CHAPTER 6

FROM KNOWLEDGE TO SOLUTIONS AND VALUE

CHAPTER 6.1

SCIENTIFIC PERFORMANCE

KEY FIGURES

20 %
of the world's publications are from the EU

39 %
of the EU's publications are open access

21 %
of the top 10 % most-cited publications are from the EU

21 %
of publications on health are from the EU

KEY QUESTIONS WE ARE ADDRESSING

- How is the EU performing in scientific output and quality?
- How is EU science contributing to the grand societal challenges?
- In which areas is EU science more specialised?

KEY MESSAGES

What did we learn?

- The European Union remains a scientific powerhouse as it produces about 20% of the world's best science despite having just 6 % of the world's population.
- China is the global leader, not only in terms of volume of scientific publications, but also in the top 10% most-cited publications. However, the US is still leading in the top 1% most-cited publications and impact.
- Southern and eastern European countries are catching up in terms of scientific output and scientific quality.
- The EU is ahead of its global competitors in sharing scientific output. Over 39% of EU publications are freely available under at least one open-access publishing pathway.
- EU science is targeted to address societal challenges, particularly in health, and to foster the green and digital transitions.

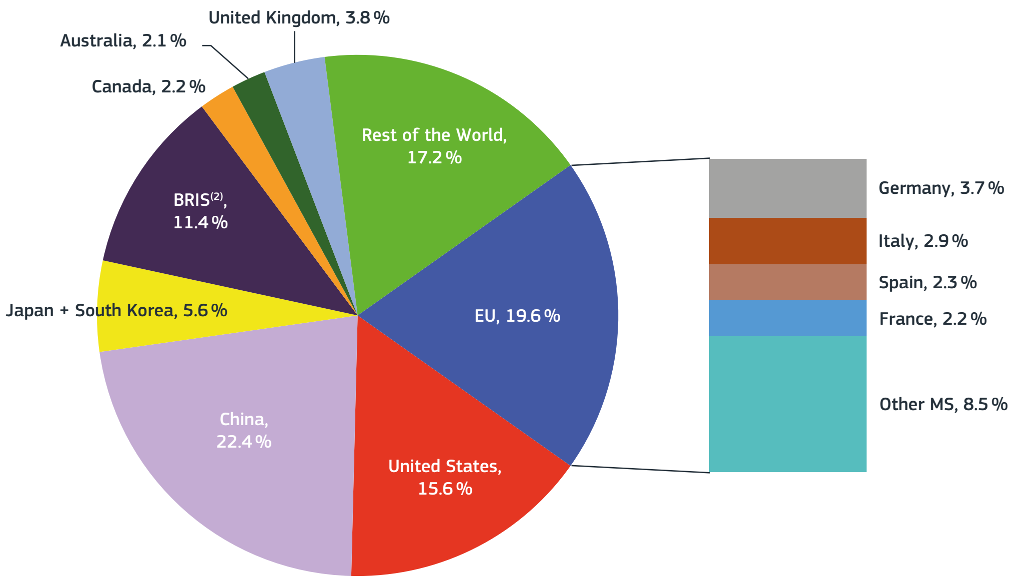
What does it mean for policy?

- For the EU to ensure scientific excellence and remain a key scientific player on the global stage, the effectiveness and performance of EU public research systems must be increased through stronger R&I investments and policy reforms.
- At the same time, it is crucial to continue reinforcing less-developed national and regional research systems in order to narrow the current knowledge gap between EU countries.
- Acknowledging open access to scientific knowledge as a key priority, efforts must be stepped up to lift existing barriers, to create the conditions and to adopt the necessary policies for making the European scientific system more open in knowledge sharing and collaboration.

1. Scientific output

The EU accounts for 19.6 % of the total number of publications registered in Scopus, with almost 620 000 publications in 2020. Despite the increase in absolute numbers, the EU lost 0.3 percentage points in relative terms compared to 2019. As Figure 6.1-1 shows, China takes the lead with a share of 22.4 % of publications. The EU ranks second and the United States is in third position, with a share of 15.6 %. Other important contributors to scientific production were Japan and South Korea, with a combined share of 5.6 %, and Brazil, the Russian Federation, India and South Africa (BRIS) with a combined share of 11.4 %. Other advanced economies were also relevant in the worldwide landscape, in particular the United Kingdom (3.8 %), Australia (2.1 %) and Canada (2.2 %). In the EU, the biggest economies had the largest shares, with Germany, Italy, Spain and France all above 2 %. Germany's world share is comparable to that of the United Kingdom (just below 4 %) following the significant decline they have both experienced since 2000, when the United Kingdom accounted for 7.5 % of the total publications and Germany for 6.5 %.

Figure 6.1-1: World share of scientific publications[1], 2020



Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [1]Fractional counting used. [2]BRIS: Brazil, Russia, India and South Africa.

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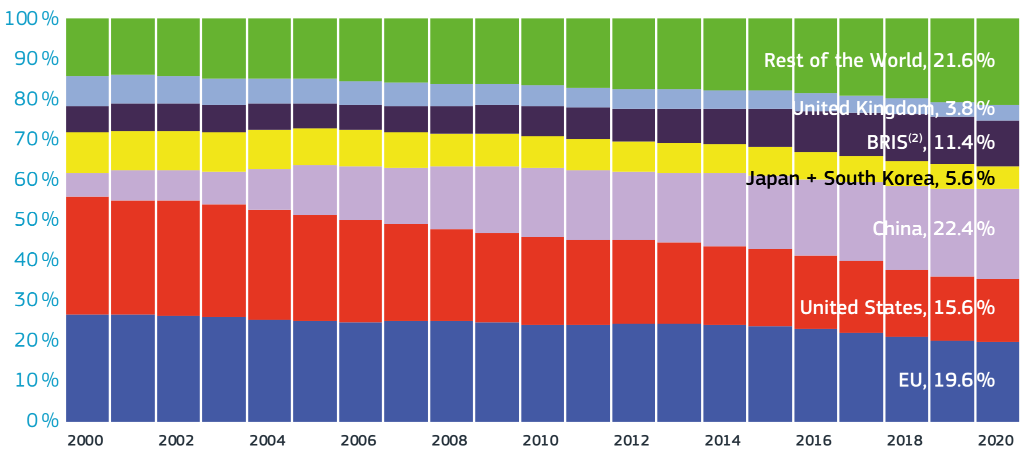
The EU, the United States and China jointly produce more than 60% of the scientific output worldwide. This has been the case for the last 20 years, with China gradually gaining the leading position (Figure 6.1-2). In 2000, China's publication output amounted to 5.9% of world production, placing it in fifth position (Figure 6.1-2). China overtook the United States in 2016 and the EU in 2019 (Elsevier's Scopus database). This incredible increase affected the relative position of the United States, which has lost 13 percentage points since 2000, and to a lesser extent the EU, with a decline of only 7 percentage points. One reason could be the EU's specialisation in less-technological fields such as health and social sciences, where China is still lagging. Interestingly, China's increase from 2019 to 2020 was significantly lower than the year before (only 0.4 percentage points, compared to 1.3 percentage points from 2018 to 2019). It is not yet clear whether this slow-down is linked to the COVID-19 pandemic or to other policy related factors, such as the recent measures taken by the Chinese government to urge its researchers to publish in home-grown journals (Nature editorial, 2020). In contrast, both the United States and the EU saw their shares dropping at a slower pace, 0.3 percentage points in 2020, possibly due to the increase in the volume of scientific publications in areas where both have an advantage.

Figure 6.1-2: World shares of scientific publications[1], 2000-2020



Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [1]Fractional counting used. [2]BRIS: Brazil, Russia, India and South Africa.

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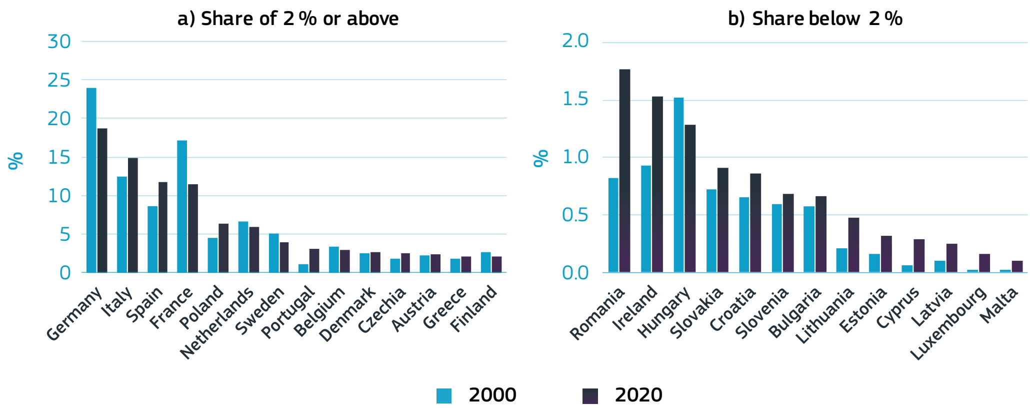
Four large EU Member States together (Germany, Italy, Spain and France) produced almost 60 % of the total EU publications in 2020. Within the EU, the shares of scientific publications vary significantly, and to a large extent depend on the size of the country (Figure 6.1-3). However, the shares have changed significantly in the last 20 years. Southern and eastern European countries have increased their share over 2000-2020, in contrast to some of the most populated countries such as Germany and France. The countries with the largest absolute increase in their shares are Spain, Italy, Poland and Portugal. On the other hand, the highest growth rates in terms of publication shares were recorded in small countries with a low overall publication volume, e.g. Malta (432 %), Cyprus (388 %) and Luxembourg (589 %), although fast growth was also observed in Portugal (167 %) and Romania (117 %).

Figure 6.1-3: Share of each EU Member State within the EU for scientific publications[(1)], 2000 and 2020



Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [(1)]Fractional counting used.

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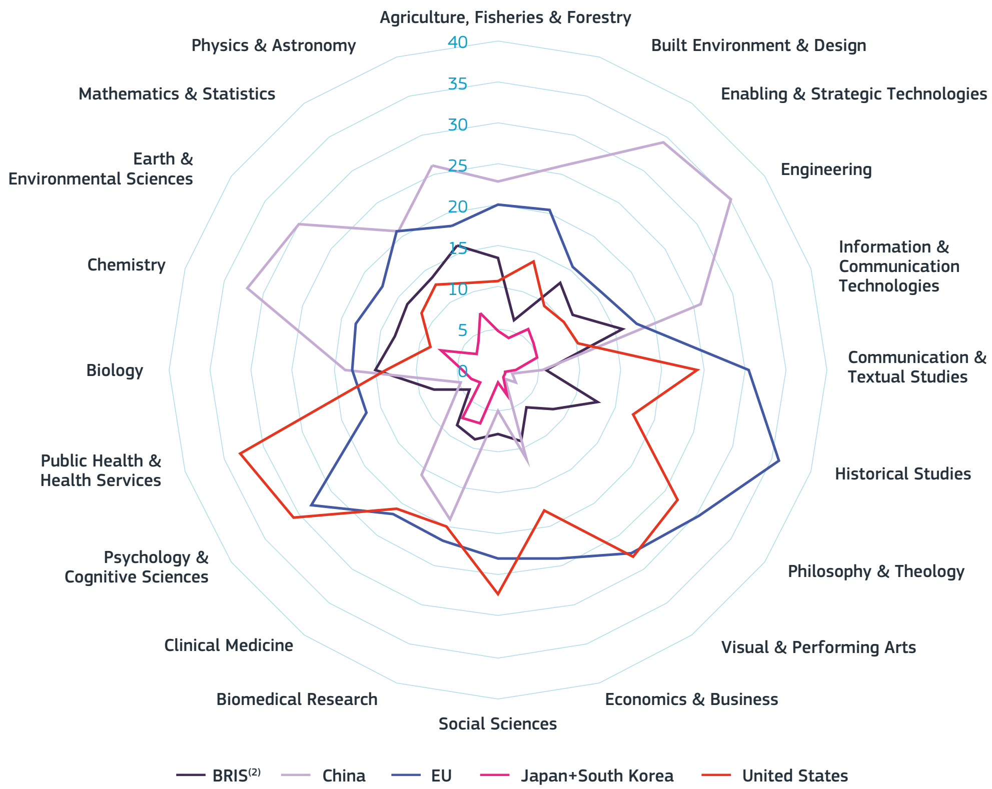
Comparisons of research productivity across countries lead to different results, depending on the metric used for standardisation. If we compare publications per USD billion GDP, the BRIS countries perform best, followed by China, while the US scores last. If we compare publications per million population, the US is at the top, followed by the EU; and if we compare publications per researcher, the results are very similar, with a slight advantage to the EU. Therefore, the choice of the unit for comparisons must be taken into consideration and results must always be interpreted cautiously.

In 2020, the EU led globally in the domains[1] of economics and social sciences and of arts and humanities. These domains comprise fields such as historical studies, and

Figure 6.1-4: World shares (%) of scientific publications per country and scientific field(1), 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: (1)Fractional counting used. (2)BRIS: Brazil, Russia, India and South Africa.

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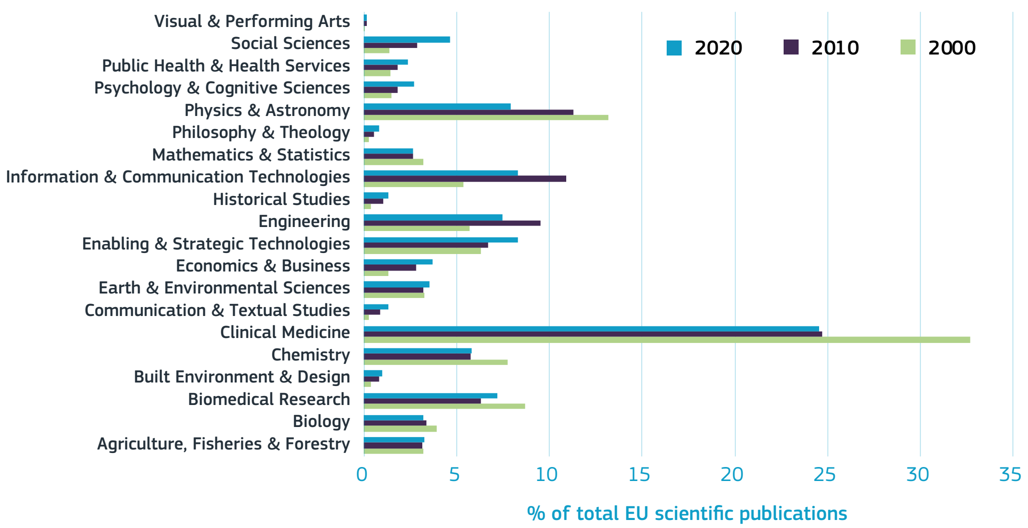
1 Each domain includes several scientific fields.

economics and business, which represent a small share of the articles published annually worldwide. To a lesser extent, the EU also leads in the fields of clinical medicine and of biomedical research. Figure 6.1-4 shows that the United States leads in the domain of health sciences, particularly in the field of public health and health services. In contrast, China leads in applied and natural sciences, especially in the fields of engineering, enabling and strategic technologies and of chemistry.

Approximately one in four EU publications are in the scientific field of clinical medicine, in which the EU leads globally. Its share within EU publications is still the highest, despite a dramatic drop of 8 percentage points since 2000 (Figure 6.1-5). Other scientific fields that have lost prominence over the years are physics and astronomy, chemistry, and biomedical research. In contrast, there has been an increase in the share of publications in the fields of information and communication technologies, enabling and strategic technologies, social sciences, and economics and business. More recently, there has been an increase in the share of publications related to earth and environmental sciences. The changes in the shares of the publications over time may reflect to a certain extent the EU's trajectory towards the green and digital transitions.

Open access means making scientific publications freely available so that anyone can read and reuse them. This free exchange of knowledge encourages creativity and promotes research excellence. There are various types of open-access publishing but the two most common are 'gold' and 'green'. **Gold open access** means immediate access

Figure 6.1-5: EU share of publications[(1)] per scientific field, 2000, 2010 and 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [(1)]Fractional counting used

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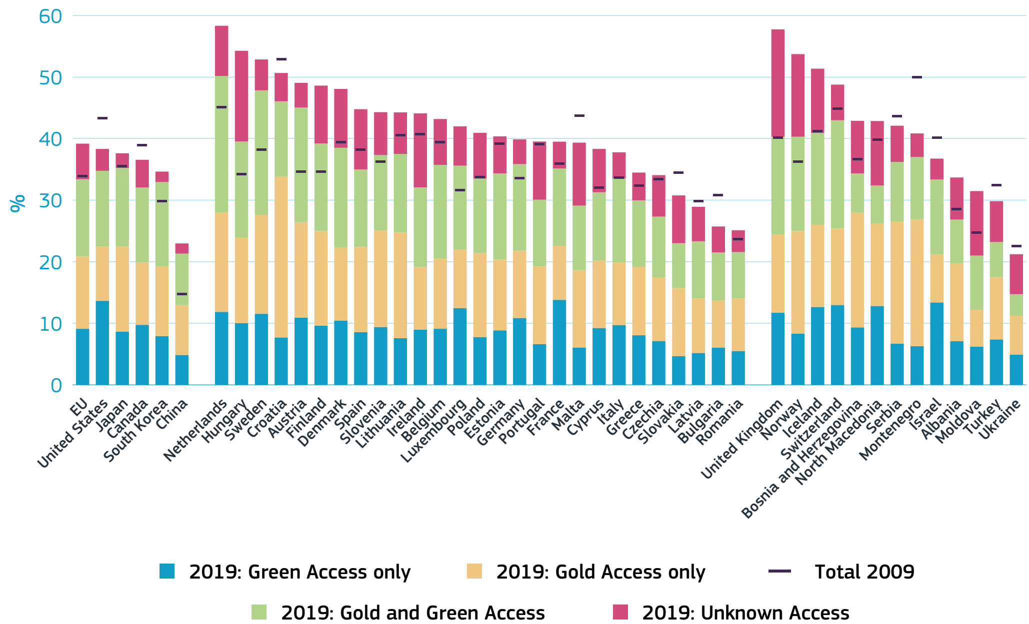
to an article in an online journal. Green open access involves publishing in a traditional subscription journal as usual then self-archiving in a publicly and freely accessible repository after an embargo period set by the publisher.

The EU is ahead of its global competitors in applying open access. Over 39% of total EU publications are freely available under at least one open-access publishing pathway (gold, green or other). The United States, Japan, Canada and South Korea are closely behind, with shares ranging from 38 % to 35 %, whereas China's share is much lower and accounts for 23 % of the total scientific production of the country.

The shares vary significantly among EU Member States. The highest share was recorded in the Netherlands (58 %) and the lowest in Romania (25 %). Nevertheless, open-access scientific publications have increased for 22 of the 27 Member States over the last decade, particularly for Finland, Austria and Hungary.

Figure 6.1-6: **Open-access scientific publications[1] with digital object identifier (DOI) as % of total scientific publications with DOI, 2009 and 2019**



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database and 1findrdatabases

Note: [(1)]Full counting used

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Open science makes R&I systems more efficient and creative, and reinforces scientific excellence and society´s trust in science[2]. The first international framework on open science was adopted by 193 countries at UNESCO's General Conference in November 2021[3]. The European Commission has already taken steps towards open science. In the New European Research Area adopted in September 2020, the Commission commits to:

- launch, via the Horizon Europe Programme, a platform for peer-reviewed open access publishing;
- analyse authors' rights to enable sharing of publicly funded peer-reviewed articles without restriction;
- ensure a European Open Science Cloud that is offering findable, accessible, interoperable and reusable research data and services (Web of FAIR);
- incentivise open science practices by improving the research assessment system.

The Horizon 2020 programme is in a leading position among funding programmes in terms of the level of open access achieved. The estimated level of compliance with the open-access policy for scientific publications under Horizon 2020 stands at 83 %, which is among the top open-access success rates of funders globally (European Commission, 2021a). The average open-access rate among Horizon 2020 publications has increased steadily over the duration of the programme, from just over 65 % of peer-reviewed publications in 2014 to 86 % in 2019. However, the shares differ between Horizon 2020 programmes' scientific fields and specific disciplines. For example, the percentage of open-access publications was highest within medical and health sciences, as well as in natural sciences.

2 A new ERA for Research and Innovation' (COM(2020) 628 final)
3 https://en.unesco.org/news/unesco-sets-ambitious-international-standards-open-science

Box 6.1-1: Effect of COVID-19 on scientific publications

The pandemic did not affect the overall volume of scientific publications, but it had an impact on the shares between countries and scientific fields. In 2020, the number of publications continued to increase worldwide, but at a lower rate (5.6 % on an annual basis, compared to 7.1 % in 2019). This is still higher than the average increase of 5.4 % over 2000-2010 (see Table 6.1-1). The United States and the EU had the biggest increase, mainly due to their publications in health-related scientific fields, where both are strong.

Table 6.1-1: Growth rate in the volume of the scientific publications (%, fractional counting)

	EU	China	United States	BRIS (Brazil, Russia, India and South Africa)	Japan + South Korea	World
2019	2.4	13.8	0.9	9.4	1.1	7.1
2020	3.6	7.5	3.8	2.8	0.5	5.6
2000-2020 Average growth	3.8	12.9	2.1	8.4	2.3	5.4

Science, Research and Innovation Performance of the EU 2022

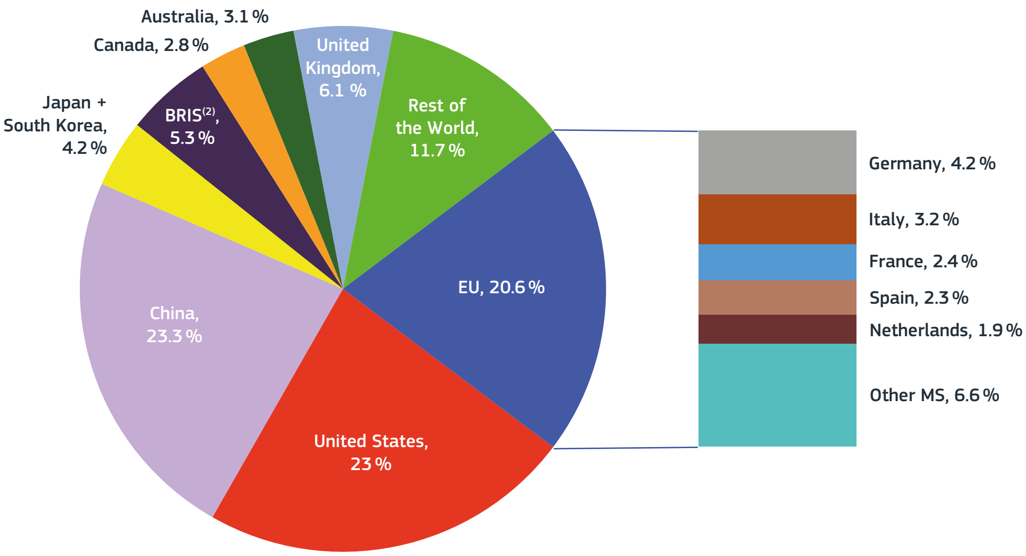
Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Science-Metrix using the Scopus database.

Scientists published well over 100 000 articles on the coronavirus pandemic in 2020 (Else, 2020). The timeline between the submission of a paper and its publication shortened, particularly for papers about COVID-19. Studies on the pandemic were prioritised, with the goal of getting them into the public domain as quickly as possible, which raised some concerns about the quality of the underlying research (Sloane and Zimmerman, 2021). However, during the early phase of the pandemic, scientists from the US and the EU reported a sharp decline in time spent on research. This decline in research activity also impacted scientific output, with a clear gender bias. The growth in submissions from female authors trailed behind growth from male authors across all subject areas, at least during the first half of 2020. These negative impacts on time spent on research were short-lived. A year later, scientists reported only minor differences compared to the pre-pandemic total work time (Gao et al., 2021).

2. Scientific excellence

China now has the highest share of the top 10 % most-cited scientific publications worldwide, overtaking the United States. China has continued to improve the quality of its scientific output, as demonstrated by the impressive increase in the share of the top 10 % most-cited scientific publications, from 2.8 % in 2000 to 23.3 % in 2018. The US, which was still the global leader in 2016, lost its leading position after declining by almost two percentage points. The EU fell to a third place after losing about two percentage points. However, the United States still leads in the top 10 % most-cited publications per million population (159.7 against 104.5 for EU and 37.7 for China) and per researcher. From the EU countries, Germany contributed 4.2 % to the global top 10 % most-cited publications, followed by Italy (3.2 %) and France (2.4 %).

Figure 6.1-7: World share of top 10 % most-cited scientific publications[1], 2018 (citation window: 2018-2020)



Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [1]Scientific publications within the 10 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting used. [2]BRIS: Brazil, Russia, India and South Africa.

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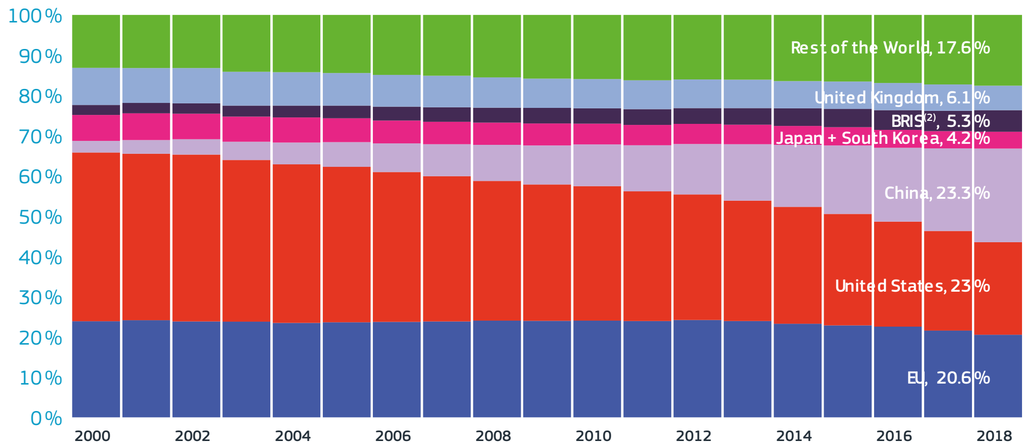
Similarly to the scientific volume, China's remarkable improvement in the quality of scientific output over time has primarily affected the ranking of the United States and, to a lesser extent, the EU. Jointly, the three leading global players (China, the EU and the US) have steadily produced about 70 % of the top 10 % most-cited publications over the years (Figure 6.1-8). Another noteworthy finding is the moderate positive trend of the BRIS countries. Other countries, such as Australia, Canada and especially the United Kingdom also contributed significantly to the 10 % most-cited publications.

Figure 6.1-8: World share of top 10 % highly cited scientific publications[1], 2000 (citation window: 2000-2002) to 2018 (citation window: 2018-2020)



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [1]Scientific publications within the 10 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting used. [2]BRIS: Brazil, Russia, India and South Africa.

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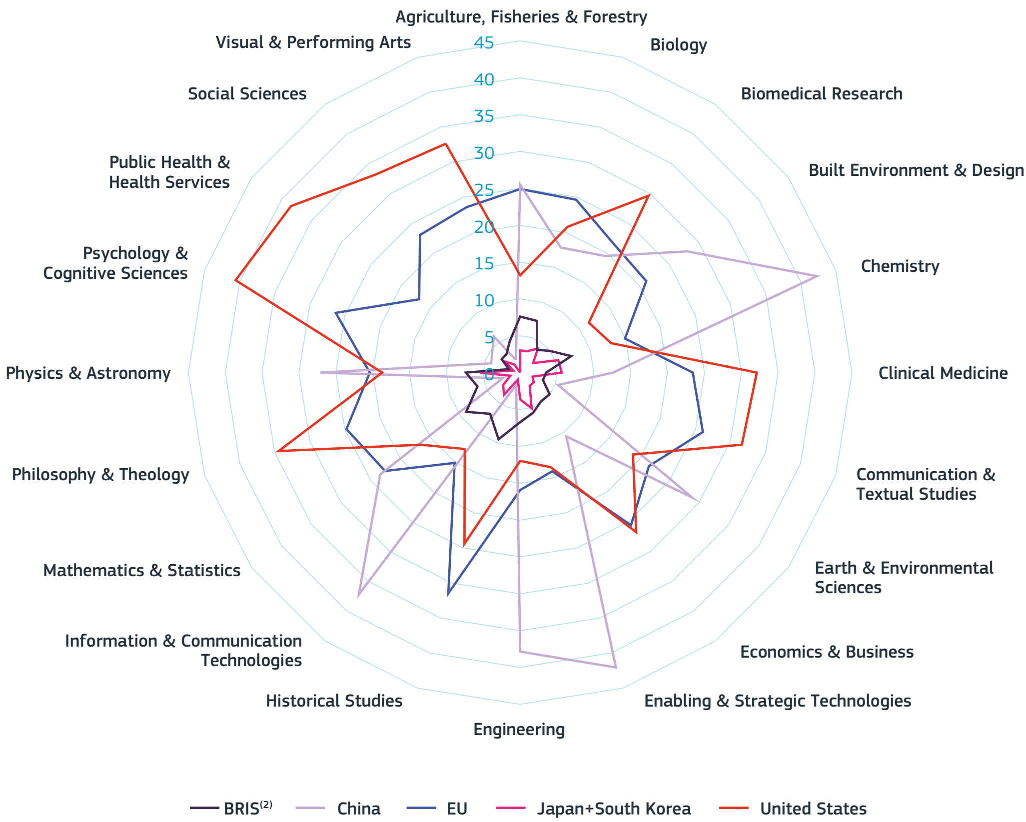
The EU has the highest share of publications among the top 10% most-cited only in the fields of biology and historical studies. The United States leads in the domain of health science and its underlying scientific fields, whereas China leads in applied and natural sciences, and in particular in chemistry, in enabling and strategic technologies, in engineering and in information and communication technologies (Figure 6.1-9).

Figure 6.1-9: World shares of the top 10% most-cited publications by country/region and scientific field[1], 2018



Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [1]Scientific publications within the 10% most cited scientific publications worldwide. Fractional counting method. [2]BRIS: Brazil, Russia, India and South Africa.

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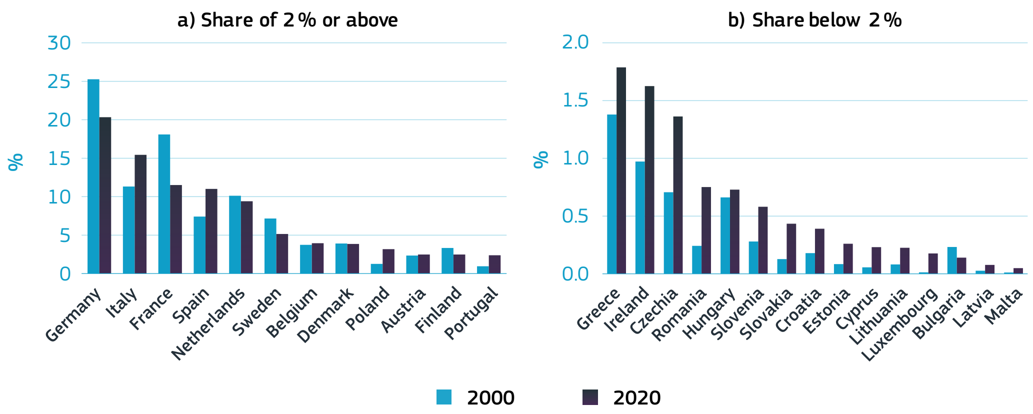
Southern and eastern European countries are catching up in terms of scientific quality. Except for Bulgaria, all EU Member States with share of less than 2 % saw an increase in their contribution to the European share of the top 10 % most-cited publications. Among those with shares above 2 % (left-hand panel of Figure 6.1-10), Italy, Spain, and Poland improved their share in quality of scientific publications the most. On the other hand, Germany has lost 4.9 percentage points since 2000, and France 6.6 percentage points, falling to the third position after Italy. The Netherlands, despite a small decline compared to 2000, produced almost 10 % of the European top 10 % most-cited scientific publications, followed by Sweden, whose share declined from 7 % in 2000 to 5 % in 2018.

Figure 6.1-10: Share of each EU Member State within the EU for the top 10% most cited scientific publications(1), 2000 vs 2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: (1)Fractional counting used.

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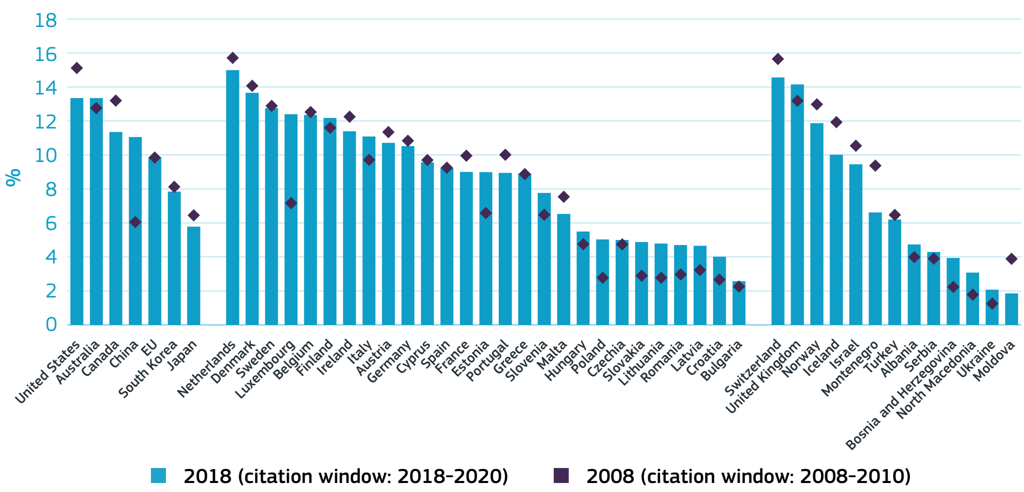
The United States has the highest percentage of publications in the top 10%, followed by Australia and Canada (Figure 6.1-12). The remarkable improvement in the quality of Chinese publications is reflected in the share of publications appearing in the top 10% most-cited publications worldwide. In 2008, only 6% of Chinese publications were in the top 10%. Ten years later, this percentage had almost doubled (11.1% in 2018), placing China in fourth position. The EU fell to fifth place with nearly 10%, which in absolute numbers reflects a stable performance over the last decade.

Within the EU, the percentage of publications in the top 10% most-cited publications varies between 15 and 2%. This indicator measures the quality of the publications for a given country and year. It is calculated as the ratio of the number of publications included in the top 10% most-cited worldwide, over the total number of publications of the country that year. The Netherlands leads globally with 15% of its publications among the top 10% most-cited, ahead of other global leaders, such as Switzerland and the United Kingdom (Figure 6.1-11). Denmark takes the second position within the EU (13.7%), followed by Sweden (12.7%). Germany, the biggest European contributor to the top 10% most-cited publications, scores above the EU average (10.5%), but below other global competitors such as Canada and Australia. Despite some improvement, the gap between northern and southern/eastern European countries persists.

Figure 6.1-11: Top 10% highly most-cited scientific publications[1], 2008 and 2018



Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [1]Share of scientific publications within the 10% most-cited scientific publications worldwide by the total number of scientific publications of the country; fractional counting used instead of method.

