CHAPTER 6.1

SCIENTIFIC PERFORMANCE

KEY FIGURES

21 %
EU's share of global scientific publications

21 %
EU's share of the top 1% highly cited scientific publications

60 000
EU publications contributing to or using machine-based learning activities

27 %
EU's share of highly cited scientific publications on food and bioeconomy

What can we learn?

- The **EU and China are the global leaders in terms of scientific output**, while the United States retains its lead in terms of scientific quality. **Output from Chinese researchers has risen exponentially** in the last two decades to almost match the EU.
- Within the EU, there is a **diversity of research intensities** and a **positive correlation between scientific quality and investments** in most countries.
- **Digitalisation is transforming science**. All areas of research are becoming data-intensive, increasingly relying upon and generating big data.
- **Science is key in addressing societal challenges**. The EU is leading in high-quality scientific publications in the food/bioeconomy and climate/environment sectors, while China is increasing exponentially across sectors, and the United States is losing its overall leadership.

What does it mean for policy?

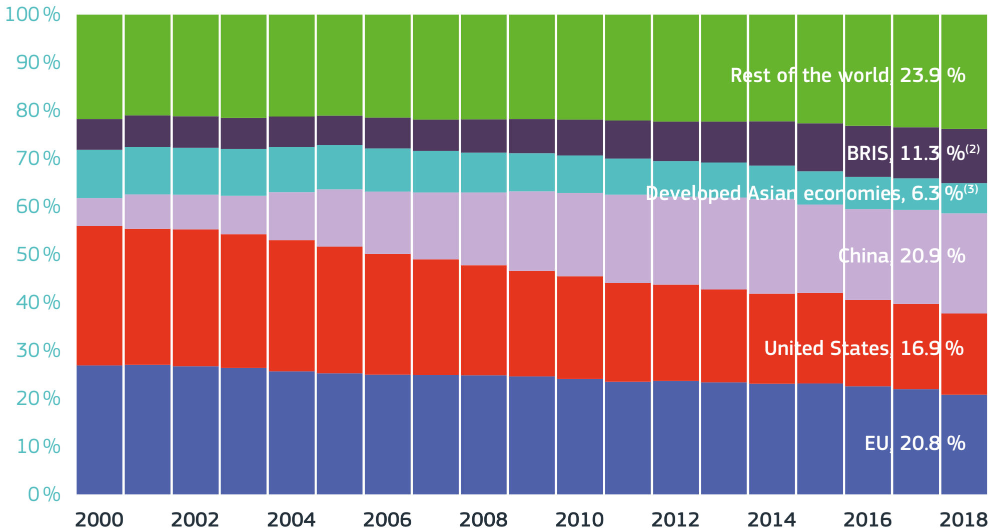
- To remain a leading global scientific player, the EU and its Member States must **strengthen their efforts to increase the effectiveness and performance of their public research systems** through stronger R&I investments and policy reforms.
- To **exploit the full potential of science digitalisation**, policies must be adapted to reinforce researchers' digital skills, promote open science as well as to ensure the necessary investment in high-quality data infrastructures.
- As science is key in addressing societal challenges, the EU must not only ensure scientific leadership in key areas but must also **foster interdisciplinarity research** that is necessary to successfully deliver on the SDGs.

1. The EU and China are global leaders in terms of scientific output, while the United States retains the lead in scientific quality

Jointly with China, the EU remains in the leading position in terms of the share of scientific output worldwide, while the US' share has continued to shrink. With 7 % of the world population, the EU is responsible for 20 % of global R&D expenditure and 21 % of scientific publications worldwide. However, with the United Kingdom leaving the EU, the EU's share declined from 30 % in 2000 to 21 % in 2018 (see Figure 6.1-1)[1].

China has established itself as a major scientific player and a competitor in high-tech sectors. The country's world share of scientific publications rose exponentially from 5.8 % in 2000 to 20.9 % in 2018 (see Figure 6.1.2), showing China's leadership in the global ranking, jointly with the EU (without the UK). Moreover, China's share of world R&D expenditure has increased from 5 % in 2000 to more than 20 % today, which means that its R&D intensity has already overtaken that of the EU (European Commission, 2019a: 59).

Figure 6.1-1 World share of scientific publications[(1)], 2000 and 2018



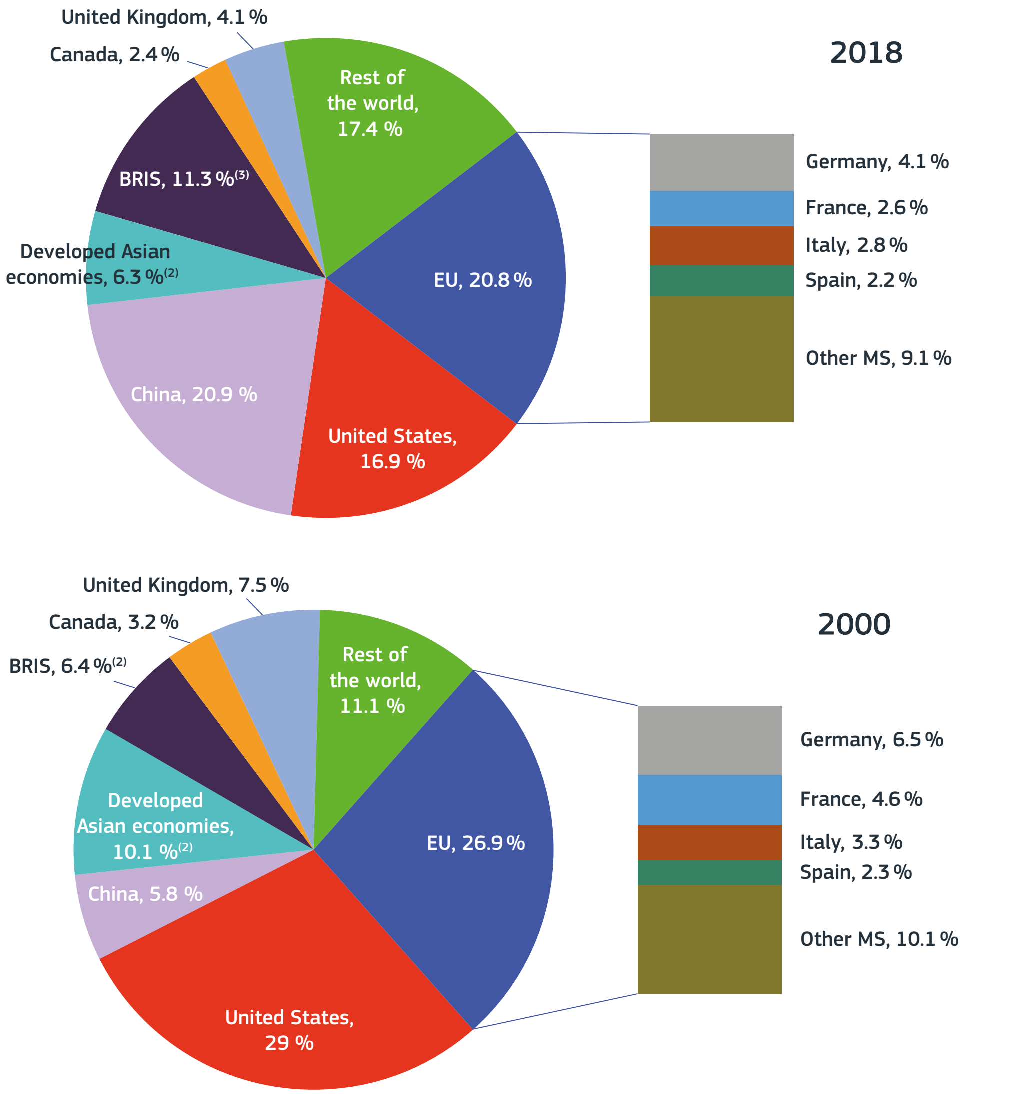
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: [(1)]Data produced by Science-Metrix based on Scopus database. Fractional counting method used. [(2)]BRIS includes Brazil, Russian Federation, India and South Africa. [(3)]Developed Asia economies includes Japan and South Korea. [(4)]Figures correspond to the latest year, 2018.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-1.xlsx

1 One way to analyse the scientific performance of countries and regions is to look at the number of scientific publications published by the researchers based there. However, the rise of international collaboration over the last 20 years needs to be taken into account as a high proportion of scientific publications now have authors in more than one country.

Figure 6.1-2 World share of scientific publications[1] %, 2000 and 2018



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: (1)Data produced by Science-Metrix based on Scopus database. Fractional counting method used. (2)Developed Asia economies includes Japan and South Korea. (3)BRIS includes Brazil, Russian Federation, India and South Africa.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-2.xlsx

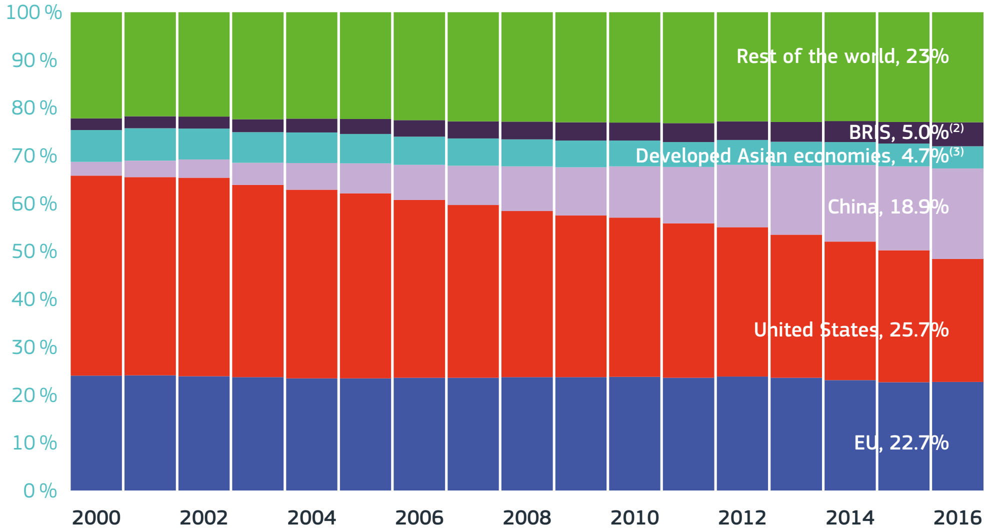
Simultaneously, the US' world share of scientific publications fell from 29 % in 2000 to 16.9% in 2018. This decline positions the US behind the EU, whose share fell from 26.9% in 2000 to 20.8 % in 2018 (both figures calculated without the UK). During the same period, BRIS countries[2] were able to increase their share from 6.4% to 11.3%.

2 Brazil, Russia, India and South Africa.

Within the EU, all of the countries with the highest number of scientific publications have seen their world share shrink. From 2000 to 2018, Germany dropped from 6.5 % to 4.1 %, France from 4.6 % to 2.6 %, Italy from 3.3 % to 2.8 %, and Spain from 2.3 % to 2.2 %. The UK's share dropped from 7.5 % to 4.1 %.

The United States maintains its global leadership in terms of highly cited scientific publications, although it has seen a dramatic decline in its share. Europe remains in second place, while China continues its sharp rise. At 22.7 %, the EU has also maintained its high global share in terms of the top 10 % highly cited publications[3] (Figure 6.1-3). However, the respective output from the Chinese science system has grown exponentially – from 2.9 % in 2000 to 18.9 % in 2016 – and is coming closer to the output from the EU and US systems. In the latter, the share of the top 10 % highly cited publications fell dramatically from 41.8 % in 2000 to 25.7 % in 2016, significantly closing the gap between the United States and the EU. Moreover, the average quality of China's publications is improving (European Commission, 2019a: 60).

Figure 6.1-3 World share of top 10 % highly cited scientific publications(1), 2000 (citation window: 2000-2002) and 2016 (citation window: 2016-2018)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

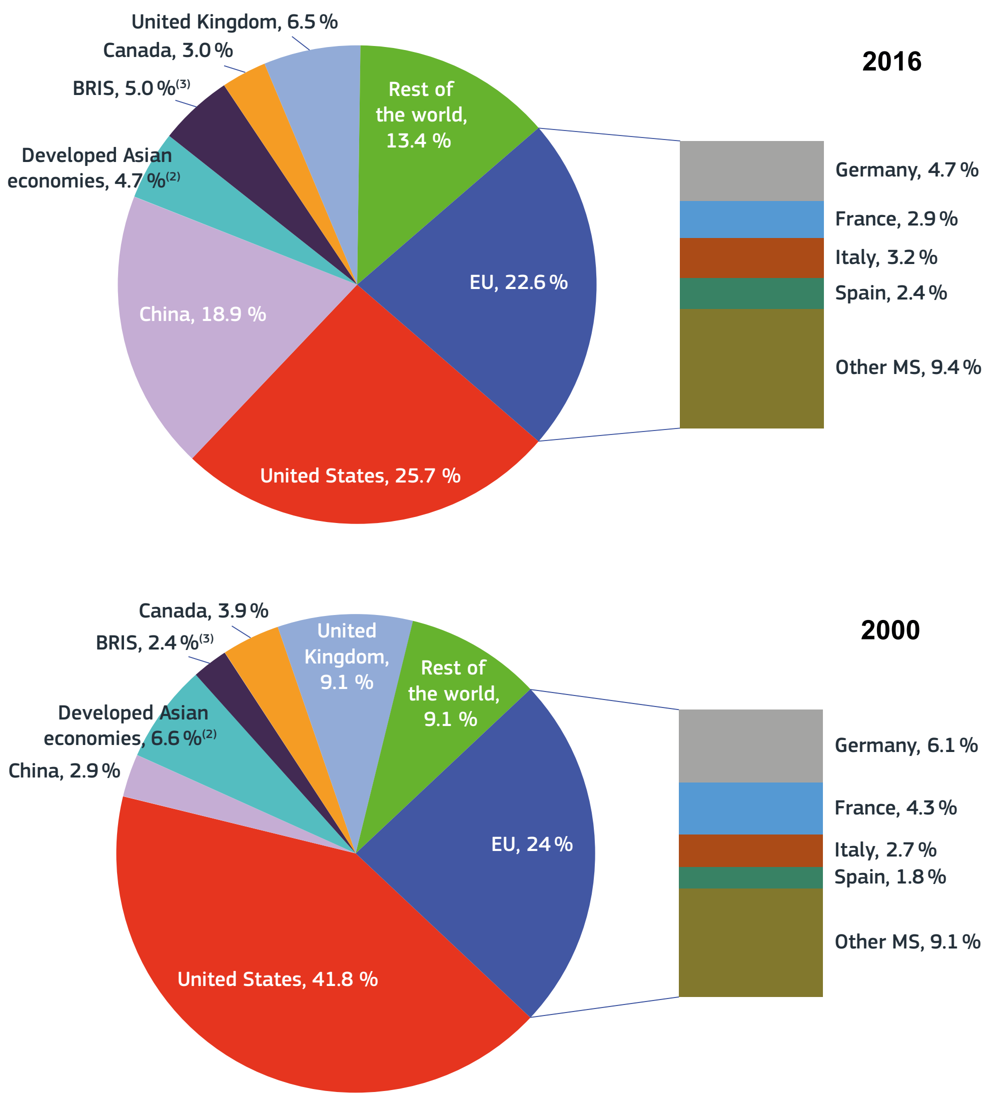
Note: (1)Data produced by Science-Metrix based on Scopus database. Scientific publications within the 10 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. (2)BRIS includes Brazil, Russian Federation, India and South Africa. (3)Developed Asia economies includes Japan and South Korea. (4)Figures correspond to the latest year, 2018.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-3.xlsx

3 In terms of quality, the number of times a publication is cited by other publications is seen as a useful proxy for the impact of that publication. The number of citations publications receive leans very heavily towards the most important or interesting findings. The top 1 % of highly cited papers receive around 25 % of all citations while a significant proportion of papers are not cited at all. International co-publications also tend to be more highly cited.

While the world share of 10% highly cited scientific publications dropped in most EU countries between 2000 and 2016, Spain saw an increase from 1.8% to 2.4% (Figure 6.1-4).

Figure 6.1-4 World share of top 10% highly cited scientific publications[1], 2000 (citation window: 2000-2002) and 2016 (citation window: 2016-2018)



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: [1]Data produced by Science-Metrix based on Scopus database. Scientific publications within the 10 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. [2]Developed Asia economies includes Japan and South Korea. [3]BRIS includes Brazil, Russian Federation, India and South Africa.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-4.xlsx

With 21.2 % in 2000 and 20.9 % in 2016, the EU is maintaining its world share of the top 1 % highly cited scientific publications at an almost constant rate. Once again, as with the other indicators, China's increase in this category is exponential, rising from 1.9 % in 2000 to 17.5 % in 2016. On the other hand, while still the leading country, the US's share is in decline, falling from 48.8 % in 2000 to 31.3 % in 2016. During this period, there was no significant change in the share of BRIS countries and developed Asian economies.

