications in the patents filed for. Among the Global South countries, India and Saudi Arabia fare better in the percentage of patents that cite their scholarly output in the WIPO database, and that were filed in each respective country. For the case of Saudi Arabia 13% of the patents citing their publications were filed by organizations in Saudi Arabia, while for India the corresponding percentual is 7%. In Saudi Arabia Aramco, King Abdullah University of Science and Technology, and Saudi Arabian Oil Company are the local entities with more patents, while in India the Council of Scientific and Industrial Research, the Indian Institute of Science, and Cadila Healthcare Limited are the main ones.

6 Concluding remarks

The research output, codified in scientific publications, represents a useful source of information about any research system.

This report describes some aspects of the scientific publications with authors in 19 countries that compose the Group of Twenty (G20). As any analysis based on bibliometric data, it shows a partial vision of the research of the landscape, not all of it. Even so, analysing the publications clarifies some aspects and, perhaps most important, stimulates new questions.

Many of the strengths and weaknesses of each country and of the system appear from the data. We expect that the information presented, when associated to additional information, codified or not, will be useful to research leaders, governmental policy planners, and research funding bodies.

The data presented allows for comparisons to better understand national research systems. One of the most important conclusions that comes from the analysis is that the capacity to create new scientific knowledge is becoming less concentrated in a small number of nations, then it used to be a few decades ago. This fact makes research collaboration among nations more important every day. Fruitful collaborations can be initiated and developed more effectively when each partner knows what they need, and which collaborators have the ability to contribute to the advancement of the desired knowledge. Researchers tend to know this, learning from reading the part of the literature that is of interest to them, attending conferences, meeting colleagues. Still, an overall vision can help find hidden gems or start to identify trends that are not completely visible early on.

Annexure

To identify in SCOPUS the publications that can be related to Artificial Intelligence themes, we built a list of 118 search terms. These terms were searched in the Title, Abstract and Keywords of each publication.

List of search terms used to identify publications mentioning terms related to Artificial Intelligence

1	{Adaptive Learning}
2	{Artificial Intelligence}
3	{Associative Learning}
4	{Automated Pattern Recognition}
5	{Autonomous Learning}
6	{Back Propagation}
7	{Bayesian Learning}
8	{Bayesian Networks}
9	{Belief Networks}
10	{Blind Deconvolution}
11	{Boltzmann Machine}
12	{Box-Jenkins}
13	{Category Learning}
14	{Causal Learning}
15	{Cellular Automaton}
16	{Central Pattern Generator}
17	{Change-point Detection}
18	{Cognitive Science}
19	{Cohen-Grossberg Neural Networks}
20	{Collaborative Learning}
21	{competitive learning}
22	{Complex Adaptive Systems}
23	{Computational Creativity}
24	{Computational Learning Theory}
25	{Computational Linguistic}
26	{Computer Aided Learning}
27	{Computer Vision}
28	{Computer-assisted Learning}
29	{Computer-based Learning}
30	{Concept Learning}
31	{Conjugate Gradient Method}
32	{Convolution Operator}
33	{Cooperative Learning}
34	{Data Mining}
35	{Data-driven Learning}
36	{Decision Tree Learning}
37	{Deep Learning}
38	{Deep Neural Network}
39	{Delayed Neural Networks}
40	{Dempster-Shafer Theory}
41	{Differential Evolution Algorithm}
42	{Distributed Artificial Intelligence}
43	{Distributed expert systems}
44	{Dynamic Bayesian Networks}
45	{Echo State Network}
46	{Elman Neural Network}
47	{Ensemble Classifier}
48	{Ensemble Learning}
49	{Evolutionary Algorithms}
50	{Evolutionary Learning}
51	{Extreme Learning Machine}
52	{Facial Recognition}
53	{Feature Extraction}
54	{Feature Selection}
55	{Fuzzy Logic}
56	{Fuzzy Neural Network}
57	{Fuzzy System}
58	{Game Theory}
59	{Genetic Algorithm}
60	{Genetic Programming}
61	{Genetics-based Machine Learning}
62	{Hopfield Nets}
63	{Image Classification}
64	{Image Recognition}