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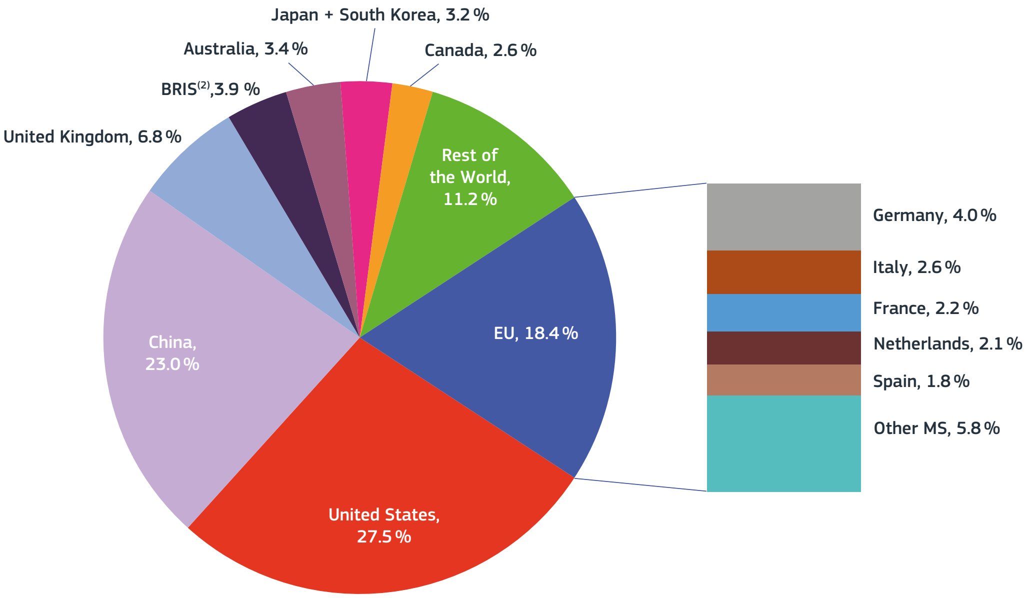
China overtook the EU in the world share of top 1 % most-cited publications, and is approaching the US. The EU, with a global share of 18.4 %, is in third position, followed by the United Kingdom with a share of 6.8 %, (Figure 6.1-12). Germany has the highest share among the EU countries with 4.0 %, followed by Italy (2.6 %), which climbed up one position, overtaking France (2.2 %). Australia also stands out with a share of 3.4 %, which is above the share of Japan and South Korea combined. The BRIS, despite their small share, have been improving over time.

Figure 6.1-12: World share of top 1 % most-cited scientific publications[1], 2018 (citation window: 2018-2020)



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [1]Scientific publications within the 1 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting used. [2]BRIS: Brazil, Russia, India and South Africa

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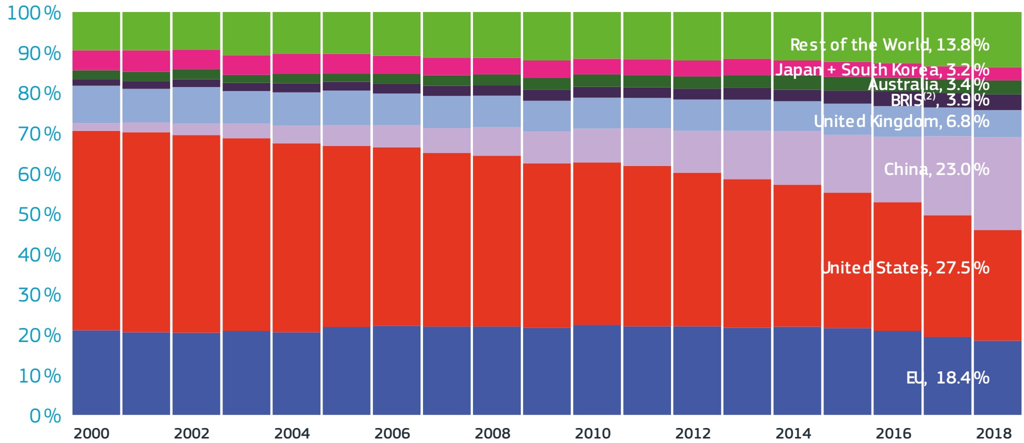
The United States preserved its leading position in the top 1 % most-cited publications. However, since 2000, it has lost about 20 percentage points in the world share of top 1 % most-cited publications (Figure 6.1-13). In contrast, the United States still records the highest number of top publications per million population (19.1), well ahead of the EU, which comes second with 9.4, and China, which comes third with 3.8. Therefore, there can be no doubt that the US still leads the world in terms of research impact.

Figure 6.1-13: World share of top 1 % most-cited scientific publications(1), 2000 (citation window: 2000-2002) to 2018 (citation window: 2018-2020)



Science, Research and Innovation Performance of the EU 2022

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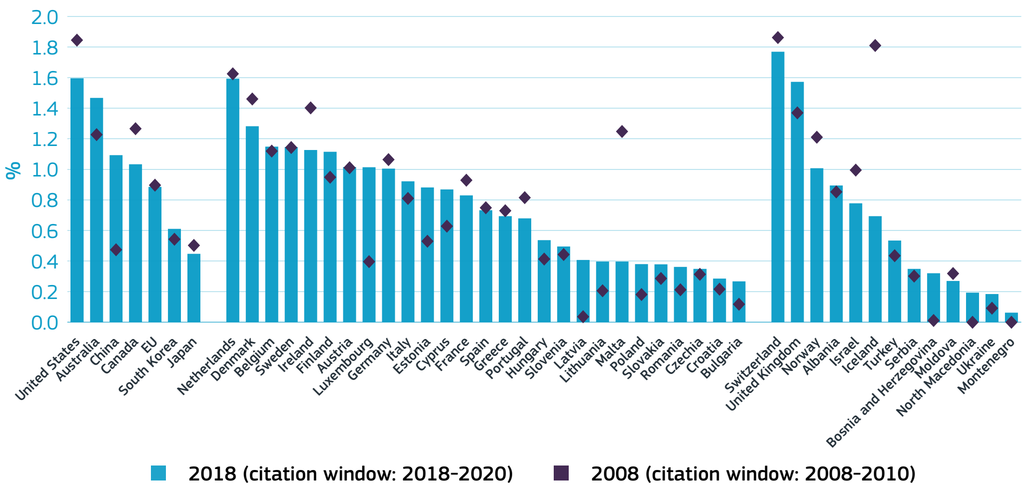
About 0.9% of all EU publications belongs to the top 1% most-cited publications. While the EU performance has remained stable over the last 10 years, the United States has shown a significant decrease over the same period. In contrast, in an impressive upward trend, China overtook Japan, South Korea, the EU and Canada to rank third in 2018, only behind Australia and the United States. The global leader in this indicator remains Switzerland, with 1.7% of its publications being among the top 1% most-cited globally. The Netherlands is third in the global league (the US is second) and first among the EU countries, followed by Denmark. Another noteworthy finding is the sharp rise of Luxembourg, which now scores ahead of the EU average. Nevertheless, given the small number of publications, results should be interpreted with caution.

Figure 6.1-14: Top 1% most-cited scientific publications(1), 2008 and 2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: (1)Share of scientific publications within the 1% most-cited scientific publications worldwide by the total number of scientific publications of the country; fractional counting used

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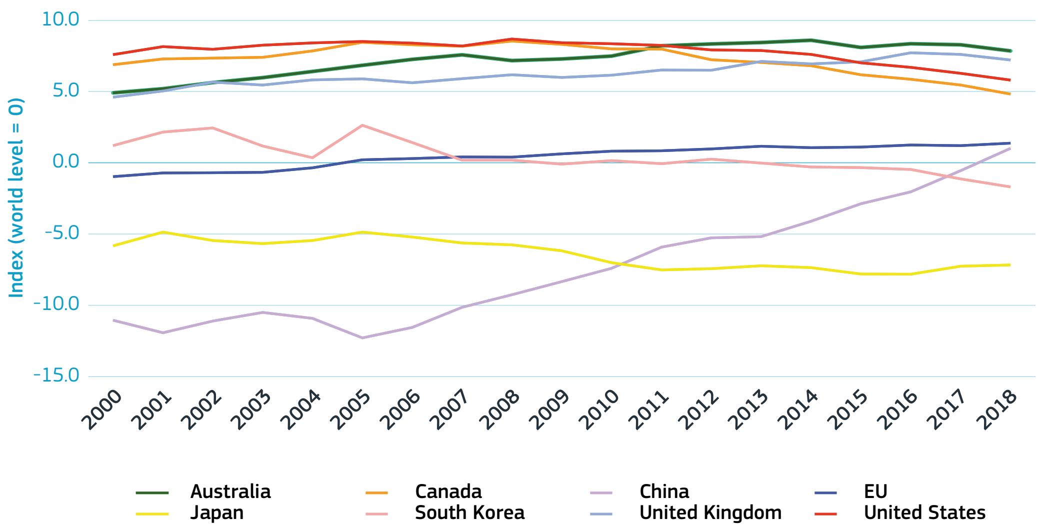
Evidence from other metrics on the scientific quality and impact, such as the Citation Distribution Index (CDI), the h-index and the Nature index, confirm the lead of the US, the EU's stable position and China's remarkable improvement. The impact of EU publications in terms of citations has been stable over the last two decades and just above the world level. This stability in the CDI [4] (Lando and Bertoli-Barsotti, 2014), (Campbell et al., 2016) is a positive result compared to the decreases in scores observed for countries such as Japan, Canada, South Korea and the United States. The highest growth in CDI score was recorded for China. China had one of the lowest CDI scores in 2000 (-11.0) but managed to improve and become on a par with the world level and to close the gap with the EU in 2018. From these observations, combined with decreasing citation impact scores between 2010 and 2018 for publications from countries such as Canada, South Korea and the United States, it is safe to conclude that Chinese publications are now widely read and used by researchers throughout the world. Chinese gains in citation impact may have come at the expense of these other countries' relative influence (European Commission, 2021b). The evolution of the CDI is shown in Figure 6.1-15.

Figure 6.1-15: Citation Distribution Index, 2000-2018



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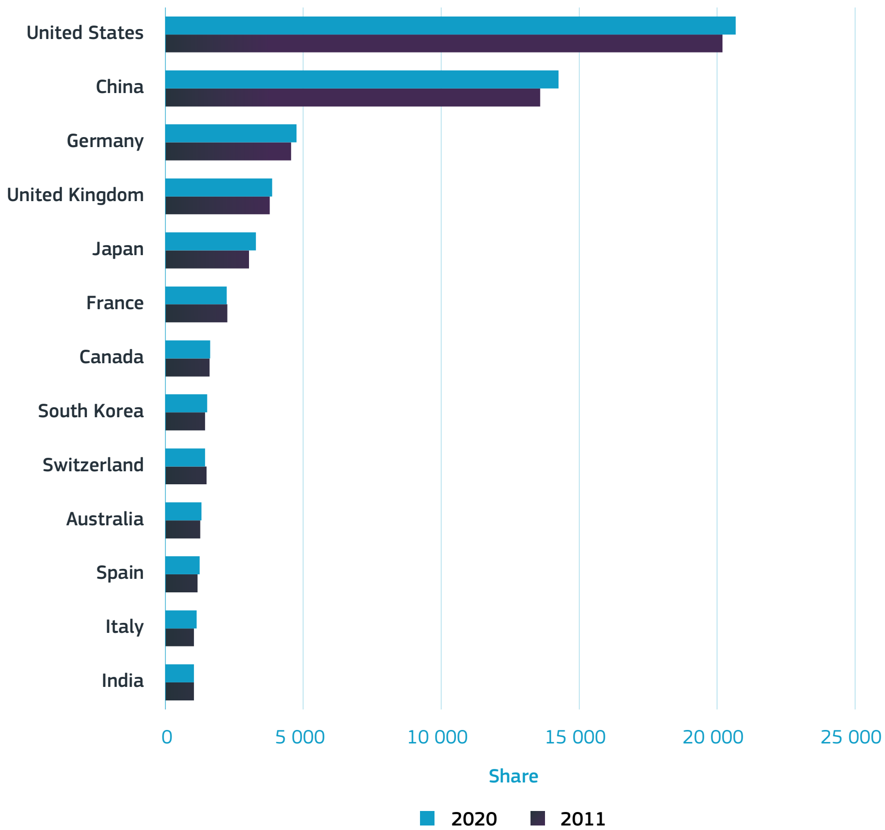
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-1-15.xlsx

4 The principle is to define, for an entity (e.g. a country) with a given number of citations, an ideal citation distribution that represents a benchmark in terms of number of papers and number of citations per publication, and to obtain an index that increases in value when the real citation distribution approaches its ideal form. To prepare this indicator, Science-Metrix divides all publications in a given research area, document type and year into 10 groups of equal size, or 'deciles', based on their normalised citation scores.

The leading position of the United States in scientific performance and impact is confirmed by the h-index. The h-index is a country's number of articles (the value h) that have received at least h citations. It quantifies both a country's scientific productivity and scientific impact and it is also applicable to scientists, journals, etc. The h-index is often used to measure and rank the scientific performance and impact of countries, journals and even researchers. In 2020, the United States was still at the top of the league, followed by the United Kingdom and Germany. In total, four EU countries are in the top ten global positions (Germany, France, Italy and the Netherlands)[5].

The Nature Index also confirms the leading position of the United States in scientific impact. The Nature Index measures publication outputs in 82 selected journals covering life sciences, physical sciences, chemistry, and earth and environmental sciences. The first

Figure 6.1-16: Nature Index 2020 (leading countries)(1)



Source: Nature Index

Notes: (1)The leading countries by research output are measured by the metric Share in the Nature Index for 2020, compared with their Share for 2019.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-1-16.xlsx

5 Scimago Journal and Country Rank. https://www.scimagojr.com/countryrank.php

year of the COVID-19 pandemic brought an end to China's run of high growth in output[6]. After growing 15.5% from 2018 to 2019, China's adjusted Share[7] in the Nature Index slowed to a 1.1% increase from 2019 to 2020, by far its slowest growth since at least 2015. Therefore China remains significantly behind the United States, followed by Germany, the United Kingdom and Japan (Figure 6.1-16). At the same time, the Chinese Academy of Sciences is clearly the leading institution, with a Share of 1886.71 (number of publications in 2020, using fractional counting), more than twice that of its nearest competitor, Harvard University, with 927.26.

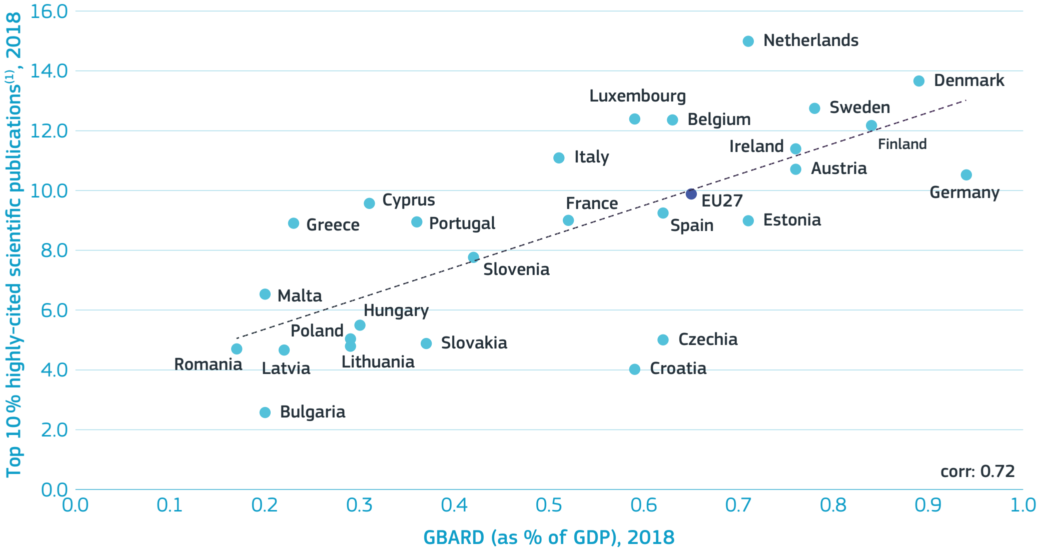
There is a positive correlation between the public budget allocated to R&D and the scientific impact measured by the share of top 10% most-cited publications, similar to the direct relationship between spending on research and scientific output. For example, the Netherlands, Denmark, Sweden, Finland, Ireland, Austria and Germany enjoy higher levels of public investment in R&D than the EU average, as well as better scientific results (Figure 6.1-17). Although this relationship cannot be interpreted as causal, it is an indicator to be considered in R&I policymaking.

Improvement in the access to excellence and prioritisation of R&D investments are two main priorities of the European Research Area. Horizon Europe, the European Union's research framework programme for 2021 to 2027, supports researchers to carry out basic and applied research and promotes collaborations within the EU to deliver R&I addressing the social and economic challenges of today. Through its Widening Participation and Strengthening the European Research Area part, Horizon Europe supports the less-performing Member States to valorise research findings and connect their ecosystems. Another flagship component of Horizon Europe is the European Research Council (ERC), which encourages the highest quality research in Europe through competitive funding that complements other funding activities in Europe, such as those of national research funding agencies.

6 https://www.natureindex.com/news-blog/nature-index-annual-tables-twenty-twenty-one-country-comparisons-difficult-year

7 Nature Index's metric is Share, a fractional count based on an institution's or location's contribution to an article. Adjusted Share is used when comparing data over time, to take account of a small variation in the number of articles published in the Nature Index journals year by year.

Figure 6.1-17: Government Budget Appropriations to R&D (GBARD) and top 10% most-cited scientific publications, 2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: (1) Scientific publications within the 10 % most cited scientific publications worldwide as % of total scientific publications of the country; fractional counting used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-1-17.xlsx

Box 6.1-2: European Research Council

Since the ERC launched its first call in 2007, it has funded over 10 000 of the best scientists in Europe. The aim of the ERC is to allow its grantees to pursue ground-breaking, high-gain/high-risk research leading to advances at the frontiers of knowledge.

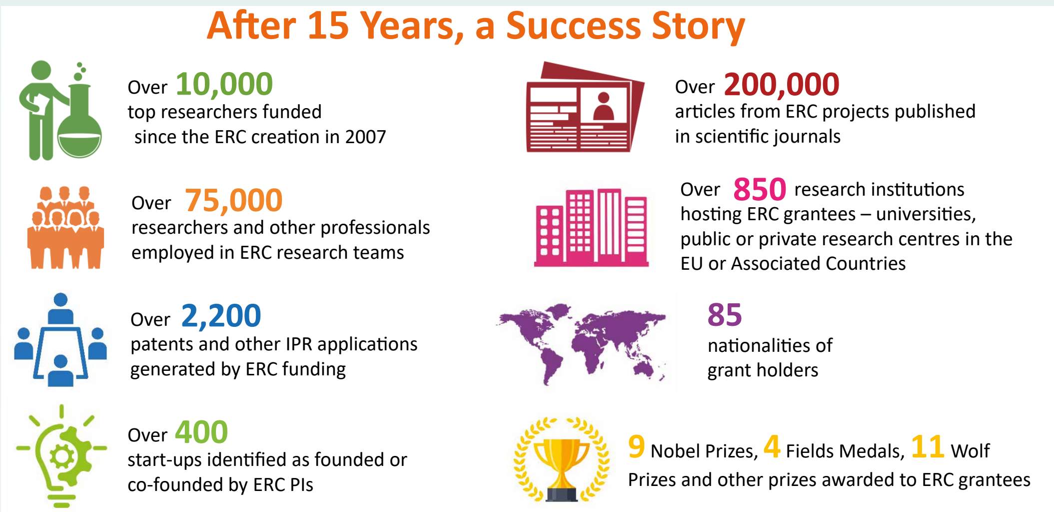
Since 2007, ERC-funded researchers have won nine Nobel Prizes, four Fields Medals and eleven Wolf Prizes. In February 2022, two ERC grantees were awarded the latest Wolf Prize in Physics **for pioneering contributions to ultrafast laser science and attosecond physics[8].**

Every year the ERC asks a group of independent experts to look at the results of the projects that the ERC has funded in the past.

The latest such exercise found that 81 % of projects funded by the ERC resulted in a scientific breakthrough or major advance[9]. Over 200 000 scientific publications have been produced by ERC grantees recording the results of their work. Publications by ERC grantees are cited by other scientists seven times more than average, indicating their significance within their fields.

ERC-funded projects have already generated over 2 000 patent and other IPR applications and created over 400 start-up companies. Out of 42 recipients of the European Innovation Council's new Transition fund, 25 originated from research funded by the ERC[10].

Figure 6.1-18: European Research Council, After 15 Years, a Success Story



Science, Research and Innovation Performance of the EU 2022

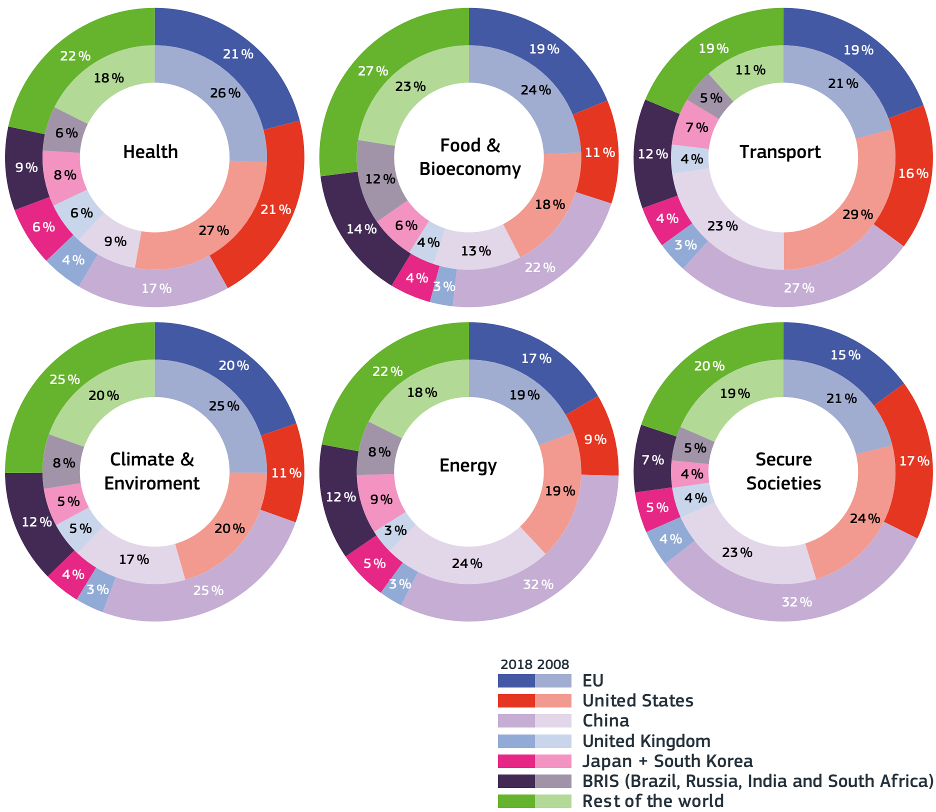
Source: European Research Council
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-1-18.xlsx

8 https://erc.europa.eu/news/wolf-prize-physics-awarded-erc-grantees
9 https://erc.europa.eu/news/impact-erc-funded-frontier-research-again-confirmed
10 https://erc.europa.eu/news/erc-funded-research-wins-most-new-eu-innovation-grants

3. Societal Grand Challenges and Sustainable Development Goals

In terms of scientific output, China is leading in all Horizon 2020 Societal Grand Challenges[11] (SGCs) except for health, where the eight percentage-point increase over 2010-2020 was not sufficient to overtake the United States and the EU. EU researchers are the authors of about 20% of scientific publications for all the SGCs worldwide, except for energy and secure societies, where the shares are lower (17% and 15% respectively). The US's publication share declined substantially for all SGCs in the last 10 years. Other noteworthy findings are the

Figure 6.1-19: World shares (%) of scientific publications(1) by country/region and Horizon 2020 Societal Grand Challenges, 2010 (interior) and 2020 (exterior)



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: (1)Fractional counting methods.

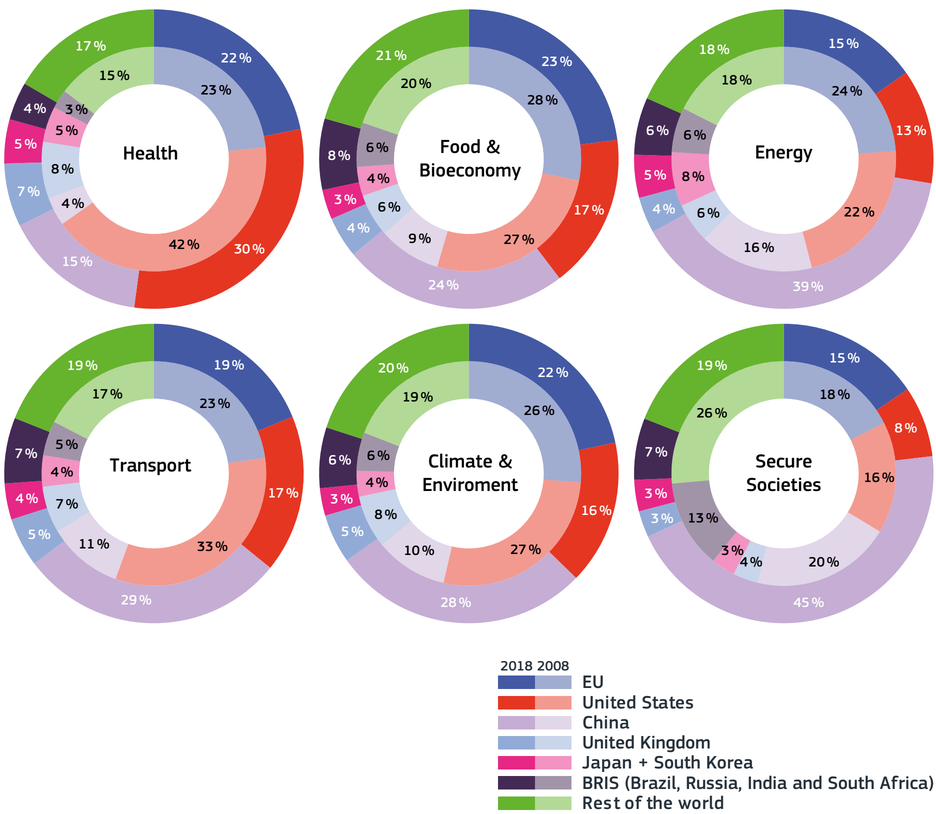
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-1-19.xlsx

11 The six SGCs analysed in this report are: 1) health, demographic change and wellbeing; 2) food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy; 3) secure, clean and efficient energy; 4) smart, green and integrated transport; 5) climate action, environment, resource efficiency and raw materials; 6) secure societies – protecting the freedom and security of Europe and its citizens.

increased contribution of the BRIS countries, with an average increase across the six SGCs of 4 percentage points, and the widening of the scientific base of the rest of the world, i.e. countries beyond those analysed individually, with an average increase of 5 percentage points in the publication share.

The EU has the second-highest world share of the top 10% most-cited publications in all Societal Grand Challenges. Ten years ago, the EU was leading in energy and in food and bioeconomy (Figure 6.1-20). The massive improvement in the quantity and quality of the Chinese output in these fields has forced the EU to second position. Chinese researchers are leading as regards the most-cited publications related to energy (with a 39% share). The United States is undoubtedly the global leader in health-related most-cited publications with a 30% share, despite the loss of 12 percentage points since 2008.

Figure 6.1-20: World shares (%) of the top 10% most-cited scientific publications[1] by country/region and Horizon 2020 Societal Grand Challenges, 2008 (interior) and 2018 (exterior)



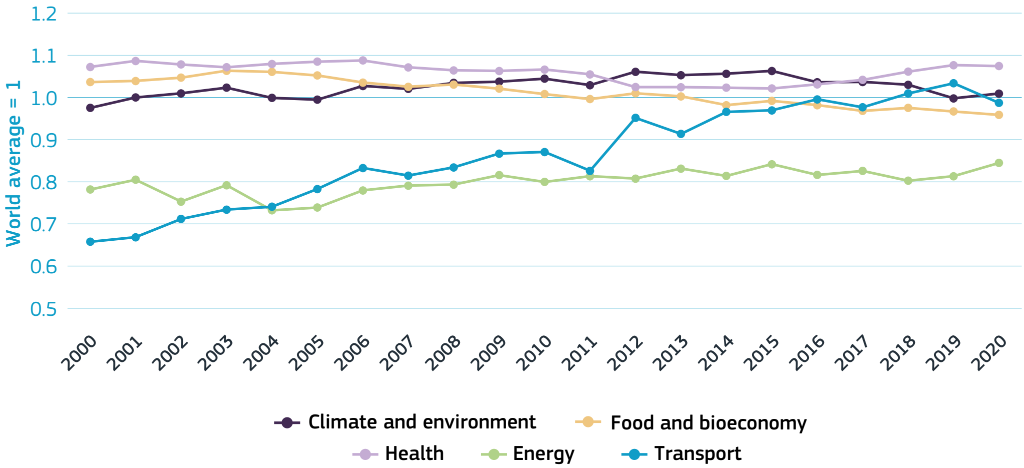
Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [1]Scientific publications within the 10% most cited scientific publications worldwide; fractional counting method.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-1-20.xlsx

Over the years, the EU has maintained its specialisation in health and, to a large extent, in climate and environment. In contrast, in food and bioeconomy, the EU has progressively become less specialised, scoring below the world average since 2014. On the other hand, transport has shown the opposite pattern, with the EU gradually becoming more specialised. However, as Figure 6.1-21 shows, this upward trend slowed down significantly after 2014. In energy-related publications, the EU is lagging behind and is much less specialised than the world average.

Figure 6.1-21: EU Specialisation Index[(1)] (SI), 2000-2020



Science, Research and Innovation Performance of the EU 2022

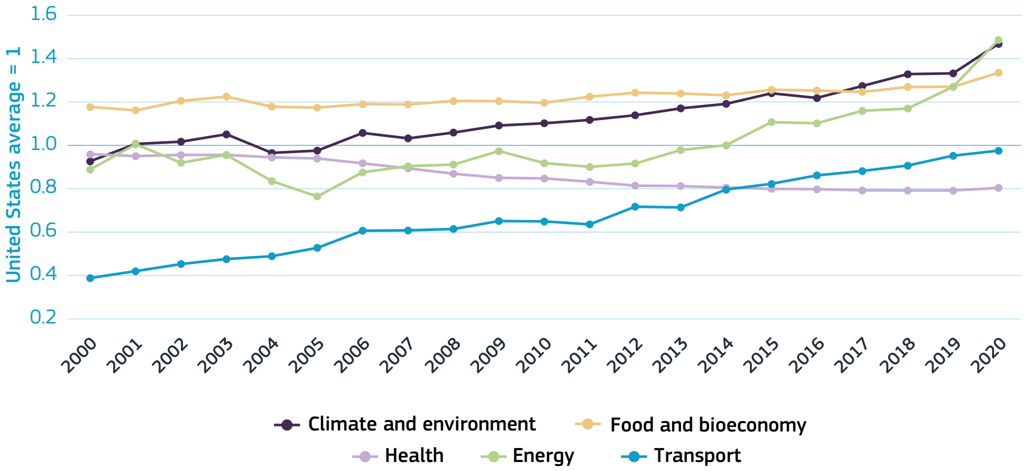
Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [(1)]The specialisation index (SI) is an indicator of research intensity in a given entity (e.g. a country) for a given research area (e.g. one of the SGCs), relative to the intensity in a reference entity (e.g. the world) for the same research area. In other words, the SI of a country in a given research domain portrays how much emphasis that country allocates to research in that domain relative to the world. Comparisons are meaningful only between countries of similar size.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-1-21.xlsx

Compared to the United States, the EU specialises in publications on climate and environment, food and bioeconomy, and energy. Over time, the EU has improved in transport, and almost reached the specialisation level of the United States in 2020. However, the EU has remained systematically below the United States in health.

Figure 6.1-22: EU Specialisation Index (SI)[1] compared to the United States, 2000-2020



Science, Research and Innovation Performance of the EU 2022

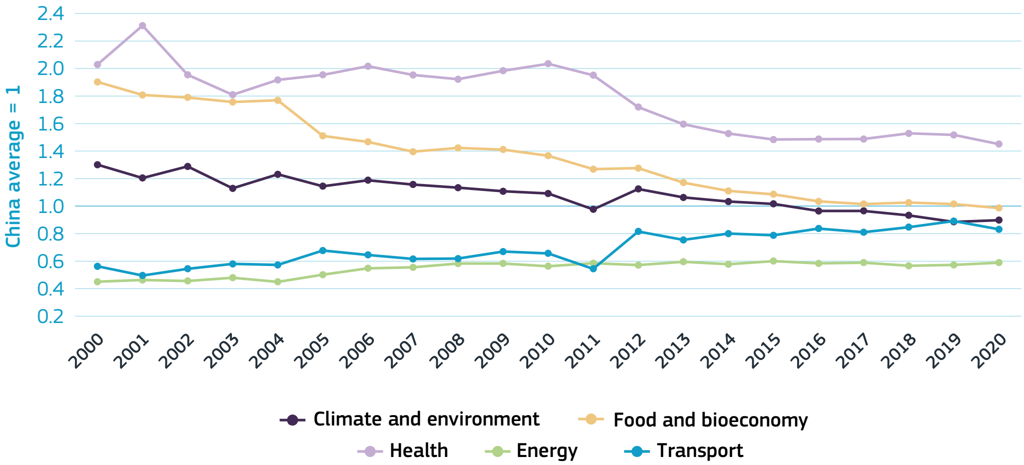
Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [1]The specialisation index (SI) is an indicator of research intensity in a given entity (a country) for a given research area (e.g. one of the SGCs), relative to the intensity in a reference entity (e.g. the world) for the same research area. In other words, the SI of a country in a given research domain portrays how much emphasis that country allocates to research in that domain relative to the world's equivalent. Comparisons are meaningful only between countries of similar size.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-1-22.xlsx

Compared to China, the EU is more specialised in health-related scientific output and on a par in food and bioeconomy despite the dramatic decline since 2000. In climate and environment, the EU has gradually declined, and it lost its competitive edge over China in 2016. In contrast, the EU has increased its specialisation in transport, particularly in 2011, but has not yet reached Chinese levels. In energy, the EU is significantly less specialised than China, with very little progress in the last 20 years.