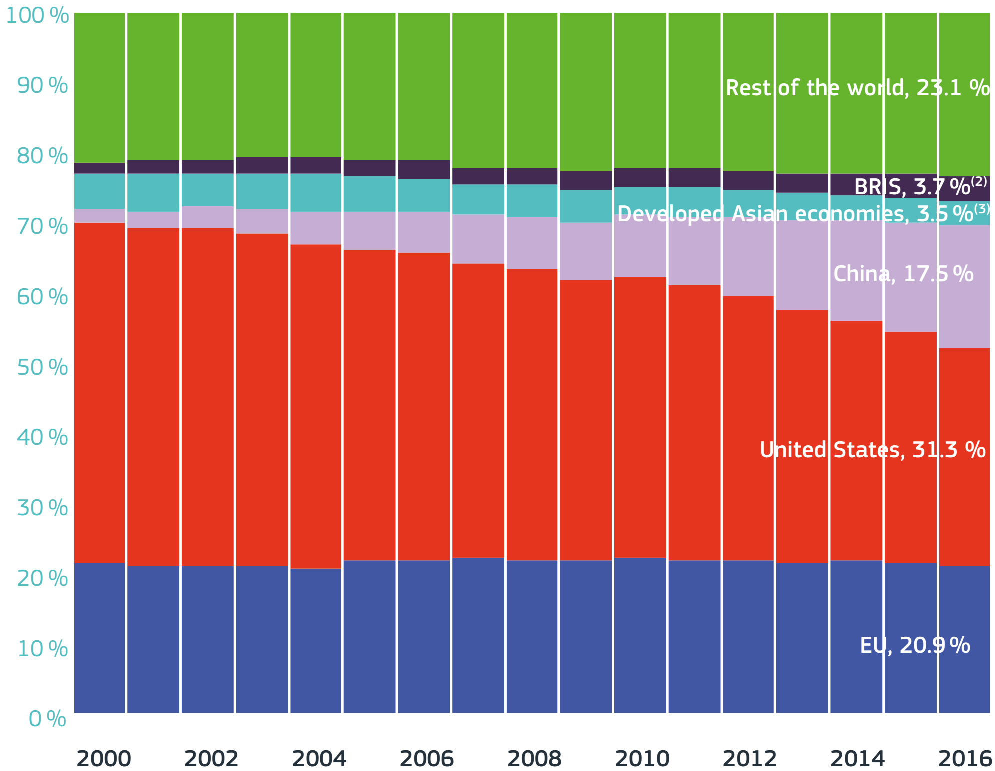
BOX 6.1-1 The European Research Council – facts and figures

The European Research Council (ERC) – the first pan-European funding body for frontier research – was set up in 2007 under the EU's Seventh Framework Programme for Research (FP7, 2007-2013). The total budget allocated to the ERC for the period 2014-2020 is EUR 13.1 billion.

- The ERC represents **17 % of the overall Horizon 2020 budget** (EUR 13.1 billion of EUR 77 billion).
- Since 2007, some **9 000 projects** have been selected for funding from more than **65 000 applications**.
- ERC grantees have won prestigious prizes, including **six Nobel Prizes**, four Fields Medals, and five Wolf Prizes.
- At the end of 2015, there were over **40 000 articles** acknowledging ERC support in international, peer-reviewed journals.
- Each ERC grantee employs on average **six team members**, thereby contributing to train **a new generation of excellent researchers**. Currently, over 50 000 postdocs, PhD students and other staff are working in their research teams.
- More than 70 % of projects assessed by an independent study made **scientific breakthroughs or major advances**, whilst around 25 % of them made incremental contributions.

Source: https://erc.europa.eu/projects-figures/facts-and-figures, accessed: 30 October 2019

Figure 6.1-5 World share of top 1% highly cited scientific publications[1], 2000 (citation window: 2000-2002) and 2016 (citation window: 2016-2018)



Science, research and innovation performance of the EU 2020

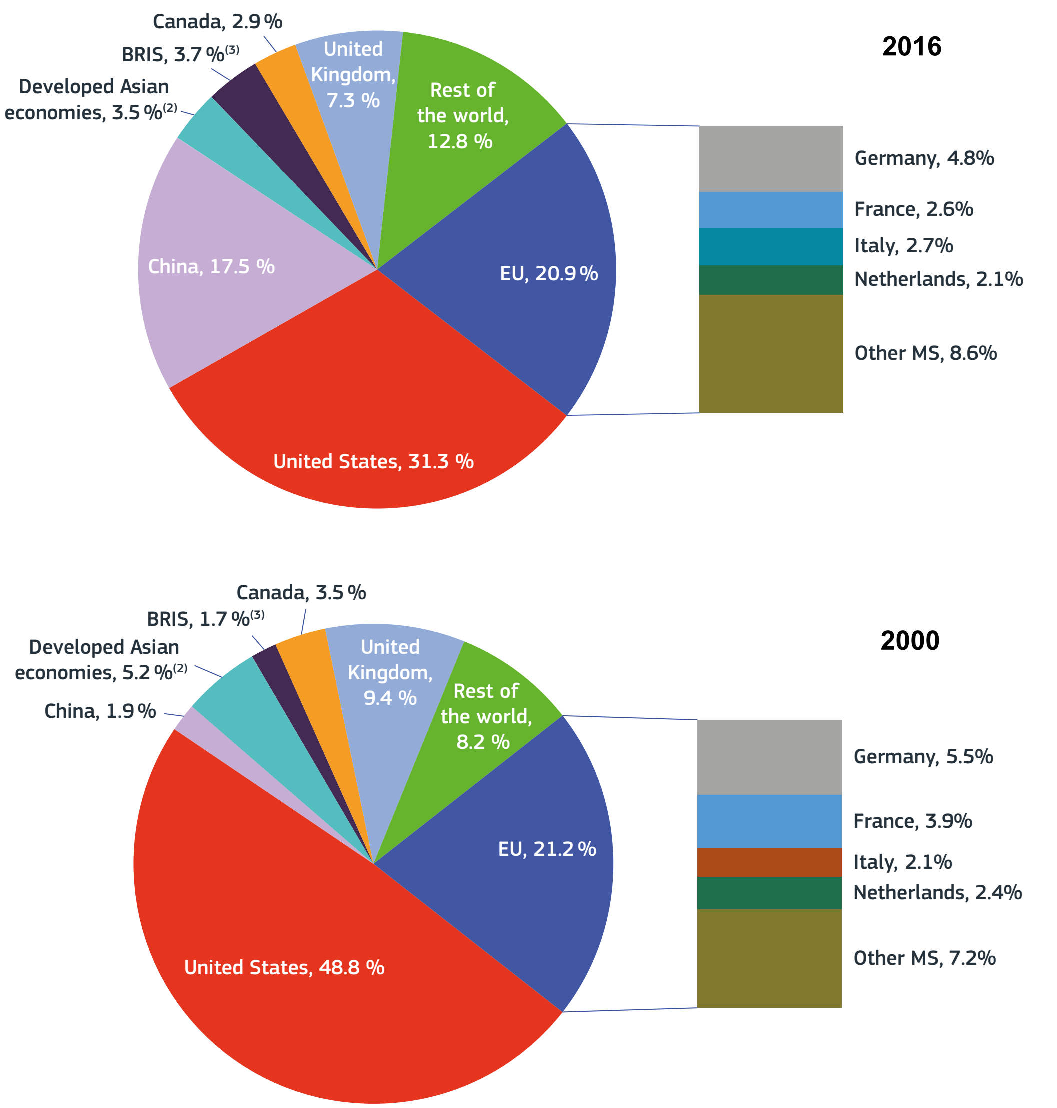
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: [1]Data produced by Science-Metrix based on Scopus database. Scientific publications within the 1 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. [2]BRIS includes Brazil, Russian Federation, India and South Africa. [3]Developed Asia economies includes Japan and South Korea. [4]Figures correspond to the latest year, 2018.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-5.xlsx

Whilst the world share of the 1 % of highly cited scientific publications dropped in most EU countries between 2000 and 2016, Spain saw an increase from 1.4 % to 2.0 %, as did Italy from 2.1 % to 2.7 %.

Figure 6.1-6 World share of top 1% highly cited scientific publications[(1)], 2000 (citation window: 2000-2002) and 2016 (citation window: 2016-2018)



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

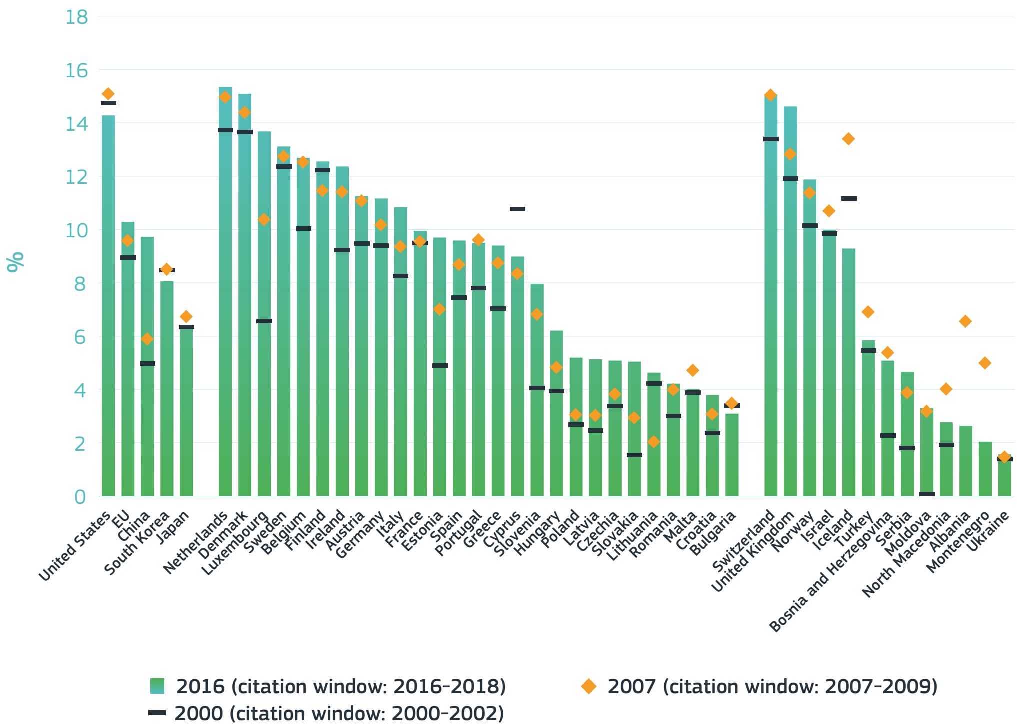
Notes: [(1)]Data produced by Science-Metrix based on Scopus database. Scientific publications within the 1 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. [(2)]Developed Asia economies includes Japan and South Korea. [(3)]BRIS includes Brazil, Russian Federation, India and South Africa.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-6.xlsx

In terms of the share of the top 10% and top 1% most-cited publications as a percentage of the total scientific publications, Europe has stabilised its position behind the United States, while China is quickly catching up. Although Europe has made some progress in raising the quality of its science, differences across Member States persist. Despite a slight fall in the share of total publications among the 10% most-cited worldwide since 2000 (Figure 6.1-7), the United States still outperforms the EU. In other words, the EU has more publications than the United States but with a lower impact in terms of citations. China is quickly bridging the gap with the EU as its top 10% most-cited publications have almost doubled since 2000.

Strong differences persist between European countries' performances. Switzerland confirms its leading global position, followed by numerous western European and Scandinavian countries, which have continued to raise their scientific performance since 2000 (e.g. Belgium, Ireland, Germany, Austria and Luxembourg). While several Mediterranean and eastern European countries like Estonia, Greece, Hungary, Italy, Slovenia and Spain have managed to raise their scientific output compared to 2000, a decline has been noted for Iceland, Israel, Malta and Turkey since 2007.

Figure 6.1-7 Top 10% highly cited scientific publications[1], 2000, 2007 and 2016



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: [1]Data produced by Science-Metrix based on Scopus database. Scientific publications within the 10 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. [2]AL: 2008. ME: 2005.

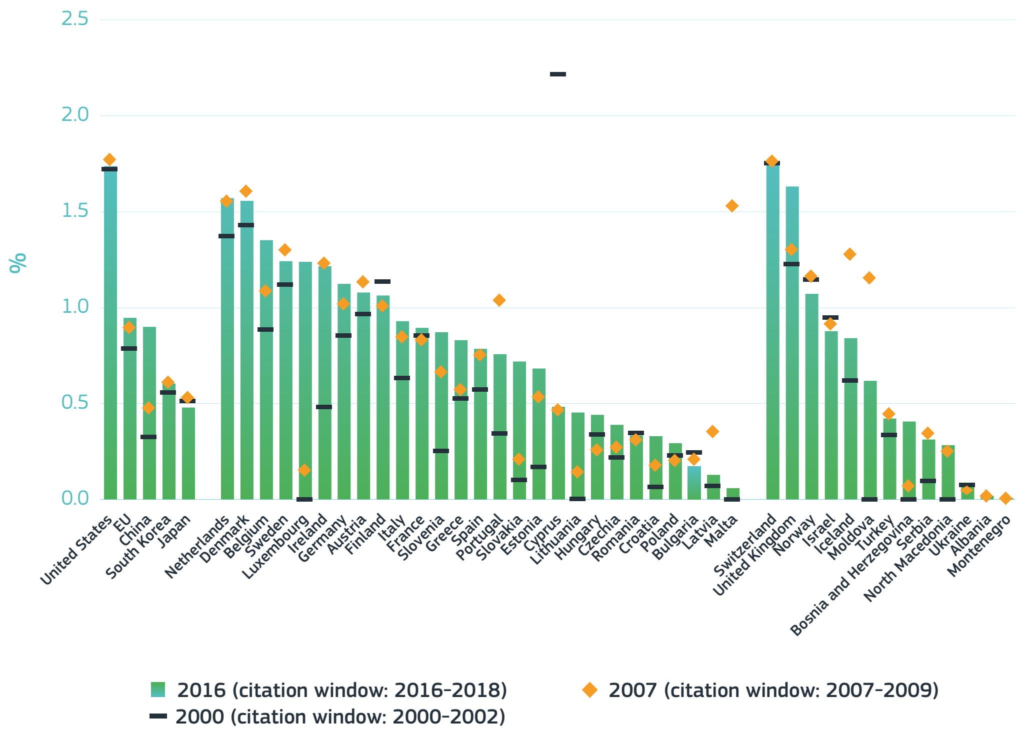
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-7.xlsx

The share of the top 1 % of highly cited scientific publications as a percentage of the total scientific publications (Figure 6.1-8) **is often used as a proxy for scientific excellence**. On this measure, the EU has remained at the same level since 2007. This trend is similar for the United States, South Korea and Japan, while China's performance continues to increase steadily.

Within Europe, although differences between the Member States persist, the majority of EU13 countries have managed to increase the proportion of their publications in the top 1 % highly cited. Switzerland is the world's top performer in science as regards the top 1 % articles, ahead of the United States and followed by the UK, the Netherlands, Denmark, Belgium, Sweden, Luxembourg, Ireland, Germany, Austria and Finland, all of which score above the EU average.

The citation impact of scientific publications demonstrates the importance of international science collaboration to reach high scientific quality. This is confirmed by the fact that the citation impact of international co-publications for all countries is greater than that of single-country publications for all countries (Figure 6.1-9). China's scientific quality benefits most as a result of international scientific collaboration.

Figure 6.1-8 Top 1% highly cited scientific publications[(1)], 2000, 2007 and 2016

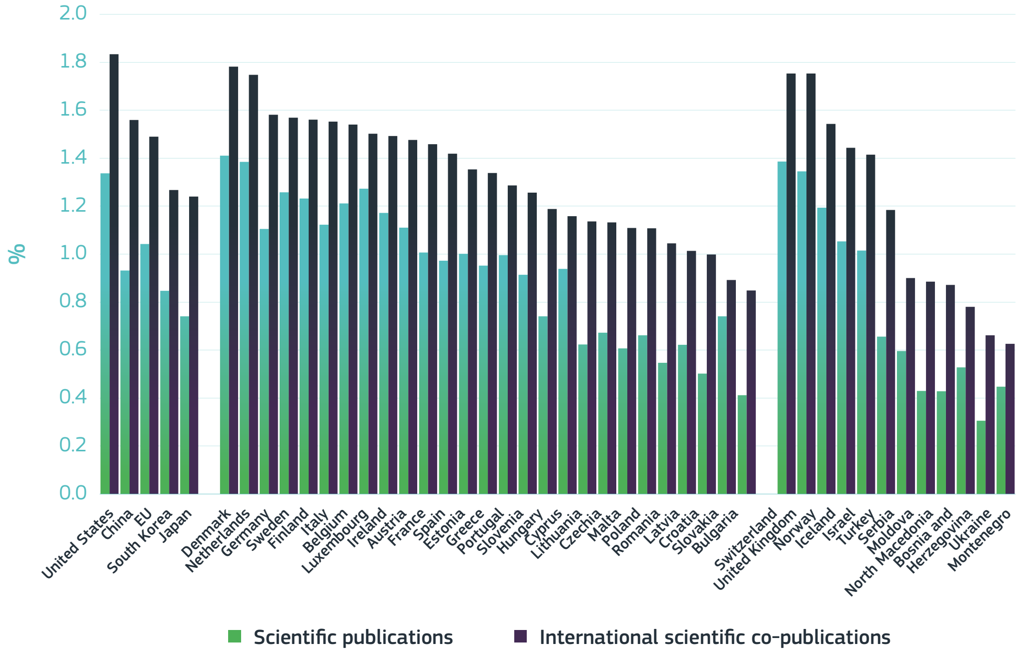


Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: [(1)]Data produced by Science-Metrix based on Scopus database. Scientific publications within the 1 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. [(2)]AL: 2008. ME: 2005.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-8.xlsx

Figure 6.1-9 Citation impact(1) of scientific publications, 2016 (citation window: 2016-2018)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: (1)Data produced by Science-Metrix based on Scopus database. Citation impact normalised by field and publication year (ratio of the average number of citations received by the papers considered and the average number of citations received by all papers in the main field, or 'expected' number of citations), citation window publication year plus two years.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-9.xlsx

Within the EU, this positive correlation is stronger for most of the countries exhibiting lower scientific performance.

The international rankings (the Shanghai and Leiden Rankings[4]) position the EU as a leader in 'world-class' universities among the top 500 institutions, while the United States still heads the top 100. **Although all innovation leader countries[5] outperform the United States, some have seen their position deteriorate over the last decade**. According to the Academic Ranking of World Universities (ARWU)[6], the EU has more universities (179) among the top 500 institutions than the United States (139), while the United States still leads in the top 100 (46, compared to 27 in the EU). The same holds true for the

4 Global international higher education rankings are perceived as a measure of quality, although the approaches vary according to the different rankings.

5 As defined by the European Innovation Scoreboard 2019, these are Sweden, Finland, Denmark and the Netherlands (see https://ec.europa.eu/growth/industry/innovation/facts-figures/scoreboards_en, accessed: 30 October 2019).