65 {Image Segmentation}
66 {Inductive Learning}
67 {Information Retrieval}
68 {Kernel Machines}
69 {K-means}
70 {Learning Algorithm}
71 {Learning Machines}
72 {Learning Method}
73 {Learning Model}
74 {Learning Outcomes}
75 {Learning Rate}
76 {Learning Software}
77 {Learning System}
78 {Learning Transfer}
79 {Learning Vector Quantization}
80 {Machine Learning}
81 {Machine Reasoning}
82 {Machine Translation}
83 {Memory-Based Learning}
84 {Multi agent system}
85 {Multi-agent System}
86 {Multilayer Neural Network}
87 {Natural Language Processing}
88 {Neocognitrons}
89 {Network Learning}
90 {Neural Network computer}
91 {Neural Network}
92 {Neural Networks Learning}
93 {Neuroevolution}
94 {Non-supervised learning}
95 {Object Detection}
96 {Particle Swarm Optimization}
97 {Pattern Recognition}
98 {Probability Learning}
99 {Random Forest}
100 {Random Forests}
101 {Recommender System}
102 {Recurrent Networks}
103 {Recurrent Neural Network}
104 {Recurrent Neural Networks}
105 {Reinforcement Learning}
106 {Semi-supervised Learning}
107 {Sentiment Analyse}
108 {Speech Recognition}
109 {Supervised Learning}
110 {Supervised Machine Learning}
111 {Support Vector Machine}
112 {Support Vector Machines}
113 {Temporal Neural Network}
114 {Temporal Reasoning}
115 {Transfer Learning}
116 {Transfer of Learning}
117 {Unsupervised Learning}
118 {Unsupervised Machine Learning}

Appendix A
Glossary of terms

Scopus and SciVal terms

In Scopus, institutions are classified into one of four main sectors: Corporate, Academic, Government, and Medical. **Academic-corporate collaboration** refers to scholarly output in which there is at least one author with an academic affiliation and at least one author with a corporate affiliation. The metric indicates the degree of collaboration between academic and corporate affiliations (universities and industry working together in research).

A **citation** is a formal reference to earlier work in another publication or patent, most frequently other publications. A citation is used to credit the originator of an idea or finding and typically indicates that the earlier work supports the claims of the work citing it. The number of citations received by a publication from subsequent publications can be used as an indication of the quality or importance of the reported research.

Field-Weighted Citation Impact (FWCI) is an indicator of mean citation impact and compares the actual number of citations received by a publication with the expected number of citations for publications of the same document type (article, review, or conference proceeding), publication year, and subject area. When the publication is classified in two or more subject areas, the harmonic mean of the actual and expected citation rates is used. The indicator is, therefore, always defined with reference to a global baseline of 1.0 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document types (e.g., reviews typically attract more citations than research articles), as well as subject specific differences in citation frequencies overall, over time, and by document type. It is one of the most sophisticated indicators in the modern bibliometric toolkit.

International collaboration in this report is indicated by publications with at least two different countries listed in the authorship byline.

Relative Activity Index (RAI) is defined as the share of an entity's publications (region, country, or institution) in a subject relative to the global share of publications in the same subject. A value of 1.0 indicates that an entity's research activity in a field corresponds exactly with the average global activity in that field; higher than 1.0 implies a greater emphasis, while lower than 1.0 suggests a lesser focus.

Scholarly output describes the products of scholarly activity, such as journal articles, books, book chapters, conference papers, and other forms of research dissemination.

Three letter country codes. The report uses the three letter country codes defined in the International Standards Organization norm ISO 3166.

Argentina	ARG
Australia	AUS
Brazil	BRA
Canada	CAN
China	CHN
France	FRA
Germany	DEU
India	IND
Indonesia	IDN
Italy	ITA
Japan	JPN
Mexico	MEX
Russian Federation	RUS
Saudi Arabia	SAU
South Africa	ZAF
South Korea	KOR
Turkey	TUR
United Kingdom	GBR
United States	USA

Appendix B
Sources

SciVal offers quick and easy access to the research performance of over 10,000 research institutions and 230 regions and countries. Using advanced data analytics technology, SciVal processes enormous amounts of data to generate powerful visualizations in seconds. The 170 trillion metrics in SciVal are calculated from 46 million publication records published in the 21,915 journals of 5,000 publishers worldwide.

https://www.scival.com/

Scopus is Elsevier's abstract and citation database of peer-reviewed literature, covering 71 million documents from more than 23,700 active journals, book series, and conference proceeding publications by 5,000 publishers.

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