Figure 6.1-23: EU Specialisation Index (SI)[(1)] compared to China, 2000-2020



Science, Research and Innovation Performance of the EU 2022

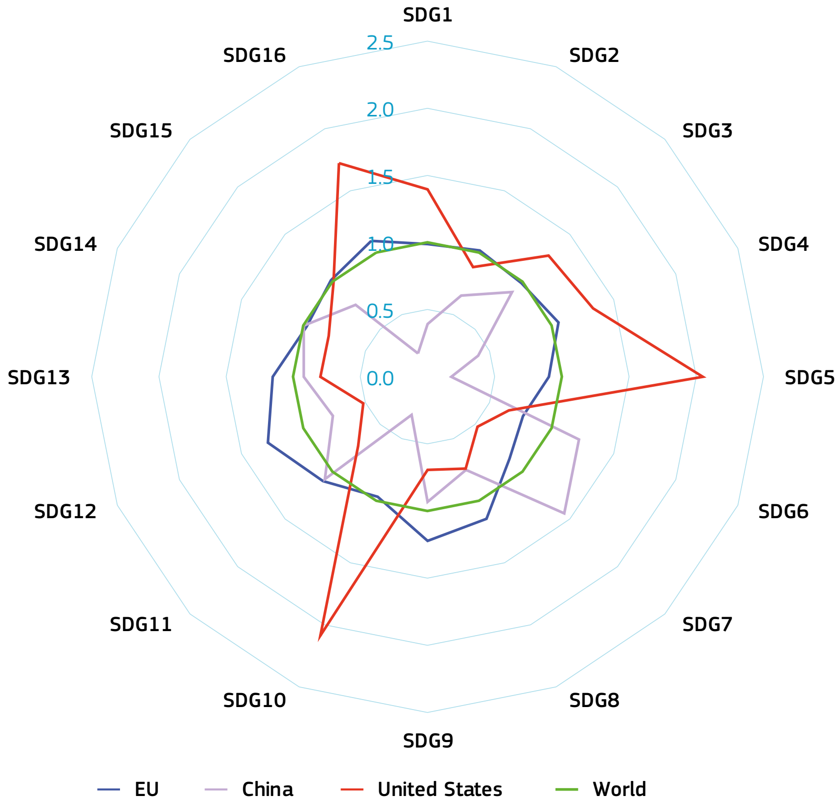
Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [(1)]The specialisation index (SI) is an indicator of research intensity in a given entity (a country) for a given research area (e.g. one of the SGCs), relative to the intensity in a reference entity (e.g. the world) for the same research area. In other words, the SI of a country in a given research domain portrays how much emphasis that country allocates to research in that domain relative to the world's equivalent. Comparisons are meaningful only between countries of similar size.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-1-23.xlsx

Sustainable development is at the heart of European policy. The European Union through its political leadership took the decision to lead the sustainability transition and accelerate the achievement of the Sustainable Development Goals (SDGs), as outlined in 'The European Green Deal'[12] and the Commission Staff Working Document 'Delivering on the UN's Sustainable Development Goals' (European Commission, 2020). While the Societal Grand Challenges (SGCs), introduced in Horizon 2020, represent complex, multi-level, multi-dimensional problems that require concerted efforts by various actors to be successfully addressed, the SDGs go a step further and offer 'the blueprint to achieve a better and more

Figure 6.1-24: Specialisation Index for each SDG(1), 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Notes: (1)SDG 1 – No poverty; SDG 2 – Zero hunger; SDG 3 – Good health and well-being; SDG 4 – Quality education; SDG 5 – Gender equality; SDG 6 – Clean water and sanitation; SDG 7 – Affordable and clean energy; SDG 8 – Decent work and economic growth; SDG 9 – Industry, innovation and infrastructure; SDG 10 – Reduced inequality; SDG 11 – Sustainable cities and communities; SDG 12 – Responsible consumption and production; SDG 13 – Climate action; SDG 14 – Life below water; SDG 15 – Life on land; SDG 16 – Peace, justice and strong institutions.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-1-24.xlsx

12 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN

sustainable future for all'[13]. They also address global challenges, including poverty, energy, climate change, inequality, economic growth, environmental degradation, peace and justice.

In 2020, publications covering SDG 3, on health, and SDG 7, on energy, accounted for the largest share of SDG-related publications in the world, 49% and 14% respectively. The effect of the pandemic on scientific output worldwide is again demonstrated by the increase in the share of health-related publications by 6 percentage points compared to 2019. The EU has been involved in roughly 20% of the world's total publications in each SDG. China has the lead in energy-related publications, confirming previous findings when using different classifications.

The EU is more specialised in terms of scientific output in SDGs 8 – Decent work and economic growth, 9 – Industry, innovation and infrastructure, 12 – Responsible consumption and production, and 13 – Climate action. The US has the lead in SDG 1 – No poverty, SDG 3 – Good health and well-being, SDG 4 – Quality education, SDG 5 – Gender equality, SDG 10 – Reduced inequalities and SDG 16 – Peace, justice and strong institutions. Finally, China is more specialised in SDG 6 – Clean water and sanitation and SDG 7 – Affordable and clean energy.

Between the EU countries, the levels and areas of specialisation vary significantly. Table 6.1-2 presents the Specialisation Index for each SDG by EU Member State. The Member States have been sorted and grouped by their overall volume of scientific publications related to the SDGs. The first group includes countries with less than 1000 publications, the second with 1000 to less than 5000, the third with 5000 to less than 15000, and the last group includes the countries with the most SDG-related publications.

Compared to the world averages, almost all EU countries are specialised in SDG 8, SDG 9 and SDG 12, followed by SDG 11, SDG 13 and SDG 4[14] (Table 6.1-2). In contrast, only a few countries are specialised in SDG 6 – Clean water and SDG – 7 Affordable and clean energy. As expected, the largest countries in terms of scientific output show low specialisation levels across most categories, with only a few categories having high specialisation scores. For example, France is specialised only in two SDGs, SDG 3 – Health and well-being and SDG 14 – Life below water. Similarly, Germany shows specialisation in SDG 9 – Industry, innovation and infrastructure and SDG 13 – Climate action.

13 https://www.un.org/sustainabledevelopment/sustainable-development-goals/

14 SDG 8 – Decent work and economic growth, SDG 9 – Industry, innovation and infrastructure, SDG 12 – Responsible consumption and production, SDG 11 – Sustainable cities, SDG 13 – Climate action and SDG 4 – Quality education.

Table 6.1-2: Specialisation index per EU Member State and SDG[1], 2020

Member States	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Sustainable Development Goals															
Malta	1.24	0.65	1.19	2.13	0.70	0.21	0.72	2.52	0.85	2.00	1.89	2.12	1.42	2.23	0.98	1.59
Luxembourg	3.23	0.56	0.54	1.33	0.64	0.43	0.90	1.88	1.35	2.92	1.64	1.67	1.02	0.22	0.50	1.99
Latvia	0.61	1.18	0.50	2.26	0.56	0.82	1.86	2.36	2.23	0.49	1.60	3.06	2.33	1.26	1.91	0.62
Estonia	1.17	1.50	0.42	2.08	1.45	0.94	1.51	1.68	1.38	1.43	1.25	1.75	1.67	1.53	1.91	2.48
Cyprus	1.87	1.14	0.83	4.31	1.74	1.37	1.18	2.41	1.31	2.54	1.90	2.45	1.94	1.03	0.86	1.95
Lithuania	1.44	1.59	0.66	1.92	0.98	0.62	1.30	2.48	1.84	1.30	1.41	2.70	1.64	1.04	1.14	1.19
Bulgaria	0.21	1.02	0.64	1.30	0.32	0.82	1.03	0.99	1.18	0.20	1.07	1.05	0.82	0.82	1.14	0.39
Slovenia	0.81	0.93	0.73	1.21	0.73	0.94	0.76	1.14	1.41	0.80	1.01	1.48	0.72	0.65	1.37	1.01
Slovakia	0.97	0.84	0.62	1.31	0.47	0.83	0.64	1.75	2.02	0.82	1.48	1.88	0.84	0.30	1.71	0.91
Croatia	0.67	1.17	0.76	2.21	0.98	0.77	0.86	1.65	1.13	0.87	1.51	1.58	1.20	1.92	1.05	1.33
Hungary	0.96	1.00	0.81	1.05	0.53	0.95	0.65	1.24	1.26	0.99	1.16	1.10	0.97	0.39	1.56	0.89
Ireland	1.57	0.91	1.04	1.72	1.81	0.73	0.75	1.10	1.09	1.70	0.82	1.04	1.10	1.15	0.84	2.52
Romania	0.82	0.88	0.75	1.97	0.45	1.34	1.10	1.91	1.91	0.79	1.64	1.75	1.12	0.71	0.91	0.76
Austria	1.08	0.86	0.86	0.82	0.73	0.41	0.65	1.19	1.46	0.99	0.93	1.30	1.28	0.48	0.84	0.98
Czechia	0.57	0.96	0.67	0.71	0.46	0.83	0.69	1.05	1.40	0.59	1.11	1.60	1.04	0.52	1.71	0.78
Finland	1.56	0.83	0.83	2.15	1.31	0.88	0.97	1.36	1.43	1.33	1.10	1.99	1.74	0.95	1.84	1.73
Greece	0.94	1.44	1.15	1.40	0.57	1.23	1.10	1.45	1.25	1.05	1.84	1.92	1.44	1.53	1.03	0.85
Belgium	1.34	1.22	0.96	1.06	1.11	0.63	0.72	0.99	1.02	1.25	0.85	1.03	1.02	0.78	0.98	1.42
Denmark	1.04	0.99	1.25	0.91	0.77	0.72	1.36	1.05	1.04	1.15	0.72	1.07	1.34	1.28	0.80	1.22
Portugal	1.03	1.12	0.89	1.74	1.03	1.35	1.07	1.92	1.84	1.01	1.63	2.38	1.63	2.40	1.46	1.22
Sweden	1.69	0.98	1.10	1.60	2.02	0.73	0.97	1.31	1.46	1.51	1.14	1.64	1.51	0.97	1.05	1.84
Poland	0.65	0.93	0.84	0.59	0.43	1.18	0.84	1.14	1.22	0.47	1.37	1.46	0.89	0.66	1.18	0.62
Netherlands	1.39	1.10	1.18	1.12	1.30	0.79	0.64	1.17	0.87	1.35	1.15	0.89	1.24	0.80	0.81	1.82
France	0.61	0.99	1.01	0.40	0.60	0.55	0.69	0.61	0.79	0.65	0.66	0.71	0.88	1.09	0.85	0.60
Spain	1.18	1.13	0.95	1.99	1.73	1.03	0.86	1.50	1.16	1.31	1.18	1.76	1.26	1.17	1.17	1.56
Germany	0.92	0.78	0.86	0.70	0.61	0.48	0.93	0.84	1.22	0.84	0.65	0.78	1.10	0.63	0.79	0.83
Italy	0.88	1.21	1.30	0.65	0.67	0.71	0.86	1.16	1.36	0.85	1.60	1.42	1.11	1.18	0.94	0.96

Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Science-Metrix, using the Scopus database

Note: [1] SDG 1 – No poverty; SDG 2 – Zero hunger; SDG 3 – Good health and well-being; SDG 4 – Quality education; SDG 5 – Gender equality; SDG 6 – Clean water and sanitation; SDG 7 – Affordable and clean energy; SDG 8 – Decent work and economic growth; SDG 9 – Industry, innovation and infrastructure; SDG 10 – Reduced inequality; SDG 11 – Sustainable cities and communities; SDG 12 – Responsible consumption and production; SDG 13 – Climate action; SDG 14 – Life below water; SDG 15 – Life on land; SDG 16 – Peace, justice and strong institutions.

Only 16 of the top 100 universities included in the Times Higher Education University Impact Ranking 2021 are located in the EU[15]. The Times Higher Education Impact Rankings measure universities' overall success in delivering the United Nations Sustainable Development Goals. It uses indicators across four areas: research, stewardship, outreach and teaching. In 2021, 1 239 institutions across 98 countries submitted data, compared to 859 institutions in 2020. This shows that the Times Higher Education University Impact Ranking has gradually become an important tool for universities to monitor their progress in delivering the SDGs. The European university with the highest position is Aalborg from Denmark, and the overall leader is Manchester University (UK). Ireland is the EU Member State with the largest number of universities (5) in the top 100, followed by Spain with 4. Portugal, Italy and Sweden are the remaining EU Member States with universities represented in the top 100. Outside the EU, the United Kingdom is the single country with the most universities in the top 100 (20), followed by Australia (17). The United States is lagging with only 9 universities but improving compared to the 2020 ranking.

Table 6.1-3: Global performance of EU universities against the UN SDGs in the Times Higher Education University Impact 2021

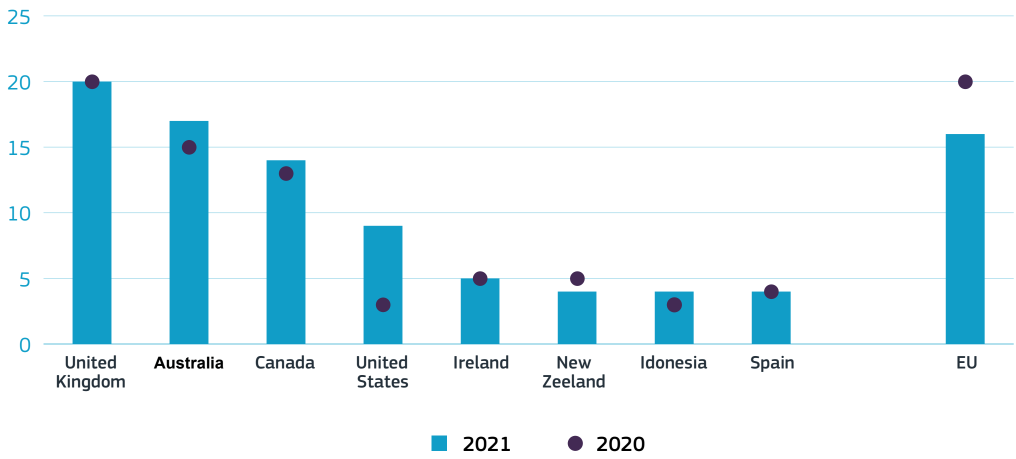
Position in ranking	Name	Country	Comparison with 2019
6	Aalborg University	Denmark	up from rank 97
8	University College Cork	Ireland	up from rank 21
20	University of Bologna	Italy	down from rank 9
21	University of Coimbra	Portugal	new
22	University College Dublin	Ireland	up from rank 58
23	University of Southern Denmark	Denmark	new
41	KTH Royal Institute of Technology	Sweden	down from rank 7
49	University of Gothenburg	Sweden	down from rank 6
50	University of Limerick	Ireland	down from rank 35
53	NOVA University of Lisbon	Portugal	new
57	Trinity College Dublin	Ireland	down from rank 28
82	National University of Ireland, Galway	Ireland	new
83	Polytechnic University of Valencia	Spain	new
90	University of Barcelona	Spain	down from rank 34
92	University of Jaén	Spain	new
98	Comillas Pontifical University	Spain	down from rank 86

Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Times Higher Education

15 https://www.timeshighereducation.com/impactrankings#!/page/1/length/25/sort_by/rank/sort_order/asc/cols/undefined

Figure 6.1-25: Number of universities by country/region in the top 100 Times Higher Education University Impact Rankings, 2020 and 2021



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Times Higher Education

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4. Conclusions: the European Union remains a scientific powerhouse

The EU, with almost 620 000 publications in 2020, has the second highest share of scientific output worldwide. The EU is leading globally in the domains[16] of economics and social sciences, and arts and humanities, which comprise significantly fewer publications than other domains, such as health science, led by the US, or applied and natural science, where China has the lead. Due to this specialisation in less-technological fields, the EU has been less affected by the incredible increase in Chinese scientific output, which has cost the United States 13 percentage points since 2000 and the EU only 7 percentage points Within the EU, the shares of scientific publications vary significantly, and to a large extent depend on the size of the country, although southern and eastern European countries have increased their share over 2000-2020.

Over the last 10 years, the EU has emerged as the leading promoter of open science. With over 39 % of publications freely available under at least one open-access publishing pathway (gold, green or other), the EU is ahead of its global competitors. Despite the differences in the shares between the Member States, open-access scientific publications have increased for 22 of the 27 Member States over the last decade. Recent studies showed that countries increased their proportion of international collaboration and open-access publications during the pandemic, especially countries with lower GDP and, predictably, smaller-sized science systems (Lee and Haupt, 2020). Therefore it is essential for the EU to continue efforts to make the European scientific system more open, which will allow researchers across Europe unrestricted access to knowledge.

China's rapid improvement in the quality of scientific output has forced the EU to third place in the global share of the top 10 % and top 1 % most-cited publications. Still, the EU's scientific publications account for 21 % and 18.4 % of the top 10 % and the top 1 % most-cited worldwide, respectively. Similarly to scientific volume, China's remarkable improvement in the quality of the scientific publications has primarily affected the United States, which, however, preserved its leading position in the top 1 % most-cited publications. The leading position of the United States in scientific quality and impact is particularly evident in health-related scientific fields, where the EU is also strong. Between the EU Member States, the share of their publications included in the top 10 % most-cited worldwide varies between 15 and 2 %, with the Netherlands leading globally, ahead of Switzerland, the United Kingdom and the United States.

The EU's contribution to the scientific publications in each of the Societal Grand Challenges worldwide is about 20 %, except for energy and for secure societies, where the shares are lower. In terms of quality, the EU has the second-highest world share of the top 10 % most-cited publications in all Societal Grand Challenges. China is leading in both scientific output and quality in all SGCs except for health, where the United States remains at the top, despite a significant decline over the last ten years. Moreover, the EU is showing specialisation in health-related scientific publications at the world level compared to China, although not to the United States, which dominates the scientific output in this domain.

16 Each domain includes several scientific fields.

References

Campbell, D., Tippett, C., Côté, G., Roberge, G., & Archambault, É. i.e. (2016), '*An approach for the condensed presentation of intuitive citation impact metrics which remain reliable with very few publications. In I. Rafols, J. Molas-Gallart, E. Castro-Martínez, & R. Woolley (Eds.)*', Proceedings of the 21st International Conference on Science and Technology Indicators, pp. 1229-1240. Valencia, Spain. doi:10.4995/STI2016.2016.4543.

European Commission (2020), *Delivering on the UN's Sustainable Development Goals – A comprehensive approach*, SWD(2020) 400 final.

European Commission (2021a), *Monitoring the open access policy of Horizon 2020: final report*, Publications Office of the European Union, Luxembourg.

European Commission, Directorate-General for Research and Innovation (2021b), *Provision and analysis of key indicators in R&I: final study report covering work packages 1-6*, Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2777/587466

Holly Else (2020), 'How a torrent of COVID science changed research publishing – in seven charts', *Nature*, pp. 588 (24/31): pp. 553.

Jian Gao et al. (2021), 'Potentially long-lasting effects of the pandemic on scientists'. *Nature Communications,* 12, 6188. https://doi.org/10.1038/s41467-021-26428-z

Lando, T., Bertoli-Barsotti, L. (2014), 'A New Bibliometric Index Based on the Shape of the Citation Distribution'. *PLoS ONE 9(12): e115962*. https://doi.org/10.1371/journal.pone.0115962

Lee, J.J, and Haupt J.P, (2020), 'Scientific globalism during a global crisis: research collaboration and open access publications on COVID-19', *Higher Education* 81, pp. 949-966, https://doi.org/10.1007/s10734-020-00589-0

Nature editorial (2020), 'China's research-evaluation revamp should not mean fewer international collaborations', *Nature*, 579, 8(2020) https://doi.org/10.1038/d41586-020-00625-0

Sloane, P., Zimmerman, S. (2021). The Impact of the COVID-19 Pandemic on Scientific Publishing. *Journal of the American Medical Directors Association*, 22(3), pp. 484-488

UNESCO (2021), *UNESCO Science Report: the Race Against Time for Smarter Development*, S. Schneegans, T. Straza and J. Lewis (eds), UNESCO Publishing: Paris.

CHAPTER
6.2

KNOWLEDGE FLOWS

KEY FIGURES

7 %
of human resources in S&T in the EU changed jobs from one year to the next in 2020

9.1 %
of public-private scientific co-publications are in the EU

12 %
of innovative enterprises in the EU cooperated with universities or other HEI on R&D

50 %
or more share of international scientific co-publications are in most EU Member States

KEY QUESTIONS WE ARE ADDRESSING

- How good is researchers' mobility in the EU?
- How well-represented is the EU in public-private collaborations?
- How is international collaboration developing?

KEY MESSAGES

What did we learn?

- At the EU level, the share of job-to-job mobility remains low at almost 7 %. However, there has been an increase in mobility in the last 10 years in all Member States except Czechia, Sweden and Romania.
- Between 2010 and 2020, the EU share of public-private co-authored scientific publications increased from 8.5 % to 9.1 %, placing the EU above the United States and behind only Japan.
- In 2020, international co-publications accounted for more than 50 % of scientific publications in most EU Member States. Between 2010 and 2020, the share of international scientific co-publications increased in all Member States, except Bulgaria.
- The EU and the United States were each other's primary partners for patent applications filed under the Patent Cooperation Treaty (PCT) with a foreign co-inventor in 2018.

What does it mean for policy?

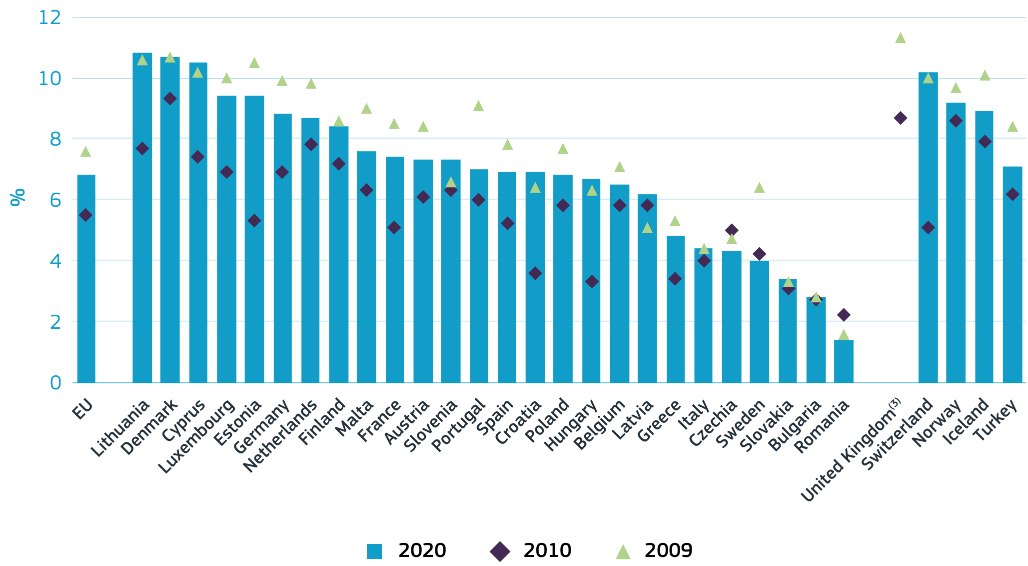
- Continuing divergence between the EU Member States on researcher mobility patterns calls for a better understanding of drivers and barriers to international and job-to-job mobility, as well as the implementation of policies to foster brain circulation.
- To increase scientific productivity and knowledge transfer, there is a need to reinforce international scientific collaboration and promote further collaboration in patenting.
- There is a need to strengthen the capacity of the business sector to engage in R&I collaborations with academia and research centres, in particular in high-tech sectors, and in countries with less-performing research systems.

1. Researchers' mobility

Mobility of researchers across jobs can be an important driver for knowledge transfer and knowledge diffusion. More generally, inventors' mobility has been deemed central to knowledge transfer and is an important source of learning for hiring organisations (Lenzi, 2013). At the EU level, the share of job-to-job mobility has remained small at almost 7 %, despite an increase between 2010 and 2020. Within the EU, there are significant differences in the mobility patterns of human resources in science and technology (Figure 6.2-1). While Lithuania, Denmark and Cyprus registered more than 10 % of human resources in science and technology (HRST) changing jobs from one year to the next in 2020, less than 2 % did so in Romania.

Except for Czechia, Sweden and Romania, all other Member States reported an increase in job-to-job mobility in the last 10 years. Mobility increased the most in Estonia, Croatia and Hungary. Despite the increase in the 10-year period, most Member States experienced a decline between 2019 and 2020, in particular Sweden and Portugal. This drop could be partly explained because of people preferring to remain in their current

Figure 6.2-1: Job-to-job mobility[(1)] of human resources in science and technology[(2)] as a % of total HRST, 2010, 2019 and 2020



Science, Research and Innovation Performance of the EU 2022

Source: Eurostat (online data code: hrst_fl_mobsex)

Notes: [(1)]The movement of individuals between one job and another from one year to the next. This does not include inflows into the labour market from a situation of unemployment or inactivity. [(2)]HRST: Persons with tertiary education and/or employed in science and technology. [(3)]No data available for UK 2020. [(4)]Figures for Ireland not available.

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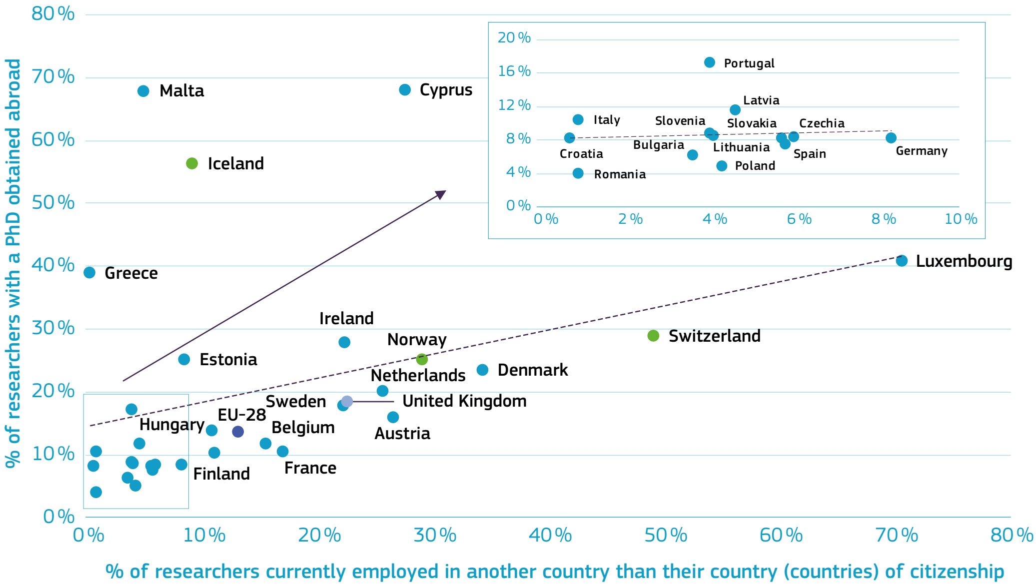
jobs rather than moving, due to the COVID-19 pandemic, and the related reduction in job openings. According to the results of the OECD Science Flash Survey 2020[1] (OECD, 2021), COVID-19 has also limited the international mobility of researchers, who expected the crisis to negatively affect their job security and career opportunities.

Another important channel of knowledge diffusion concerns the mobility of researchers across countries. Data from the MORE study (European Commission, 2021) suggests the presence of strong differences between EU Member States in terms of inflow of researchers, measured by the number of foreign researchers working in a country, and the share of researchers having obtained their PhDs abroad (Figure 6.2-2). These indicators are also proxies for the attractiveness of the national research system to researchers. It is important to highlight that several factors can impact the mobility of researchers, such as working conditions, career prospects and cultural and linguistic aspects. Several studies (Franzoni et al., 2012; Geuna, 2015; IDEA Consult, 2013a, 2013b; Janger et al., 2019) confirm these reasons.

Overall, smaller countries and/or those performing better in R&I show a relatively high inflow of researchers and a higher share of researchers who obtained a PhD abroad. Among this group of countries, Luxembourg, Switzerland and Cyprus display the highest percentages (Figure 6.2-2). On the other hand, other small countries, such as Malta and Iceland, report a relatively high

Figure 6.2-2: International mobility of researchers



Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on European Commission, MORE4 study (2019)

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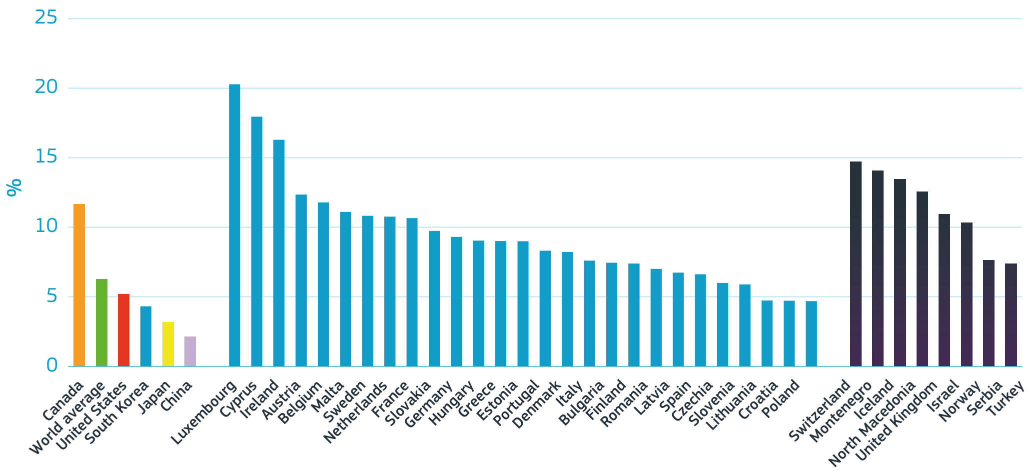
1 https://oecdsciencesurveys.github.io/2020flashsciencecovid/

share of researchers with PhD obtained abroad but a much lower share of foreign employed researchers. An extreme case is Greece, which shows a relatively high share of researchers who obtained a PhD abroad but has a very small share of foreign researchers. At the same time, a group of more innovative European countries such as Denmark, Norway, Netherlands, Ireland and Austria are characterised by relatively high influx of researchers, as well as a relatively high share of mobile PhDs. However, given the survey-based nature of the data and the cultural and local specificities of each national research system, the results must be interpreted with caution.

The analysis of scientific publications over a 15-year period shows a similar trend in the outflow of researchers. Using scientific publications data (Figure 6.2-3), it is possible to calculate the share of researchers that left the country at some point. Similarly to the trend observed for researchers' inflows, smaller and/or more innovative countries, such as Luxembourg, Switzerland, Cyprus and Ireland, report the highest shares of researchers who left the country over 2005-2020. Given the high level of performance of some of those countries' research systems, this pattern should not be seen simply as a brain drain phenomenon, but as a way for researchers to improve their research careers by moving to another country. Within the EU, the eastern countries have the lowest shares of researchers that were mobile in the last 15 years. Outside the EU, Canada has the highest share, while China reports the lowest performance. Once again, the method applied demands a cautious interpretation of the results.

Figure 6.2-3: Share of researchers leaving the country[1] at some point during the period 2005-2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Science-Metrix using Scopus database

Note: [1]To investigate the mobility of individual researchers, Scopus author IDs (AUIDs) were selected as unique identifiers for individual researchers. AUIDs are generally quite precise and allow for the identification of sets of publications related to unique researchers. One drawback is that they are not as precise for common names, which mostly affects Chinese and Korean researchers, as well as researchers with highly frequent English names. In addition, because an AUID relies partially on institutional affiliations, mobility may cause a rupture in the portfolio of publications of researchers, resulting again in a split of the output between the original AUID and a new distinct AUID assigned after moving, again impacting the measurement of mobility. Therefore, the indicator will tend to underestimate mobility because of the aforementioned issues.

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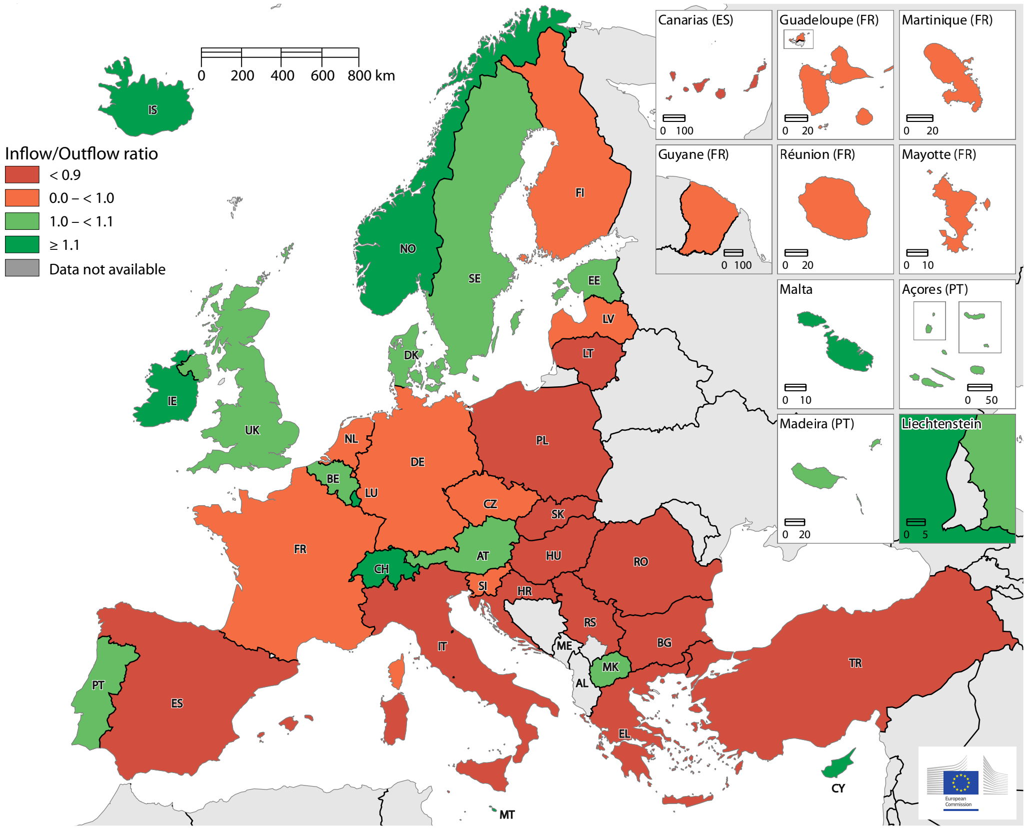
The mobility of researchers, based on bibliometric data, suggests that many European countries are suffering a brain drain. This is particularly the case of most eastern and southern European countries, such as Italy, Greece, Hungary and Poland, for which the outflow of researchers outstrips the inflow when calculating the ratio between the inflow and outflow of researchers in Europe during the last 20 years to and from the rest of the world (Figure 6.2-4). These results might be explained by poor career conditions and unattractive research systems that have led researchers to look for better conditions abroad. In contrast, the inflow of researchers outpaces the outflow in most northern and western European countries (including Switzerland, Luxembourg, Norway and the United Kingdom). As regards EU countries only, most Member States report a ratio of researcher inflow over outflow below 1, suggesting that the number of researchers who left the country over the period considered was lower than the number of researchers who entered it. This might be explained by the fact that in most EU Member States, the top destination for European researchers is not another Member State but a country outside the EU such as the United States, which is a top destination (data not shown). In addition, the outflow of European researchers to the United States is higher than the inflow of American researchers to the EU. These results are confirmed by other studies such as Khan (2021).

Mobility patterns are influenced by several factors, such as the dynamics of labour markets, security of research careers and ease of changing jobs, as well as other external factors (e.g. a pandemic or an economic crisis). The report on researchers' mobility flows in Marie Skłodowska-Curie Actions (MSCA) investigates mobility determinants, looking at push and pull factors at three levels: individual (such as career prospects and conditions), organisational (such as peer support and infrastructure), and systemic (such as level of openness/closedness of the research systems). The study shows that the most advanced R&I systems remain the most attractive for researchers but also that the MSCA are effective at attracting and retaining European talent, as well as attracting European researchers back to Europe and supporting return mobility, particularly towards widening countries. Based on these findings, the study does not recommend reintroducing return grants for researchers. Instead, it provides a set of policy recommendations aimed at enhancing the quality and attractiveness of the less advanced R&I systems, including their capacity to support more balanced flows of researchers (PPMI, 2022).