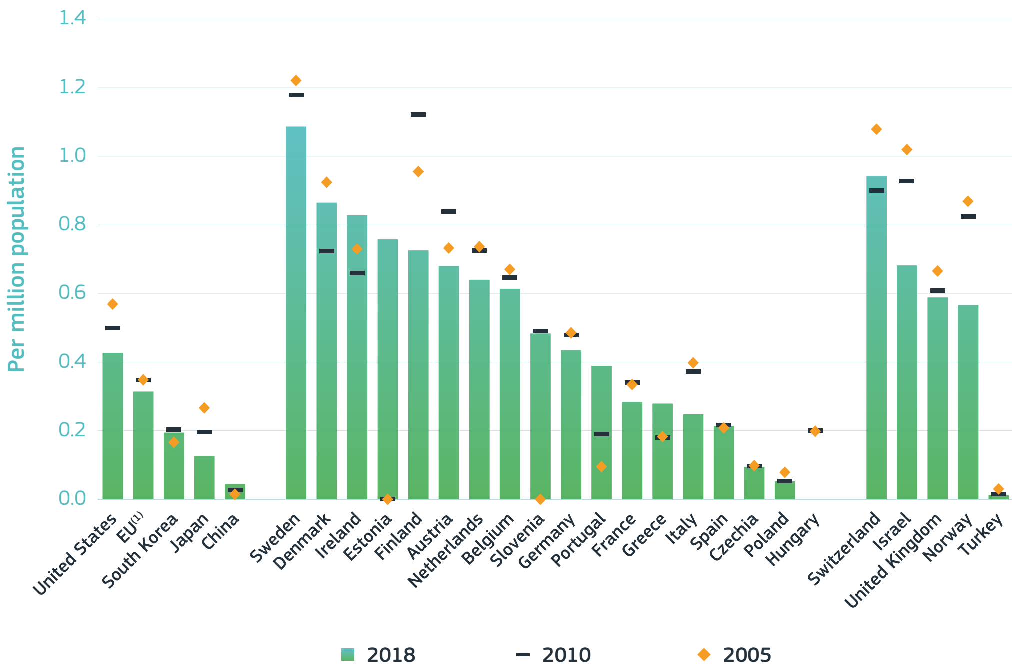
6 Also called Shanghai Ranking, which is based on six indicators mainly related to an institution's scientific output (number of Nobel Prizes and Fields Medals, highly cited researchers, papers published).

Leiden Ranking[7], which shows a total of 211 EU universities and 146 US universities in the top 500 list of institutions, and 33 EU universities and 52 US universities in the top 100 list[8].

Overall, the United States still slightly outperforms the EU in terms of the number of top 500 universities per million population. However, all EU countries classed as 'innovation leaders' and 'strong innovators' outperform the United States on this indicator when using the Shanghai Ranking. The EU also outperforms South Korea, Japan and China[9] in terms of top institutions per million population (see Figure 6.1-10).

According to the Leiden Ranking, some of the best-performing countries in terms of the number of top 500 universities per million population (Sweden, Belgium, Finland and Switzerland) have seen their position drop since 2011. Yet, countries such as Ireland, Austria, Denmark and Norway have experienced a strong improvement in their performance compared to 2011 (Figure 6.1-11).

Figure 6.1-10 Number of top 500 universities in the Shanghai Ranking per million population, 2005, 2010 and 2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Shanghai ranking (http://www.shanghairanking.com/)

Note: (1)EU was estimated by DG Research and Innovation based on the data available for the Member States.

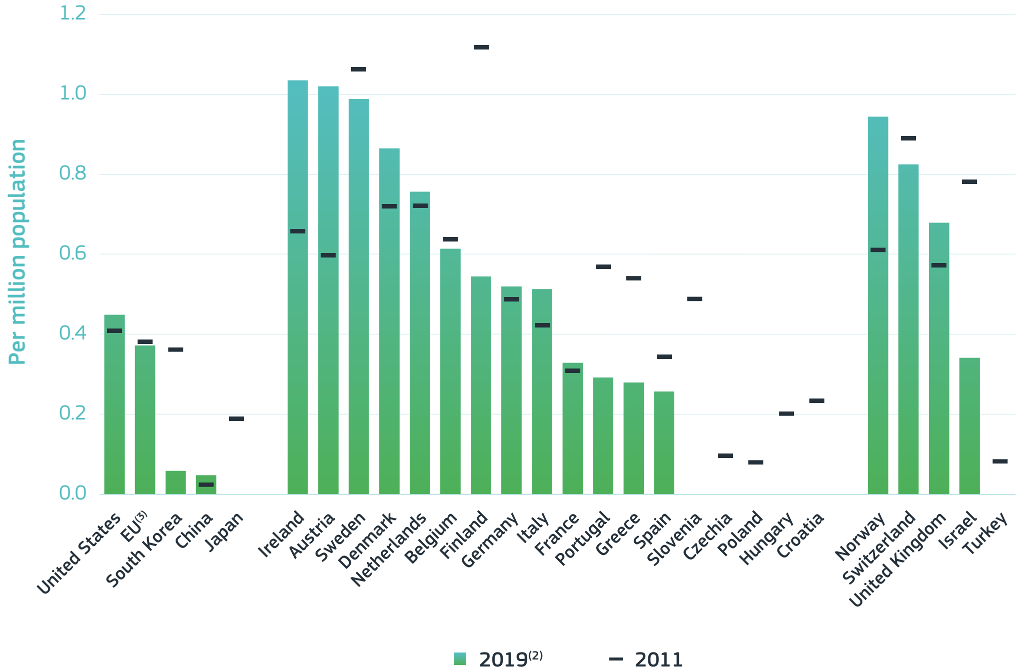
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-10.xlsx

7 The Leiden Ranking 2019 is based on a set of bibliometric indicators that provide statistics at the level of universities on scientific impact, collaboration, open access publishing, and gender diversity (for further details see https://www.leidenranking.com/information/indicators, accessed: 30 October 2019.

8 Please note that university rankings do not take into account research efforts made by publicly funded research performing organisations.

9 In the ARWU, this includes Hong Kong, Macao and Taiwan.

Figure 6.1-11 Number of top 500 universities in the Leiden Ranking per million population[(1)], 2011 and 2019



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Leiden ranking (http://www.leidenranking.com/)

Notes: [(1)]All publications included. Fractional counting used. Universities ranked by proportion of top 10 % publications. [(2)]Population refers to 2018 for all countries except US, JP, CN, and KR in respect of which population refers to 2017. [(3)]EU was estimated by DG Research and Innovation based on the data available for the Member States.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-11.xlsx

2. Within the EU, there is a diversity of research intensities and a positive correlation between scientific quality and investments

In Europe, a positive correlation between R&D intensity and scientific quality is evident in most countries. The Netherlands, Switzerland, Denmark, Sweden, Belgium, Finland, Austria, Norway and Germany enjoy higher levels of public investment in R&D than the EU average, as well as better scientific results (Figure 6.1-12). All Mediterranean (except Italy) and central and eastern European countries show below-EU-average R&D investment levels matched with below-EU-average levels of scientific excellence.

At the global level, the United States has a higher scientific impact than the EU despite lower public R&D intensity. Japan and South Korea show lower levels of scientific quality in relation to public investments. At the same time, China's scientific quality is approaching the EU level, despite a slightly lower R&D-intensity (Figure 6.1-12).

Figure 6.1-12 Public R&D intensity, 2016 and top 10 % highly cited scientific publications[1] 2016 (citation window: 2016-2018)

Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: rd_e_gerdtot), OECD and Science-Metrix using data from the Scopus database

Notes: [1]Scientific publications within the 10 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. [2]CH: 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-12.xlsx

Although several EU Member States are making numerous efforts to increase the effectiveness and performance of their public-sector research systems, further efforts are needed to introduce the necessary policy reforms. Between 2013 and 2016, research excellence in the EU28 increased at an annual growth rate of 3.2 %[10]. However, further efforts are needed to ensure well-functioning, efficient and impactful national R&I systems. The European Research Area (ERA) Priority 1 recognises this by calling for more effective national research systems and richer R&I policy mixes geared towards making a stronger impact by science and innovation in society.

10 Headline indicator composed of: share of top 10 % most highly cited publications per total publications (data source: CWTS); PCT patent applications per population (OECD); European Research Council (ERC) grants per public R&D (DG RTD, Eurostat, OECD); and participation in Marie Skłodowska-Curie fellowships (DG EAC); see European Commission (2019c: 11).

The European Semester 2019 also shows that further progress must be made, and it has demanded, for the first time, that all EU Member States make greater investments in R&I. A number of countries received additional country-specific recommendations (CSRs) for policy action to promote the quality and efficiency of their national R&I systems (quality of R&I policies and systems, stronger science-business links, support for breakthrough innovations and scale-up of high-growth firms, and sound framework conditions for business R&D).

The European Structural and Investment Funds (ESIF) and smart specialisation strategies are also prioritising investments in R&I in support of these reforms. Other reform-supporting tools include the Structural Support Reform Programme and the Horizon 2020 Policy Support Facility (PSF), which give advice to those Member States willing to improve the design, implementation or evaluation of their national R&I policies.

To ensure the effective use of public R&I funds, competitive funding is widely applied in EU Member States. However, the 2018 ERA Progress Report found that 'the balance between competitive funding and block funding still varies greatly between countries. In some countries with less-developed R&I systems, less competitive research-performing organisations rely mainly on block funding; this often affects their ability to attract the best talent and to develop and maintain research infrastructures' (European Commission, 2019b: 3). The Horizon 2020 PSF Mutual Learning Exercise on Performance-Based Funding[11] recommended Member States to carefully consider the proportion of institutional funding governed by performance-based criteria as a means of enhancing the effectiveness and performance of their public-sector research systems.

3. Digitalisation is transforming science. All areas of research are becoming data-intensive, increasingly relying upon and generating big data

Digitalisation has the potential to increase the productivity of science, enable novel forms of discovery and enhance reproducibility. Deep learning has become an increasingly popular method in most scientific disciplines. Digitalisation is a game-changer for science. The development and use of big data, for example, and the application of artificial intelligence (AI) is becoming increasingly relevant across all scientific domains (see Chapter 7 - R&I enabling artificial intelligence).

Digitalisation has the potential to promote collaboration as well as improve the efficiency of scientific research (OECD, 2019b: 57). The most noted potential – one that applies across all disciplines, including the humanities – concerns exploiting data and machine-learning techniques to support the research process (OECD, 2019c: 69ff).

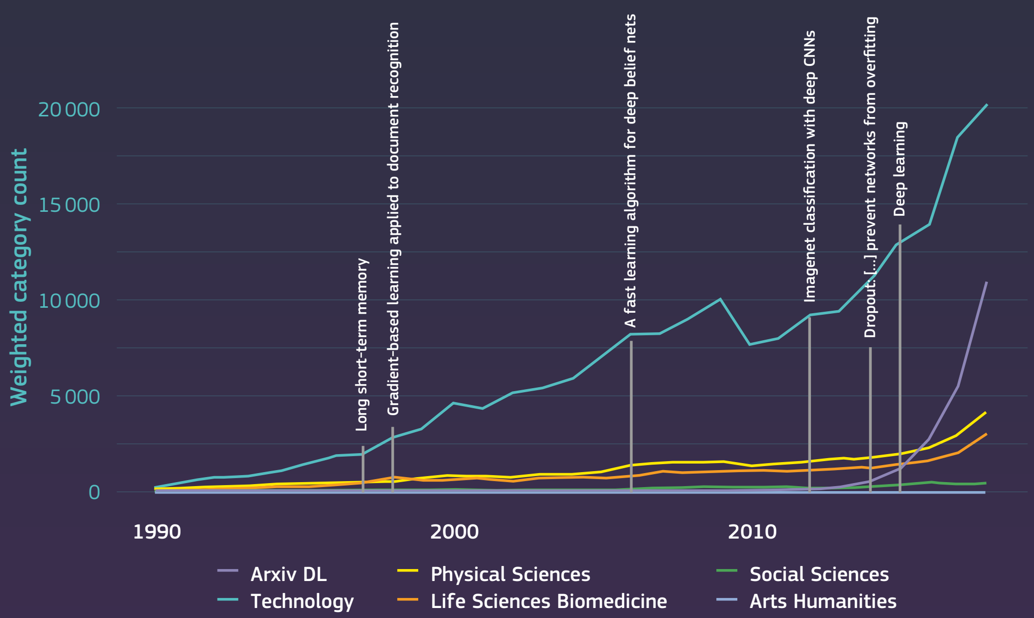
11 See https://rio.jrc.ec.europa.eu/en/policy-support-facility/mle-performance-based-funding-systems, accessed 22 October 2019.

BOX 6.1-2 The rise of deep learning and its impact on global science[12]

Based on a contribution by Stefano Bianchini, Moritz Muller and Pierre Pelletier, BETA – University of Strasbourg

Much of the recent success of AI has been spurred by impressive achievements within a broader family of machine-learning methods, commonly referred to as deep learning. Deep learning enables computational models to learn representations of data with multiple levels of abstraction. Deep learning can be viewed as an 'invention in the methods of invention' – i.e. A technology that transforms the process of knowledge creation and improves the potential for discoveries in combinatorial-type research problems.

Figure 6.1-13 Publication activity related to deep learning



Science, research and innovation performance of the EU 2020

Source: Stefano Bianchini, Moritz Muller and Pierre Pelletier, BETA – Université de Strasbourg

Note: This figure represents the annual trends in deep-learning documents divided into five WoS subject categories. It also shows the yearly trend in deep-learning research published in arXiv, an open archive of academic preprints widely used by the computer-science community. The vertical grey lines indicate important methodological achievements in the field of deep learning. These breakthroughs (especially those in recent years) precede a strong upward trend in the application of the technology in various domains.

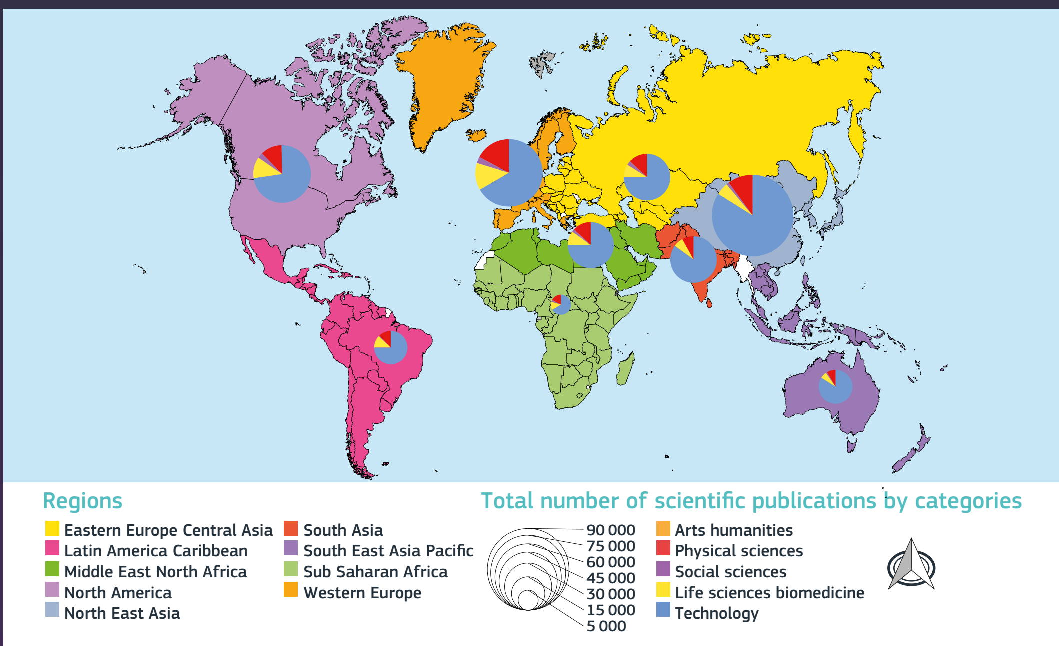
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-13.xlsx

12 Methodology: Web of Science (WoS) publication statistics are used to document how deep learning is being spread in science. Natural language processing techniques are used on text corpus (i.e. abstracts of scientific documents) for the identification of deep-learning-related terms (e.g. deep neural networks). Then a selected list of terms is used to identify those WoS documents that involve deep learning. These documents can either contribute methodologically to deep learning or use deep-learning-based tools to address disparate research questions. The WoS subject categories assigned to each document and authors' affiliations are used to map the diffusion of deep learning across the scientific system.

Figure 6.1-14 presents the geography of deep-learning activity by regions. The map shows a high level of activity in a small number of regions ranked as follows: north-east Asia, western Europe and North America. The map also documents a substantial variation in the applications across regions. Regions such as north-east Asia and eastern Europe seem to deploy deep learning mainly in the field of technology, while western Europe and North America show a significantly larger proportion of applications in life sciences and biomedicine.

The evidence suggests that **deep learning is spreading rapidly in many areas in the scientific system**. However, the important geographical dimension inherent in the process of creating and disseminating deep-learning-related knowledge suggests that countries are likely to exhibit heterogeneous patterns of specialisation. The performance of any deep-learning system relies heavily on good data. As such, science and technology policies should **improve access to high-quality data infrastructures through a well-designed data strategy**, which includes ethical and legal considerations. In addition, to achieve the full potential of deep learning, complementary resources are necessary. Among these assets, human resources (i.e. talented AI researchers) are the most important. **Deep learning also implies organisational changes in the scientific system**, such as team structure, public-private interaction, data sharing, etc.

Figure 6.1-14 Geography of deep-learning activity



Science, research and innovation performance of the EU 2020

Source: Stefano Bianchini, Moritz Muller and Pierre Pelletier, BETA – Université de Strasbourg

Note: This figure represents the geography of deep-learning activity by regions in the period 1990-2018. It also shows the share of WoS subject categories for each region.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-14.xlsx

Moreover, the use of AI in science could enable novel forms of discovery and enhance reproducibility (OECD, 2018).

Avenues to promote the digitalisation of public research include strengthening researchers' digital skills, promoting open science (access to publications and data), ensuring appropriate investments in digital infrastructures for research, and creating incentives for interdisciplinary research. Promoting digitalisation of public research has become a priority for almost all EU Member States. In addition to open science[13], Member States are supporting various other measures, including strengthening researchers' digital skills by reinforcing interdisciplinarity (i.e. combining computer science with traditional disciplines) or offering specific trainings to master digital tools.