The mobility of researchers is positively correlated with the share of international scientific co-publications. As reported in Figure 6.2-5, a high level of researcher mobility can lead to a higher level of international collaboration. When researchers move to other countries, they usually keep ties with their place of origin, increasing the level of collaboration between home and reception countries. At the same time, a high level of international collaboration might lead to a more attractive research system, thereby attracting more researchers and promoting mobility.

Figure 6.2-4: Map of inflow and outflow ratio of researchers[1] during the period 2001-2020[2] by country



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Science-Metrix using Scopus database

Note: [1]To investigate the mobility of individual researchers, Scopus author IDs (AUIDs) were selected as unique identifiers for individual researchers. AUIDs are generally quite precise and allow for the identification of sets of publications related to unique researchers. One drawback is that it is not as precise for common names, which mostly affects Chinese and Korean researchers, as well as researchers with highly frequent English names. In addition, because an AUID relies partially on institutional affiliations, mobility may cause a rupture in the portfolio of publications of researchers, resulting again in a split of the output between the original AUID and a new distinct AUID assigned after moving, again impacting the measurement of mobility. Therefore, the indicator will tend to underestimate mobility because of the aforementioned issues. [2]RO: period corresponds to 2001-2019.

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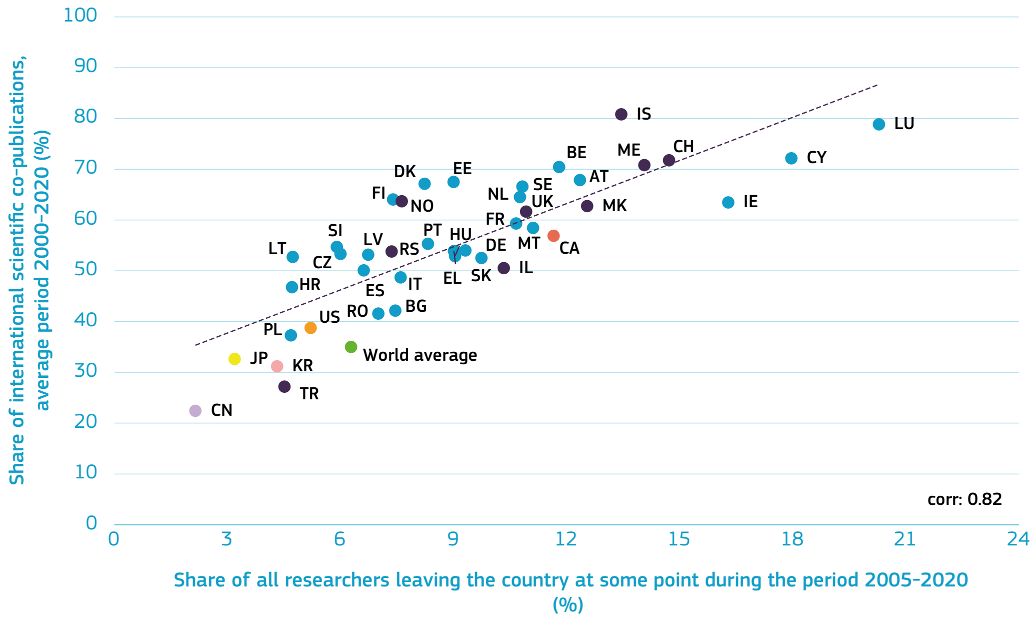
Figure 6.2-5: Share of mobile researchers vs share of international co-publications



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Science-Metrix using Scopus database

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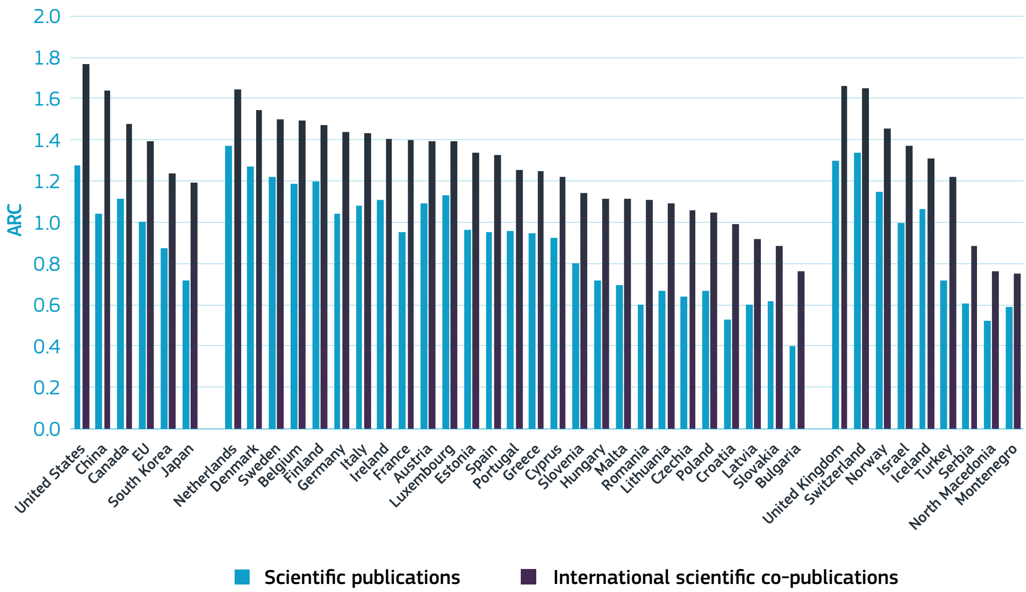
Overall, international scientific co-publications have a higher citation impact than scientific publications. The higher the citation impact of international scientific co-publications, the higher the quality of the scientific production. Several studies have examined the effect of international mobility on scientific productivity, providing evidence that international mobility increases the number of publications (Netz et al., 2020). Another study suggests substantial gains from mobility on scientific output, with mobility inducing a long-lasting increase in a researcher's publications by 32% and citations by 63% (Ejermo et al., 2020). In 2018, the United States had the highest average relative citations of international co-publications, followed by China, Canada and the EU (Figure 6.2-6). Within the EU, the Netherlands, Denmark and Sweden topped the ranking, while Bulgaria, Slovakia and Latvia were the worst performers.

Figure 6.2-6: Average of relative citations (ARC)[1], 2018 (citation window 2018-2020)



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Science-Metrix using Scopus database

Note: [1]The average of relative citations uses a variable citation window, fractional counting and corresponds to the total relative citations/total valid publications for impact indicators.

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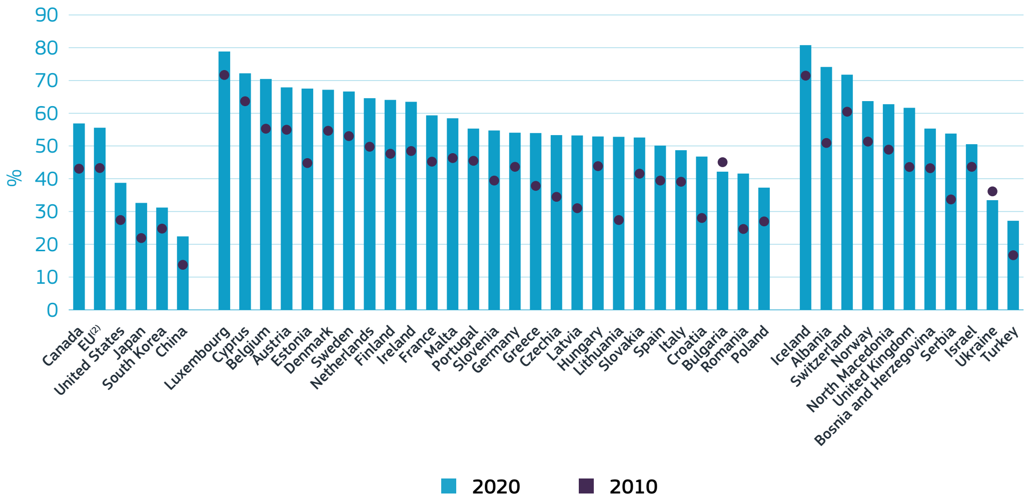
2. International collaboration

Cross-border research and collaboration among researchers are important channels of knowledge flow and knowledge transfer. International collaboration via scientific co-publications improves scientific quality since researchers achieve greater impact and citations from their international collaborations. International co-publications gain, on average, more citations than domestic co-publications (Puuska et al., 2014).

In 2020 in most EU Member States, more than 50 % of scientific publications were international co-publications. (Figure 6.2-7) The share increased between 2010 and 2020 in all selected countries, except Bulgaria and Ukraine. This growth was significant in the three Baltic countries, Estonia, Lithuania and Latvia, where the share increased by more than 20 percentage points. Countries such as Luxembourg and Iceland, due to their small but innovative research systems, show the highest shares, with around 80 % of their publications being international. As seen previously, these results might also be linked to the internationalisation of universities measured as the share of foreign researchers, which for these two countries is very high.

Among the international partners, Canada tops the list of selected countries with a share of 57 %, followed by the EU with 56 %.

Figure 6.2-7: Share of international scientific co-publications per total scientific publications(1), 2010 and 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Science-Metrix using Scopus database

Note: (1)Full counting method used. (2)The EU average includes intra-EU collaborations. The EU figure without intra-EU collaborations is 37 % for 2020.

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China comes last, with around 22% of its scientific co-publications being international. When excluding intra-EU publications, the EU is at 37%, which is slightly below the share of the United States (39%) but above that of Japan and South Korea. Even though big countries tend to collaborate less with international partners due to their internal large research systems, there are still some exceptions such as Canada, the United Kingdom, France and Germany, for whom more than 50% of their publications are international co-publications (Figure 6.2-7).

European-level funding programmes and initiatives such as MSCA contribute to the high figures and trends. These programmes also have an important role in promoting international cooperation to tackle societal challenges[2]. A recent report on the contribution of EU R&I funding to COVID-19-related research shows that out of the analysed publications (1 419), 56% were internationally co-authored (European Commission, 2021). Furthermore, earlier framework-programme evaluations show that international cooperation in MSCA projects significantly contributes to the advancement of certain new and emerging research areas that are highly relevant for tackling particular global challenges common to Europe and its neighbouring countries (European Commission, 2019). However, some eastern EU countries, such as Poland, Romania and Bulgaria, can improve further.

2 In Horizon 2020, 39% of all researchers involved in MSCA were from third countries, accounting for nearly 50% of all international participations in Horizon 2020. This translated into funding 13 420 researchers from 1 300 organisations in more than 100 countries.

Box 6.2-1: Research trends on the Sustainable Development Goals and alignment with SDG 17 on international partnerships

Paul Khayat, Simon Provençal and David Campbell
Science-Metrix

The 17 Sustainable Development Goals (SDGs), part of the United Nations' 2030 Agenda for Sustainable Development, are interconnected goals that aim at achieving a better and more sustainable future for all. Given the increasing emphasis placed by the European Commission on achieving the SDGs (e.g. through Horizon 2020 and Horizon Europe), three policy briefs examined how European research, at the level of the European Union (EU) and the ERA, in comparison to key international comparators (the United States, China, Japan and South Korea), contributed to research for the SDGs. This was achieved by relying on sets of scientific publications covering each of the SDGs (except SDG 17) in Scopus database. These data sets were constructed by Science-Metrix using advanced keyword-based queries designed to capture literature relevant to each SDG's underlying target. They were then grouped by the People (SDGs 1–5, Brief H), Prosperity (SDGs 7–11 and 16, Brief I) and Planet (SDGs 6 and 12–15, Brief J) thematics.

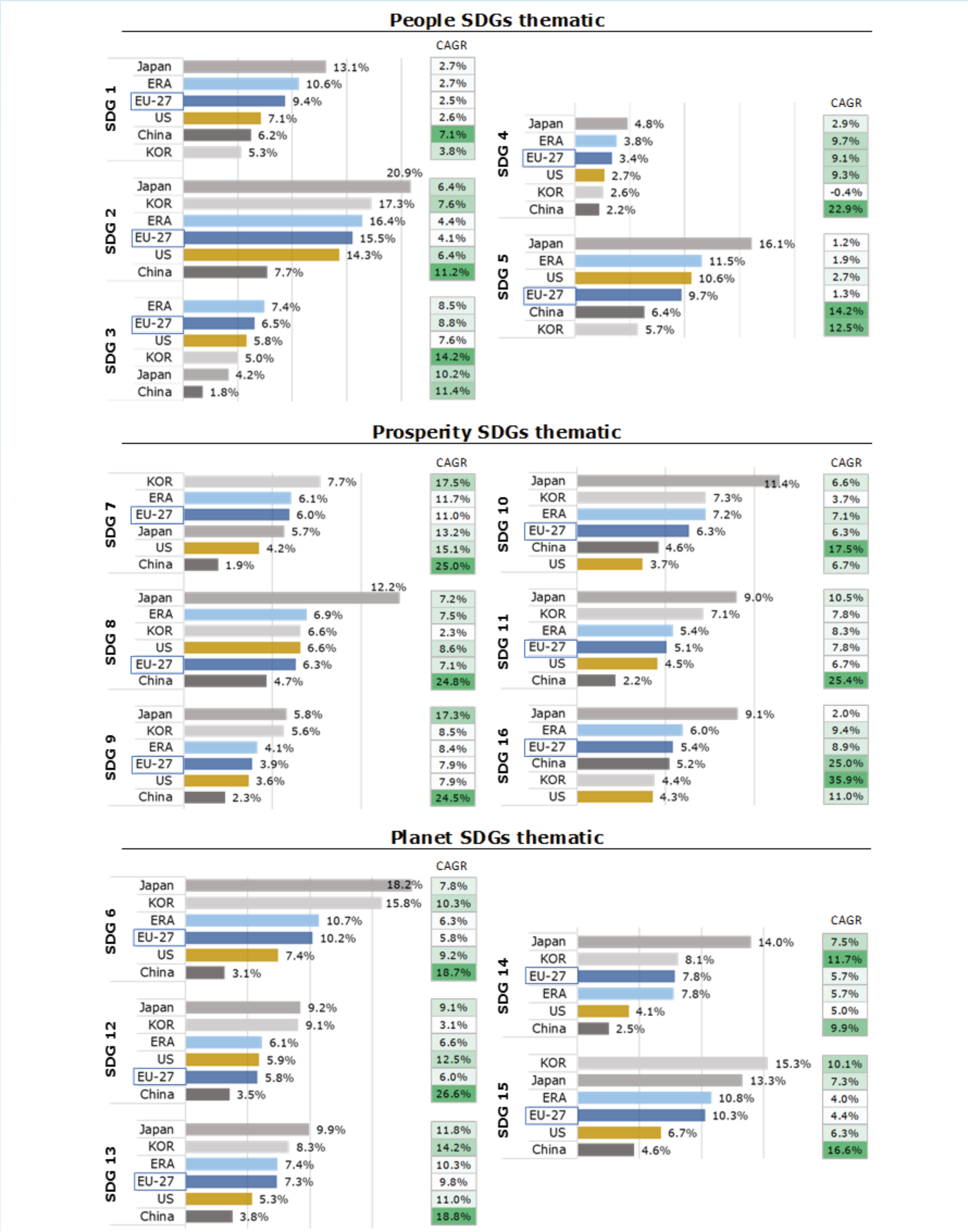
Among the seventeen SDGs, SDG 17 on 'partnerships for the goals' cuts across all other SDGs and is intended, in part, to promote inclusive collaborations among a broad range of actors (e.g. North–South co-publications) –To assess whether SDG-related research at the level of the EU/ERA (and comparators) is aligned with SDG 17 on 'partnerships for the goals' the policy briefs examined the evolution in the proportion of international co-publications along North–North and North–South axes in research related to the SDGs. Here, North and South were interpreted in terms of income level rather than geographic distribution, with North corresponding to high income (according to the World Bank) and South corresponding to low income. Two indicators based on co-publications were used: (1) share of co-publications with high- or low-income countries, and (2) diversity of international partners, particularly among low-income countries.

Given the much larger research output of high-income versus low-income economies, the international co-publication rates of all presented regions/countries in 2019 were much higher with the former than the latter group in all SDGs. Among international comparators, the EU and the ERA were the most active in co-publication with high-income countries (which includes co-publications between EU or ERA members), having comparable co-publication shares of 40% to 60%. These co-publications predominantly involved collaborations with major European scientific contributors such as the United Kingdom, Germany, Italy, Spain, France and the Netherlands, as well as the United States and China.

In parallel, the EU and the ERA co-published 16% or less of their SDG-related publications with low-income countries (Figure 6.2-8). Among the top 10 largest EU scientific contributors, France and Belgium were consistently among the top countries having the highest shares of co-publications with low-income countries in all SDGs.

Relative to the selected international comparators, the EU and ERA were leading in co-publication activity with low-income countries in SDG 3 (Figure 6.2-8). In the other SDGs, the smallest contributors to the SDGs in output size among selected comparators (i.e. Japan and

Figure 6.2-8: Share of co-publications and annual growth (CAGR) of the EU and selected comparators with the low-income countries



Science, Research and Innovation Performance of the EU 2022

Source: Science-Metrix using Scopus (Elsevier) data, European Commission (2021)

Note: The share of co-publication is calculated for the period 2017–2019, and the CAGR estimates the annual growth between the period 2011–2013 and the period 2017–2019.

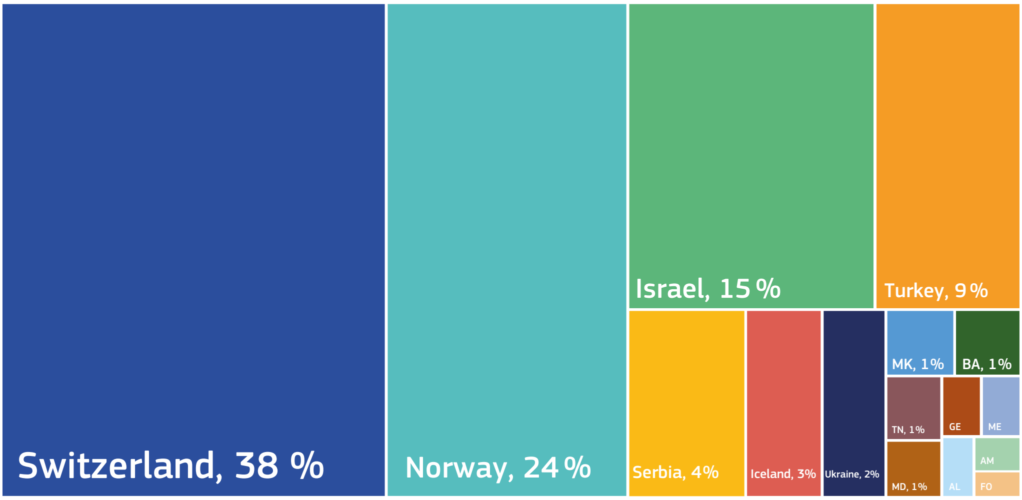
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-2-8.xlsx

South Korea) displayed the highest co-publication shares with low-income partners – Japan led in 13 SDGs and South Korea in 2 SDGs (SDG 7 and SDG 15). The EU's share of co-publication with low-income countries was higher than that of the other major scientific contributors – China in all SDGs, and the United States in most SDGs (except in SDGs 5, 8 and 12).

Over the past decade (since 2011-2013), the growth in co-publication shares of each presented region/country has generally evolved at a faster pace with low-income compared to high-income countries. At the level of the EU, the co-publication growth with low-income countries has been particularly dynamic in some SDGs, reaching about 8% to 11% in SDGs 3 and 4 (People), SDGs 7, 9, 11 and 16 (Prosperity) and SDG 13 (Planet) (Figure 6.2-8). However, despite the relatively good placement of the EU along the collaboration dimension with low-income countries, it did not exhibit the fastest annual growth since 2011–2013. Instead, China experienced the sharpest growth in most SDGs, as did South Korea in SDGs 3, 16 and 14. Given China's co-publication growth, it may also soon become a key figure in scientific collaborations with low-income countries in these SDGs.

The growth in co-publication activity with the low-income group over the past decade was largely due to an increase in the proportion of new, low-income countries active in SDG research (from 55 to 60 countries on average in the period 2011–2013, to about 70 countries in 2017–2019). It was also influenced by an increase in the intensity of co-publication links with developing countries. In general, the co-publication activity of EU Member States was not distributed evenly across the low-income countries but was instead dominated by a handful of countries. It is not surprising that, in all SDGs, India was consistently the leading (or a top leading) partner with most individual EU countries. Apart from India, other low-income countries had large bilateral links with EU countries in specific SDGs, including Kenya, Ethiopia, Vietnam, Ukraine, Pakistan, Morocco, Egypt, Tunisia, Algeria, Nigeria and Ghana (data not shown; for further details, see the full Policy Briefs H, I and J).

Figure 6.2-9: Share of participations from associated countries in Horizon 2020 as % of all associated countries' participation



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Horizon Dashboard data (data extracted April 2022)

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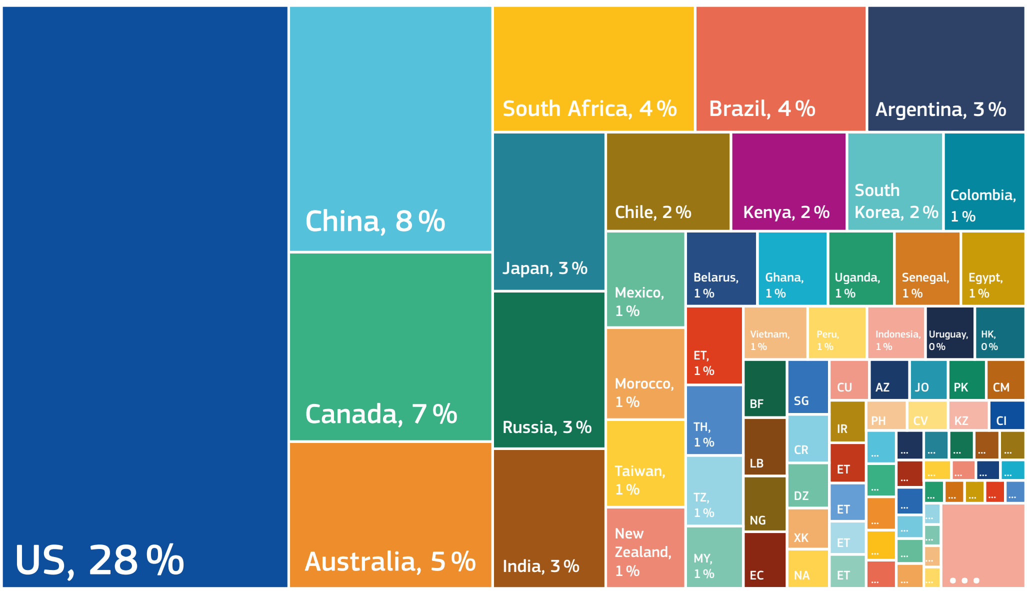
Figure 6.2-10: Share of participations from non-associated third countries in Horizon 2020 as % of all non-associated third countries' participation



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Horizon Dashboard data (data extracted April 2022)

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-2-10.xlsx

With applicants from 147 countries, Horizon 2020 promoted broad international collaboration. Concerning the associated countries (Figure 6.2-9), Switzerland, with its strong R&I system, was the most active associated country, with 5 137 participations – i.e. a share of 38 % of all associated countries. Norway, Israel and Turkey, followed, accounting for 23 %, 17 % and 9 %, respectively. The associated countries with the lowest participation (equal or less than 1 %) were Tunisia, Moldova, Georgia, Montenegro and Albania. Concerning the non-associated third countries (Figure 6.2-10), the United States came on top, accounting for 28 %. In far second place came China with 9 %, followed by Canada (7 %), Australia (5 %), South Africa (4 %) and Brazil (4 %). Overall, the top 10 participating non-associated third countries, which also includes Japan, India, Russia and Argentina, gathered 68 % of these participations, with a low level of participation from many developing economies.

Albeit at a lower extent than scientific publications, international collaboration can also occur in patent applications. Patent applications with a foreign co-inventor are also an important vehicle of knowledge diffusion, which in this case, is much closer to the market and allows the diffusion of new technologies. Motives to collaborate are access to complementary knowledge or access to research facilities, instruments or results, allowing international knowledge flows in co-patents (Frietsch et al., 2009).

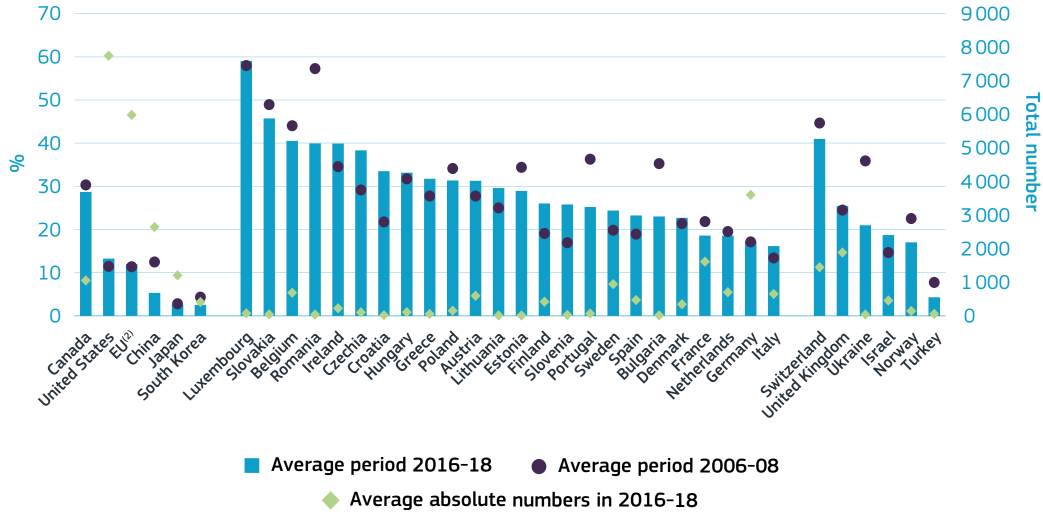
With an average of 7 747 patent applications, the United States had the highest number of patent applications filed with a foreign co-inventor under the PCT in 2016-2018. The EU came second, with an average of 5 988 patent applications, followed far behind by China (2 649) and Japan[3] (1 206). In relative terms (as a share of the total number of patents), Figure 6.2-11 shows that despite having a lower absolute number of co-patent applications, Canada has the highest share (an average of almost 30 % during 2016-2018) among the selected international competitors . The United States came second, with an average of 13 %, and the EU third, with 12 %. China, Japan and South Korea all come next with shares of 5 % or less.

Within the EU, there is significant variability, both in terms of shares, absolute figures and variations over time. In relative terms, Luxembourg came top, with almost 60 % of its patent applications taking place with a foreign co-inventor. Conversely, Italy had the lowest share, with an average of 16 % in 2016-2018. Generally, the countries with highest absolute numbers, such as Germany, France or United Kingdom, had the lowest shares, while the countries with low absolute numbers had the highest shares. However, Switzerland and Belgium, which have relatively high figures of both absolute numbers and shares of patent applications with a foreign co-inventor, are notable exceptions.

Over time, most EU countries have increased their shares, in particular Croatia and Slovenia. However, some countries recorded significant declines, such as Romania, Portugal and Bulgaria. It is important to highlight that for some countries the absolute number of patents is very small, which consequently increases their volatility. Among the selected competitors, all countries showed stable performance. China was the only exception, with a significant decline in its share between the two periods considered.

3 Although Japan is one of the main patent applicants, as shown in Chapter 6.3.

Figure 6.2-11: Share (%) of PCT patents with foreign co-inventor(s) in total number of patents[1], 2006-08 and 2016-18, and total number of patents with foreign co-inventor(s), 2016-18



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on OECD (international co-operation in patents) data

Notes: [1]PCT patents at the international phase designating the European Patent Office. Full counting and priority date used. Countries with fewer than 10 patent applications were excluded. Average of 3 years used to reduce volatility. [2]EU figures

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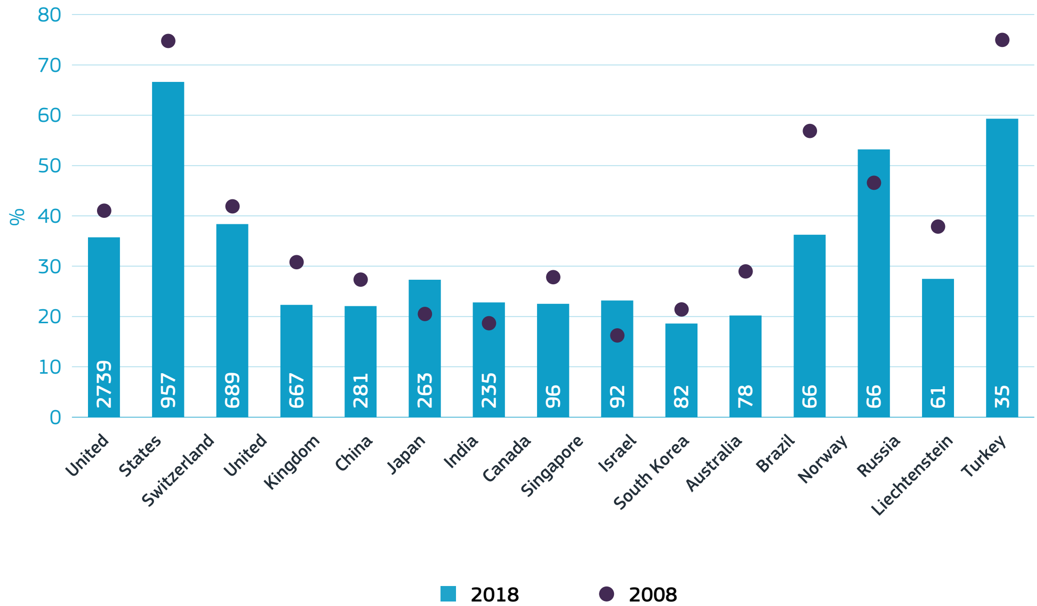
In 2018, the United States had the highest absolute number of patent applications filed under PCT with a foreign co-inventor from the EU. In relative terms, however, this accounted for only 36% of the total patent applications with a foreign co-inventor for the United States. Figure 6.2-12 shows the top 15 countries with the highest absolute number of patent applications filed under the PCT with an EU foreign co-inventor. Out of the 15 countries, the EU was co-inventor for more than 50% of patent applications in 2018 for only Switzerland (67%), Norway (53%) and Liechtenstein (59%). Over time, the share of the EU as foreign co-inventor declined for most of the countries selected and increased only for Norway, Canada, Israel and India.

Figure 6.2-12: Share of patent applications filed under the PCT[1] with the EU as foreign co-inventor, top 15 countries, 2008 and 2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on OECD (International co-operation in patents) data

Notes: [1]PCT patents at the international phase designating the European Patent Office. Full counting method and priority date used. Countries ordered by the absolute number of patent applications with the EU as foreign co-inventor (figures at the bottom).

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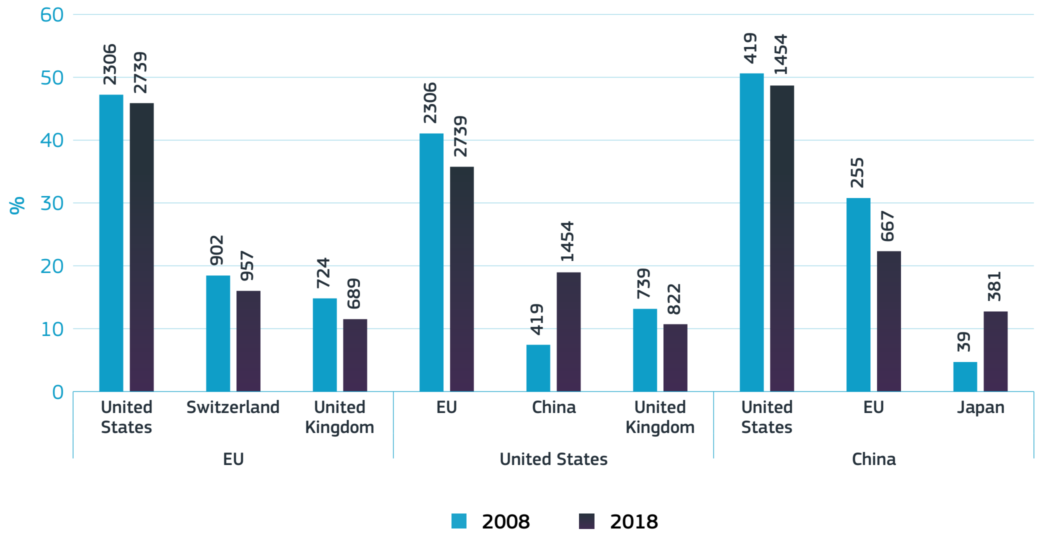
The EU and United States were each other's primary partners for patent applications filed under PCT with a foreign co-inventor in 2018. However, the EU represented less than 40 % of patent applications with a foreign co-inventor for the United States, while the United States co-inventors accounted for 46 % of EU patent applications (Figure 6.2-13). For the EU, the second main partner was Switzerland, with 16 %, followed by the United Kingdom with 12 %. For the United States, China was the second main partner, with a share of almost 20 % and an impressive increase since 2008, followed by the United Kingdom with 11 %. For China, the picture is slightly different: the United States was its main partner in 2018, with a share of 49 %, while the EU came far behind with 22 %, followed by Japan with 13 %.

Figure 6.2-13: Top three main partners of patent applications filed under PCT[1] with a foreign co-inventor (%) for the EU, United States and China, 2008 and 2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on OECD (International co-operation in patents) data

Notes: [1]PCT patents at the international phase designating the European Patent Office. Full counting and priority date used. Absolute numbers shown on top of the bars.

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In absolute terms, with the exception of the EU-United Kingdom pair, all remaining pairs increased patenting collaboration during 2008-2018. The decline in collaboration between the EU and the United Kingdom was compensated by an increase in collaboration between the EU and the United States and Switzerland, as well as with China, Japan and India (data not shown). Collaboration improved the most between China and the United States, with an increase of 247 %, and between China and Japan, with an increase of 877 %. In relative terms, only China became more important to the United States, and Japan became more important to China.

3. Public-private cooperation

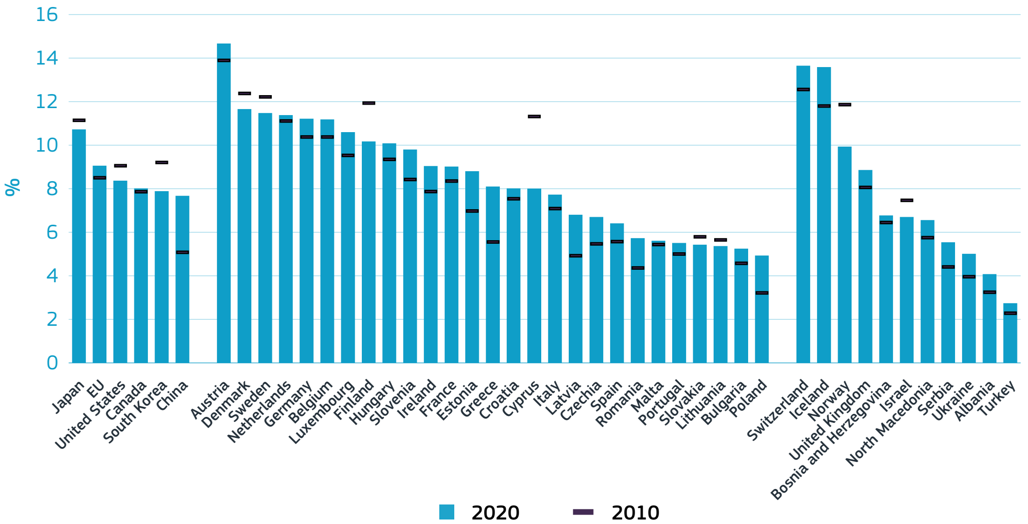
Collaboration between public research-performing institutions and the business sector is one of the most important channels for knowledge diffusion and valorisation. Motivations among companies for engaging in industry-university cooperation are: access to key research staff, complementary research activity and relevant results; providing promising new areas of applied R&D; avoiding wasteful experimentation; offering an understanding of novel directions on inventions and technological innovations; and augmenting the capacity to solve complex problems (e.g. Rosenberg, 1990; Fleming and Sorensen, 2004; Tijssen, 2012). The number of public-private co-authored scientific publications is an indicator to assess the level of collaboration between public research institutions and companies. A public-private co-publication involves several actors, including businesses' R&D departments (or R&D staff in other private-sector organisations), and offers several opportunities, such as co-authoring a research publication with partners in a public-sector organisation, including the academia. This type of collaboration represents a successful channel for knowledge transfer ('knowledge spillover').

Between 2010 and 2020, the share of public-private co-authored scientific publications increased from 8.5 % to 9.1 % in the EU. As reported in Figure 6.2-14, this small growth enabled the EU to overtake the United States in this period. However, the increase was not enough to overtake Japan, which remains the best-performing country among the selected international competitors, with a share of 10.7 %. Although China continues to lag, it showed a significant improvement (from 5.1 % to 7.7 %) during the same period.

Within the EU, there are significant differences between the Member States. Austria ranks first, with a share of 14.7 %, while Poland is the least-performing Member State, reporting a share of 4.9 %. Outside the EU, Switzerland and Iceland stand out with shares above 13 %, whereas Turkey falls behind with a share of less than 3 %. Countries with higher business R&D expenditure tend to have a higher share of public-private co-publications (as shown by the high correlation between the two variables), as enterprises procure public research-oriented institutions to perform research, leading to more scientific publications. This research is then applied by the enterprises to develop new products or processes.

Over time, most EU Member States have seen a rise in the share of public-private co-authored scientific publications. Greece and Latvia showed the biggest improvements, whereas Cyprus and Finland experienced the biggest declines. In absolute terms, all countries except Japan reported an increase in the number of public-private co-publications between 2010 and 2020. However, this growth was smaller than the overall growth in scientific production in countries such as Cyprus, Denmark, South Korea and Norway, explaining the declines reported in Figure 6.2-14.

Figure 6.2-14: Share of public-private co-authored scientific publications in total scientific publications[1], 2010 and 2020



Science, Research and Innovation Performance of the EU 2022

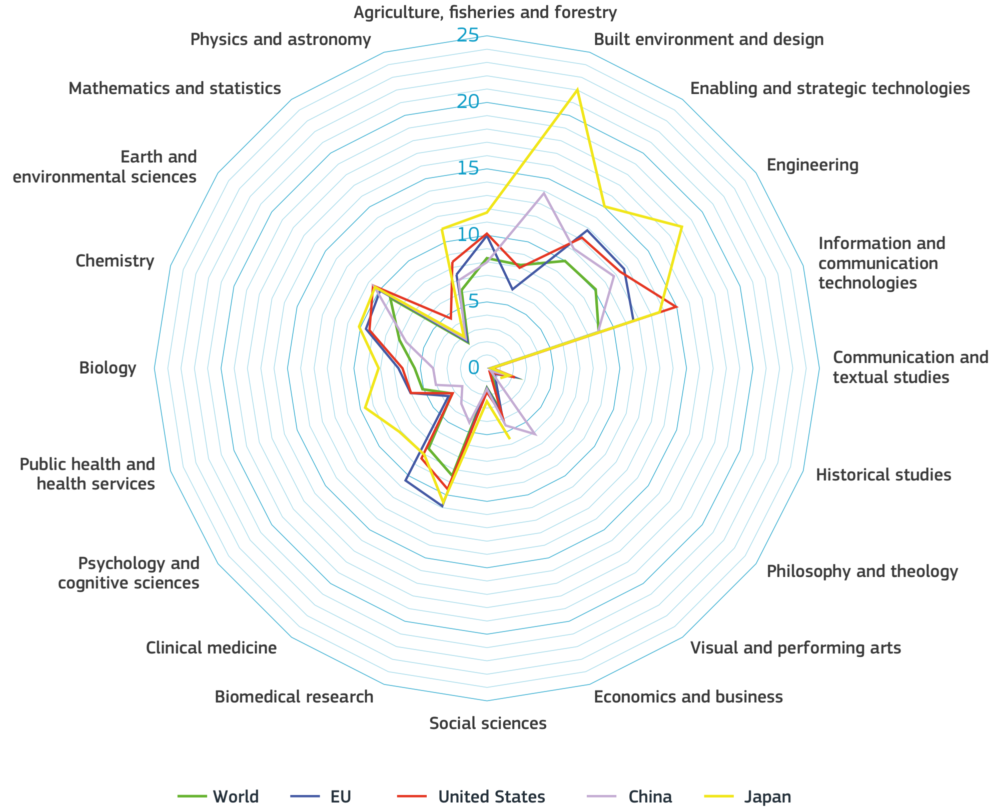
Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Science-Metrix using Scopus database

Note: [1]Full counting method used. Accordingly, weighted averages are used for computing the share country aggregates. Both public and private entities are counted.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-2-14.xlsx

Generally, public-private cooperation is more frequent in the fields of applied sciences, natural sciences and health sciences. Figure 6.2-15 shows the share of public-private co-publications by fields of science and technology. Overall, natural and applied sciences are the areas characterised by the highest shares of collaboration, in particular in the fields of engineering and technologies. Japan is leading public-private collaboration in most fields but mainly in built environment and design, with 22%, and engineering, with 18%. The EU stands out in the health sector, while the United States is the strongest in ICT.

Figure 6.2-15: Share (%) of public-private co-authored scientific publications (in total scientific publications) per field of science and technology[(1)], 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Science-Metrix using Scopus database

Note: [(1)]Full counting used. Accordingly, weighted averages are used for computing the share country aggregates. Both public and private entities are counted.

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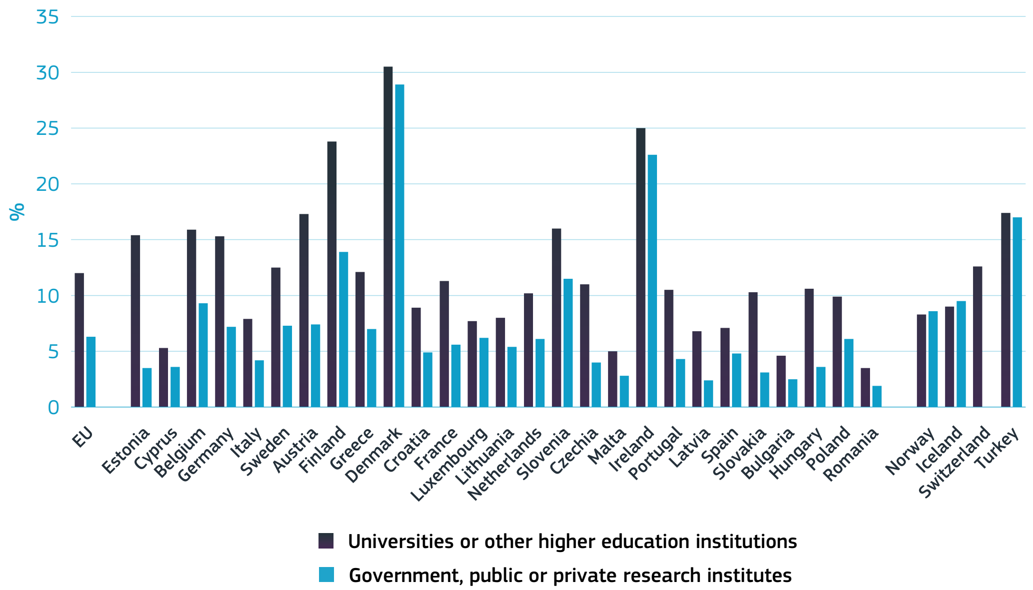
EU innovative enterprises tend to collaborate more with universities than with research institutes. A different indicator to assess the level of collaboration between the business sector and public research-oriented institutions is the share of innovative enterprises that co-operated on R&D and other innovation activities with universities (or other higher education institutions, HEI) and government, public or private research institutes[4]. Results from the Community Innovation Survey (CIS) suggest that 12 % of EU innovative enterprises cooperate on R&D with universities or other HEI, while only 6.3 % cooperate with government, public or private research institutes.

There are significant differences in the level of collaboration across the EU Member States. During 2016-2018, Denmark reported the highest level of cooperation

4 In the available data, it is not possible to separate private research institutes from other public research institutions. However, the number of private research institutes is relatively small in the EU.

between innovative enterprises and universities, with a percentage of 31 %. Conversely, Romania performed very poorly, with a share of less than 2 % (Figure 6.2-16). The data also suggests that a higher share of innovative enterprises does not necessarily lead to higher collaboration. For instance, Ireland, which ranks low in terms of innovative enterprises, has the second-best performance in terms of cooperation, both with universities and research institutes. On the other hand, Cyprus, reporting the second highest share of innovative enterprises, is a country where they cooperate the least.

Figure 6.2-16: Share of innovative enterprises that co-operated on R&D and other innovation activities, 2016-2018

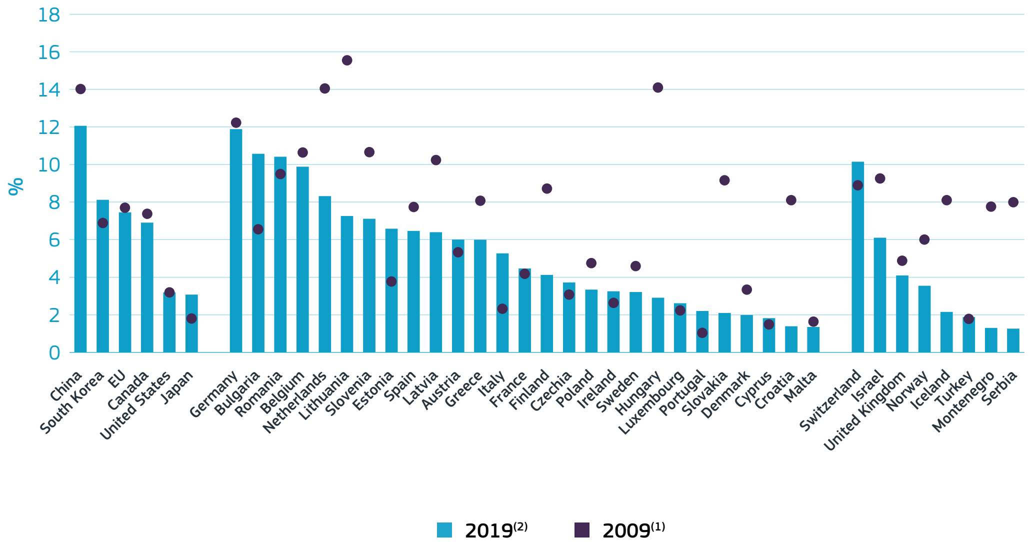


Science, Research and Innovation Performance of the EU 2022

Source: Eurostat – Community Innovation Survey 2018 (online data code: inn_cis11_coop)
Note: Countries ranked by their share of innovative enterprises
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-2-16.xlsx

China has the highest percentage of public R&D expenditure financed by the private sector, i.e. 12 %. Despite the decline between 2009 and 2019, China remains the country accounting for the highest share of public R&D expenditure financed by business enterprises, followed by South Korea, with 8 %, and the EU with 7.5 % (Figure 6.2-17). The United States and Japan fell behind, with shares below 4 %. Within the EU, only five countries perform above the EU average, notably Germany (reporting the same share as China), Bulgaria, Romania, Belgium and Netherlands, while important differences persist between the remaining EU countries. While most Member States experienced sharp declines over 2009-2019 (in particular Hungary, Lithuania and Slovakia), other Member States such as Bulgaria, Italy and Estonia saw significant increases. At the EU level, the share remained roughly stable (Figure 6.2-17).

Figure 6.2-17: Public expenditure (GOVERD + HERD) on R&D financed by business enterprise sector as % of total public expenditure on R&D



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Eurostat (online data code: rd_e_gerdfund) and OECD

Note: (1)Greece, Montenegro: 2011. Switzerland: 2010. (2)Israel, UK, Montenegro: 2018

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MSCA support for university-business cooperation impacted positively on both participating businesses (SMEs and large businesses) and individual MSCA fellows' career development, according to a study linked to the ex-post and mid-term evaluation of the FP7 and H2020 R&I programmes. Additionally, MSCA support was found to have a broader impact on R&I ecosystems and inter-sectoral cooperation (European Commission, 2017). In particular:

- around 47 % of all business beneficiaries indicated that as a result of their project at least one job (FTE equivalent) was created in their organisation;
- business participation significantly increased the chance of a patent application being registered as a result of the MSCA project;
- as a result of the MSCA, the vast majority (89 %) of businesses started to collaborate with at least one new academic organisation.

4. Conclusions: mobility of researchers and collaboration are essential engines for knowledge flows

There is a divergent pattern in researcher mobility observed across Member States both in terms of geographical mobility and across jobs. At the EU level, the share of job-to-job mobility of human resources in science and technology from one year to the next has remained small at almost 7% in 2020, despite an increase between 2010 and 2020. Across the EU, the share varies from more than 10% in Lithuania, Denmark and Cyprus to less than 2% in Romania. Except for Czechia, Sweden and Romania, all other Member States had an increase in mobility in the last 10 years.

Smaller countries and/or those with better-performing R&I tend to show higher levels of researcher mobility. Using survey-based data, Luxembourg, Switzerland and Cyprus display the highest percentages of both inflow of researchers and researchers who obtained a PhD abroad. Using bibliometric data, the same countries report the highest shares of researchers who left the country over 2005-2020. However, many European countries appear to be suffering a brain drain, with the outflow of researchers outstripping the inflow of researchers from the rest of the world.

Collaboration between public research-performing institutions and the business sector is one of the most important channels for knowledge diffusion and valorisation. Between 2010 and 2020, the EU share of public-private co-authored scientific publications increased from 8.5% to 9.1%, placing the EU above the United States and only behind Japan. Within the EU, there are strong differences, from 14.7% in Austria to 4.9% in Poland. Results from the CIS suggest that EU innovative enterprises tend to collaborate more with universities than research institutes, with significant differences in the level of collaboration across the EU Member States. Denmark reported the highest level of cooperation between innovative enterprises and universities, with a percentage of 31%; while Romania performed very poorly, with a share of less than 2%. In terms of public R&D expenditure financed by the private sector, China has the highest share at 12%, compared to 7.5% in the EU.

Cross-border research and collaboration among researchers are important channels of knowledge flow and result in higher citation impacts. In 2020, more than 50% of the scientific publications in most EU Member States were international co-publications, with Luxembourg as the top performer. Between 2010 and 2020, this share increased in all Member States, except Bulgaria. This growth was quite important in the three Baltic countries, Estonia, Lithuania and Latvia, where the share increased by more than 20 percentage points.

With an average of 7747 patent applications, the United States had the highest number of patent applications filed under the PCT with a foreign co-inventor in 2016-2018. The EU came second, with an average of 5 988 patent applications, followed far behind by China (2649) and Japan (1206). In relative terms, however, Canada had the highest share (an average of almost 30% during 2016-2018). Second came the United States, with an average of 13%, and third the EU with 12%. In 2018, both the EU and the United States were each other's primary partners for patent applications filed under PCT with a foreign co-inventor. The EU was also the main partner for Switzerland (67%), Norway (53%) and Liechtenstein (59%). Over time, the share of the EU as a source of a foreign co-inventor increased for Norway, Canada, Israel and India.

References

Lenzi, C. (2013), 'Job Mobility, Patent Ownership and Knowledge Diffusion: Evidence on a Sample of Italian Inventors', *Industry and Innovation*, 20:4, pp. 297-315, DOI: 10.1080/13662716.2013.805930

Ejermo, O., Fassio, C., & Källström, J. (2020), 'Does mobility across universities raise scientific productivity?', *Oxford Bulletin of Economics and Statistics* 82.3, pp 603-624.

European Commission, Directorate-General for Research and Innovation (2021), *MORE4: support data collection and analysis concerning mobility patterns and career paths of researchers,* Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2777/645537

European Commission, Directorate-General for Education, Youth, Sport and Culture (2017), *Study of business participation and entrepreneurship in Marie Skłodowska-Curie actions (FP7 and Horizon 2020): executive summary*, Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2766/46752

European Commission, Directorate-General for Education, Youth, Sport and Culture (2019), *Study on international cooperation in the Marie Skłodowska-Curie actions: final report*, Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2766/621682

European Commission, Directorate-General for Research and Innovation (2021), *Provision and analysis of key indicators in R&I: final study report covering work packages 1-6*, Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2777/587466

Fleming L, Sorensen O. (2004), 'Science as a Map in Technological Search', *Strategic Management Journal*, vol. 25, pp. 909-928.

Franzoni, C., Scellato, G., & Stephan, P. (2012), 'Foreign-born scientists: mobility patterns for 16 countries', *Nature Biotechnology*, 30(12), pp. 1250.

Frietsch, Rainer, and Taehyun Jung (2009), *The internationalisation of international co-inventions*, Georgia Institute of Technology.

Geuna, A. (2015), Global Mobility of Research Scientists: The Economics of Who Goes Where and Why, Amsterdam: Academic Press.

IDEA Consult. (2013a), *Mobility of Researchers 2. Brussels: Report on survey of researchers in EU HEI.*

IDEA Consult. (2013b), *Mobility of Researchers 2. Brussels: Report on survey of researchers outside EU.*

Janger, J., Campbell, D.F.J. & Strauss, A. (2019), 'Attractiveness of jobs in academia: a cross-country perspective', *High Education*, 78, 991-1010. https://doi.org/10.1007/s10734-019-00383-7

Khan, J. (2021), 'European academic brain drain: A meta-synthesis', *European Journal of Education* 56.2, pp. 265-278.

tKhayat, P., Campbell, D., Provençal, S. (2021), *Provision and analysis of key indicators in research and innovation. Policy brief I, Research trends on the Sustainable Development Goals (SDGs) and alignment with SDG 17 on international partnerships: focusing on SDGs 7–11 plus 16 (prosperity),* European Commission, Directorate-General for

Research and Innovation, Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2777/291062

Mugabushaka, A. (2021), *Meeting the pandemic challenges: contribution of EU R&I funding to COVID-19 related research*, European Commission, Directorate-General for Research and Innovation, Working Paper 2021/01, Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2777/616617

Netz, N., Hampel, S., & Aman, V. (2020), 'What effects does international mobility have on scientists' careers? A systematic review', *Research Evaluation*, Volume 29, Issue 3, pp. 327-351. https://doi.org/10.1093/reseval/rvaa00

OECD (2021), *Reducing the Precarity of Academic Research Careers,* OECD Science, Technology and Industry, No. 113.

PPMI (2022), *Study on mobility flows of researchers in the context of the Marie Skłodowska-Curie Actions: analysis and recommendations towards a more balanced brain circulation across the European Research Area Final report*, European Commission (forthcoming).

Provençal, S., Campbell, D., Khayat, P. (2021), *Provision and analysis of key indicators in research and innovation. Policy brief H, Research trends on the Sustainable Development Goals (SDGs) and alignment with SDG 17 through international co-publications: focusing on SDGs 1-5 (People)*, European Commission, Directorate-General for Research and Innovation, Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2777/70734

Provençal, S., Campbell, D., Khayat, P. (2021), *Provision and analysis of key indicators in research and innovation. Policy brief J, Research trends on the Sustainable Development Goals (SDGs) and alignment with SDG 17 through international co-publications: focusing on SDGs 12-15 plus 6 (Planet)*, European Commission, Directorate-General for Research and Innovation, Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2777/03227

Puuska, H. M., Muhonen, R., & Leino, Y. (2014), 'International and domestic co-publishing and their citation impact in different disciplines', *Scientometrics*, 98. 10.1007/s11192-013-1181-7.

Rosenberg N. (1990), 'Why do Firms do Basic Research (with their Own Money)?', *Research Policy*, vol. 19, pp. 165-174.

Robert J. W. Tijssen (2012), 'Co-authored research publications and strategic analysis of public-private collaboration', *Research Evaluation,* Volume 21, Issue 3, pp. 204-215. https://doi.org/10.1093/reseval/rvs013

CHAPTER 6.3

INNOVATION OUTPUT AND SOCIETAL AND MARKET UPTAKE

KEY FIGURES

50% of companies in the EU are innovative	**1 in 5** worldwide patent applications filed under PCT come from the EU
23% of patent applications in climate & environment are from the EU	**62%** total EU exports are medium-and-high-technology products

KEY QUESTIONS WE ARE ADDRESSING

- How is the EU performing in terms of innovation output?
- What is the economic impact of innovation in the EU?

KEY MESSAGES

What did we learn?

- Among European businesses, the ability to innovate is related to firm size. Large companies have a higher propensity to innovate than SMEs, especially regarding the development of innovative products.
- The EU continues to lag behind Japan and the United States in the innovation output indicator. One of the main drivers is patent intensity, for which the EU also falls behind China and South Korea.
- The innovation divide persists across Member States, with Germany accounting for more than 40 % of patent applications filed under the PCT in the EU in 2018.
- The EU was the top patent applicant in the fields of climate and environment (23 %), energy (22 %) and transport (28 %) worldwide in 2018.
- The share of exports of medium and high-technology products in the EU remained stable over the years, while the share of exports of knowledge-intensive services declined.

What does it mean for policy?

- It is important to continue supporting European IP policy and foster a stronger knowledge-valorisation policy for societal, environmental and economic impact. In addition to improving innovation systems, the EU must encourage structural reforms that upgrade the technology profiles of Member States and address the persistent innovation divide.
- The EU needs to strengthen innovation capacity across Member States, especially in the high-tech economic sectors.
- The EU has the human capital and science base, but can be more effective in translating it into innovations and commercialising innovation output.

1. Innovation Performance

Measuring the innovation performance of the EU is essential for improving existing and designing new R&I policies for economic growth and sustainable development. A key principle of the Oslo Manual (OECD/Eurostat 2018) is that innovation can and should be measured. To this end, the manual provides guidelines for collecting and interpreting data on innovation to facilitate international comparisons. The Community Innovation Survey (CIS)[1], which is the reference survey on innovation in enterprises in the EU, EFTA and the EU Candidate Countries, is based on the Oslo Manual. The survey was introduced in 1992 and has become a regular biennial data collection.

EU innovation performance has increased. According to the 2021 European Innovation Scoreboard (EIS), all EU countries improved their innovation performance in 2020[2]. However, most of the underlying data refers to the pre-pandemic period and does not account for the COVID-19 shock. Sweden is the most innovative country in the EU, followed by Finland, Denmark and Belgium. The distribution of EU countries in the four performing groups[3] clearly indicates the persistent innovation gap between north-west and south-east Europe (Figure 6.3-1).

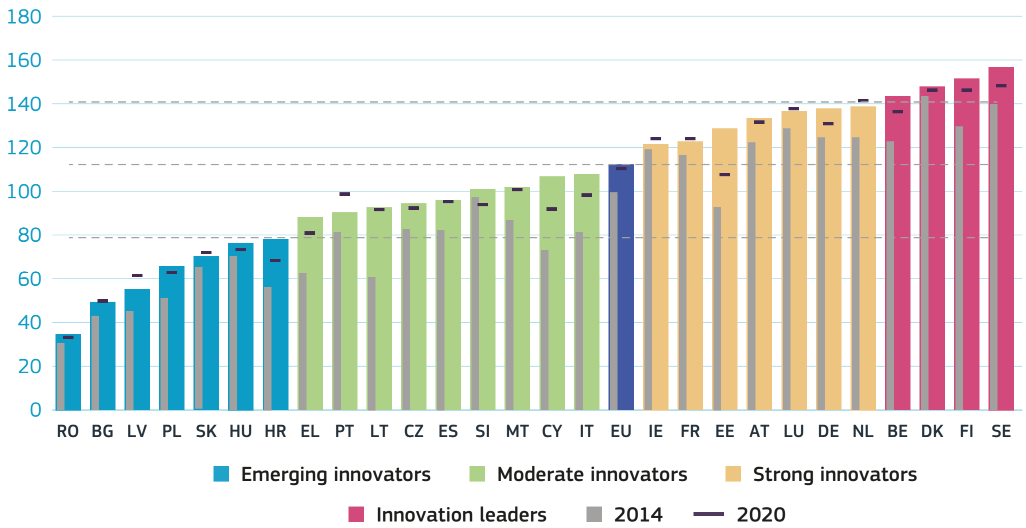
The Global Innovation Index (GII) 2021 finds that investment in innovation has shown remarkable resilience during the COVID-19 pandemic, but varies across sectors and regions (WIPO, 2021). As discussed in other parts of this report, scientific output, public R&D support, IP filings and venture capital (VC) deals continued to grow in 2020. According to the GII 2021, the majority of the top 25 most innovative economies continue to be from Europe. Switzerland, Sweden, and the United Kingdom are among the top five.

1 https://ec.europa.eu/eurostat/web/microdata/community-innovation-survey

2 For most indicators, the reference year lags one or two years behind the year to which the EIS refers.

3 **Innovation Leaders** are all countries with a relative performance in 2021 above 125 % of the EU average in 2021. **Strong Innovators** are all countries with a relative performance in 2021 between 100 % and 125 % of the EU average in 2021. **Moderate Innovators** are all countries with a relative performance in 2021 between 70 % and 100 % of the EU average in 2021. **Emerging Innovators** are all countries with a relative performance in 2021 below 70 % of the EU average in 2021

Figure 6.3-1: European Innovation Scoreboard 2021 – Performance of EU Member States' innovation systems



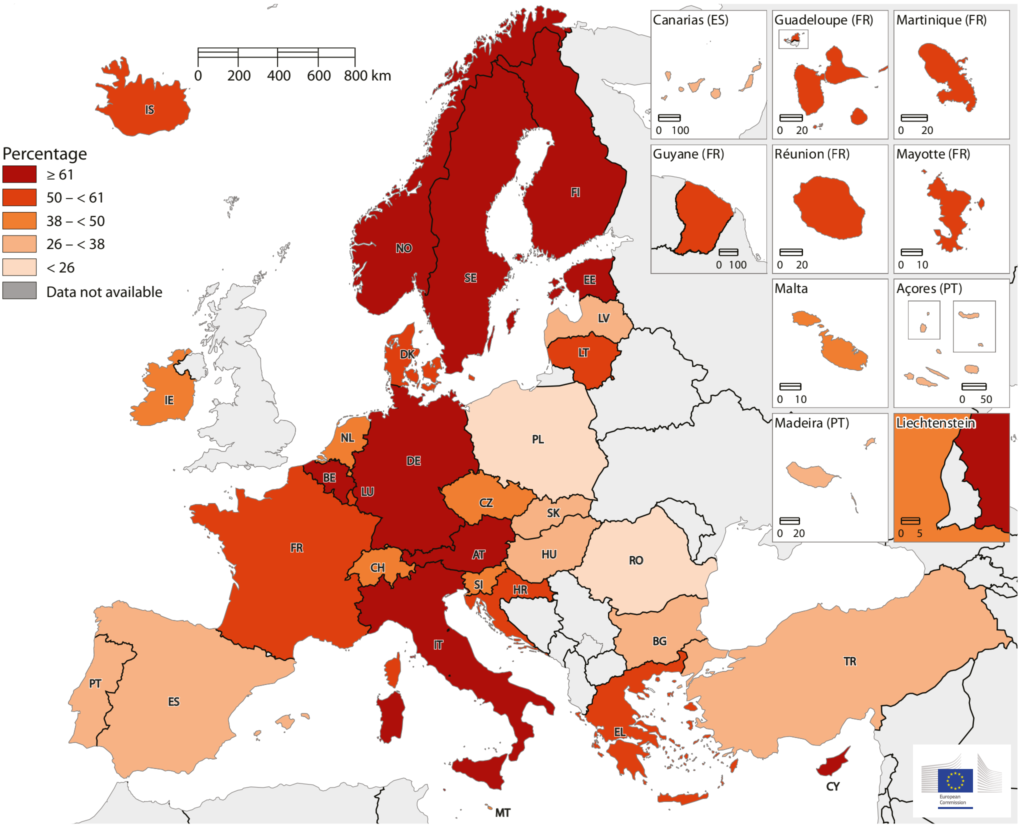
Source: European Innovation Scoreboard 2021, European Commission (2021)

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-1.xlsx

The propensity to innovate is higher for large companies than for SMEs. This pattern is observable in all EU and neighbouring countries (Figure 6.3-3). Estonia, Belgium and Greece report the highest share of innovative large enterprises (more than 90%), performing well above the EU average of 78%. The highest shares of innovative SMEs (above 65%) can be found in Estonia, Cyprus, Belgium and Germany.

Intra-country differences in the shares of innovative large companies and SMEs varies significantly within the EU, ranging between 48 p.p. in Bulgaria and 8 p.p. in Ireland. Large differences suggest that innovation is performed by a few large, possibly multinational companies, while the majority of the SMEs are not innovative.

Figure 6.3-2: Map of share of innovative enterprises (number of innovative enterprises as % of total number of enterprises), 2016-2018



Science, Research and Innovation Performance of the EU 2022

Source: Eurostat - Community Innovation Survey 2018, (online data code: inn_cis11_bas)

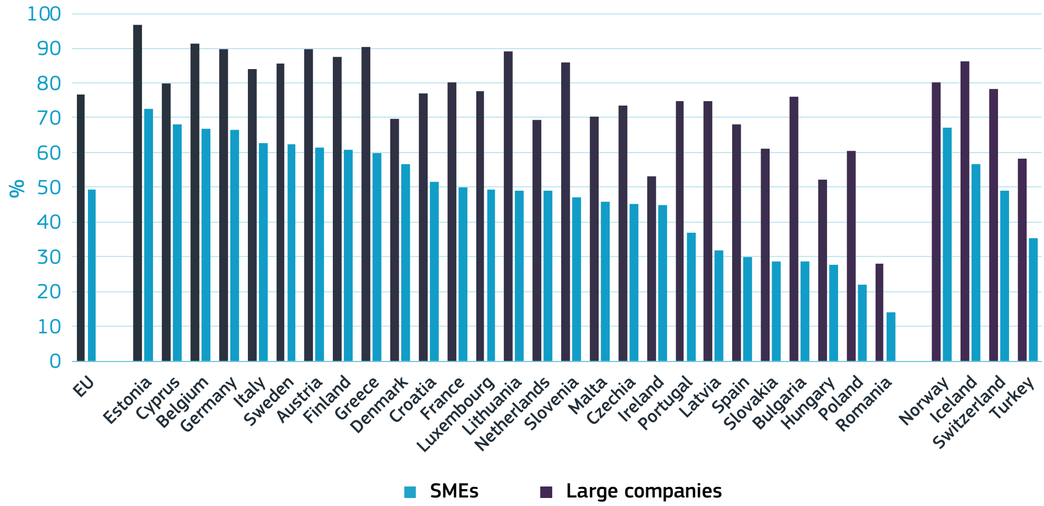
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-2.xlsx

In 2018, 50% of EU firms reported innovation activities, showing an increase of 2 percentage points (p.p.) compared with 2016. Based on the Community Innovation Survey, more than half of Member States showed an increase in their share of innovative enterprises compared with the period 2014-2016. For 14 Member States, this share is higher than the EU average. Estonia and Cyprus are the countries with the highest shares (73.1% and 68.2%, respectively), followed by Belgium and Germany (both with 67.8%).

On the opposite side, Romania and Poland show the lowest performances, reporting only 15% and about 24% of innovative companies, respectively. Italy and Sweden experienced an increase of 9 p.p. over the period 2016-2018. Portugal recorded a dramatic decline of 29 p.p., which may not entirely reflect a decrease in the innovativeness of the country, as other methodological factors need to be examined[4].

4 For example, changes in the questionnaire and the order of the questions, changes in way the survey was conducted etc.

Figure 6.3-3: Share of innovative enterprises by size class(1), 2016-2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation, Chief Economist - Common Strategy & Foresight Unit based on Eurostat - Community Innovation Survey 2018 (online data code: inn_cis11_bas)

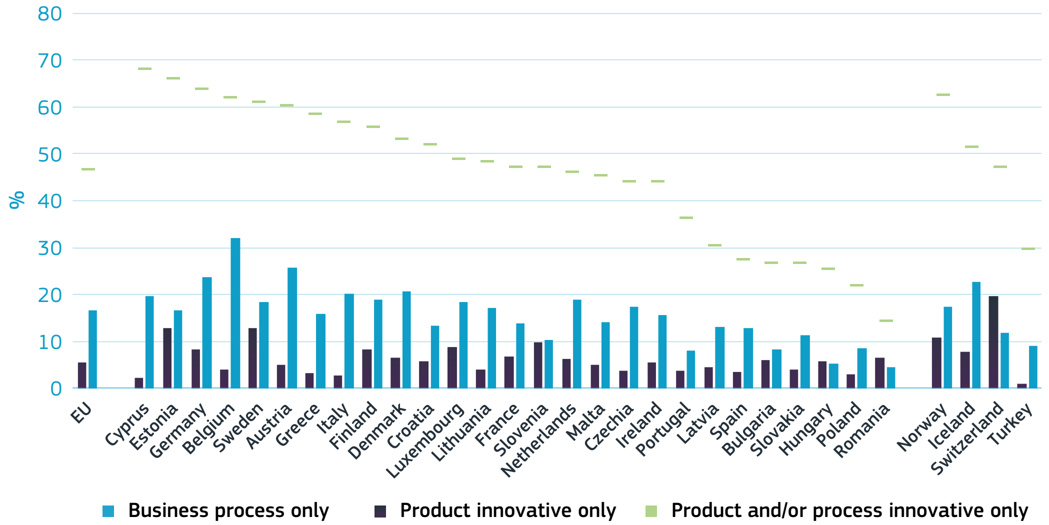
Note: (1)SMEs are firms with 10-249 employees, large companies 250 employees or more.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-3.xlsx

Most companies engage in a combination of product and business process innovation activities. The EU share of product and/or business process innovative enterprises only (regardless of any other innovation activities) is about 47% and varies significantly among Member States, from 68% in Cyprus to 14% in Romania. In contrast, the shares of companies engaging in one type of innovation, either product or business, are significantly lower (see Figure 6.3-4). Product innovation is a new or improved good or service that differs significantly from the firm's previous goods or services and that has been introduced to the market. A business process innovation is a new or improved business process for one or more business functions. According to the revised Oslo Manual, business process innovation merges marketing and organisational innovation.