Moreover, Member States are investing in digital infrastructures that are critical for research (for example, platforms for sharing data and supercomputing facilities for AI). In 2018, the EU launched the European High-Performance Computing Joint Undertaking (EuroHPC JU) with a budget of around EUR 1 billion to develop top-of-the-range exascale supercomputers for processing big data, based on competitive European technology (see Chapter 7 - R&I enabling artificial intelligence)[14].

The digital transformation is also likely to change the accessibility of publications and data which has been limited to date[15]. While immediate open access is steadily increasing, the traditional subscription model remains the most prevalent, 'representing over 80% of the total number of articles published globally last year' (OECD, 2019a: 73). Access to data must consider legal and ethical constraints as well as normative attitudes and the availability of infrastructures (OECD, 2019a: 73).

4. Science is key in addressing societal challenges. The EU is a leader in high-quality scientific publications in the food/bioeconomy and climate/environment sectors

European Member States dominate the analysis targeting the UN SDGs. Figure 6.1-15 shows that Europe dominates the analysis targeted on the UN SDGs, indicating primarily the commitment of researchers to better understanding the goals, interactions between each of them, and potential trade-offs when addressing them. The figure is based on papers directly pertaining to SDGs, i.e. research articles with a title, abstract or keywords that explicitly contain the phrase 'sustainable development goal(s)'. North America and the Asia and Pacific region contribute less. Notably, the highest level of collaboration within the SDG papers surveyed was among European countries (see the 'dark purple cell'). Moreover, Europe

13 See Chapter 6.2 - Knowledge flows.

14 https://ec.europa.eu/digital-single-market/en/eurohpc-joint-undertaking#Budget, accessed 9 October 2019.

15 See Chapter 6.2 - Knowledge flows.

Figure 6.1-15 Regional collaboration matrix for SDG core and citing papers[(1)]

	Latin America	North America	Africa	Europe	Asia & Pacific	Arab States
Latin America	275	408	179	434	237	63
North America	408	1329	656	1446	1089	114
Africa	179	656	262	863	432	90
Europe	434	1446	863	**2602**	1300	169
Asia & Pacific	217	1089	432	1300	1623	108
Arab States	63	114	90	169	108	41

Source: Institute for Scientific Information (2019: 10)
Note: [(1)]The figure is a pair-wise matrix showing the number of SDG papers authored by researchers in countries within each regional pair represented by the intersection of the row and column.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-15.xlsx

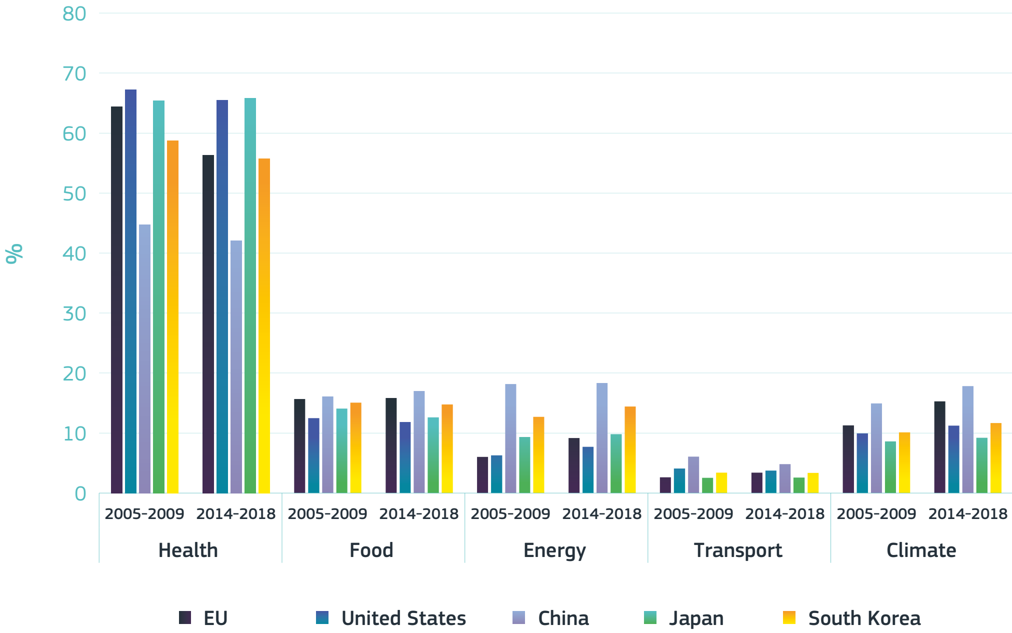
is the largest collaborator with North America (even larger than the intra-North American collaboration) and the largest collaborator with the Asia and Pacific region (while intra-Asia and Pacific region collaboration is slightly higher). Africa, the Arab States and Latin America have more frequent co-authorships with Europe than with North America.

The share of scientific publications remains the highest in 'health, demographic change and well-being' field. For all major science producers, the shares of scientific publications are highest for the societal challenge 'health, demographic change and well-being', although the EU saw a decrease from 64.4% to 56.3% between the periods of 2005-2009 and 2014-2018. Yet, for all other challenges, EU shares increased over the same periods. The same trend can be observed for China.

Scientific publications on 'food security, sustainable agriculture and forestry, marine, maritime and inland water research, and the bioeconomy' have the second highest share for all countries except China, for which both 'secure, clean and efficient energy' and 'climate action, environment, resource efficiency and raw materials' rank second (Figure 6.1-16).

16 Figure 6.1-15 is a pair-wise matrix showing the number of SDG papers authored by researchers in countries within each regional pair represented by the intersection of the row and column.

Figure 6.1-16 Share of scientific publications by societal challenge[(1)], 2005-2009 and 2014-2018)



Science, research and innovation performance of the EU 2020

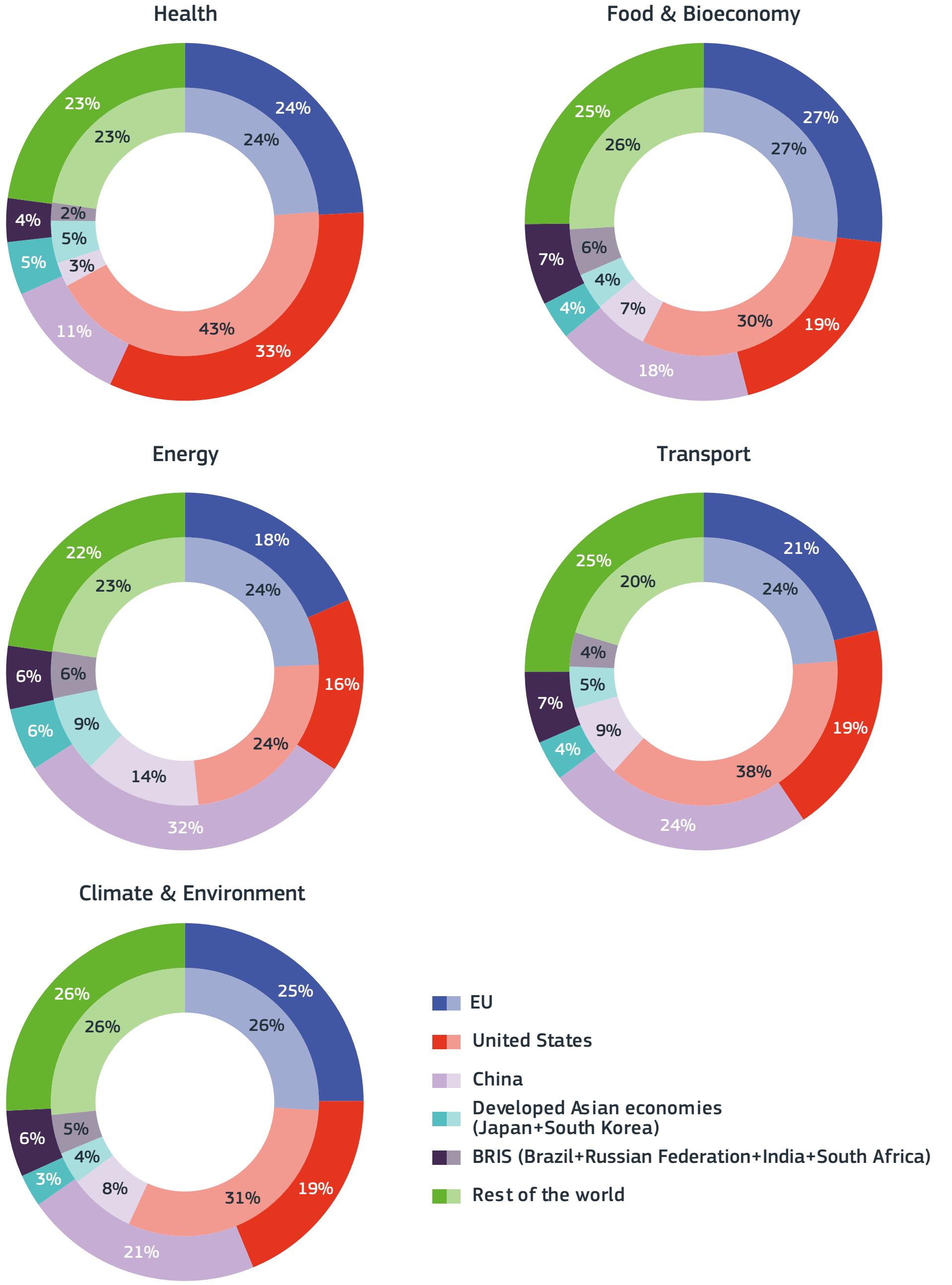
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: [(1)]Data produced by Science-Metrix based on Scopus database. This presents the overall % of publications by area. The specialisation indices below are just dividing the % of EU by the % of other countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-16.xlsx

The EU leads in high-quality scientific publications in the food and bioeconomy and climate and environment sectors when compared to its major competitors. While China increased its shares exponentially across all societal challenges, the United States lost its leadership in all of them. When comparing the EU to its major competitors (the US, China, and Japan), the EU leads in scientific publications related to food and bioeconomy and climate and environment (Figure 6.1-17). In all fields, the EU's share remained stable between 2006 and 2016, with the exception of energy where its share dropped from 24% to 18%. During the same period, China increased its shares exponentially across all societal challenges, taking top position in the areas of energy (from 14% in 2006 to 32% in 2016) and transport (from 9% in 2006 to 25% in 2016). At the same time, it reached second place in climate and environment (with 22% in 2016) behind the EU (with 25% in 2016). In contrast to the rise of China, the United States lost its leadership in all fields.

Figure 6.1-17 Shares (%) of top 10 % of scientific publications by Societal Grand Challenges, 2006 (interior) and 2016 (exterior)



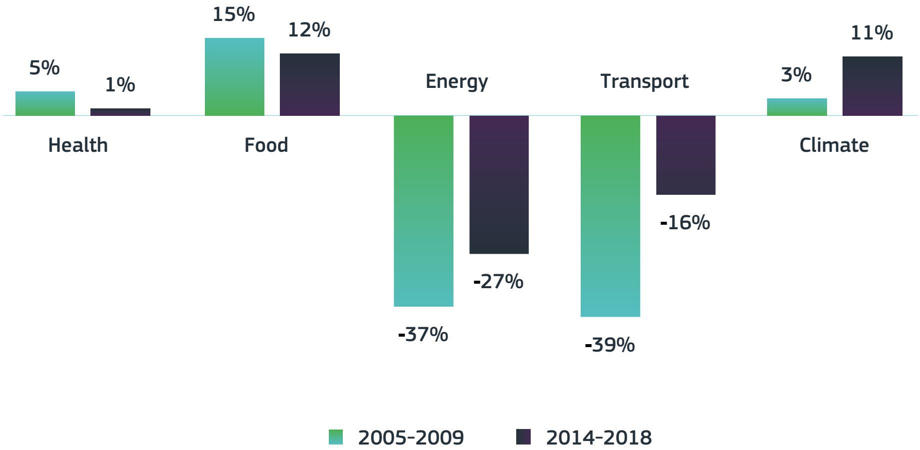
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: [(1)]Data produced by Science-Metrix based on Scopus database.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-17.xlsx

Compared to its main competitors, the EU is particularly specialised in food- and climate-related scientific publications. In comparison to its major competitors (the United States, China, Japan and South Korea), Europe shows a particular specialisation in food and climate change challenges (Figure 6.1-18). During the period 2014-2018, the share of EU publications in food-related challenge was 12% higher than for its competitors (falling from 15% during the period 2005-2009). In the climate-change challenge, it was 11% higher (increasing from 3% during the period 2005-2009). On the other hand, the EU lags behind in the energy and transport challenges.

Figure 6.1-18 Percentage difference in EU specialisation index (vs. US, China, Japan and South Korea), 2005-2009 and 2014-2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

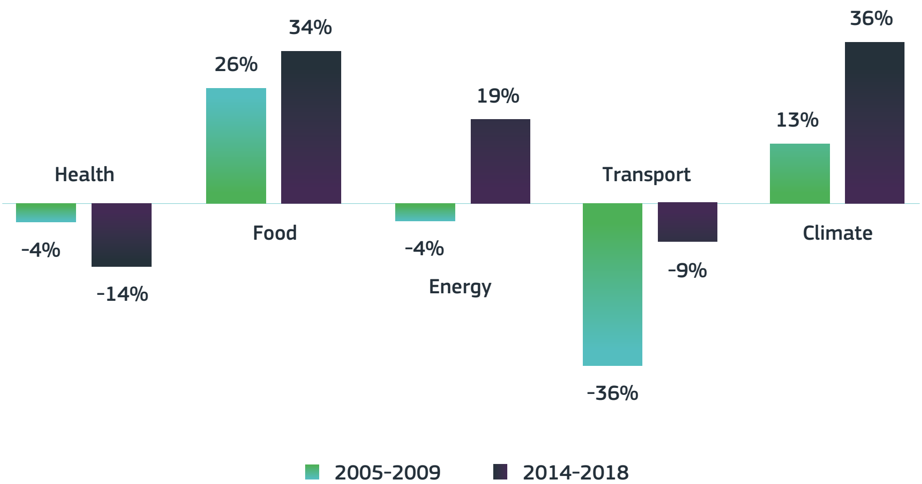
Note: [1]Data produced by Science-Metrix based on Scopus database. These figures compare the percentage of publications in the EU in one area (% of all EU publications) with the percentage of publications in the US, China, Japan and South Korea in the same area (% of all publications in these countries).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-18.xlsx

When compared only to the United States, the EU is stronger in the areas of food, energy and climate change, but lags behind it in health and transport-related publications. From 2005 to 2018, the EU increased its advance in the climate change area vis-à-vis the United States by almost three times (Figure 6.1-19).

Compared to China, the EU only appears stronger in health challenge, where its share of scientific publications is 34% higher (2014-2018). In all other areas, the EU appears weaker than China, especially in the energy challenge where the former produced 50% (2014-2018) fewer scientific publications than the latter (Figure 6.1-20).

Figure 6.1-19 Percentage difference in EU specialisation index (vs. US), 2005-2009 and 2014-2018



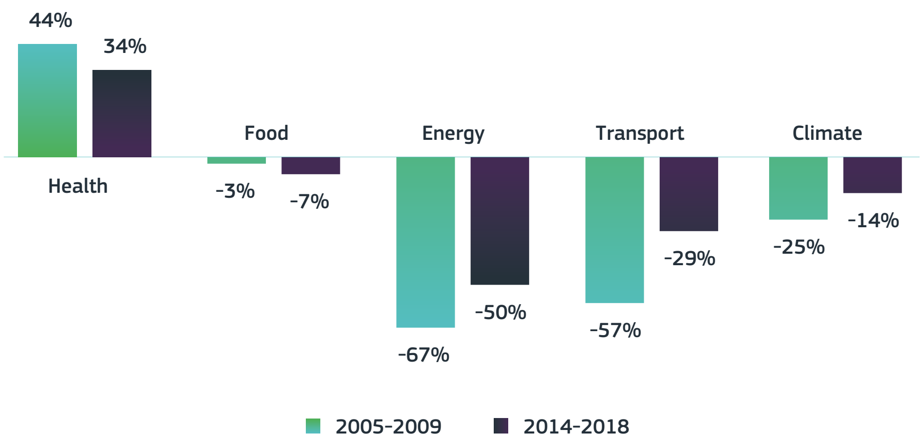
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: [1]Data produced by Science-Metrix based on Scopus database. These figures compare the percentage of publications in the EU in one area (% of all EU publications) with the percentage of publications in the US in the same area (% of all publications in these countries).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-19.xlsx

Figure 6.1-20 Percentage difference in EU specialisation index (vs. China), 2005-2009 and 2014-2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: [1]Data produced by Science-Metrix based on Scopus database. These figures compare the percentage of publications in the EU in one area (% of all EU publications) with the percentage of publications in China in the same area (% of all publications in these countries).

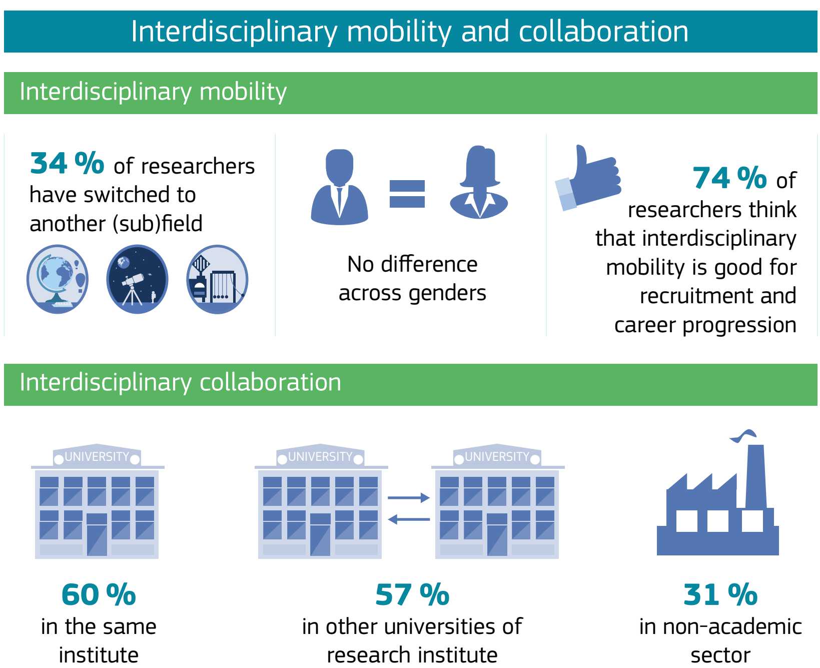
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-20.xlsx

Research addressing SDGs requires interdisciplinarity. One third of all researchers in the EU have switched to another field or sub-field during their academic career. As all SDGs are interconnected, interdisciplinary and transdisciplinary research will be key to identifying positive complimentary interactions between the SDGs, as well as trade-offs that can constrain or stop progress on certain SDGs (International Council for Science, 2017).