The average share of companies undertaking only product innovations activities in the EU is 5.5%. Estonia and Sweden reported the highest share (about 13%), while Cyprus and Italy showed the lowest performance (less than 3%). The share of companies carrying out activities targeting only business process innovations is significantly higher and averages around 16.7% at EU level. Belgium leads with a share of 32.1%, followed by Austria and Germany.

Figure 6.3-4: Share of innovative enterprises by type of innovation activity, 2016-2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Eurostat - Community Innovation Survey 2018 (online data code: inn_cis11_bas)

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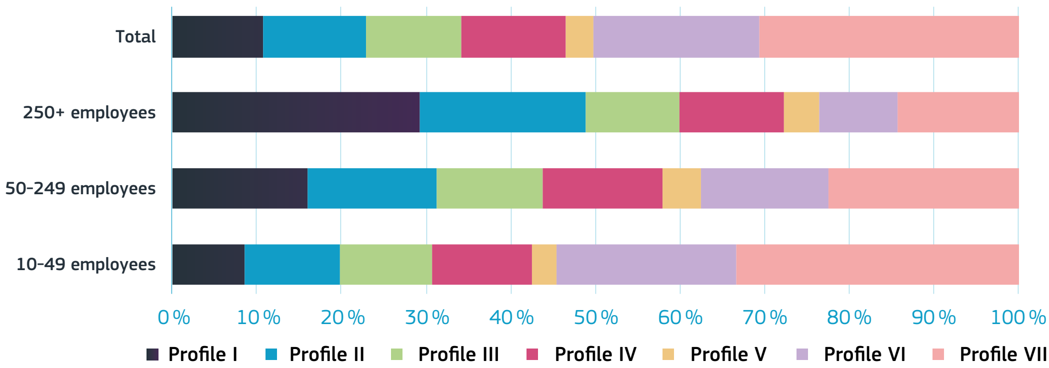
Developing product innovation with market novelties (profile I) is limited to a few large firms with internal competences. Data from the innovation profiling (Box 6.3-1) shows that about 11 % of all enterprises in the EU are in-house innovators with market novelties (Profile I). These enterprises are most frequent (one in three) among larger enterprises (250 or more employees), which represent about 4 % of the reference total.

Within European businesses, the capa-bi-lity to innovate is mostly related to firm size characteristics. Figure 6.3-5 shows that enterprises of Profile I and II, i.e. product innovators, are more common among large enterprises. Similarly, non-innovators of Profiles VI and VII are significantly more frequent among small enterprises, which represent the vast majority of European businesses (almost 80 % of the reference total). Profiles III and IV are not sensitive to the size of the enterprises.

Figure 6.3-5: Distribution of enterprises by size class and innovation profile[1]



	10-49 employees	50-249 employees	250+ employees	Total
Profile I	9 %	16 %	29 %	11 %
Profile II	11 %	15 %	20 %	12 %
Profile III	11 %	12 %	11 %	11 %
Profile IV	12 %	14 %	12 %	12 %
Profile V	3 %	4 %	4 %	3 %
Profile VI	21 %	15 %	9 %	20 %
Profile VII	33 %	23 %	14 %	31 %

Science, Research and Innovation Performance of the EU 2022

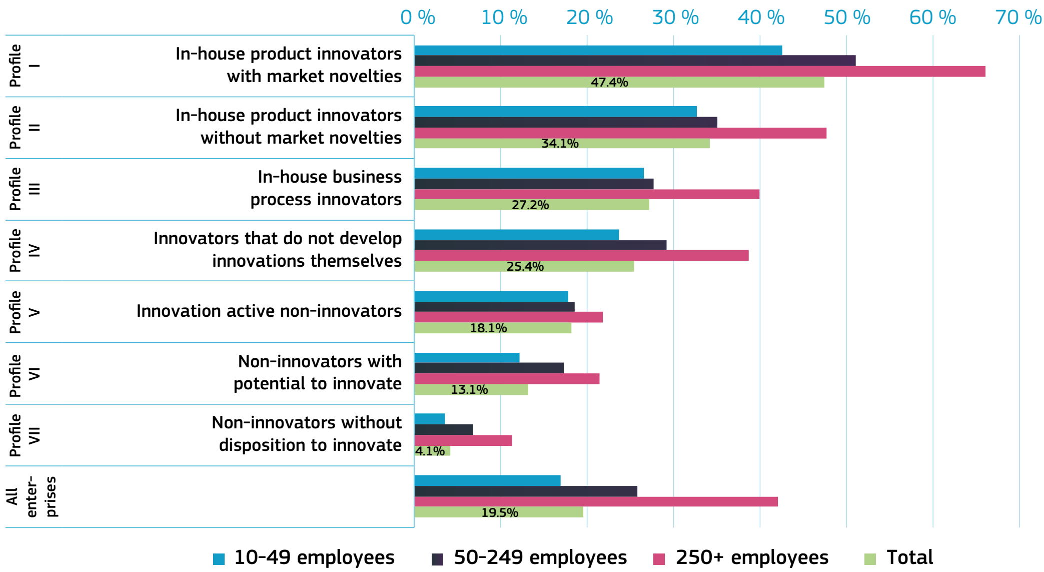
Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Eurostat - Community Innovation Survey 2018

Note: [1]Based on 18 EU Member States. Data are not available for Austria, Czechia, and Sweden.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-5.xlsx

The propensity of an enterprise to invest in new technologies is related to the size and the type of innovative activity. The acquisition of new technology represents an important source of embodied knowledge for innovation in enterprises. On average, only one-fifth of enterprises invested in new embodied technologies, with the propensity to invest increasing significantly with firm size. Figure 6.3-6 shows, for each of the innovation profiles, the shares of enterprises that purchase new technology, which was not used in enterprise before. About half of the product innovators with market novelties purchased new technologies. Medium-sized firms that internally develop new products with market novelties tend to purchase new technologies more than the big firms with product innovators without market novelties (Figure 6.3-6).

Figure 6.3-6: Share of firms which purchased new technology that was not used in enterprise before by size class and innovation profile[1]



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Eurostat - Community Innovation Survey 2018

Note: [1]Based on 18 EU Member States. Data are not available for Austria, Czechia, and Sweden.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-6.xlsx

Box 6.3-1: Innovation profiling

DG Eurostat

Innovation in businesses involves a range of activities requiring multiple capabilities. With different characteristics and innovation abilities, enterprises can contribute to economic growth and social development in various ways. In this perspective, the profiling of enterprises according to their innovation behavior may improve our knowledge of the diversity of the innovation patterns.

Using Community Innovation Survey (CIS) microdata, analysed in collaboration with most National Statistical Offices, it is possible to identify seven mutually exclusive innovation profiles.

The logic followed in developing the profiles is in line with policy purposes, focusing on the conditions that allow innovation to occur in businesses, rather than on the characteristics of successful innovators. The process identifies enterprises with and without innovation activities at the first level. The second level distinguishes enterprises that have implemented an innovation during the CIS reference period, or not. Finally, at the third level, it focuses on the innovation capabilities of enterprises, including the presence and level of R&D activities, innovation cooperation, the presence of ongoing or abandoned innovation efforts, and the innovation potential of companies that have not introduced innovations.

Figure 6.3-7: Combining the Community Innovation Survey core variables: innovation profiling

Combining the CIS core variables: innovation profiling

	Enterprises												
	Total	**with innovation activities**										**without innovation activities**	
		Total	**with innovations**						**without innovations**				
			Total	**with substantial own innovation capabilities**				**without substantial own innovation capabilities**	**Total**	**that worked on innovations but did not implement them**	**Total**	**that tried or considered to innovate but were impeded**	**that did not try or consider to innovate**
				Total	*View: Market relevance of innovation*								
					with product innovations not offered before by competitors	with an enlarged assortment 1)	with only business process innovation	**Total**		**Total**			
	I + II + III + IV + V + VI + VII	I + II + III + IV + V	I + II + III + IV	I + II + III	I	II	III	IV	V + VI + VII	V		VI	VII
with R&D activities					I.A	II.A	III.A	IV.A		V.A			
without R&D activities					I.B	II.B	III.B	IV.B		V.B			

Seven innovation profiles:

I - In-house product innovators with market novelties, including all enterprises that introduced a product innovation that was developed by the enterprise and that was not previously offered by competitors.

II - In-house product innovators without market novelties, including all enterprises that introduced a product innovation that was developed by the enterprise but that is only new to the enterprise itself.

III - In-house business process innovators, including all enterprises that did not introduce a product innovation, but that did introduce a business process innovation that was developed by the enterprise.

IV - Innovators that do not develop innovations themselves, including all enterprises that introduced an innovation of any kind but did not develop it themselves (enterprises without significant own innovation capabilities).

V - Innovation active non-innovators, including all enterprises that did not introduce any innovation but that either had ongoing or abandoned innovation activities.

VI - Non-innovators with potential to innovate, including all enterprises that did not introduce any innovation, and which had no ongoing or abandoned innovation activities but that did consider to innovate.

VII - Non-innovators without disposition to innovate, including all other enterprises, those that neither introduced an innovation nor had any ongoing or abandoned innovation activities nor considered to innovate.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-7.xlsx

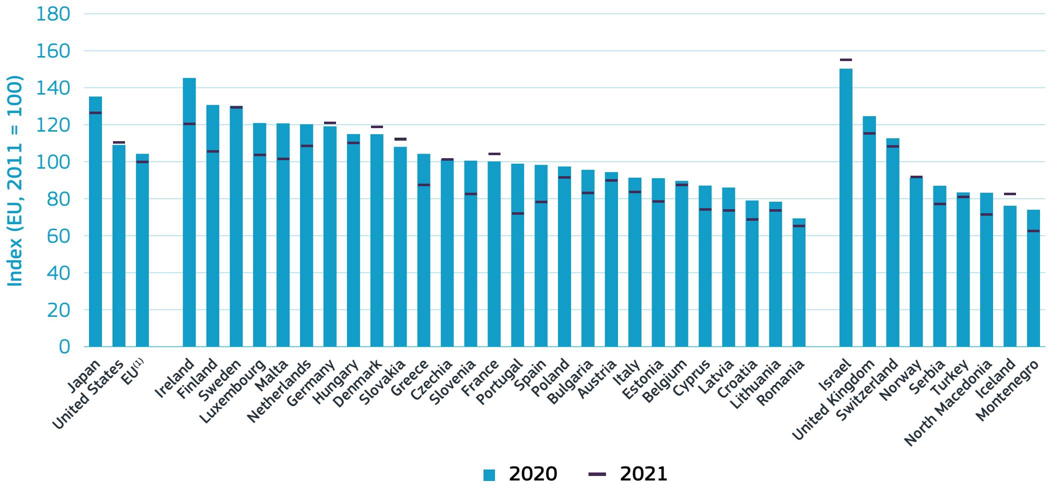
2. Innovation output

Innovation output is the result of innovation activities within an economy. Several indicators, from composites to single indicators, can be used to measure innovation output. In its latest edition, the Global Innovation Index (GII) used several metrics, from indicators on knowledge creation and diffusion to intangible assets, to produce its innovation output sub-index. For several years now, the European Commission has published a composite indicator that aims to measure the extent to which ideas from innovative sectors can reach the market, providing better jobs and making Europe more competitive. The innovation output indicator aggregates four components to measure innovation output: patents, employment in knowledge-intensive activities, trade in knowledge-based goods and services, and innovativeness of high-growth enterprises.

In 2020, the EU lagged behind the US and Japan in terms of innovation output. These results are mainly due to weak EU performance in the components related to patent applications, employment in knowledge-intensive activities, and trade in knowledge-intensive services. Between 2011 and 2020, the EU's performance improved, helping to close the gap with US (Figure 6.3-8). However, the gap with Japan grew. Despite a small improvement in some of the indicator's components (namely, the innovativeness of high-growth enterprises, employment in knowledge-intensive activities and trade in knowledge-based goods), the overall EU performance did not suffice to catch up with Japan. These results are in line with the European Innovation Scoreboard, according to which the EU lags behind Japan and the US; and with the GII, in which Japan and the US perform particularly well in the output sub-index.

Ireland, Finland and Sweden are the top three EU countries in terms of innovation output. While Ireland underperforms in the component of patent applications, it is the top performer in the components of trade in knowledge-intensive services and innovativeness of high-growth enterprises. Finland and Sweden, on the other hand, are very strong in terms of patent applications. Conversely, Romania, Lithuania and Croatia reported the lowest performance in 2020. A more detailed analysis of the performance per component is presented in section 3 – Economic Impact of Innovation. Between 2011 and 2020, the innovation performance improved in 22 out of the 27 EU Member States, especially in Portugal, Ireland and Finland. Performance declined slightly in Germany, Denmark, Slovakia and France, and stagnated in Czechia. The strong progress of Portugal was mainly due to a significant increase in employment of fast-growing enterprises.

Figure 6.3-8: Innovation output indicator, 2011 and 2020



Science, Research and Innovation Performance of the EU 2022

Source: European Commission, DG Joint Research Centre (Bello, M. et al., 2022)

Note: (1)EU: Two sets of values are available: for worldwide and for European comparison. The values for worldwide comparison, which exclude trade within EU countries, are shown on the graph. The value for European comparison for 2020 is 105.2.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-8.xlsx

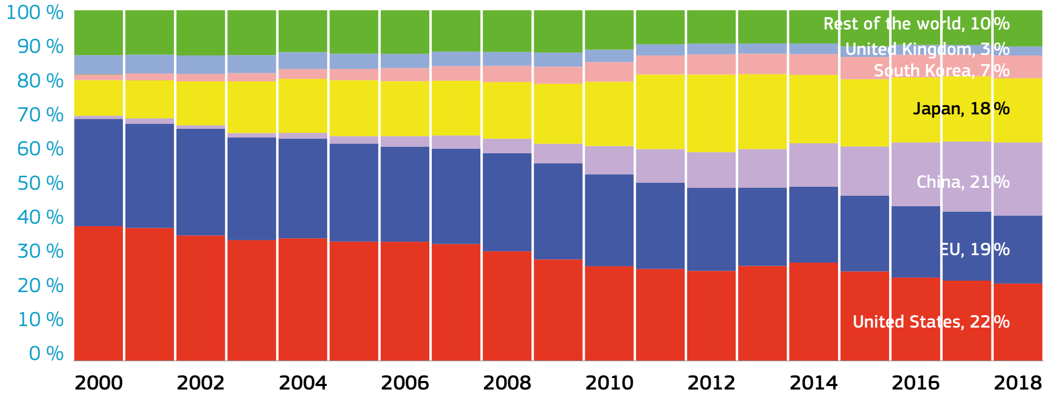
Patent data provides a useful way to measure innovation performance. Around 80% of the patent applications filed under the PCT[5] worldwide came from Japan, China, the EU and the US (Figure 6.3-9). However, the distribution of the share of applications among them changed over time. While the EU and the US accounted for 31% and 38% of worlds' patent applications in 2000 respectively, their share declined to 19% and 22% in 2018. In contrast, China is the country with the largest increase over time, especially after 2008, overtaking both the EU and Japan in 2017. If the trend shown in Figure 6.3-9 continues, China will overtake the US in coming years. Unlike scientific publications, for which the rise of China was mostly at the expense of the US (see Chapter 6.1), in the case of patent applications, the rise of China and Japan came at the expense of both the US and the EU.

The sectoral distribution of patent applications varies between the four global players. On the one hand, the EU applies for proportionally more patents in the medium and low-tech sectors, such as the automotive and machinery sectors. On the other hand, China and the US apply for proportionally more patents in high-tech fields such as the pharmaceutical and other chemistry sectors (polymers, materials or nano-technology) and in knowledge-intensive services like IT (despite the fact that knowledge-intensive services represent a very low share worldwide). Finally, Japan appears to be stronger mainly in the medium-tech sector. [6]

5 The Patent Cooperation Treaty (PCT) is an international patent law treaty which assists applicants in seeking patent protection internationally for their inventions. By filing one international patent application under the PCT, applicants can simultaneously seek protection for an invention in a large number of countries.

6 See Chapter 2.2- Zoom Out: Technology and Global Leadership for more details.

Figure 6.3-9: World shares (%) of patent applications filed under PCT[(1)], 2000-2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database

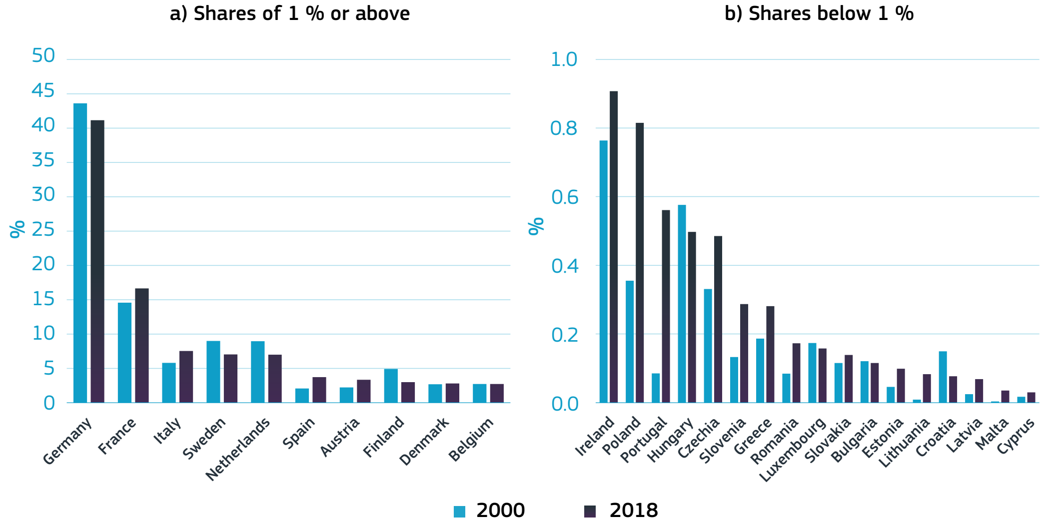
Notes: [(1)]Patent Cooperation Treaty (PCT) patents, at the international phase designating the European Patent Office. Fractional counting method, inventor's country of residence and priority date used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-9.xlsx

There exists a clear regional divide in patent applications in the EU (Figure 6.3-10). In the EU, Germany accounted for over 40 % of patent applications filed under the PCT in 2018. France came a distant second with a share of 17 %, followed by Italy (8 %) and Sweden (7 %). Unlike scientific publications, patent applications in the EU are considerably more concentrated, with 95 % coming from only 10 Member States. However, there is a similar trend to that of scientific production, with eastern and southern EU Member States like Portugal, Italy, Spain and Poland increasing their share between 2000 and 2018, while countries like Germany, Netherlands, Sweden and Finland lost ground.

Although looking at the world share is important, using relative terms provides a better comparison across countries. In this case, Japan and South Korea topped the ranking with more than 10 patent applications per billion GDP in 2018. Trailing in third place, the US had four patent applications, followed closely by China, the EU and Canada (Figure 6.3-11). Over time, despite their already high share, both Japan and South Korea managed to improve enormously, with 5 and 4.6 more patent applications per billion GDP, respectively. However, the impressive growth (315 %) came from China. It overtook both EU and Canada, having increased considerably from a very low level in 2008. The EU and the US on the other hand showed a small decline.

Figure 6.3-10: EU share of patent applications filed under PCT by Member State, 2000 and 2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database

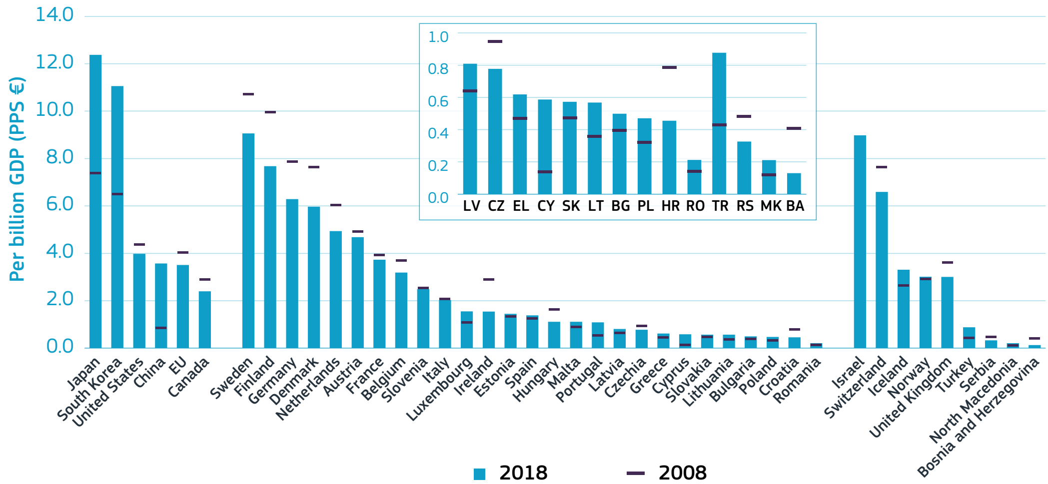
Notes: [1]Patent Cooperation Treaty (PCT) patents, at the international phase designating the European Patent Office. Fractional counting method, inventor's country of residence and priority date used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-10.xlsx

Within the EU, performance varies considerably across Member States, with a persistent regional divide. While northern and western EU countries like Sweden, Finland and Germany perform well, southern and eastern countries like Romania, Croatia and Poland perform poorly. Between 2008 and 2018, about half of the Member States reported a stagnation or decline in the share of patent applications per billion GDP (Figure 6.3-11). Among those, Finland displayed the biggest drop, with -2.3 patent applications per billion GDP, followed by Sweden and Denmark, both with -1.7. In percentage terms, however, Ireland declined by 47 % and Croatia 42 %. Conversely, Portugal and Cyprus increased the most during the same period.

It is important to highlight that patenting is affected by several structural factors. These include: the share of the manufacturing sector in the economy as manufacturing companies tend to patent more than service-sector companies (EPO and EIPO, 2019); the technological intensity of both the manufacturing and the service sectors; the size distribution of the enterprises (larger enterprises tend to have higher patent propensity); and the location of the company's headquarters (patenting tends to be carried out in countries with favourable legislation).

Figure 6.3-11: Patent applications filed under the PCT[1] per billion GDP (PPS €), 2008 and 2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database, Eurostat and OECD

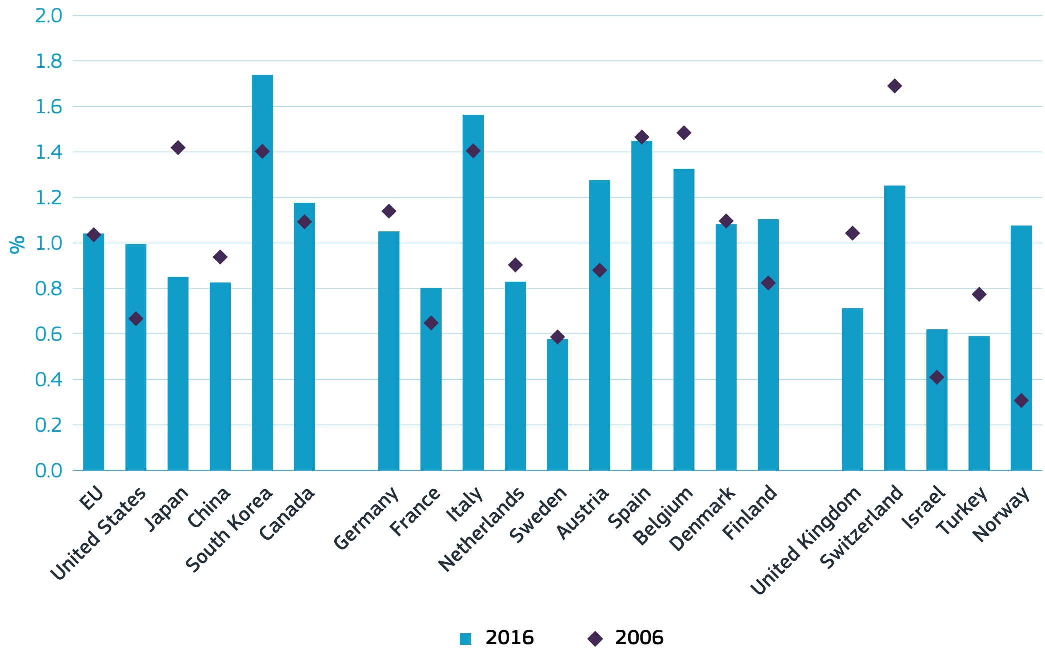
Notes: [1]PCT patents at the international phase designating the European Patent Office. Fractional counting, inventor's country of residence and priority date used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-11.xlsx

Particularly novel patented innovations will be the subject of greater citation. For this reason, the number of citations received by a patent (forward citations) has been used in the literature as a measure of the innovative output embodied in the technology (Alan C. Marco, 2007). In addition, an analysis of patent citations is a core methodology in the study of knowledge diffusion (Alcácer, 2006). Outside the EU, South Korea is the top performer, with 1.7 % of its patent applications to the EPO among the top 1 % most cited patent applications worldwide (Figure 6.3-12). Canada (1.2 %) is in second place, followed by the EU (1 %). The US is next with a share of less than 1%, followed by Japan and China. However, in absolute terms, the EU has the highest number of patent applications overall due to a European bias in using the EPO. Among the top 10 EU countries with the highest number of patent applications to the EPO, Italy has the highest share. On the opposite side, Sweden is the EU country with the lowest share.

Between 2006 and 2016, patent quality in the EU has remained stable. On the other hand, Japan showed a significant decline and South Korea and the US a considerable increase. Out of the 10 EU countries analysed, both Finland and Austria displayed a substantial increase. The figures suggest that, despite the lower number of patent applications overall, countries like South Korea, Spain, Belgium or Norway, are able to have, proportionally, more patent citations, than countries with a bigger number of patent applications. The only exceptions are Italy and Switzerland with high numbers of patent applications of higher quality.

Figure 6.3-12: Top 1% most cited patent applications to the EPO[(1)], 2016 and 2006



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database

Note: [(1)]Patent counts are based on the priority date, the inventor's country of residence and fractional counts. This indicator represents the WIPO technology field and year normalised counts of the number of patents cited by other patents. This indicator is normalised by year and WIPO technology field to account for variations in patterns of citations between fields and years. Only the top 10 EU countries in terms of patent applications to the EPO were considered. Countries ranked by the number of patent applications to the EPO in 2016.

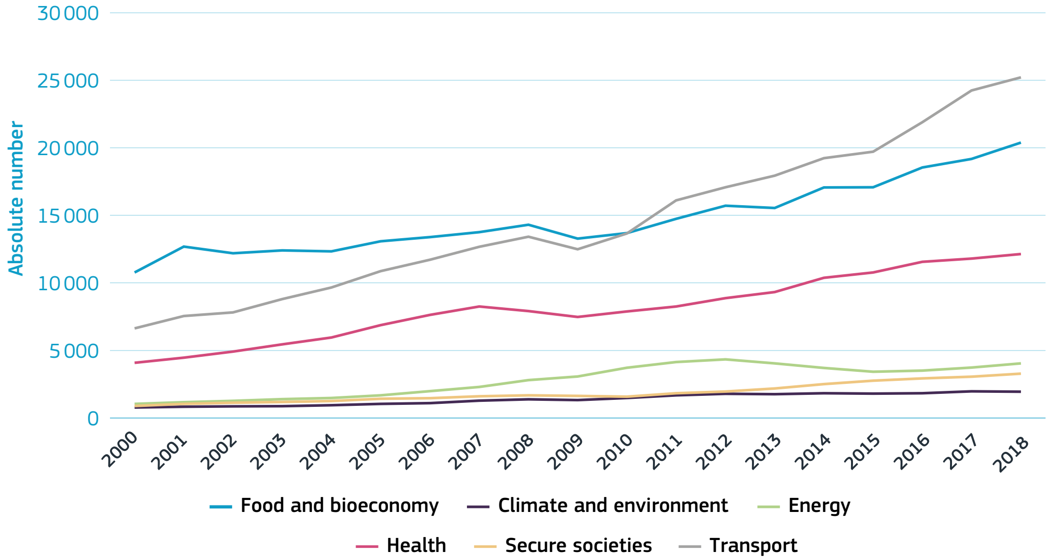
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-12.xlsx

The world's number of patent applications filed under the PCT increased in all Societal Grand Challenges over time. The Societal Grand Challenges, defined under Horizon 2020, are one way of assessing how innovation contributes to addressing sustainability and the challenges our society is facing. Between 2000 and 2018, the fields with the highest number of patent applications filed under the PCT were transport and food and bioeconomy. In 2018, they recorded more than 25 000 and more than 20 000 patent applications, respectively. Health came third with around 12 000 patent applications in 2018.

All three fields have a high propensity for patenting[7]. Despite a decline between 2012 and 2015, due to a change in the methodology, energy was the field that increased the most in relative terms (+288 %). Transport showed the second-largest percentage increase (280 %), and the largest growth in absolute terms, with about 18 500 more patents in 2018 than in 2000, overtaking food & bioeconomy in 2010.

7 EPO and EIPO (2019), IPR-intensive industries and economic performance in the European Union.

Figure 6.3-13: Total number of patent applications filed under the PCT in the world by Horizon 2020 Societal Grand Challenge[(1)], 2000-2018



Science, Research and Innovation Performance of the EU 2022

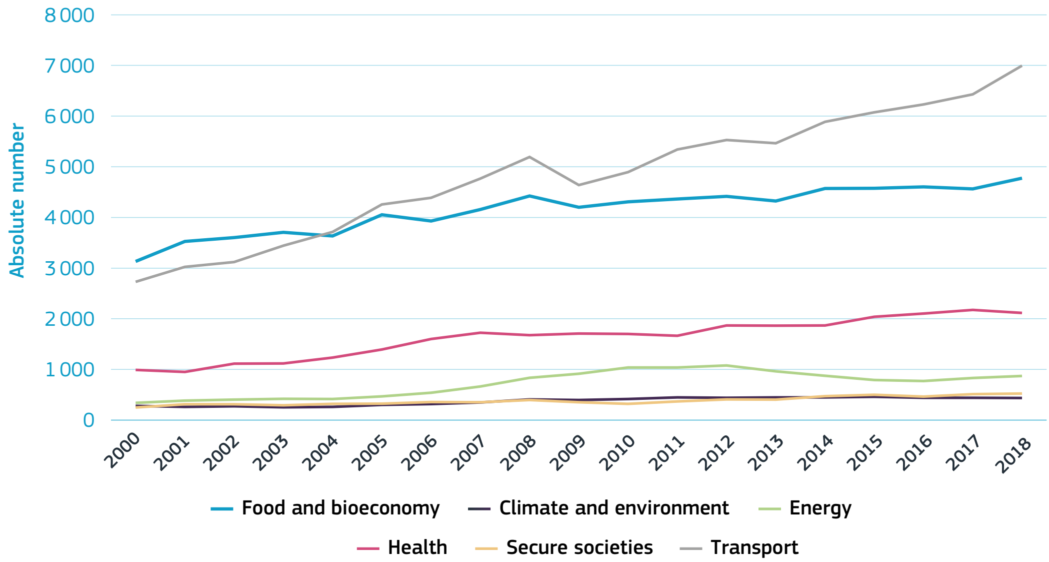
Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database

Notes: [(1)]PCT patents at the international phase designating the European Patent Office. Fractional counting, inventor's country of residence and priority date used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-13.xlsx

The EU was unable to match the level of growth seen worldwide. Figure 6.3-14 shows that the number of patent applications in the EU has remained stable over time, especially in the fields of food and bioeconomy, climate and environment, and energy. The only exception is transport, which continued to increase significantly, overtaking food and bioeconomy in 2004. In relative terms, however, four fields (energy, health, security and transport) more than doubled their number of patent applications. Food and bioeconomy and climate and environment increased by 53 % and 55 %, respectively, between 2000 and 2018.

Figure 6.3-14: Total number of patent applications filed under the PCT[1] in the EU by Horizon 2020 Societal Grand Challenge, 2000-2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database

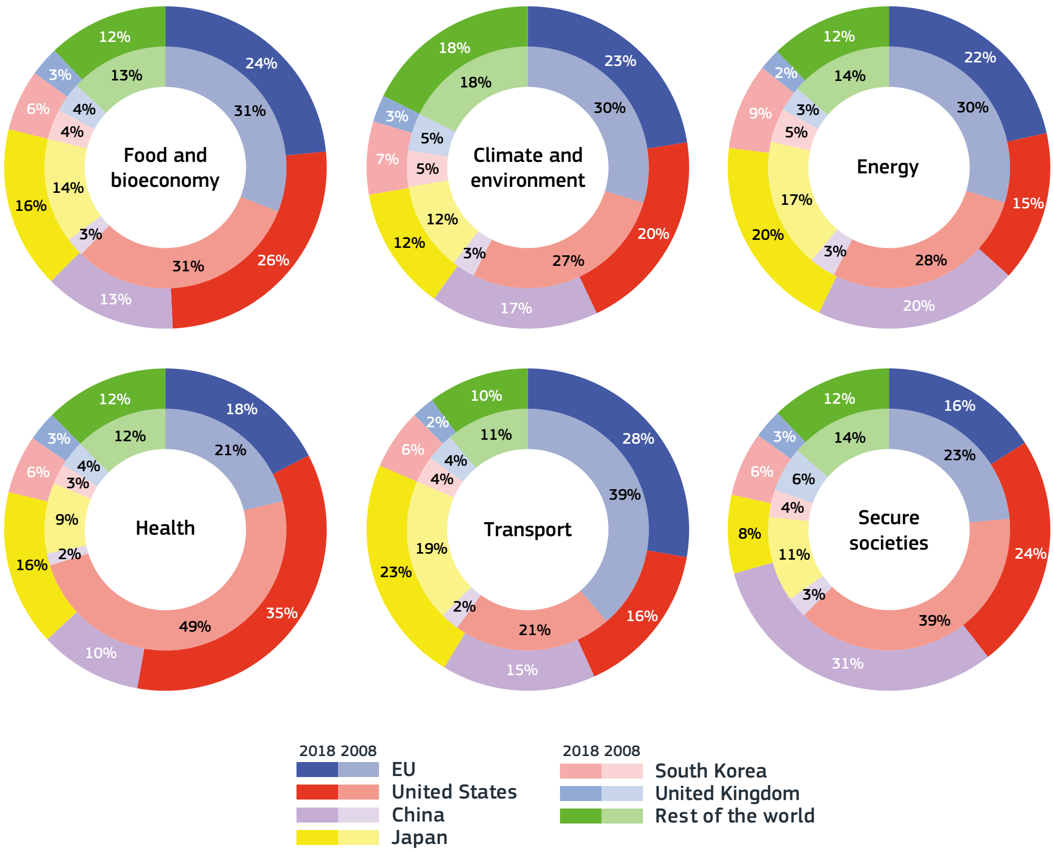
Notes: [1]PCT patents at the international phase designating the European Patent Office. Fractional counting, inventor's country of residence and priority date used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-14.xlsx

The EU remained the top worldwide patent applicant in the fields of climate & environment (23%), energy (22%) and transport (28%). However, the analysis per SGC, displayed in Figure 6.3-15, shows that the EU experienced significant losses in the world shares in all fields between 2008 and 2018. The biggest decline was in transport, with minus 11 percentage points (p.p.), despite an increase in the absolute number of patent applications over the same period. The US, while maintaining leadership in the fields of health and food & bioeconomy, followed the same pattern, with an even stronger decline, especially in security (-15 p.p.), health (-14 p.p.) and energy (-13 p.p.).

China increased its world share in all fields. However, unlike scientific production, where it leads in almost all fields, China only topped the rank in security, with an impressive increase of more than 28 p.p., from 3% in 2008 to 31% in 2018. China's performance also improved significantly in the energy sector, with an increase of more than 17 p.p. Japan, despite being weak in scientific production, stands out strongly in technology output, with important shares in the societal challenges of health, energy, and transport.

Figure 6.3-15: Share in the world (%) of patent applications filed under the PCT[1] by country/region and Horizon 2020 Societal Grand Challenge, 2018 (exterior) and 2008 (interior)

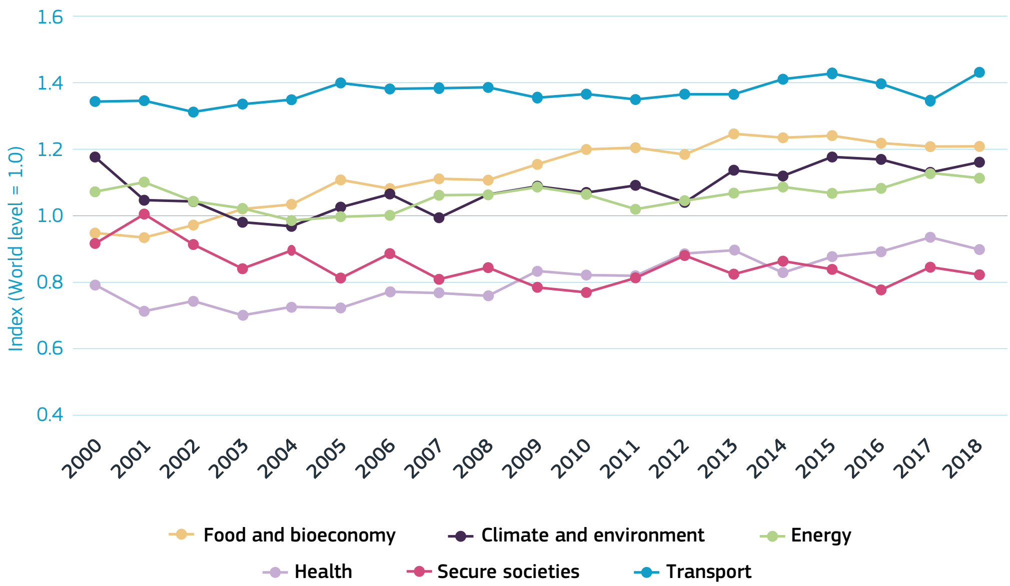


Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database

Notes: [1]PCT patents at the international phase designating the European Patent Office. Fractional counting, inventor's country of residence and priority date used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-15.xlsx

Figure 6.3-16: EU specialisation index[1] compared to the world by Horizon 2020 Societal Grand Challenge, 2000-2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database

Notes: [1]Specialisation refers to the intensity in the EU for a given societal challenge relative to the intensity in the world for the same societal challenge. Fractional counts and date of application used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-16.xlsx

Compared with the world, the EU is more specialised[8] in the fields of energy, climate and environment, food and bioeconomy and transport. These results might be explained by the very strong patent-intensity automotive sector in some Member States (such as Germany), as well as by some strong performance in renewables and energy-efficiency sectors (Hoogland et al., 2021). On the other hand, the EU is less specialised than the world in the fields of health and security.

Between 2000 and 2013, the EU improved substantially in food and bioeconomy, with a stagnation after that year. To a lesser extent, the EU became progressively more specialised in energy and climate and environment, especially since 2007, when the European Commission launched its Communication to limit climate change[9]. Compared with scientific publications, the EU appears to be stronger in the societal challenge of climate and environment, with both specialisation indexes above world level.

8 The Specialisation Index (SI) is an indicator of intensity in a given entity (e.g. Belgium) for a given area (e.g. health patents), relative to the intensity in a reference entity (e.g. the world or the entire output as measured by the database) for the same area. In other words, when a country is specialised in a given area, it places more emphasis, compared with the reference entity, on that area at the expense of others. An index value above 1 means that a given entity is specialised relative to the reference entity, whereas an index below 1 means the entity is not specialised. Specialisation is therefore said to be a zero-sum game: the more an entity specialises somewhere, the less it does elsewhere. To ensure that it is a real zero-sum game, the application or registration numbers used to compute the SI are based on fractional counting.

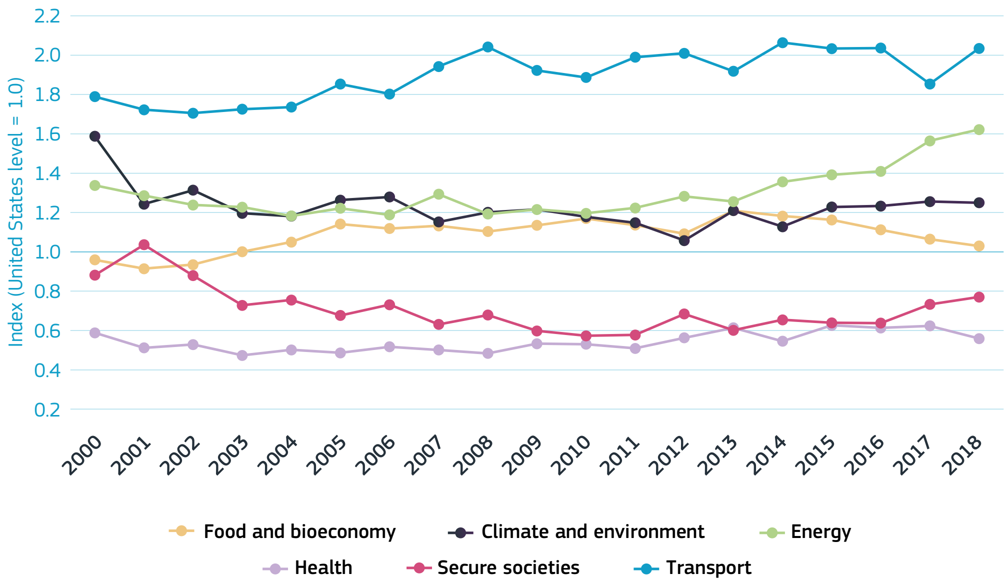
9 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - Limiting global climate change to 2 degrees Celsius - The way ahead for 2020 and beyond. EUR-Lex - 52007DC0002 - EN - EUR-Lex (europa.eu)

The EU is also more specialised in several challenges when compared with both the US and China. In particular, the EU is more specialised than the US in the challenges of energy, climate & environment, food & bioeconomy and transport (Figure 6.3-17). In addition to those, the EU is also more specialised than China in health (Figure 6.3-18). However, the EU is less specialised than both countries in the challenge of security. Over time, when compared with the US, and especially in the last years, the EU progressed in the field of energy, but lost ground in food & bioeconomy. Compared with China, energy and food & bioeconomy have been relatively stable, while secure societies and health have declined.

The EU holds a competitive advantage in health over China and in energy and climate & environment over the US. When combining the specialisation indexes of scientific publications (analysed in Chapter 6.1) with patent applications in health, the EU is more specialised than China in both cases. This gives the EU a competitive edge over China in that field. The same applies to the US for the fields of energy and climate & environment, in which the EU shows a competitive edge, as both specialisation indexes, in scientific production and patent applications, are significantly above 1.

Non-technological innovation is a major factor of competitiveness and productivity growth in the economy, notably in the service industries. However, the measurement of non-technological innovation and of innovation

Figure 6.3-17: EU specialisation index[1] compared with the United States by Horizon 2020 Societal Grand Challenge, 2000-2018

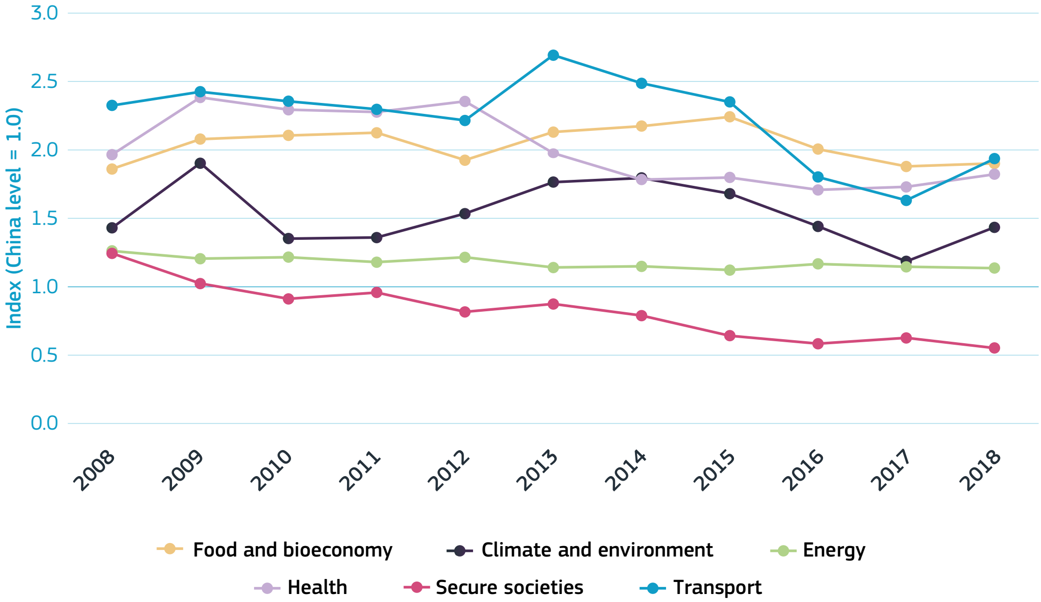


Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database

Notes: [1]Specialisation refers to the intensity in the EU for a given societal challenge relative to the intensity in the United States for the same societal challenge. Fractional counts and date of application used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-17.xlsx

Figure 6.3-18: EU specialisation index[(1)] compared with China by Horizon 2020 Societal Grand Challenge, 2008-2018



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Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database

Notes: [(1)]Specialisation refers to the intensity in the EU for a given societal challenge relative to the intensity in China for the same societal challenge. Fractional counts and date of application used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-18.xlsx

Read more in Chapter 13 – Part 2 on The green and digital twin transitions across EU regions *(Julie Delanote, Ludovica Massacesi, Désirée Rückert, Christoph Weiss, EIB)*

It is shown that the EU is a global leader for patenting activities at the crossroads of digital and green technologies. It also found that less developed and transition EU regions have a relatively high share of patents in green-digital technology domains: they hold fewer patents than more developed EU regions, but have a strong focus on green and digital innovation.

in the service industries is currently very poor, as traditional data sources like R&D or patents do not apply to these types of innovations (Millot, 2009). For this reason, data on other types of intellectual property rights such as trademark[10] and community design[11] applications can help assess non-technological innovation. In particular, trademarks constitute a rich and easily accessible data source; they are highly correlated with various innovation variables (patents, share of innovative sales); and they are present in almost every sector of the economy. Trademark data are then likely to convey information on two key (overlapping) aspects of innovation that are not well covered by traditional indicators: innovation in the service sectors and marketing innovation (Millot, 2009). In addition, trademark analysis can contribute in capturing relevant aspects of innovation phenomena and the process of industrial change (Mendonça et al., 2004); and trademarks for brand creation relate more often to product innovation (Flikkema et al., 2019). On the other hand, design innovation is a pillar of product differentiation, especially in crowded marketplaces (Sarlangue, 2021).

The innovation divide among EU Member States is less pronounced in trademarks and community design applications than in patent applications. Although the most innovative countries, like Denmark and Finland, are top performers in patent applications and also in trademarks and community designs, small countries like Malta, Cyprus, Estonia or Luxembourg tend to perform particularly well in one or both types (trademarks and community designs) of IPRs (Figures 6.3-19a and 6.3-20a). This might be due to the innovation capacity of firms in less technology-oriented sectors, favourable legislation, easy procedures and attractive taxation systems for IPR applications.

The relative importance of some sectors in the economy also plays a significant role. For example, high propensity sectors for trademarks like business services and advertisement have a substantial share in Luxembourg, while the gaming and software sectors are relevant in Malta. Comparing countries of similar size, Italy stands out with a good performance in both types of IP, primarily due to its strong fashion and alcoholic beverages sectors, for which both community designs and trademarks are important.

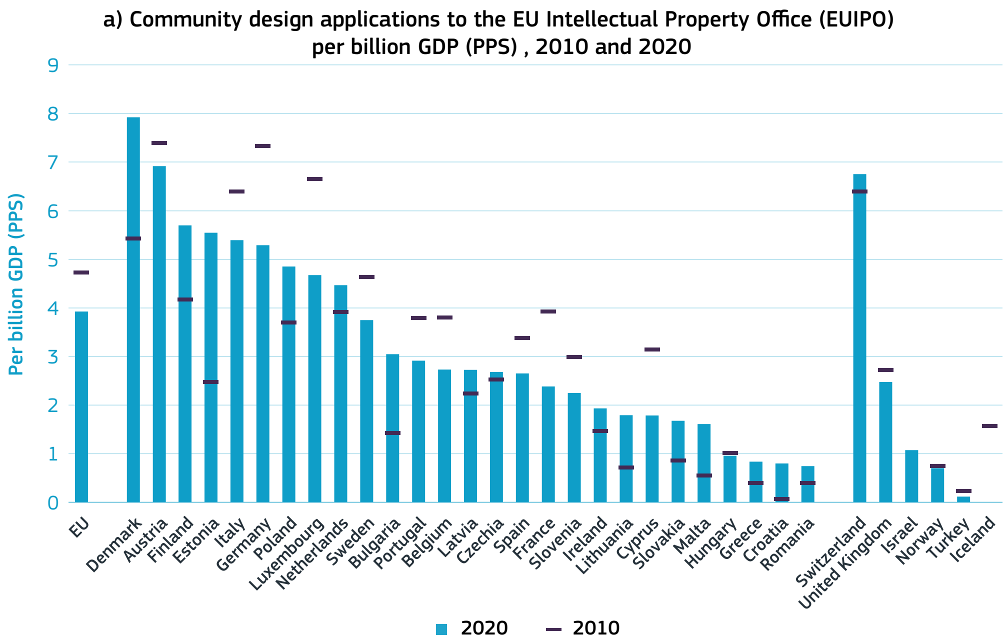
China is the top performer in both types of IP applications. Using data from the World Intellectual Property Office (WIPO), the EU comes third in terms of community designs, well behind China and South Korea. In terms of trademarks, the EU lags behind Japan and Canada. In contrast with patent applications, the EU performs better than the US in the two types of IP analysed (Figures 6.3-19b and 6.3-20b).

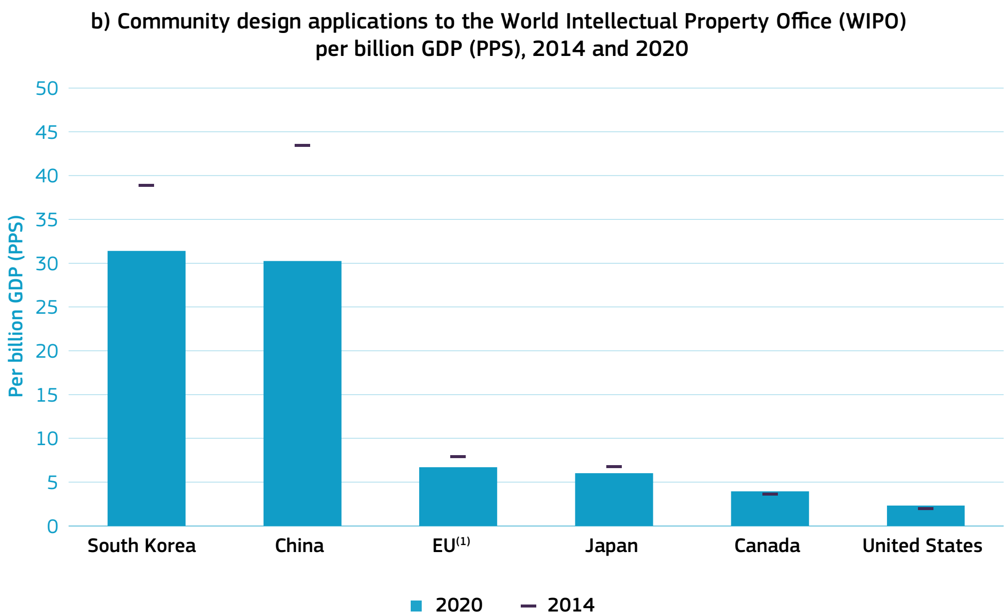
Over time, the EU improved in trademark applications, but declined in community designs. Most Member States reported an increase in their application intensities, especially for trademarks. Significant improvements were seen in Malta, Estonia and Cyprus for trademarks, and in Denmark and Estonia for community designs. China, despite showing a similar trend, reported a much larger degree of variation, with a big drop in community designs, but an impressive rise in trademarks – i.e. from an intensity similar to that of Canada and South Korea in 2014, to more than double this in 2020.

10 A trademark is a sign capable of distinguishing the goods or services of one enterprise from those of other enterprises. Trademarks can be words, pictures, stylised words, logos, a colour or colour combination, a shape, a sound or a combination of those signs. (source: WIPO)

11 A registered Community design (RCD) is an exclusive right that covers the outward appearance of a product or part of it. It covers the visual appearance of a product, part of a product and/or its ornamentation, i.e. a design covers the appearance of a product but cannot protect its functions, which fall under the regime of patent protection. (Source: EUIPO)

Figure 6.3-19a and 6.3-19b: Community design applications





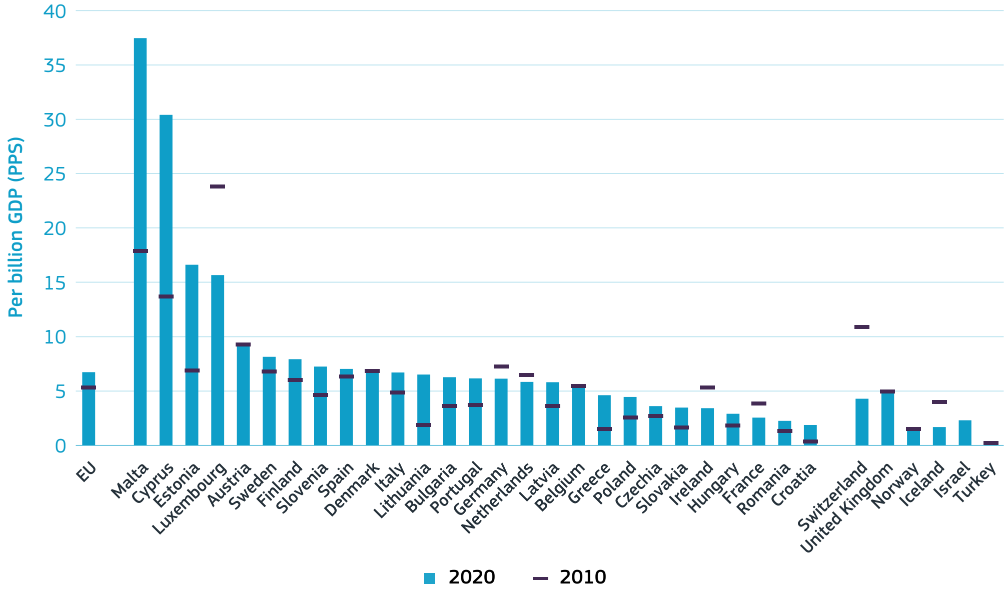
Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using data from EUIPO database, Eurostat, OECD and EIS 2021

Note: [(1)]Figures for international comparison come from the European Innovation Scoreboard 2021, which uses data from WIPO to avoid European bias.

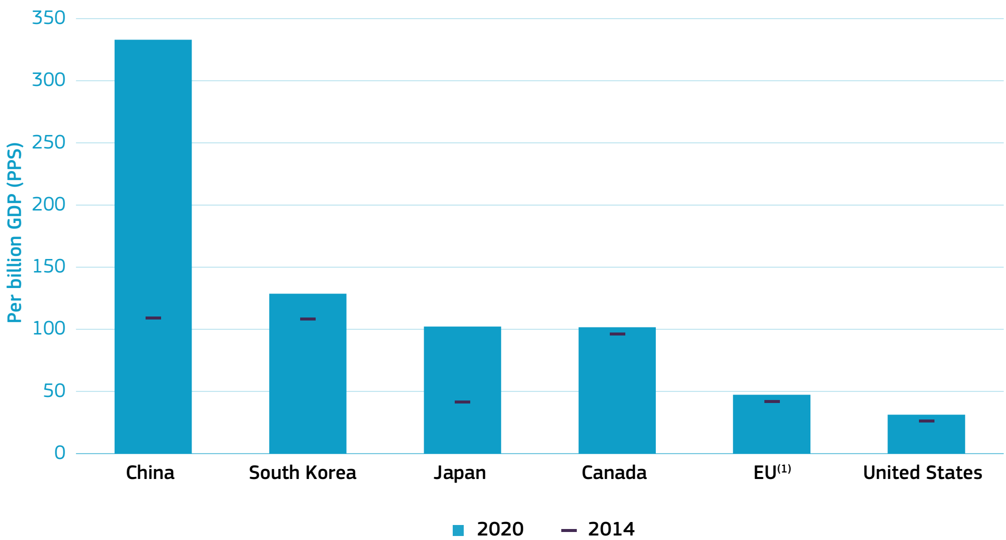
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-19.xlsx

Figure 6.3-20a and 6.3-20b: Trademark applications

a) Trademark applications to the EU Intellectual Property Office (EUIPO) per billion GDP (PPS), 2010 and 2020



b) Trademark applications to the World Intellectual Property Office (WIPO) per billion GDP (PPS), 2014 and 2020



Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using data from EUIPO database, Eurostat, OECD and EIS 2021

Note: (1)Figures for international comparison come from the European Innovation Scoreboard 2021, which uses data from WIPO to avoid European bias.

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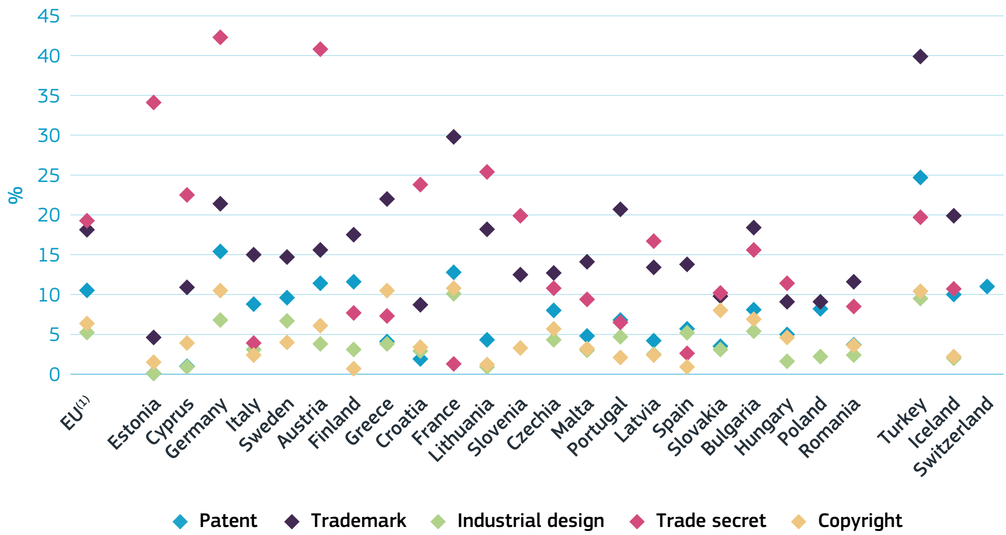
Figure 6.3-21: Share of innovative enterprises that applied for IPR, 2016-2018



Science, Research and Innovation Performance of the EU 2022

Source: Eurostat, Community Innovation Survey 2018 (online data code: inn_cis11_ipr)

Note: (1)EU value is calculated by DG Research and Innovation based on the availability of data per Member State.

Countries are ranked by their share of innovative enterprises.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-21.xlsx

Overall, trade secrets[12] and trademarks were the most commonly used IPR by innovative enterprises in the EU for the period 2016-2018. Based on the Community Innovation survey data, countries with the highest share of innovative firms (such as Estonia, Cyprus and Germany) are characterised by the largest use of trade secrets and trademarks (Figure 6.3-21). These findings might be explained by the fact that trade secrets and trademarks can be applied to both products/services and processes that are new to the market and new to the firm (Wajsman et al., 2017), thereby increasing the scope of these types of IP for innovation protection.

Regarding patent applications by innovative enterprises, Germany, France, Austria, and Finland have the highest values, with shares between 10% and 15%, in line with previous findings. Despite having the highest share of innovative enterprises, Estonia shows very low shares of these enterprises applying for IP other than trademarks. As mentioned before, differences in the dominant economic sector to which innovative companies belong and variations in IPR legislation can explain the variation across countries.

12 Trade secrets are intellectual property (IP) rights on confidential information which may be sold or licensed. In general, to qualify as a trade secret, the information must be: commercially valuable because it is secret; be known only to a limited group of persons; and be subject to reasonable steps taken by the rightful holder of the information to keep it secret, including the use of confidentiality agreements for business partners and employees. (Source: WIPO)

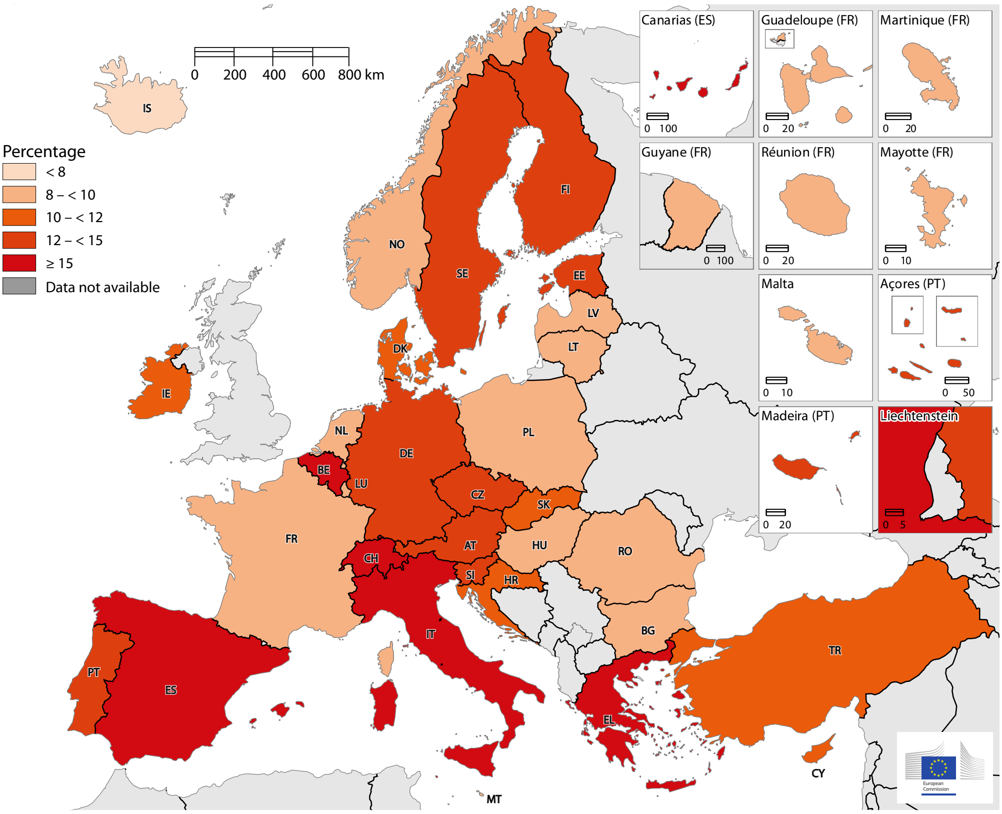
3. Economic impact of innovation

Innovation is a key driver of economic growth. The link between innovation and economic growth and the impact of innovation on productivity have been investigated by many economists and are analysed in chapter 4.1. Innovative products and processes tend to generate more output with the same input (i.e. increase productivity). As productivity rises, businesses profits rise, more goods and services are produced, wages increase, and consumers can buy more – in other words, the economy grows. However, in some cases, it has been noticed that large investments in innovation-related activities have generated little economic return in terms of new products, competitiveness, growth and employment (Edquist and McKelvey, 1998). Research on this phenomenon, known as the 'innovation paradox', suggests that the increasing dependence on a small number of large firms can negatively affect the long-term productivity potential of national economies (Fragkandreas, 2021). This section provides evidence on the economic impact of innovation in EU Member States and selected global competitors.

In 2018, the share of turnover from new or significantly improved products in the EU was 12.9 %, slightly higher compared with 2016 (+ 0.4 p.p.). The highest shares are recorded in southern European countries such as Greece (23 %), Italy (16.9 %) and Spain (16.1 %). Compared with the previous reporting period 2014-2016, 19 out of 27 Member States showed an increase in their shares. Greece achieved the largest improvement (7 p.p.), followed by Sweden (+ 5 p.p.) and Denmark (+ 5 p.p.). On the opposite side, Slovakia dropped by 9 p.p., and Ireland by 6.5. Luxembourg, a strong innovator according to the latest edition of the EIS, is ranked last in this indicator. Similarly, the Netherlands, despite its strong innovation system, ranks fourth.

The more innovative enterprises, the more the turnover from innovation. Figure 6.3-23 shows that the level of innovation of an economy, measured by the share of innovative enterprises, is positively correlated with the economic output of the innovation activities, measured by the share of turnover from innovation. Exceptions such as Spain, Romania and others (where the share of turnover from innovation corresponds to a low share of innovative enterprises) may indicate that innovation is performed mainly by a few large companies, while most SMEs do not innovate. The opposite trend (i.e., share of innovative enterprises corresponding to a relatively low share of turnover from innovation) observed, for example, in Estonia or Luxembourg, may be linked to the type of innovation and the economic sectors of the innovative enterprises.

Figure 6.3-22: Map of share (%) of turnover of innovative enterprises from new or significantly improved products(1), 2016-2018



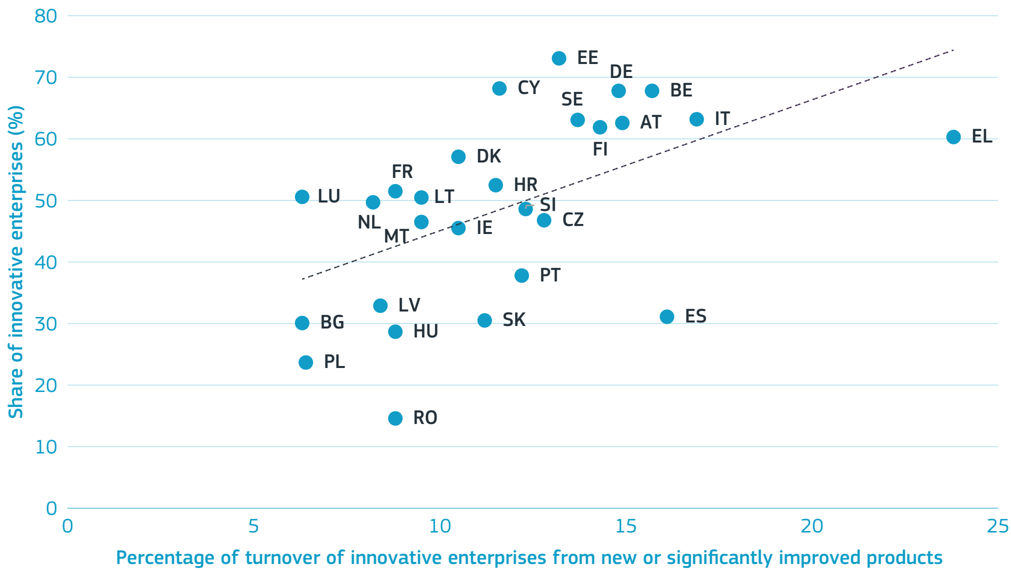
Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Eurostat - Community Innovation Survey 2018 (online data code: inn_cis11_prodt)

Note: (1)Total turnover of new or significantly improved products as a percentage of total turnover.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-22.xlsx

Figure 6.3-23: Share of innovative enterprises compared with percentage of turnover from innovation



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Eurostat - Community Innovation Survey 2018 (online data code: inn_cis11_prodt and inn_cis11_bas)
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-23.xlsx

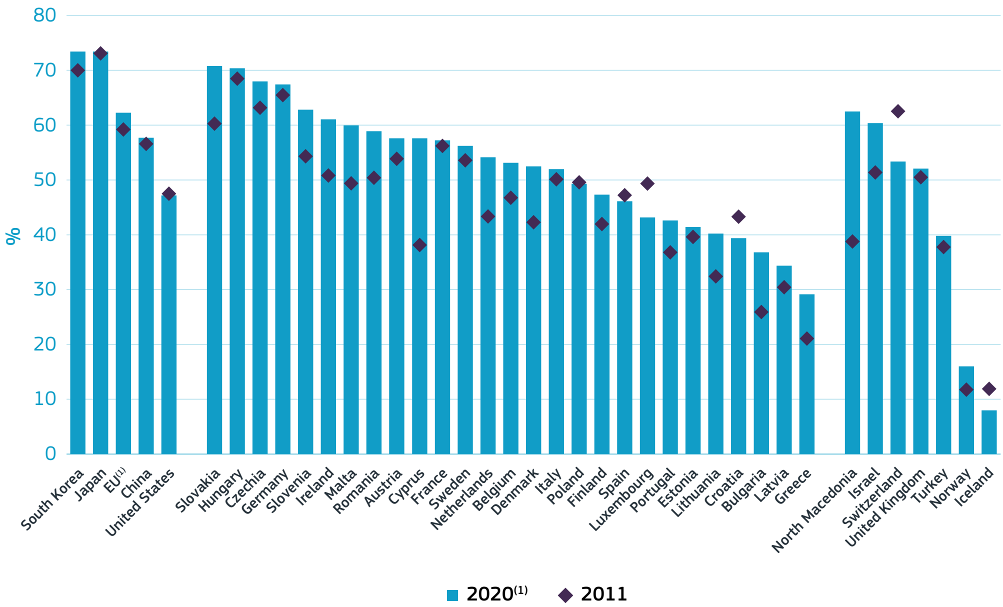
Scientific evidence shows that medium-and-high-technology products are positively associated with economic growth, productivity and welfare (Bello et al., 2022). The indicator on the exports of medium-and-high-technology products as a percentage of total product exports measures the technological competitiveness of a country, but also reflects the ability to commercialise the results of research and innovation products. On the other hand, the indicator on exports of knowledge-intensive services aims to capture the competitiveness of the services sector, by reflecting the ability of an economy to export services with high levels of value added and successfully take part in knowledge-intensive global value chains. Both indicators are part of the innovation output indicator.

In 2020, about 62 % of total EU exports concerned medium-and-high-technology products. The EU is third among its global competitors in the exports of medium-and-high-technology products as a percentage of total product exports (excluding intra-EU trade). Although the EU share has improved since 2011 by 3 p.p.[13], it has not reached the levels of Japan and South Korea, both leading with 73.4 % thanks to their strong ICT and automotive sectors. However, the EU remains ahead of the US and China.

13 The increase in MHT export share between 2011 and 2020 is mainly driven by an increase in the total value of MHT exports. No COVID-19 effect was detected.