A wide range of research approaches are needed to address the breadth and nature of the challenges reflected by the SDGs (SDSN Australia Pacific 2017). This goes beyond research between disciplines and demands the creation of new ones, such as 'sustainability science'. As a unique trans-, inter-, and multidisciplinary endeavour, sustainability science (Kates et al., 2001) aims to identify problems, opportunities and trade-offs between human, environmental and engineered systems. According to this concept, scientific, lay, practical and indigenous knowledge, as well as varying world views, are brought together (UN, 2019).

The MORE3 Final Report[17] provides evidence that one third of all researchers switch to another field or sub-field during their academic career. Below average shares of interdisciplinary collaboration are observed in the social sciences and humanities (Figure 6.1-21).

Figure 6.1-21 Interdisciplinary mobility and collaboration



Source: Based on MORE EU HE report
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-21.xlsx

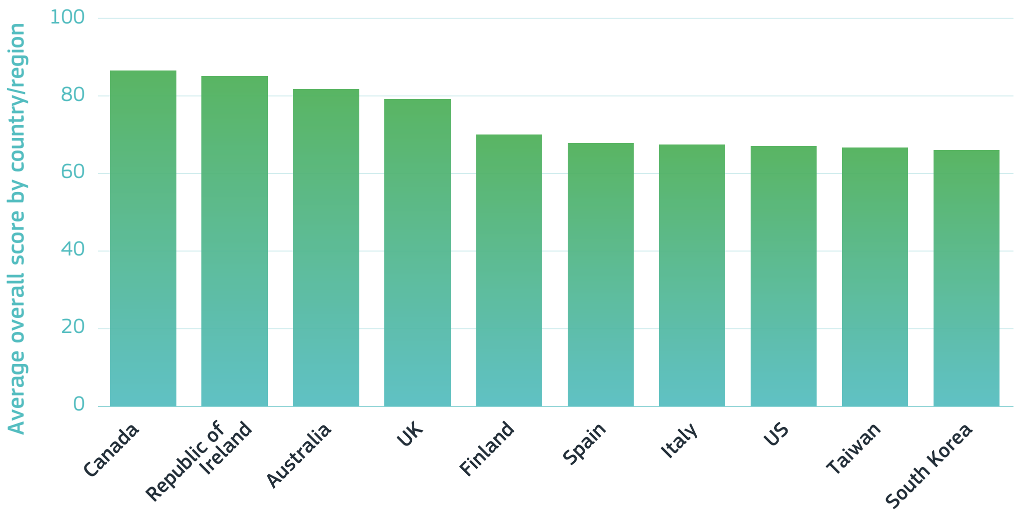
17 See XXXX

Although interdisciplinarity may be well suited to addressing complex societal challenges while fostering academic excellence and innovation, the development of policies pursuing interdisciplinary careers is hampered by the absence of a clear-cut definition of interdisciplinarity.

Universities play a critical role in providing the necessary knowledge to support social, environmental and economic transitions. Canada, Ireland and Australia are the top countries where universities are leading the way in supporting just and responsible social change. The Times Higher Education University Impact Rankings 2019 is the first attempt to measure global universities' success in delivering the SDGs[18]. It uses calibrated indicators to provide comparisons across three broad areas: research, outreach, and stewardship. Metrics are based on 11 of the 17 UN SDGs.

Results from the first edition reveal a new hierarchy of global institutions compared to research-focused rankings, with New Zealand's Auckland and two Canadian institutions – McMaster University and the University of British Columbia – comprising the top three overall, alongside the UK's University of Manchester. On average, universities in Canada are the highest performing, with Ireland and Australia coming next[19] (Figure 6.1-22). When it comes to overall representation, Japan tops the list of the 76 countries represented with 41 ranked institutions, while the United States has 31 and Russia 30. Twenty-six EU universities feature among the top 100 performing universities, followed by 17 from the UK.

Figure 6.1-22 Average overall score by country/region in the Times Higher Education University Impact Rankings 2019



Science, research and innovation performance of the EU 2020

Source: THE Impact Rankings
Note: Excludes territories with fewer than five institutions in ranking.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-22.xlsx

18 For the ranking, see: https://www.timeshighereducation.com/rankings/impact/2019/overall#!/page/0/length/25/ sort_by/rank/sort_order/asc/cols/undefined; for the methodology, see: https://www.timeshighereducation.com/ world-university-rankings/ methodology-impact-rankings-2019, accessed 4 September 2019.

19 https://www.timeshighereducation.com/news/university-impact-rankings-2019-canada-leads-way, accessed 16 October 2019.

Figure 6.1-23 Global performance of EU universities against UN SDGs in the Times Higher Education University Impact Rankings 2019

Global performance of EU universities against UN SDGs (Top 100)		
Position in THE ranking	Name	Country
6	University of Gothenburg	Sweden
7	KTH Royal Institute of Technology	Sweden
9	University of Bologna	Italy
15	University of Helsinki	Finland
16	University of Padua	Italy
16	Vrije Universiteit Amsterdam	The Netherlands
19	Aalto University	Finland
21	University College Cork	Ireland
28	Trinity College Dublin	Ireland
29	Pompeu Fabra University	Spain
34	Autonomous University of Barcelona	Spain
35	University of Limerick	Ireland
43	Aix-Marseille University	France
58	University College Dublin	Ireland
60	University of Hamburg	Germany
65	University of Amsterdam	The Netherlands
75	University of Eastern Finland	Finland
76	Comenius University in Bratislava	Slovakia
78	University of L'Aquila	Italy
83	University of Minho	Portugal
86	Comillas Pontifical University	Spain
92	University of Latvia	Latvia
94	University of Girona	Spain
97	Aalborg University	Denmark
98	Dublin City University	Ireland

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Times Higher Education ranking (https://www.timeshighereducation.com/rankings/impact/2019)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-23.xlsx

5. Conclusions

The EU's scientific performance is framed by several grave developments, including the UK's exit from the EU, the rise of China, digitalisation, and a new focus on the SDGs. This chapter has shown that the **EU and China are the global leaders in terms of scientific output, while the United States retains the lead in scientific quality**. Notably, output by Chinese researchers has risen exponentially over the last two decades to nearly match the EU.

Within the EU, there is a diversity of research intensities among the Member States and a positive correlation between scientific quality and R&I investments in most countries. Although several EU Member States are making numerous efforts to enhance the effectiveness and performance of their public-sector research systems, further efforts are needed to introduce the necessary policy reforms.

Digitalisation has the potential to increase science productivity, enable novel forms of discovery and enhance reproducibility. It is transforming science. This chapter has illustrated that all areas of research are becoming data-intensive, increasingly relying upon and generating big data.

Last but not least, this chapter points out that science is key in addressing societal challenges. The EU leads high-quality scientific publications in the food/ bioeconomy and climate/environment sectors, while China's output is increasing exponentially across sectors and the United States has lost its overall leadership.

These findings trigger certain policy implications. First, to remain a leading global scientific player, the EU and its Member States must **strengthen their efforts to enhance the effectiveness and performance of their public research systems through stronger R&I investments and policy reforms**. Second, to exploit the full potential science digitalisation, policies must be adapted to reinforce researcher's digital skills, promote open science as well as ensure the necessary investments in high-quality data infrastructures. And third, as science is key to addressing societal challenges, the **EU must not only ensure scientific leadership in key areas but must also foster interdisciplinarity research which is necessary to successfully deliver on the SDGs**.

6. References

ASGARD and Berger, R. (2018), Artificial Intelligence - a strategy for European startups, Munich.

European Commission (2019a), China - Challenges and Prospects from an Industrial and Innovation Powerhouse, Brussels.

European Commission (2019b), The European Research Area: advancing together the Europe of research and innovation, COM(2019) 83 final, 15 February 2019.

European Commission (2019c), ERA Monitoring handbook 2018, European Commission.

International Council for Science (2017), a guide to SDG interaction: from science to implementation.

Institute for Scientific Information (2019), Navigating the Structure of Research on Sustainable Development Goals.

Kates, R.W. et al. (2001), Sustainability science, in: Science, 292(5517), pp. 641-642.

OECD (2018), OECD Science, Technology and Innovation Outlook 2018, Paris.

OECD (2019a), Going Digital: Shaping Policies, Improving Lives, Paris.

OECD (2019b), Measuring the Digital Transformation - a Roadmap for the Future, Paris.

OECD (2019c), Digital Innovation – Seizing Policy Opportunities, Paris.

SDSN Australia/Pacific (2017), Getting started with the SDGs in universities: a guide for universities, higher education institutions, and the academic sector, Australia, New Zealand and Pacific Edition. Sustainable Development Solutions Network – Australia/Pacific, Melbourne.

Times Higher Education University Impact Rankings 2019.

UN (2019), The future is now – science for achieving sustainable development, Global Sustainable Development Report 2019, New York.

CHAPTER 6.2

KNOWLEDGE FLOWS

KEY FIGURES

13 %
EU researchers currently employed in another country with large differences between MS

3rd
place for EU in public-private co-publications after USA and South Korea

11 %
of EU patents are filed with foreign co-inventors while USA ranks first with 13 %

60 %
of publications in open access for Croatia, the Netherlands and Luxembourg

What can we learn?

- **Researchers' mobility remains key to knowledge diffusion**, yet stark disparities remain between countries in international and intersectoral mobility patterns in the EU. In general, countries with a higher R&I performance tend to have a greater inflow and outflow of researchers.
- **In terms of public-private co-publications, the EU is catching up with South Korea and the United States**. Private financing of public research is stagnating at the global level. A few large innovative companies are making the most of international and inter-sectoral cooperation.
- **The US and EU are leading in international technological cooperation**, whilst China and Japan are falling behind. In some EU countries, knowledge diffusion and technological transformation continues to be stimulated through foreign direct investment and foreign business research investment.
- **The EU continues to lead on open science policy and international scientific collaboration**, with its EU Framework Programme playing an important role.

What does it mean for policy?

- Divergence between the EU Member States on researcher's mobility patterns calls for a **better understanding of drivers of and barriers to international and intersectoral mobility** as well as the implementation of **policies to foster brain circulation**.
- There is a need to **strengthen the capacity of small firms to engage in R&I collaborations**, including with academia. Despite digitalisation, the geographical proximity of academia is still paramount for innovative activities in industry.
- **International technological cooperation policies need to be put into a wider perspective of changing global approaches** to trade and technological sovereignty.
- While the open access policy in the EU is well advanced, **efforts in implementing its ambitious European open data policy and mainstreaming open science policies and practices must be stepped up**.

Knowledge flows are paramount in creating solutions to the challenges that Europe and the world are currently facing (i.e. from carbon neutrality through sustainable food systems to smart mobility) and in ensuring the competitiveness of European companies. The diffusion of knowledge and technology across companies, regions and countries helps to address differences in productivity growth and the take-up of digital technologies, and is a pre-requisite to cope with the growing complexity of innovation processes. Free circulation of knowledge has been at the heart of the European Research Area initiative.

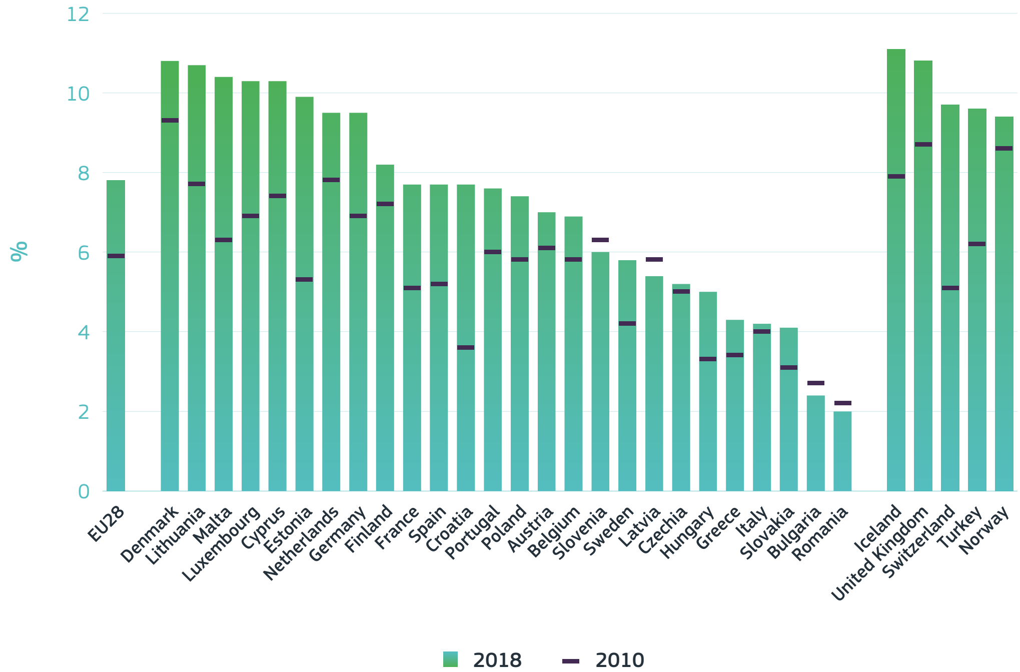
1. Researchers' mobility remains key to knowledge diffusion, yet stark disparities remain between countries in international and intersectoral mobility patterns in the EU

Researchers – progressively mobile between sectors, disciplines and countries – provide an important channel for knowledge diffusion between research organisations, business, non-profit organisations and public administrations. Mobility enables faster absorption and valorisation of knowledge, fosters lasting cooperation and, at the same time, increases researchers' career prospects. Yet, mobility patterns diverge between Member States in terms of mobile human resources in science and technology (HRST), international mobility of researchers as well as intersectoral mobility[1]. Greater asymmetric mobility of high-skilled professionals and academics may exacerbate existing inequalities, thereby further weakening the economy of post-industrial and/or peripheral regions and countries (Iammarino et al., 2019). It may also undermine efforts to raise the quality and efficiency of all European national R&I systems. This calls for a strengthened role of place-based innovation based on the partnership of enterprises, universities and government, as well as a better understanding of drivers of and barriers to international and intersectoral mobility.

While mobile human resources in science and technology have increased only slightly at the EU level in the last 10 years, they remain a small share of the total R&I workers, with differences between the Member States. Between 2007 and 2018, the mobility of human resources in science and technology (HRST) increased only slightly in the EU to reach 7.8%, with the majority of countries oscillating between 10% and 5% of the mobile HRST workforce. However, the overall trend remains disappointing and shows a very mixed pattern, as can be seen in Figure 6.2-1. A decline in mobility occurs both in northern countries (Denmark, Finland, Sweden, Iceland and Norway), which were characterised by higher mobility, and eastern and southern countries (Spain, Italy, Latvia, Bulgaria and Romania) that showed lower mobility. Conversely, mobility increased most significantly in Lithuania, Luxembourg, Malta, France, Germany and Switzerland.

1 The (physical) mobility of researchers from one sector (academia) to another (e.g. industry).

Figure 6.2-1 Job-to-job mobility[1] of human resources in science and technology (HRST)[2] as % of total HRST, 2010 and 2018



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: hrst_fl_mobsex)

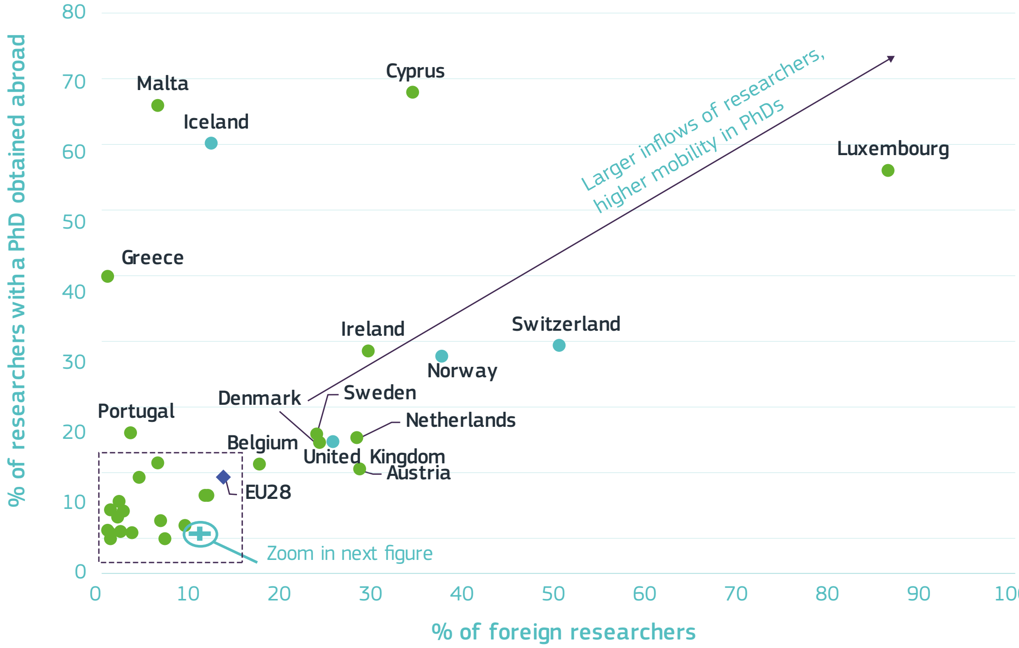
Notes: [1]Shows the movement of individuals between one job and another from one year to the next. It does not include inflows into the labour market from a situation of unemployment or inactivity. [2]HRST: People with tertiary education and/or employed in science and technology.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-1.xlsx

As regards the international mobility of researchers, there are vast differences between countries with a higher share of inflow of researchers observed in higher-performing countries and an overall higher mobility of researchers from smaller R&I systems. Brain circulation across countries and regions continues to be unbalanced. Malta, Greece and Iceland have the highest share of researchers who have obtained PhDs outside of their country of origin, as well as lower inflows of foreign researchers. At the same time, the Nordic countries, Austria, Switzerland and the UK, have the highest share of inflows of researchers. Luxembourg, Ireland and Cyprus – albeit to a lesser extent – present both high inflows of researchers and high mobility during PhD programmes (Figure 6.2-2).

In general, countries with higher R&I performances tend to have a higher share of researchers who have obtained their PhD in another country and higher researcher inflows. Yet, France, Germany, Spain, Italy and Finland report degrees of mobility that are lower than the EU average. The size of the national research system also has an impact on researchers' mobility. In the case of Cyprus, Malta and Luxembourg, this has resulted in mobility which is higher than EU average, while Germany and France show the opposite trend (Figures 6.2-2 and 6.2-3).

Figure 6.2-2 International mobility of researchers

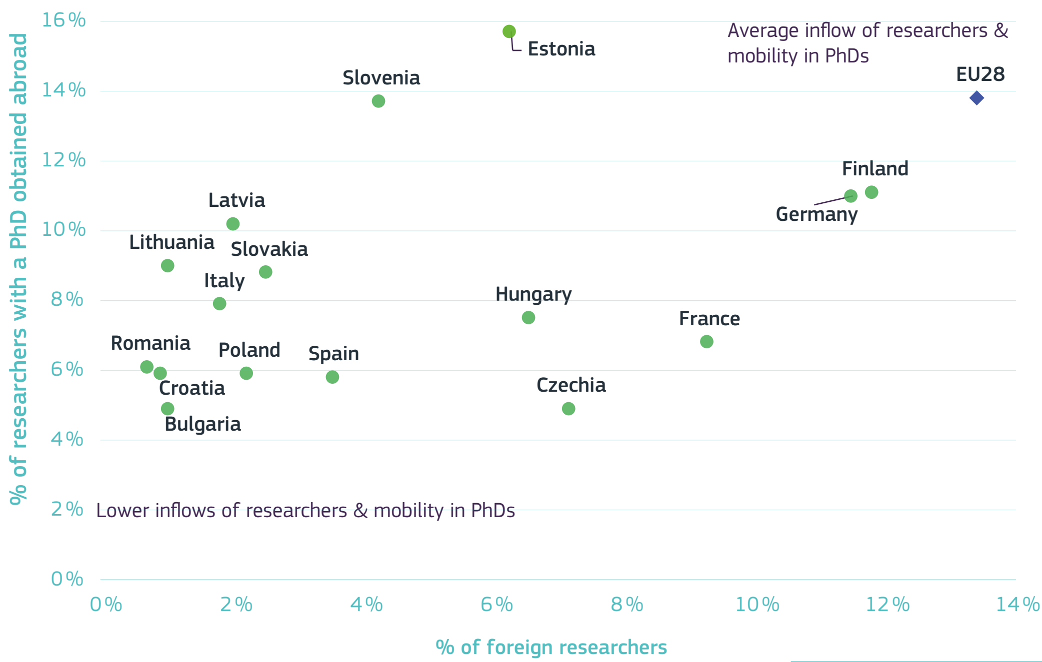


Science, research and innovation performance of the EU 2020

Source: European Commission, MORE3 study (2016)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-2.xlsx

Figure 6.2-3 International mobility of researchers - zoom from the previous figure



Science, research and innovation performance of the EU 2020

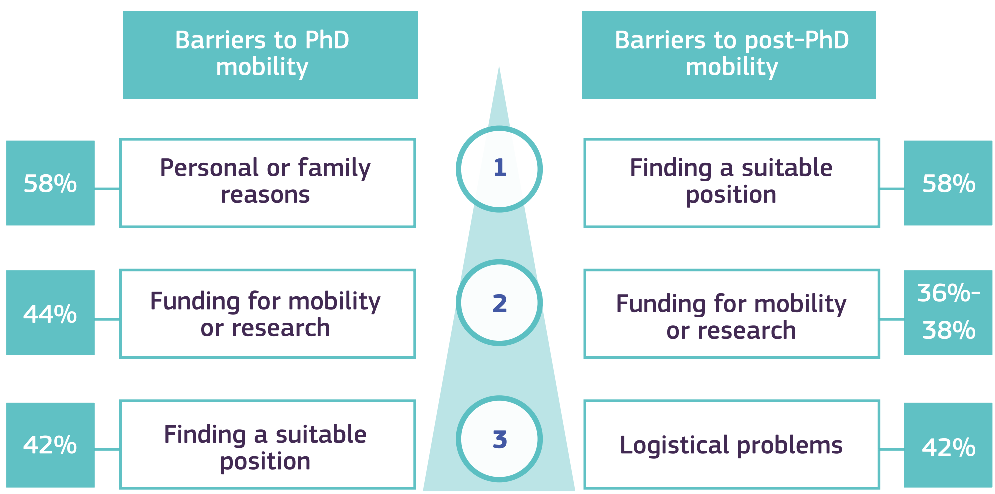
Source: European Commission, MORE3 study (2016)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-3.xlsx

The asymmetry in mobility flows, while highly beneficial for hosting countries, may prove detrimental to lower-performing research systems if mobility is one directional (Veugelers, 2017). This calls for an active strategy of enticing international researchers while providing attractive opportunities for returning researchers. There is ample evidence that returning researchers are more productive and maintain collaborative links with their previous institutions (Jonkers and Cruz-Castro, 2013). Wagner et al. (2018) point to the correlation between a country's internationalisation in terms of international co-authorship of scientific articles and the mobility of researchers and the high impact of scientific work.

Dedicated studies[2] report various factors that act as barriers to researchers' international mobility, such as personal or family reasons, funding, and finding a suitable position. The MORE3 study[3] also notes that 16 % of mobile researchers have experienced 'forced mobility' – i.e. the extent to which researchers feel forced to move to another country due to the lack of career options in their home country or the requirements of the system. At the EU level, 16 % of the researchers report international mobility during their PhD and 13 % are currently employed in a country other than their country of citizenship.

Figure 6.2-4 **Top three barriers to mobility of researchers (%)**



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on MORE3 study

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-4.xlsx

2 The MORE3 study, funded by the EC, collects detailed information and data on the mobility patterns and career paths of EU researchers.

3 https://cdn1.euraxess.org/sites/default/files/policy_library/final_report_2.pdf

Intersectoral mobility of researchers increased by 6 percentage points compared to 2010. In 2017 51 % of EU researchers worked in the private sector, only 20 % of those researchers were female. Intersectoral mobility, understood as the mobility of researchers from academia to industry (and vice versa), is an important mechanism for fostering knowledge transfer and valorisation (in addition to graduates working in industry, collaborative and contract R&D, and (informal) consulting).

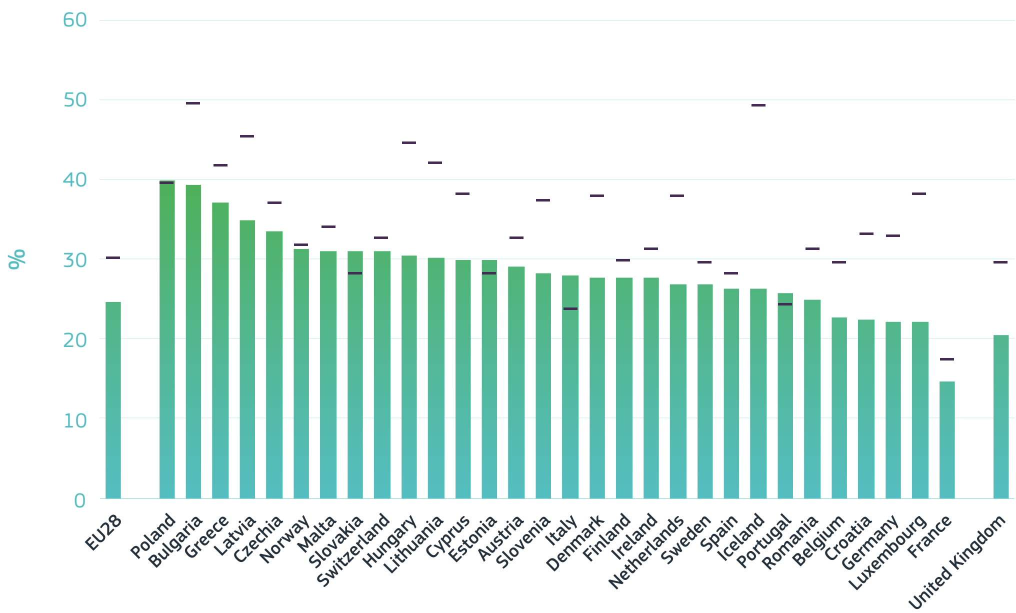
Based on Eurostat data[4], 51 % of EU researchers worked in the private sector in 2017 (not including not-for-profit organisations) compared to 45 % in 2010. In terms of gender, only one fifth (20 %) of researchers in the private sector are female (She Figures 2018). More specifically, women researchers were under-represented in 35 of the 39 countries examined by the report. In the majority of European countries, women researchers are more likely to work in the higher education sector or in government. However, between 2008 and 2015, in the business enterprise sector, the annual growth rate among women researchers was higher than that of men (6.5 % for women and 5.6 % for men in the EU28). The proportion of women researchers was within the 40 % to 60 % range in only four countries (North Macedonia, Bosnia and Herzegovina, Croatia and Latvia), while all the other countries failed to reach the 40 % threshold.

Figure 6.2-5 presents the intersectoral mobility of researchers currently working for a higher education institution and shows the share of researchers moving to another sector at some point in their research careers. The highest levels of mobility are observed in the eastern and southern Member States, with Poland, Bulgaria, Greece, Czechia and Latvia, while the lowest levels of mobility are seen in the northern and western Member States. Therefore, there is a clear pattern of higher intersectoral mobility in the lower-performing countries that may be due to poorer prospects for the exclusively academic path. Interestingly, Norway, Croatia and Romania are all outliers to this trend. More granular data from the MORE3 study show that later-career-stage researchers are more inclined to take positions in government organisations, postdoctoral researchers tend to move to private industry and, in particular, to small and medium-sized enterprises (SMEs) and start-ups, while established researchers are more likely to move to the not-for-profit sector.

The EU Framework Programme's Marie Skłodowska-Curie Actions (MSCA) support intersectoral mobility via co-funding of doctoral programmes and the MSCA Research and Innovation Staff Exchange (RISE), which are based on flexible intersector (within Europe) and international (with third countries) exchanges of highly skilled R&I staff.

4 Based on Eurostat, total R&D personnel (researchers) by sectors of performance, occupation and sex (rd_p_persocc); cf. indicator 1.6 in the MORE3 Indicator report on researchers.

Figure 6.2-5 Evolution of intersectoral mobility, 2012 and 2016



Science, research and innovation performance of the EU 2020

Source: European Commission (2017), MORE3 study

Note: Data from MORE3 EU HE survey (2016) and MORE2 EU HE survey (2012).

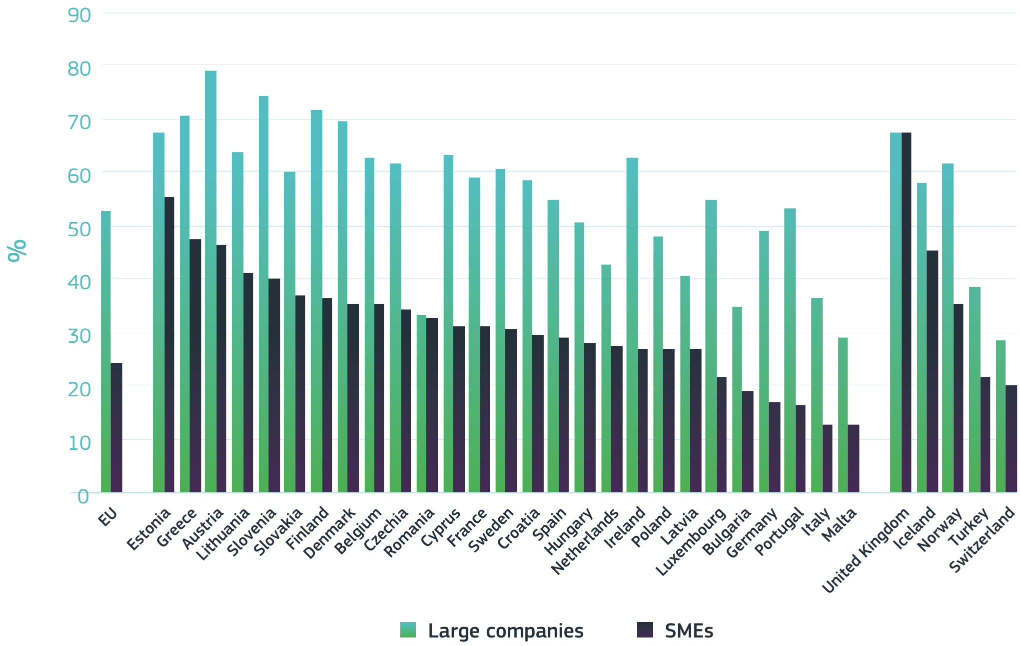
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-5.xlsx

2. In academia-industry co-publications, the EU is catching up with South Korea and the United States while privately financed public research is stagnating at the global level

Collaboration between enterprises and with public research-performing organisations enables faster knowledge diffusion and valorisation; it is a strong driver of innovation. Companies can benefit from highly qualified human resources, access – often tacit – knowledge and technology, as well as from using research infrastructures. Higher education institutions can gain additional revenue streams from consultancy work, licensing or patenting, equip their researchers with new skills and gain insights into the innovation process (Rybnicek and Königsgruber, 2018). In a globalised world, this collaboration is enabled and further stimulated by digitalisation and is becoming increasingly international. This type of intersectoral, interdisciplinary and international collaboration will be crucial to achieve the UN's Sustainable Development Goals (SDGs)[5], given the need for the participation of private companies, non-profit organisations, citizens and public administrations to achieve systemic transitions for sustainable growth.

All EU countries have a higher share of large innovative companies engaging in cooperation than innovative SMEs, although the differences between the Member States are stark for both types of enterprises. Figure 6.2-6 depicts the degree of business cooperation with other enterprises or organisations divided between large and small and medium-sized enterprises (SMEs). More than half of the innovative large companies engage in cooperation activities with third parties across the EU, compared to one in three innovative SMEs. All countries are characterised by higher shares of collaboration among large enterprises (with the exception of the UK where the shares are almost equal between large companies and SMEs). The highest participation of SMEs is noted in Estonia, Greece and Austria as well as in the UK and Iceland, while Austria, Slovenia, Finland, Denmark, Ireland and Norway display the highest shares of participation by large companies.

Figure 6.2-6 Share of innovative enterprises[(1)] involved in any type of cooperation (%), 2016



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: inn_cis10_coop)

Note: [(1)]Product- and/or process- innovative enterprises, regardless of organisational or marketing innovation (including enterprises with abandoned/suspended or ongoing innovation activities).

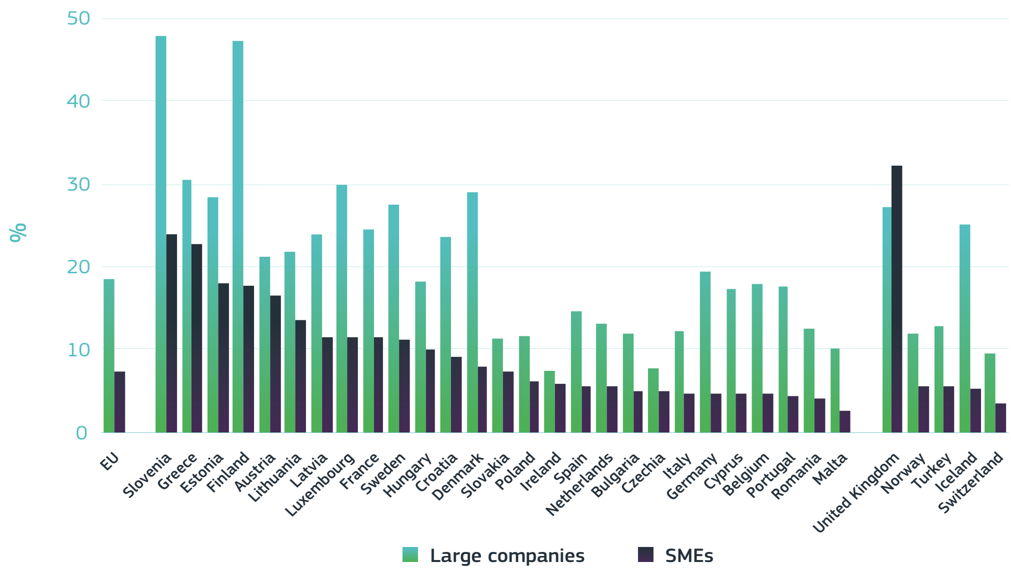
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-6.xlsx

5 https://sustainabledevelopment.un.org/?menu=1300

When looking at the innovative companies involved in collaboration with competitors or other enterprises in the same economic sector, in all countries except the UK, where the shares are equal, large companies tend to be more collaborative within their economic sectors than SMEs. While in all countries except the UK, where the shares are almost equal at around 30%, large companies tend to be more collaborative within their sectors than SMEs in cooperation that is very often organised vertically around supply chains. However, the differences between countries are very important with almost 50% of large companies in Slovenia and Finland involved in cooperation, compared to only 7% in Czechia and Ireland. SMEs display a much lower tendency to collaborate in their sector, with two-digit figures only in Baltic countries, Greece, Slovenia, Austria, Luxembourg, France and Sweden and less than 5% in Czechia, Italy, Germany, Cyprus, Belgium, Portugal, Romania and Malta (Figure 6.2-7).

In all EU countries, the number of public-private co-publications continues to rise although the EU still lags behind the United States and South Korea. Japan and China occupy the fourth and fifth position, respectively. The EU's good standing has to be considered in the context of important differences between the Member States. A public-private co-publication involves R&D staff in businesses, or other private-sector organisations, co-authoring a research publication with partners in a public-sector organisation. In addition to inter-firm cooperation, this type of collaboration represents a successful channel for knowledge transfer ('knowledge spillover').