Within the EU, Slovakia and Hungary report the highest share (both above 70%), followed by Czechia and Germany. The high performance of these countries, except for Germany, results mainly from the presence of foreign-affiliated companies in the automotive, machinery, and electrical and electronic equipment sectors, which jointly dominate their exports. Noteworthy are the increases in Cyprus, Bulgaria, the Netherlands, Slovakia, Malta, Ireland, and Denmark (with more than 10 p.p. since 2011). Another important finding is the stagnation in exports of medium-and-high-technology products as a percentage of total product exports for the major EU economies: Germany, France, Italy, and Spain.

Figure 6.3-24: Exports of medium-and-high-technology products as a % of total product exports, 2011 and 2020



Science, Research and Innovation Performance of the EU 2022

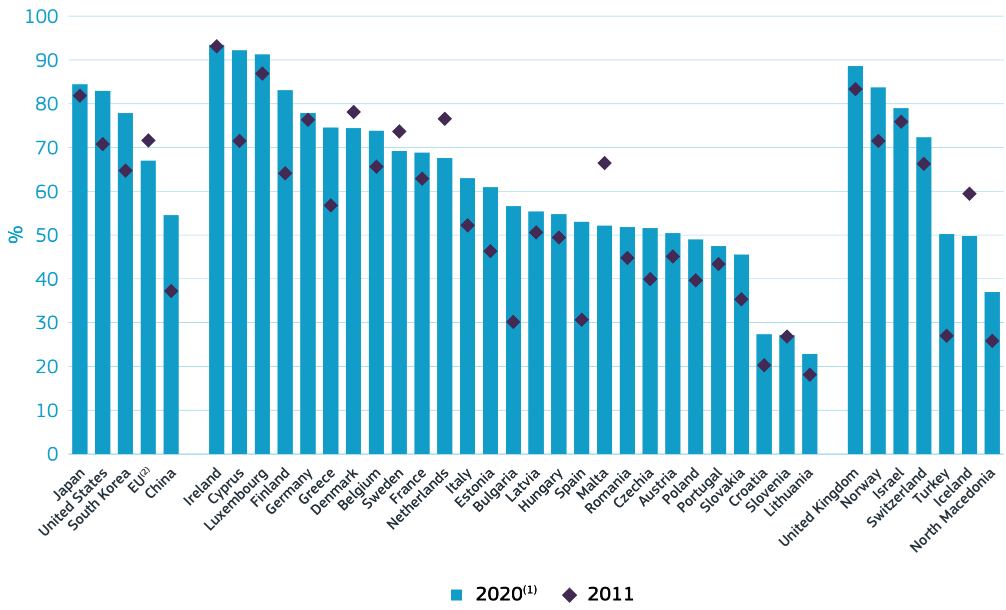
Source: European Commission, DG Joint Research Centre based on Eurostat, Comext 'DS-018995' and UN Comtrade (Bello, M. et al, 2022)

Note: (1)Two sets of values are available: for worldwide and for European comparison. The values for worldwide comparison are shown in the graph. The value for EU comparison for 2020 is 57.7%.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-24.xlsx

In 2020, 67 % of EU services exports were knowledge-intensive. Due to a decrease of 4.5 p.p. since 2011, the EU lost second position and fell behind Japan, the US and South Korea, but remained ahead of China. Interestingly, the better performance of the EU, when excluding intra-EU trade, indicates that the share of knowledge-intensive services exported outside the EU is proportionally larger than the share of knowledge-intensive services exported to EU Member States (Bello et al., 2022). The top-performing countries globally with shares between 89 % and 94 % are Ireland, Cyprus and Luxembourg, followed by the UK. Within the EU, all but four Member States (Malta, the Netherlands, Sweden, and Denmark) have increased their performance since 2011. The EU countries experiencing the largest increase are Bulgaria, Spain, and Cyprus. By contrast, the largest drop was observed in Malta.

Figure 6.3-25: Exports of knowledge-intensive services as a % of total service exports, 2011 and 2020



Science, Research and Innovation Performance of the EU 2022

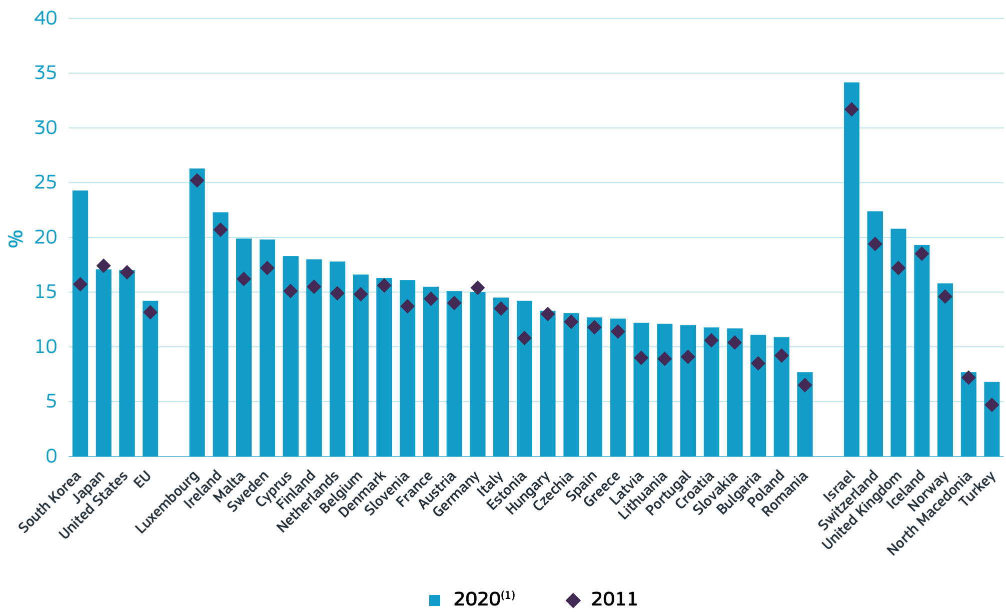
Source: European Commission, DG Joint Research Centre based on Eurostat (bop_its6_det), OECD (TISP_EBOPS2010) and ITC (Bello, M. et al, 2022)

Note: [1]IE, LU, IL, DK, IS, SI: year 2019. [2]Two sets of values are available: values for worldwide and for European comparison. The values for worldwide comparison are shown in the graph. The value for EU comparison for 2020 is 63.2 %.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-25.xlsx

The creation of jobs in knowledge-intensive activities remains a challenge for the EU. In 2020, employment in knowledge-intensive activities in business industries as a percentage of total employment was less than 15 %, well below South Korea, Japan and the US (Figure 2.3-26). Israel is the global leader, with 34 % of its employment in knowledge-intensive activities. Among EU Member States the top performers are Luxembourg (26.3 %) and Ireland (22.3 %). The EU average showed a small increase since 2011, reflecting the improvement in all Member States, except Germany (which recorded a slight decreasing trend). Malta and Estonia experienced the largest increases, with 3.7 p.p. and 3.4 p.p., respectively, followed by Cyprus, Latvia and Lithuania. The structure of the economy has a significant impact on this indicator. Countries with strong financial and/or ICT service sectors tend to perform better than the rest.

Figure 6.3-26: Employment in knowledge-intensive activities in business industries as a % of total employment, 2011 and 2020



Science, Research and Innovation Performance of the EU 2022

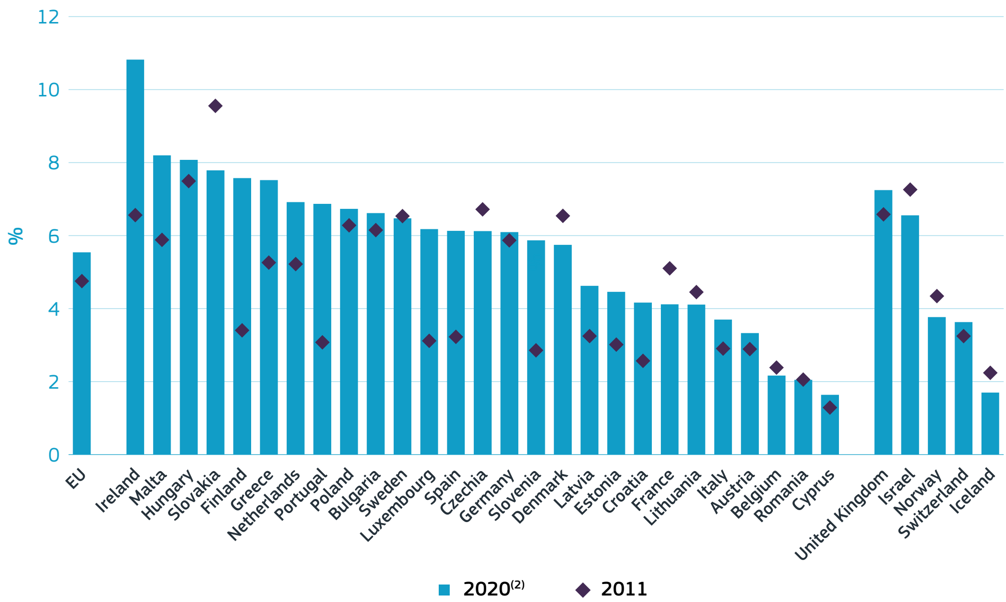
Source: European Commission, DG Joint Research Centre based on Eurostat (online data source: htec_kia_emp2) Japan Statistical Office, US BLS CBP and OECD (Bello, M. et al, 2022)

Note: [1]KR: year 2015. IL: year 2018.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-26.xlsx

Member States' capacity to rapidly transform their economies in response to new socio-economic needs varies significantly. The employment share in the fast-growing enterprises in innovative sectors is used as a proxy to measure this capacity. In 2019, Ireland was the top EU performer (10.8%), followed by Malta (8.2%) and Hungary (8.1%) (Figure 6.3-27). Looking at the evolution over the period 2011-2019, most EU countries improved their performances, leading to a 1 p.p. increase in the EU average. Ireland is again at the top of the ranking, reporting the highest growth over the period considered. Finland and Portugal follow. Conversely, the most significant drops are observed in Slovakia, France, Denmark, and Czechia. Interestingly, countries with strong innovation systems (according to the European Innovation Scoreboard) such as Belgium, Austria, and France score very low in this indicator, while countries experiencing strong economic changes (e.g., Eastern Member States, Ireland or Greece) have better scores and growth performance. This pattern may suggest that the indicator captures both the dynamism of the economy and the overall performance of innovative sectors (IOI).

Figure 6.3-27: Employment in fast-growing enterprises[1] in the top 50% most innovative sectors as a% of total employment, 2011 and 2020



Science, Research and Innovation Performance of the EU 2022

Source: European Commission, DG Joint Research Centre based on Eurostat (online data code: bd_9pm_r2)(Bello, M. et al, 2022)

Note: [1]Number of employees in high growth enterprises measured in employment (growth by 10% or more). [2]Data for 2020 were in some cases partly available. Thus, for calculating the composite indicator, missing data have been estimated by replicating the data of the closest available year, (Bello, M. et al, 2022).

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-27.xlsx

4. Knowledge valorisation

Knowledge valorisation is becoming increasingly important. In its latest Communication *A new ERA for Research and Innovation*[14], the European Commission calls for 'strengthening innovation ecosystems for knowledge circulation and valorisation' by developing and testing a 'networking framework in support of Europe's R&I ecosystems', as well as by updating and developing 'guiding principles for knowledge valorisation and a code of practice for the smart use of intellectual property'. Collaboration, mobility and further investment are identified as key aspects to achieve a strong system for knowledge creation and valorisation.

Knowledge valorisation encompasses several dimensions. In the literature, knowledge valorisation is a broader concept than innovation because the latter only refers to a successful introduction into the market. In contrast, knowledge valorisation also includes the often long lasting chain of processes that starts with first thoughts about market introduction and the research/development steps needed to reach this goal. There is also a broader conceptualisation of knowledge valorisation, namely as a complex and interactive process in which knowledge is made ready and available, and in which interaction between knowledge institutes and firms is crucial in all stages (Geenhuizen, 2010). Knowledge valorisation, the transfer of knowledge from R&D organisations to other parties envisaging the creation of social and economic value from it, is fundamentally driven by the fact that industrial economies need to change their development paradigm from one based on resources exploitation to a new one based on knowledge and innovation (Ala et al., 2014). In addition, a single focus on the economic dimension neglects other important impacts of research, such as the impact of knowledge on the general public and societal welfare (van de Burgwal, 2019).

Knowledge valorisation is sometimes confused with knowledge transfer. However, whereas knowledge transfer highlights the formal transfer of academic knowledge to parties in the commercial sector for economic benefit, knowledge valorisation takes a broader scope and looks at the creation of societal value from knowledge by translating research findings into innovative products, services, processes and/or business activities (van de Burgwal, 2019). As the European Commission's Expert Group defined it: 'Knowledge Transfer (KT) aims to maximise the two–way flow of technology, IP and ideas. In turn this enables companies (existing and new) or other non–academic organisations and the public sector, to drive innovation leading to economic and social benefit and enables publicly funded research organisations (PROs) to advance research and teaching.' (Campbell et al., 2020).

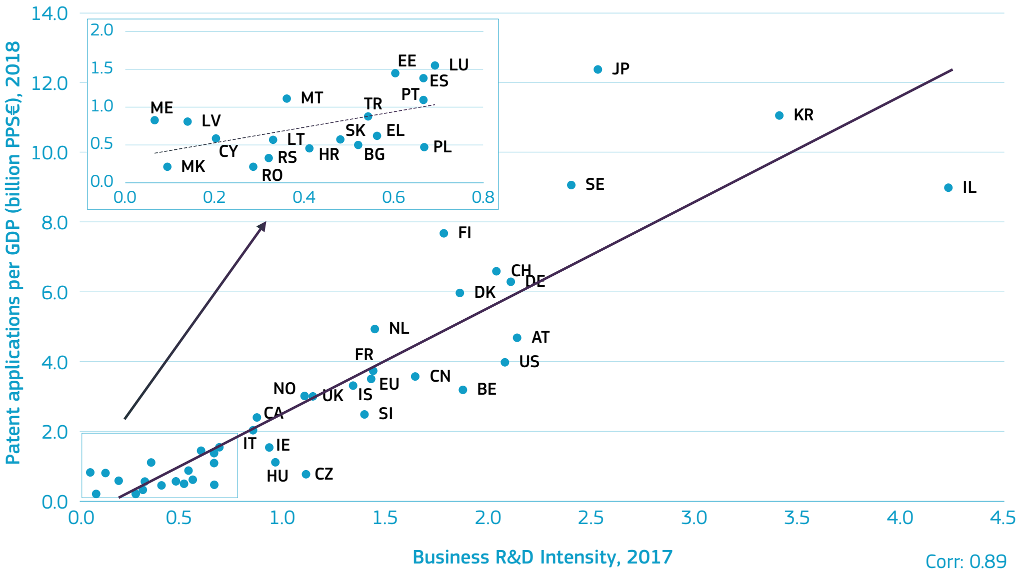
Countries with higher business expenditure in R&D tend to have higher patent applications. In 1942, Schumpeter indicated that R&D is an activity rewarded by the possession of a patent that generates profits for its owner. And in 1990, economist Paul Romer admitted that a patent is an instrument for encouraging R&D and the transfer of scientific knowledge.

14 COM(2020), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A new ERA for Research and Innovation. EUR-Lex - 52020DC0628 - EN - EUR-Lex (europa.eu)

In other words, by assuming business investment in R&D as knowledge input and patents as knowledge output, patents can be considered a return on investing in R&D (Mohnen, 2019). This suggestion is confirmed by the strong correlation between business R&D intensity and patent intensity (Figure 6.3-28). South Korea, and to a lower extent Switzerland, Germany and Denmark follow exactly the trend line, with both high levels of business expenditure in R&D and high levels of patent applications. On the lower side, a group of countries like Cyprus, Lithuania, and Turkey show both low levels of business expenditure in R&D and low levels of patent applications.

Japan, with relatively high patent intensity, seems to make the most out of its business investment in R&D. The same can be said for some EU countries like Finland, Sweden, and to some extent, Estonia. On the other hand, Israel seems unable to translate its relatively high business expenditure in R&D into more patent applications. The same situation is seen in EU countries like Czechia, Belgium, or Poland. Economic structure might be an important factor in explaining those results, with sectors with low patent propensity investing more in R&D, and vice-versa. The EU, with a similar level of patent intensity to that of China and the US, but lower business R&D intensity, seems to make more out of its business expenditure in R&D than those two

Figure 6.3-28: Patent applications filed under the PCT per billion GDP (in PPS€), 2018 and business R&D intensity, 2017

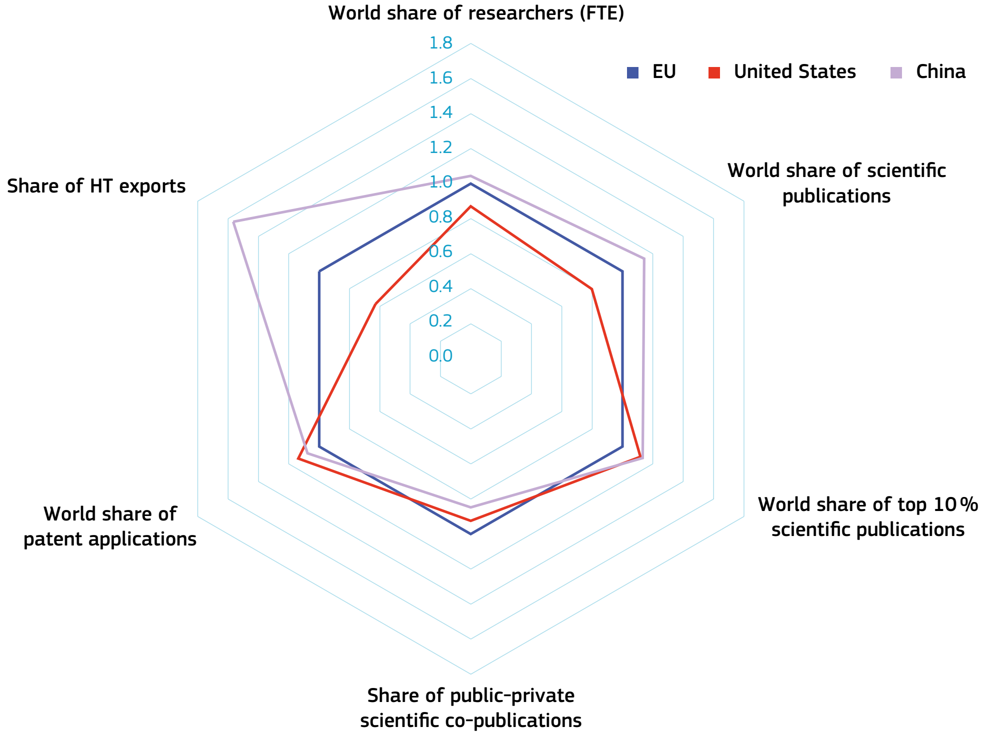


Science, Research and Innovation Performance of the EU 2022
Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using data from EPO PATSTAT database, Eurostat and UNESCO
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-28.xlsx

countries. Similarly, the relative importance of some sectors in the economy play a role. According to the latest Industrial R&D Investment Scoreboard[15], the top US R&D performers are companies in the ICT sector, while in the EU the top R&D performers are companies in the automotive and pharmaceutical sectors, which are patent intensive, but less R&D intensive.

More efforts are needed to bridge the gap between basic research, innovation and marketable solutions. When looking at Figure 6.3-29, even though the EU has a large qualified workforce and strong collaboration between academia and the business sector, the US and China outperform it in terms of patent applications. Equally worryingly, despite the enormous scientific production of the EU, especially in comparison with the US, its quality is proportionally lower than that of China and the US. In addition, the EU fails to excel in the share of high-tech exports, especially in comparison with China. If the EU wants to catch up and become more competitive internationally, it needs to promote a culture of knowledge valorisation in its R&I system, ensuring that knowledge-based institutions manage their intellectual capital effectively, and by improving the links between academia, industry, citizens, and policymakers.

Figure 6.3-29: Knowledge valorisation approach, latest available year



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using data from EPO PATSTAT and Scopus database, Eurostat, JRC, OECD and UNESCO

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-6-3-29.xlsx

15 European Commission (2021), The 2021 EU Industrial R&D Investment Scoreboard.

Read more in Chapter 15 – From Lab to Market: Evidence from Product Data
(Gaétan de Rassenfosse, EPFL)

'One key piece of information that scholars and analysts have been missing so far concerns how science translates into actual products'. Understanding how scientific results reach the market is essential to better understand the dynamics underpinning innovation ecosystems, and to provide more targeted policy instruments and incentive schemes.

The chapter investigates this issue, providing a method to trace ideas as they progress from the lab to consumers. The analysis provides interesting insights on the factors that facilitate technological transfers from academic level to full market deployment, with a focus on the European science landscape.

A strong valorisation policy relies on a toolbox of instruments that acknowledges different knowledge valorisation channels (European Commission, 2020). Many strategies, instruments and measures have been developed at European, national, and regional level by private and public players, to enhance knowledge transfer and valorisation. In the context of the 2021 consultation on the guiding principles for knowledge valorisation, stakeholders pointed out the need for an extended policy incorporating a new direction:

- Academia-industry connections and the interaction of innovative companies in different sectors provide key channels for knowledge diffusion and valorisation. The EU Framework Programmes and Member States support these collaborations through, for example, collaborative research or public-private partnerships. Digital solutions such as platforms provide new opportunities for industry cross-fertilization and for better linking the various actors in the innovation system. However, to maximise this collaboration, entrepreneurial practices, processes and skills need to be developed.
- Ensuring the valorisation of R&I-based knowledge assets is today a much broader activity based on co-creation between many actors, including local communities and citizens, in the socio-economic ecosystem. Without citizen engagement even the best-designed valorisation strategies and activities would not achieve the highest impact or support the economic, social and ecological transition in a way that includes all EU communities or regions.
- Intellectual property fosters innovation, creativity and knowledge sharing as the basis for progress, growth and employment. IP protection is a tool to balance the interests of both society and innovators. Nevertheless, the report contains recommendations for broadening the scope from management of intellectual property to intellectual asset management to cover results and products generated by R&I activities more broadly (e.g. publications, data, know-how, processes, practices, technologies, inventions, software etc.).

- A modern valorisation policy requires a change of focus from management of intellectual property in knowledge transfer activities, to knowledge valorisation and value-creation. It is vital to consider the broadest possible societal utilisation of intellectual assets generated by R&I activities and to include elements such as policy uptake, standardisation (see Box 2), tacit knowledge, social sciences, humanities and arts.

In addition, examining and sharing experiences and best practices of knowledge valorisation is a powerful way to improve national and European strategies. **The EU Knowledge Valorisation Platform[16] connects players across the EU, enabling them to share their knowledge and experiences** in putting excellent research results and data to practical use. The platform promotes cross-border peer learning and sharing of best practices. It provides a forum to stimulate cooperation across borders and sectors by involving all knowledge valorisation actors, from academia and industry to policy-makers and civil society. It enables the exchange of knowledge and expertise to support the design, implementation and evaluation of policies, investments and measures.

16 Stakeholder consultation on the guiding principles for knowledge valorisation – Report of the results https://ec.europa.eu/info/research-and-innovation/research-area/industrial-research-and-innovation/eu-valorisation-policy/knowledge-valorisation-platform_en

Box 6.3-2: The important role of standardisation

Standards help to bridge the gap between research and market and increase the probabilities of market uptake of technological innovations. Standardisation has an important role in R&I investment agendas as it helps pave the way for large-scale deployment of new and strategic technologies. Horizon Europe, the new Framework Programme for R&I for 2021-2027, will support valorising R&I results through standardisation to the highest possible extent.

As emphasised in the European Green Deal and in the New Industrial Strategy for Europe, developing new standards, coupled with increased EU participation in international standardisation bodies, is essential to boosting the competitiveness and resilience of European industry and to building a sustainable future. Standards will help to valorise and channel scientific discoveries and inventions to the green and digital transition and the EU's open strategic autonomy.

The EU Standardisation Strategy stresses the untapped potential of EU-funded pre-normative research in supporting future trends in standardisation, by allowing new technologies to create opportunities for our industries. The role of Horizon Europe is underlined as it entails a strong anticipation of standardisation needs and strong linkages between strategic priorities and pre-normative research.

The Commission is assessing how to better support researchers and innovators participating in EU-funded R&D&I projects take part in standardisation activities. It launched the Standardisation Booster, a platform to help beneficiaries – whose Horizon 2020 and Horizon Europe research results are likely to lead to the revision or creation of a standard – test the relevance of their results for standardisation. Engaging the research and innovation community early on in standards development also provides an opportunity to build expertise and skills in standardisation.

Today, researchers, spin-offs and start-ups often do not consider standardisation a priority: they are not always aware of the benefits of standardisation, they do not have the necessary resources or they consider that time spent on standardisation activities is not sufficiently rewarded. A consistent approach to facilitate standardisation activities and raise strategic awareness among researchers and innovators will be promoted by a dedicated European code of practice for researchers on standardisation.

5. Conclusions: innovation capacity in the EU is strong, but improvements are needed

Between 2020 and 2021, innovation performance, as measured by the European Innovation Scoreboard, improved for most Member States and the EU in general. Nevertheless, the performance gap between north-western and eastern and southern EU countries persists. Globally, despite improvements since 2014, the EU is still underperforming compared with South Korea, Canada, Australia, the US, and Japan, mainly due to low intellectual property applications and R&D expenditure by the business sector. Europe's insufficient patent intensity has been flagged by the innovation output indicator as the main reason for the EU falling behind Japan and the US.

Patent data are a useful tool to measure innovation performance. In 2018, around 80 % of patent applications filed under the PCT worldwide came from Japan, China, the EU and the US. Over time, China showed the largest increase, overtaking both the EU and Japan in 2017. If the trend continues, China will overtake the US in the coming years. In terms of patent applications per billion GDP, in 2018, Japan and South Korea toped the ranking, followed by the US, China and the EU. However, it is important to highlight that patenting is affected by structural factors such as the share of the manufacturing sector in the economy, or the technological intensity of the manufacturing and service sectors.

The innovation divide persists across Member States, with Germany accounting for more than 40 % of patent applications filed in the EU under the PCT in 2018. France came a distant second, with a share of 17 %, followed by Italy (8 %) and Sweden (7 %). In relative terms, northern and western EU countries like Sweden, Finland, and Germany perform very well, while southern and eastern EU countries like Romania, Croatia, and Poland perform poorly. In addition, in the 2008-2018 period, about half of the Member States reported a stagnation or decline in the share of patent applications per billion GDP. However, in terms of contributions to the EU total, eastern and southern EU Member States like Portugal, Italy, Spain, and Poland increased their share between 2000 and 2018, while countries like Germany, the Netherlands, Sweden, and Finland lost some ground.

The EU remained the top patent applicant in 2018 in the fields of climate & environment (23 %), energy (22 %) and transport (28 %) worldwide. However, the EU experienced significant losses in the world shares in all fields between 2008 and 2018. The US, while maintaining leadership in the fields of health and food & bioeconomy, followed the same pattern, with an even stronger decline. **China, on the other hand, increased its world share in all fields**, but unlike scientific production, where it leads in almost all fields, China only topped the ranking in security. Japan, despite being weak in scientific production, stood out strongly in technology output, with important shares in the societal challenges of health, energy, and transport.

The EU holds a competitive advantage in health over China, and in energy and climate & environment over the US. When combining the specialisation indexes of scientific publications with those of patent applications in health, the EU is more specialised than China in both cases. The same applies to the US for the fields of energy, and climate & environment, as both specialisation indexes, in scientific production and patent applications, are significantly above 1.

Non-technological innovation is a major factor of competitiveness and productivity growth in the economy, notably in the service industries. Data on other types of intellectual property rights, such as trademark and community design applications, can help assess non-technological innovation. The innovation divide among Member States is less pronounced in trademarks and community design applications than in patent applications. Small countries like Malta, Cyprus, Estonia, and Luxembourg perform particularly well in both trademark and community designs applications. Over time, most Member States reported an increase in their applications intensities, especially for trademarks.

The share of EU companies engaging in innovation activities increased to 50% in 2018, but the discrepancies between Member States are significant. Innovation is particularly important for large companies, as almost 80% of them reported innovation activities. In the EU, large companies are driving product innovations, as one in three in-house product innovators with market novelties belong to this category (250 or more employees). This represents about 4% of the total number of enterprises. For SMEs, important hampering factors to innovation are high costs, lack of internal finance and lack of qualified employees. However, the impact of these factors varies significantly across Member States (Community Innovation Survey, 2018).

The EU remains one of the key global manufacturers of medium-and-high-technology products, behind South Korea and Japan. In 2020, these represented about 62% of total EU exports (excluding intra-EU trade). The EU performs less well in exports of knowledge-intensive services. With 67% in 2020 and a gap of about 15 p.p. with the top scorer, the EU ranks behind Japan, the US, and South Korea. However, regarding patent applications, the EU applies for proportionally more patents in the medium and low-tech sectors; while China and the US apply for proportionally more patents in the high-tech sectors in knowledge-intensive services.

More efforts are needed to bridge the gap between research, innovation and marketable solutions. Although the EU has a large, qualified workforce and strong collaboration between academia and business, the US and China outperform it in patent applications. If the EU wants to become more competitive internationally, it needs to promote a culture of knowledge valorisation in its R&I system, ensure that knowledge-based institutions manage their intellectual capital effectively, and improve the links between academia, industry, citizens and policy-makers.

A modern policy requires a change of focus from managing intellectual property in knowledge transfer activities, to knowledge valorisation and value creation. It entails broadening the scope from intellectual property management to intellectual asset management, to cover more results or products generated by R&I. Furthermore, it needs to address all ecosystem actors involved in R&I activities, including local communities and citizens. Finally, it must develop an entrepreneurial mindset with its practices, processes and skills.

References

Ala, Soraia, Pedro Vilarinho, and COTEC PORTUGAL (2014), 'Knowledge valorization and the European Paradox: a case study', *Recent Advances in Applied Economics: 6th International Conference on Applied Economics, Business and Development (AEBD'14). Eds. Mastorakis, Nikos E., Panos M. Pardalos and Michael N. Katehakis. Lisbon: WSEAS Press.*

Alan C. Marco (2007), 'The dynamics of patent citations', *Economics Letters*, Volume 94, Issue 2, pp. 290-296, ISSN 0165-1765. https://doi.org/10.1016/j.econlet.2006.08.014

Bello, M., Caperna, G., Damioli, G. and Mathevet, I. (2022), *Innovation Output Indicator 2021*, Publications Office of the European Union, Luxembourg, JRC129410, Forthcoming.

Campbell, A., Cavalade, C., Haunold, C., Karanikic, P. and Piccaluga, A. (2020), *Knowledge Transfer Metrics - Towards a European-wide set of harmonised indicators*, Karlsson Dinnetz, M. editor(s), EUR 30218 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-18885-8 (online), doi:10.2760/907762 (online), JRC120716.

Campbell, D. (2021), *Policy brief D, Framework Programme contribution to knowledge transfer between the public and private sectors (in the form of co-publications and citation of publications in patents)*, European Commission, Directorate-General for Research and Innovation. https://data.europa.eu/doi/10.2777/193111

Edquist, C. and Mckelvey, M.D. (1998), *High R&D intensity without high tech products: a Swedish paradox? In: Institutions and economic change*. Cheltenham: Edward Elgar.

Emmanuelle Sarlangue (2021), 'Registered Community designs in the video game industry: a neglected yet potent tool', *Interactive Entertainment Law Review*, pp. 87-101, doi: 10.4337/ielr.2021.0002.

EPO and EIPO (2019), *IPR-intensive industries and economic performance in the European Union*, ISBN: 978-3-89605-235-3.

European Commission (2021)*, European Innovation Scoreboard 2021*, Publication Office of the European Union, ISSN 2467-4427. https://data.europa.eu/doi/10.2873/340166

European Commission, Directorate-General for Research and Innovation (2020), *Research & innovation valorisation channels and tools: boosting the transformation of knowledge into new sustainable solutions*, Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2777/480584

Fragkandreas, Th. (2021), *Innovation-Productivity Paradox: Implications for Regional Policy*, Background paper for the OECD-EC High-Level Expert Workshop series "Productivity Policy for Places", March 3 and 5.

Geenhuizen, Marina (2010), *Valorisation of knowledge: preliminary results on valorisation paths and obstacles in bringing university knowledge to market,* The Eighteenth Annual High Technology Small Firms Conference, University of Twente, Enschede, the Netherlands, May 27-28 2010.

Hoogland, O., Torres, P., Janzow, N., et al., (2021), *Patents as a measure of innovation performance : selection and assessment of patent indicators : provision of technical assistance and study to support the development of a composite indicator to track clean-energy innovation performance of EU members*, European Commission, Directorate-General for Research and Innovation, Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2777/77424

Juan Alcácer, Michelle (2006), 'Gittelman; Patent Citations as a Measure of Knowledge Flows: The Influence of Examiner Citations', *The Review of Economics and Statistics*, 88 (4), pp. 774–779. doi: https://doi.org/10.1162/rest.88.4.774

Meindert Flikkema, Carolina Castaldi, Ard-Pieter de Man, Marcel Seip (2019), 'Trademarks' relatedness to product and service innovation: A branding strategy approach', *Research Policy*, Volume 48, Issue 6, pp. 1340-1353, ISSN 0048-7333. https://doi.org/10.1016/j.respol.2019.01.018

Millot, V. (2009), *Trademarks as an Indicator of Product and Marketing Innovations*, OECD Science, Technology and Industry Working Papers, No. 2009/06, OECD Publishing, Paris. https://doi.org/10.1787/224428874418

Mohnen, Pierre (2019), 'R&D, innovation and productivity', *The Palgrave handbook of economic performance analysis*, pp. 97-122.

OECD/Eurostat (2018), *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition, The Measurement of Scientific, Technological and Innovation Activities*, OECD Publishing, Paris/ Eurostat, Luxembourg. https://doi.org/10.1787/9789264304604-en

Ramzi, Trabelsi, Kallal Rahim, and Maher Skhiri (2022), 'Scientific Knowledge Valorization in the Public R&D Sector: a Survey and a PLS-SEM Approach', *Journal of the Knowledge Economy*, pp. 1-29.

Romer, Paul M. (1990), 'Endogenous technological change', *Journal of political Economy* 98.5, Part 2, pp. S71-S102.

Sandro Mendonça, Tiago Santos Pereira, Manuel Mira Godinho (2004), 'Trademarks as an indicator of innovation and industrial change', *Research Policy*, Volume 33, Issue 9, pp. 1385-1404, ISSN 0048-7333. https://doi.org/10.1016/j.respol.2004.09.005.

Schumpeter, Joseph (1942), 'Capitalisme, socialisme et démocratie', *Première traduction française publiée en*, Paris.

Van de Burgwal, Linda HM, Ana Dias, and Eric Claassen (2019), 'Incentives for knowledge valorisation: a European benchmark', *The Journal of Technology Transfer* 44.1, pp. 1-20.

Wajsman, Nathan, and Francisco García-Valero (2017), *Protecting innovation through trade secrets and patents: Determinants for European Union firms*, European Union Intellectual Property Office.

WIPO (2021), *Global Innovation Index 2021: Tracking Innovation through the COVID-19 Crisis*. Geneva: World Intellectual Property Organization.