Figure 6.2-7 Share of innovative enterprises[1] cooperating with competitors or other enterprises in the same sector (%), 2016



Science, research and innovation performance of the EU 2020

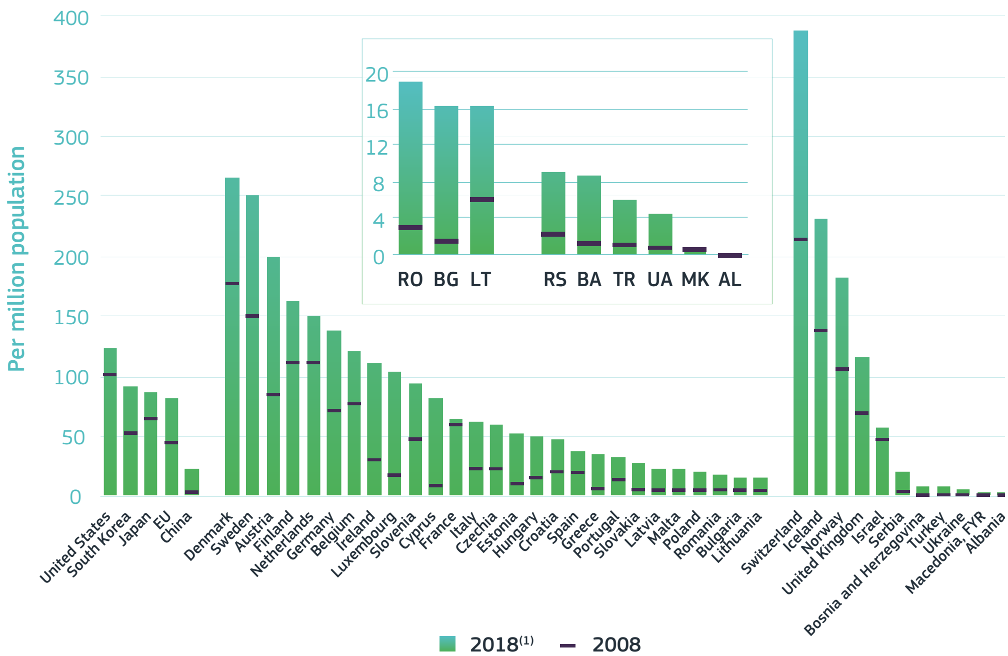
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: inn_cis10_coop)

Note: [1]Product- and/or process- innovative enterprises, regardless of organisational or marketing innovation (including enterprises with abandoned/suspended or ongoing innovation activities).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-7.xlsx

Figure 6.2-8 shows that, while the EU improved its position in terms of growth and overtook Japan between 2008 and 2018 (from 47.1 to 86.4 with Japan rising from 65.7 to 86.1 per million population), the United States and South Korea continued to expand their public-private collaboration (from 105 to 122.7 and from 53.4 to 92.6, respectively). Although China also noted very important growth (from 4 to 22.5), it remains relatively far from other countries. There are major differences within the EU, with Denmark, Sweden and Austria featuring impressive rates of 267.1, 257 and 200.5 per million population. Eastern and southern European countries are mainly situated at the bottom of the ranking with Poland, Romania, Bulgaria and Lithuania registering the lowest rates at 20.9, 19.1, 16.5 and 16.4, respectively. The associated countries are also divided between high rankings, such as Switzerland, Iceland and Norway (388.5, 232.5 and 182.4, respectively) and very low rankings, such as Albania (0.7), North Macedonia (4.3) and Ukraine (5.8). These stark differences may be due to the quality of the science base, as well as the absorptive capacity of the private sector and its R&I intensity.

Figure 6.2-8 Public-private co-authored scientific publications per million population, 2008 and 2018



Science, research and innovation performance of the EU 2020

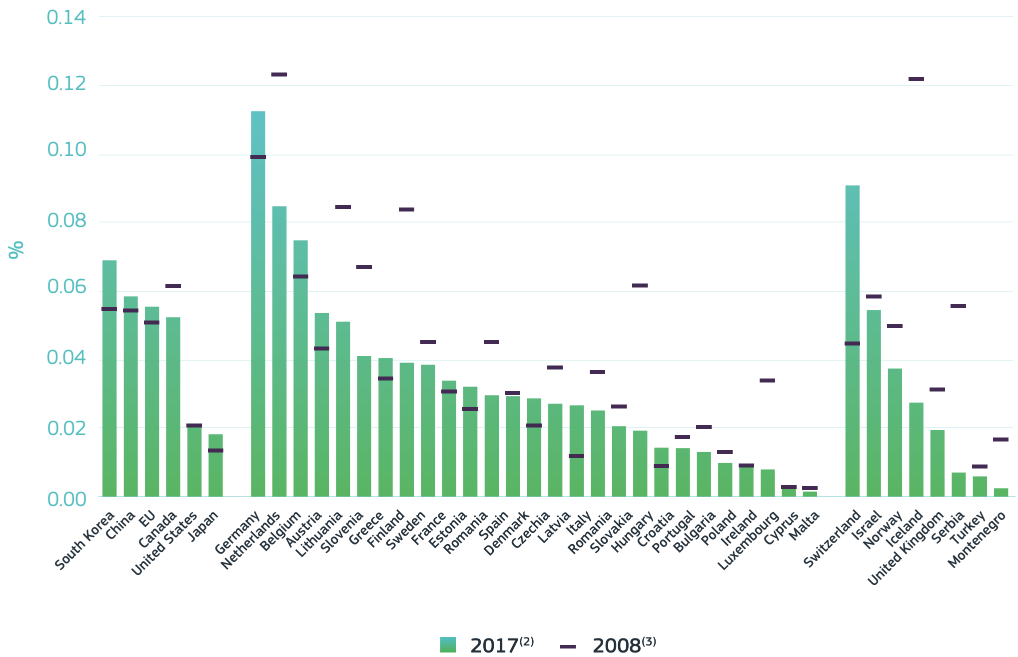
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Science-Metrix using data from the Scopus database, Eurostat and World Bank data

Note: (1)US, JP, CN, KR: 2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-8.xlsx

In the EU, public expenditure on R&D financed by business enterprises has risen only slightly with important differences between the Member States, associated countries and third countries. Collaboration between business and academia is often measured by the share of public spending on R&D that is financed by private companies as a percentage of GDP. Figure 6.2-9 shows that while this type of collaboration has risen slightly in the EU over the last 10 years, several countries face a sharp decline in this value. The Netherlands, Finland, Lithuania, Slovenia and Hungary as well as Iceland and Serbia report significant declines, while Germany and Belgium as well as Switzerland and Bosnia and Herzegovina note relatively important increases. Among third countries, South Korea and China are the best performers, putting the EU average into third place while far outperforming both the United States and Japan. Although the international comparison confirms the EU's good position, the stark differences and decline in some Member States call for enhanced linkages between the public and private sectors.

Figure 6.2-9 Public expenditure on R&D financed by business enterprise[1] as % of GDP, 2008 and 2017



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Data: Eurostat (online data code: rd_e_gerdfund), OECD

Notes: [1]Public expenditure on R&D financed by business enterprise does not include financing from abroad. [2]SI, UK, IS, IL: 2016. [3]DK, LU, NL, AT, SE, NO, RS: 2009; EL, ME: 2011. [4]US, JP, CN, CA, BE, FR, NL, RO, SI, IS, RS: breaks in series occur between 2008 and 2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-9.xlsx

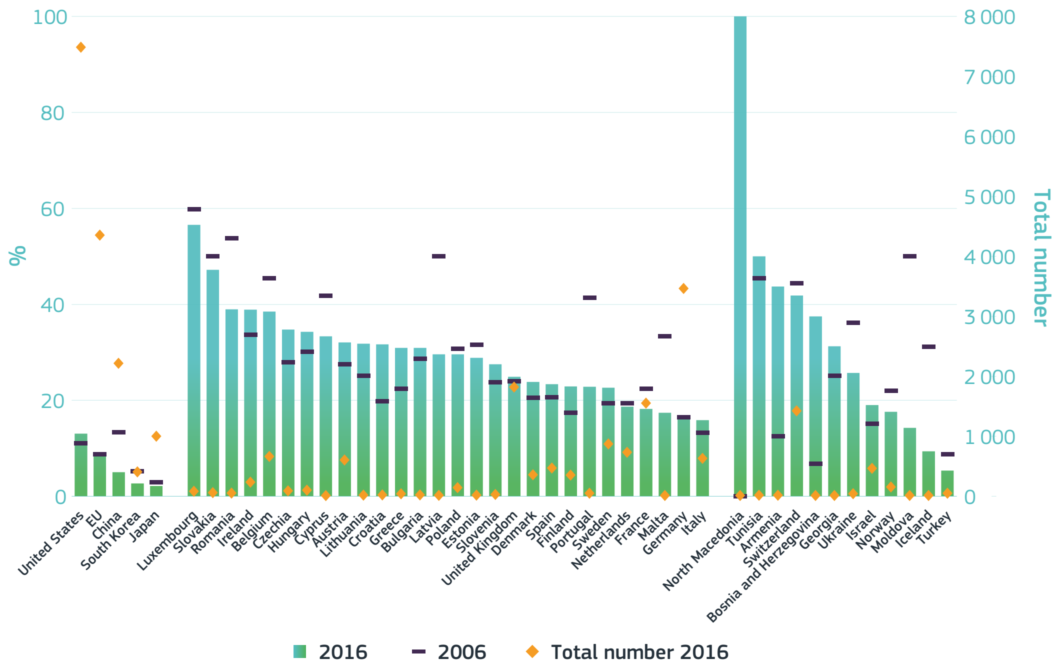
3. The US and EU are leading in international technological cooperation. In some EU countries, foreign direct investment and foreign business research investment still play an important role in knowledge diffusion

In some European Member States, as well as globally in catching-up economies, knowledge diffusion and technological transformation are driven by foreign business research investment and foreign direct investment (FDI).

The intensity of knowledge flows can be proxied by the share of foreign value added in exports (share of foreign value added in exports shows how much of a country's value added of inputs were imported in order to produce intermediate or final goods/services to be exported). A high share of added value shows a high amount of knowledge flowing into a given country. It can also be measured by the share of patents with foreign co-inventors in the total number of patents.

The United States and EU are leading in international technological cooperation, while China and Japan are falling behind, as shown by the share of patents with foreign co-inventors in the total number of patents. Figure 6.2-10 shows European countries' performance including extra and intra-European collaboration, while the EU performance refers only to collaboration with extra European inventors. As for other indicators of collaboration, large variations are observed between the Member States, with Luxembourg and the eastern European countries taking the lead. The smallest shares are reported by larger Member States with a strong industry base, such as Germany, Italy and France, as well as Malta which relies heavily on the - less patent-intensive - information and communications technology industry. For countries associated with the Framework Programme, this variation is important, although given the very low absolute values for many of them, the results are difficult to interpret (e.g. only two patents for North Macedonia).

Figure 6.2-10 Share (%) of PCT[1] patents with foreign co-inventor(s) in total number of patents[2], 2006 and 2016 and total number of patents with foreign co-inventor(s) in 2016



Science, research and innovation performance of the EU 2020

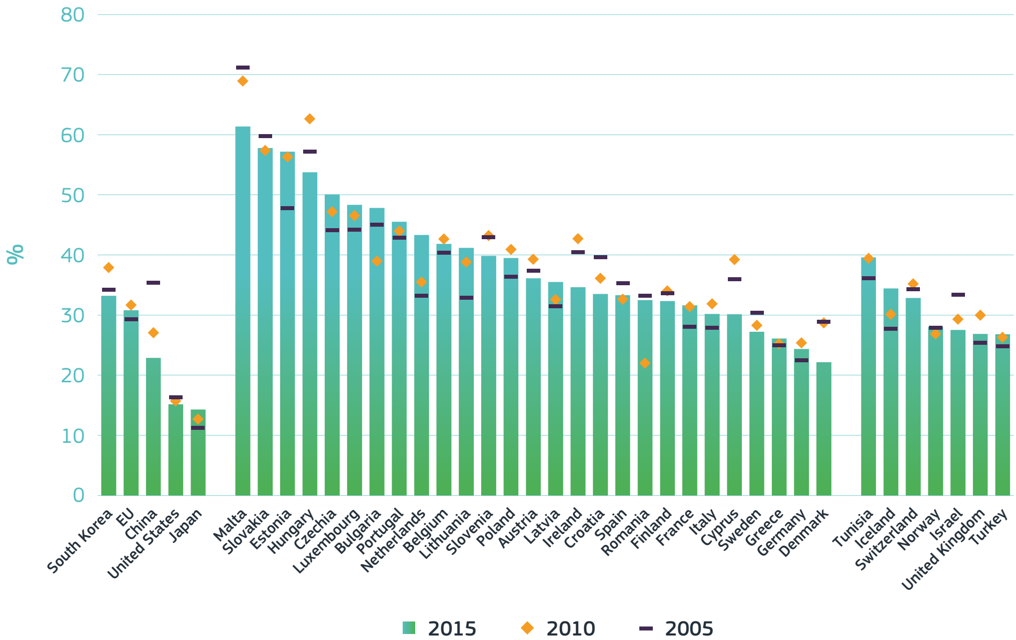
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on OECD (International co-operation in patents) data

Notes: [1]Patent Cooperation Treaty (PCT) patents, at the international phase designating the European Patent Office. [2]Full counting method used.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-10.xlsx

The foreign value-added share of gross exports in high-tech and medium-high-tech sectors is still very important in Europe, notably for southern and central eastern European countries. At the global level, it is still significant for South Korea and China, with China having an active policy in place to reduce its needs for foreign-based technology. In the EU, Slovakia, Estonia, Hungary, Czechia and Bulgaria, together with Malta and Luxembourg, exhibit the highest share of foreign value added at between 61 % and 48 %. Germany, Denmark, Greece and Sweden exhibit the lowest share (under 30 %, which is the EU average) in the EU. For Slovakia, Hungary and Czechia – with its strong manufacturing base – FDI is still a major source of external R&D financing. With their open economies, both Malta and Luxembourg attract foreign investment in specific tech sectors. At the global level, South Korea and China's shares are still significant albeit declining (in 2015, 33 % for South Korea and 23 % for China, a fall of 35 % over 10 years). The EU shares remain high at 31 %, while the United States and Japan rank lower (15 % and 14 %, respectively). The gradual decrease for China will most probably continue given the 'Made in China 2025 strategy' (2015) which seeks to steadily reduce the need for foreign-based technology by fostering domestic competitiveness and to further facilitate the access of Chinese companies to international markets (JRC 2019).

Figure 6.2-11 Foreign value added share (%) of gross exports in high-tech and medium-high-tech sectors, 2005, 2010 and 2015



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on OECD (Trade in Value Added - TiVA) data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-11.xlsx

4. The EU continues to lead on open science policy and international scientific collaboration with its Framework Programme playing an important role

Advances in technology make science both an increasingly open and global enterprise. Technological advances, including digital infrastructures, strong open science bottom-up activism as well as funders and institutional policies, drive these changes in science practices.

The progress both in data production and its availability through open data standards is speeding up the research process, addressing the reproducibility crisis (e.g. Ioannidis and Khoury, 2011) **and increasing the efficiency of public investment in research**. Sharing publicly funded scientific results openly democratises the access to science across countries and widens it to companies and citizens. Open access[6] and transdisciplinary data reuse and interoperability (FAIR principles[7])

6 Immediate, online, free availability of research outputs without restrictions on use commonly imposed by publisher copyright agreements – OpenAIRE definition.

7 The FAIR data principles define a minimal set of community-agreed 'aspirational' guidelines for the publication of digital resources such as datasets, code, workflows, and research objects, to achieve a state of 'FAIRness' (Wilkinson et al., 2018).

are vital for addressing the interconnected and pressing socio-economic and environmental challenges we are currently facing (UN SDGs). While open access policies are already mature within existing European, national and institutional policies, advances in data sharing face many obstacles, given the lack of data-sharing valorisation (journal impact factors and citations; Scheliga and Friesike, 2014). Changing the reward and incentive system for researchers is key to ensuring higher take-up and demands the involvement of major stakeholders (higher education institutions, funding agencies, ministries of science and higher education). The Commission has already made provisions for cost eligibility for open science activities in its next Framework Programme.

Several EU Member States and associated countries are ahead of the United States, leading the transition to the open access of research outputs, while China and South Korea are lagging behind. Research stakeholders are pursuing a global process of facilitating the transition to open science, which is most visible in mature policies of open data and open access to scientific publications. As shown in Figure 6.2-12, country performances regarding open access to scientific publications made available through online repositories (green access)[8] is very disparate with lower shares in lower-performing countries, while the performance on open access to scientific publications made available through publishers' websites (gold access)[9] oscillates at around 10% for most countries. The differences in performance in open access through online repositories may be due to differences in the availability of national and university research repositories and the existence of national and institutional policies.

As observed in Figure 6.2-12, Croatia, the Netherlands, Luxembourg, Sweden, Austria, the UK, Norway and Switzerland are ahead of the United States, while China and South Korea are lagging behind.

The European Commission co-designed and co-implemented an ambitious and holistic open science policy[10]. It introduced a strong open access and open data mandate in Horizon 2020 and has included potentially stricter requirements in Horizon Europe (research data open by default, mandatory data management plans, mainstreaming of FAIR principles, strengthened requirements on open access) as well as support for citizen involvement in research (citizen science). The European Commission's approach was endorsed by several funders and institutions and inspired international, national and regional policies (e.g. the Australian Research Data Commons[11] or the African Open Science Platform[12]). The Commission also supports the efforts of cOAlition S[13] to accelerate the full transition to open access to scientific

8 Research outputs that are not made open access from the publisher's website but from an open access repository, whether institutional or thematic. This is commonly referred to as green open access.

9 Research outputs are made openly accessible on the journal website by the publisher. This is commonly referred to as gold open access.

10 For example, laid out in the Commission Communication: European Cloud Initiative - Building a competitive data and knowledge economy in Europe: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016DC0178&from=EN and Commission Recommendations on access to and preservation of scientific information: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018H0790&from=EN

11 https://ardc.edu.au/about/

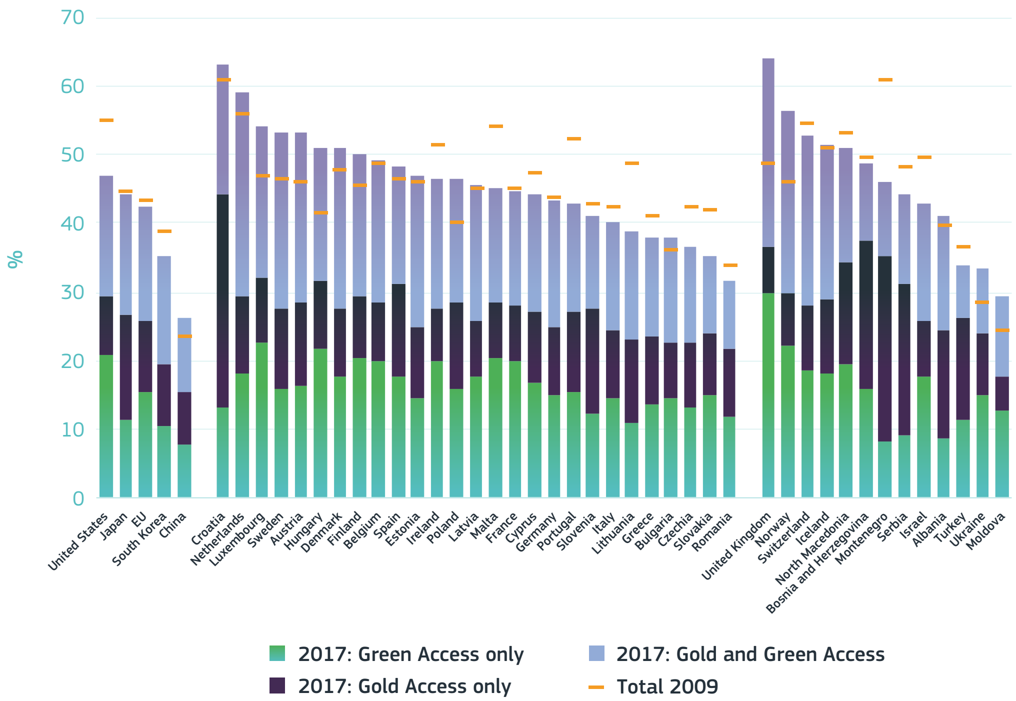
12 http://africanopenscience.org.za/

13 https://www.coalition-s.org/

publications. Open science principles and practices are an integral part of EU policy, including the new Directive on open data and the reuse of public-sector information[14], the revised Recommendation on access to and preservation of scientific information[15] and the General Data Protection Regulation[16]. National initiatives in the Netherlands, Finland and Italy show that Member States are taking up these policies and activities. Recent evidence finds that – as a direct result of directional policies by research funders – open science activities have structuring effects on both scientific outputs and knowledge flows, as well as on institutional research structures and practices, increasing research performance and economic performance (Tennant et al., 2016; Fell, 2019).

The work on open science principles and incentives is also spreading globally through the work of the G7, OECD and under the auspices of the Research Data Alliance (RDA)[17].

Figure 6.2-12 Open access scientific publications[(1)] with digital object identifier (DOI) as % of total scientific publications with DOI, 2009 and 2017



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit
Note: [(1)]Data produced by Science-Metrix using data from Scopus and 1findr databases. The full counting method was used.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-12.xlsx

14 https://ec.europa.eu/digital-single-market/en/european-legislation-reuse-public-sector-information
15 https://ec.europa.eu/digital-single-market/en/news/recommendation-access-and-preservation-scientific-information
16 https://ec.europa.eu/info/law/law-topic/data-protection/data-protection-eu_en
17 https://rd-alliance.org/

BOX 6.2-1 The European Open Science Cloud

Most of the underlying data of scientific work is not published and therefore not accessible to the research community or the public. If relevant data was findable, accessible and interoperable for scientists, these combinations would lead to (unforeseen) reuse and to faster developments in science. This is the aim of the European Open Science Cloud (EOSC).

The EOSC will enable data sharing and offer Europe a trusted and open environment for the scientific community, provide seamless access to data and interoperable services addressing the whole research data life cycle. The development of the EOSC achieves EU policy objectives such as Open Science, FAIR data implementation and the Digital Single Market.

The EOSC will be a virtual commons (resources accessible to all researchers) **where science producers and science consumers come together for greater insights, new ideas and more innovation**. By federating research data and services, the EOSC adds value. The EOSC uses information technologies to change the way scientists conduct research, and how collective scientific knowledge is created across disciplines and borders. The EOSC will evolve into a system that is flexible by design and can adapt to the changing landscape and technological advances.

A minimal viable EOSC environment is planned for the end of 2020, including agreed rules of participation, supporting services for the EOSC federation, an initial set of data services for researchers, a persistent identifier policy, metrics for FAIR data and certified services, and strategic orientations for financing models, the legal set-up and governance of the EOSC after 2020.

The resulting EOSC environment will then be progressively extended and scaled up while building on the following **common values**:

- Focus on research and innovation needs
- Community-driven
- Inclusive and respectful of diversity
- Accessible to all from large equipment, large computers and 'big data' to 'small data' and long-tail research
- Open by default – closed where necessary
- Hands-on and participatory
- Transparent and trustworthy.

Two thirds of researchers in the EU have collaborated or worked in more than one discipline, which is key to addressing the economic, social and environmental transitions required for a more sustainable Europe. Interdisciplinary collaboration, understood as collaboration between researchers working in different disciplines, is key to fostering knowledge and technology circulation across Europe. In addition, interdisciplinary research is needed to address the SDGs, enhance the ability to understand the complex challenges the world currently faces (Eagan, Cook and Joeres, 2002) as well as bring diverse perspectives together to find solutions and establish and exploit synergies.

The MORE3 survey shows that 73.5% of researchers have collaborated with researchers in other fields. In the EU, 60% of researchers collaborate with other researchers working in other disciplines but within the same institute, and 57% in other universities or research institutes. However, only 31% have collaborated with the non-academic sector. This limited knowledge flow outside of academia is one of the key issues to tackle in order to strengthen the valorisation of knowledge in Europe. More efforts are needed to embed a 'valorisation culture' in publicly funded research. The same study shows that 34% of researchers working in the EU have switched to another (sub-)field of science during their research career. Overall, researchers tend to have a positive view on this type of mobility in spite of the debates on the caveats of interdisciplinarity – e.g. difficulties in publishing articles based on interdisciplinary approaches, limitations over the peer-review process and scientific standards.

Figure 6.2-13 Share of researchers who have collaborated with or worked in more than one field in their current position

	Of all researchers (n=9,412)			
	EU28 total	**Per career stage**	**Per FOS**	**Per gender**
2016	73.5%	R1: 66.2%	NAT: 74.4%	F: 74.0%
		R2: 73.7%	ENG: 75.5%	M: 73.2%
		R3: 73.2%	MED: 76.2%	
		R4: 77.5%	AGR: 84.7%	
			SOC: 67.7%	
			HUM: 71.6%	

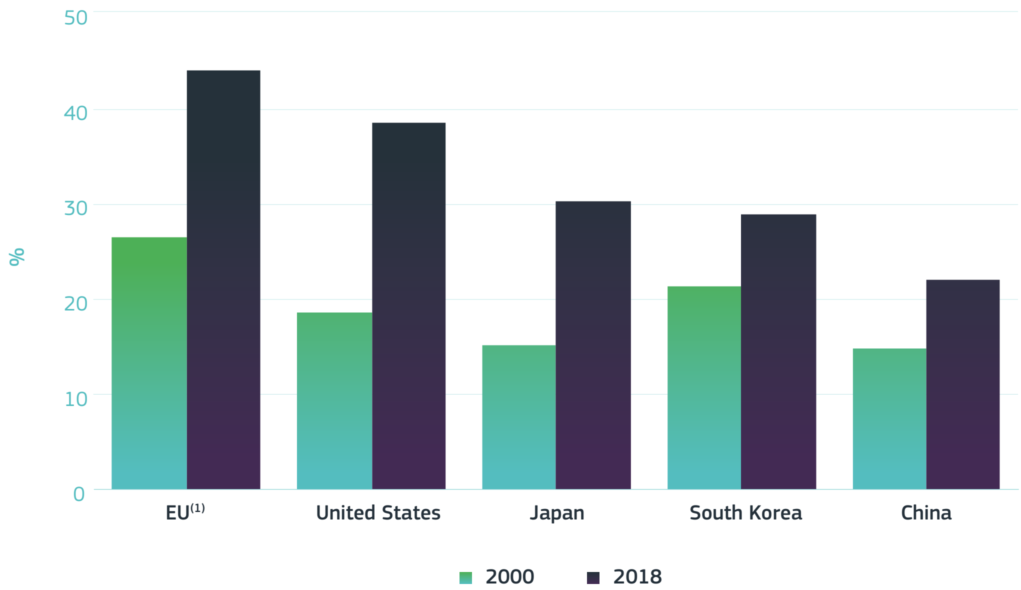
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on MORE3 study

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-13.xlsx

The EU has secured its leading position in international scientific collaboration, which has seen sharp increases both in the EU and in the United States and Japan. The EU28's share of international scientific co-publication almost doubled between 2000 and 2018 (from 24.6% to 43.7%, including intra-EU collaborations), with an even more significant rate of growth observed in the United States (from 18.7% to 38.3%) and Japan (from 15% to 30.3%). South Korea and China also increased their shares of international co-publications (from 21.2% to 28.9% and 14.8% to 22%, respectively). This trend leads to improved scientific quality since scientists achieve greater impact from their international collaborations. This is actively supported at the European level through specific Framework Programme funding and initiatives such as Marie-Curie Skłodowska Actions (MSCA). However, granular data on EU Member State collaboration shows that several eastern European countries (Romania, Bulgaria, Poland) still report lower levels of international exposure and collaboration (Figure 6.2-14).

Figure 6.2-14 International scientific co-publications as % of total scientific publications, 2000 and 2018(1)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit
Data: Science-Metrix based on Scopus database
Note: (1)EU average includes intra-EU collaborations.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-14.xlsx

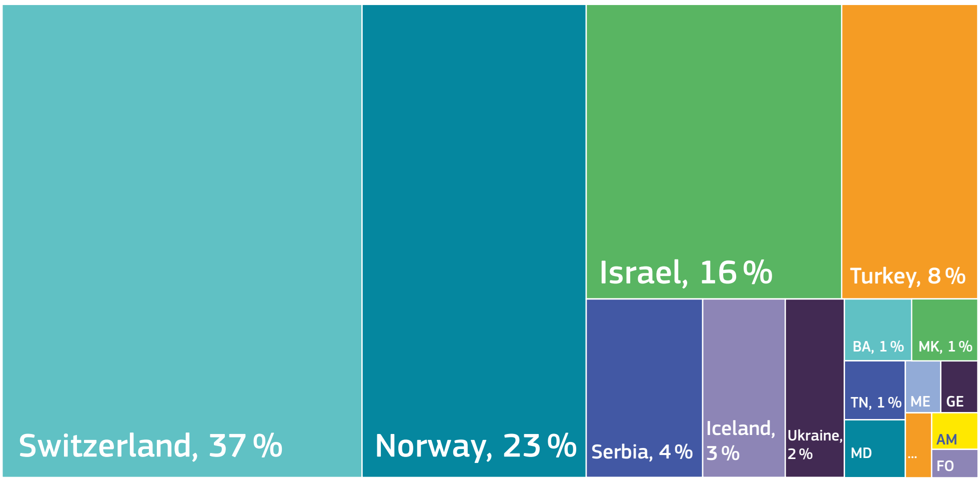
Horizon 2020 demonstrates broad international outreach attracting talent from around the world. Countries with strong R&I performances, such as Switzerland, Norway and Israel, are the most active associated countries in Horizon 2020, while almost one third of the participation from non-associated third countries comes from the United States. As per Figure 6.2-15, Switzerland is the most active associated country in terms of participation, with 2 808 – i.e. A share of 37 % of all associated countries. Norway, Israel and Turkey account for 23 %, 17 % and 9 %, respectively. The associated countries with the lowest participation (less than 1 % participation from associated countries) are Tunisia, Moldova, Georgia, Montenegro, Albania, Armenia and the Faroe Islands. Moreover, the networked analysis shows that Switzerland occupies a very central position in the collaboration network amongst participants in Horizon 2020, next to other EU28 countries such as Sweden, Greece and Austria[18].

With applicants from 163 non-associated third countries to date, Horizon 2020 demonstrates a broad international outreach. Currently, with over 1 100 participations, the US accounts for about 30 % of the participation from non-associated third countries (Figure 6.2-16). The United States

18 https://ec.europa.eu/info/sites/info/files/research_and_innovation/knowledge_publications_tools_and_data/documents/h2020_monitoring_flash_022019.pdf

is followed by China (9% of participations from non-associated third countries), Canada (6%), Australia (5%), South Africa (4%) and Brazil (4%). Overall, the top-20 participant non-associated third countries gather 81% of these participations, with a lower level of participation from many developing economies.

Figure 6.2-15 Share of participations from associated countries in Horizon 2020 (% of all associated countries' participation)

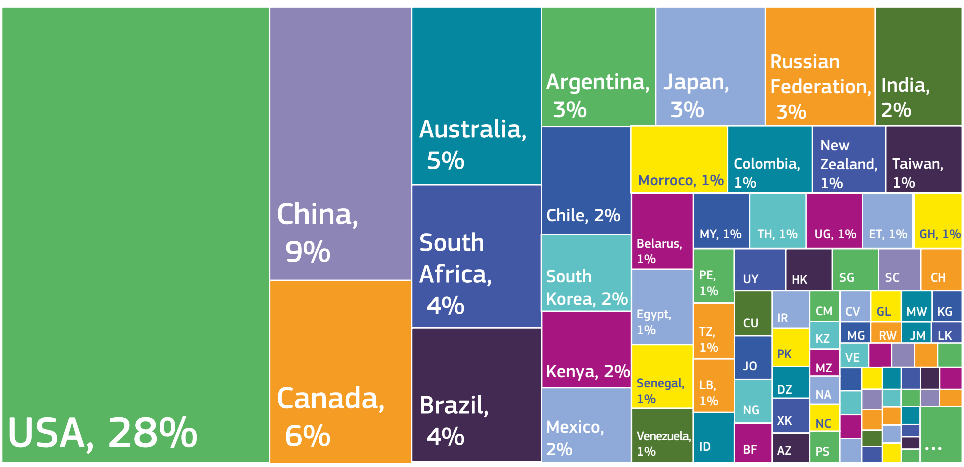


Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on CORDA data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-15.xlsx

Figure 6.2-16 Share of participations from non-associated third countries in Horizon 2020



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on CORDA data

Note: Cut - off date - January 2020.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-16.xlsx

Most of the collaborations are with countries with advanced R&I capabilities, in particular through researcher mobility schemes such as MSCA but also through specific projects and multilateral initiatives to support sustainable development and address global societal challenges. Countries with strong R&I performances, such as Switzerland, Norway and Israel, are the most active associated countries, while almost one third of participations from non-associated third countries come from the United States (partly due to its significant participation in MSCA schemes).

Interestingly, an analysis of the EU's R&I Framework Programme participation patterns shows specific preferences for cross-country collaborations. Geographical and cultural proximities among participants seem to play an important role in shaping the structure of collaboration networks, at least in the case of the EU Framework Programme (Balland et al., 2019).

5. Conclusions

Although researchers' mobility remains key to knowledge diffusion, stark disparities remain between countries in international and intersectoral mobility patterns in the EU. In general, countries with a higher R&I performance tend to have higher inflows and outflows of researchers and the size of the R&I system also plays an important role. Those divergences call for a better understanding of drivers of and barriers to international and intersectoral mobility as well as the implementation of policies to foster brain circulation.

The EU is catching up with South Korea and the United States in terms of public-private co-publications. However, private financing of public research remains stagnated at the global level, with large disparities between EU countries. Collaboration patterns show that a few large innovative companies are making the most of international and intersectoral cooperation. In order to raise the competitiveness of European SMEs, the capacity of small firms must be strengthened to enable them to engage in R&I collaborations. As the geographical proximity of academia is still paramount for industry's innovative activities – in spite of the importance of digitalisation policies – the interaction between industry and academia must continue to be facilitated and strengthened.

The United States and the EU are leading in international technological cooperation, while China and Japan have taken a step back. In some EU countries, as well as in globally catching-up economies, knowledge diffusion and technological transformation continues to be stimulated through foreign direct investment and foreign business research investment. International technological cooperation data points to an active policy in China which is trying to reduce its need for foreign-based technology through domestic competitiveness and to further facilitate Chinese companies' access to international markets. This places international technological cooperation policies in a wider perspective of changing global approaches to trade and technological sovereignty.

The EU continues to lead in open science policy. Among the global trend for intensification of international scientific collaboration, the EU has secured its leading position with its Framework Programme playing an important role by involving participants from third countries. While the EU's open access policy is well advanced, there is a need to step up efforts to implement Europe's ambitious open and FAIR data policy.

6. References

Andrews, D., Criscuolo, C. and Gal, P.N. (2015), Frontier firms, technology diffusion and public policy: micro evidence from OECD countries, The Future of Productivity Main Background Papers, OECD.

Balland, P.A., Boschma, R. and Ravet, J. (2019), Network dynamics in collaborative research in the EU, 2003-2017, *European Planning Studies*, 27(9), 1811-1837, https://doi.org/10.1080/09654313.2019.1641187.

Eagan, P., Cook, T. and Joeres, E., (2002) Teaching the importance of culture and interdisciplinary education for sustainable development, *International Journal of Sustainability in Higher Education*, 3 (1), pp. 48-66, https://doi.org/10.1108/14676370210414173.

European Commission Directorate General for Research and Innovation (2019) She Figures 2018, Publication Office of the European Union.

European Commission, Joint Research Centre (2019), China: Challenges and Prospects from an Industrial and Innovation Powerhouse, EUR - Scientific and Technical Research Reports, Publication Office of the European Union, https://doi.org/10.2760/445820.

Fell, M. (2019), The Economic Impacts of Open Science: a Rapid Evidence Assessment, Publications, 7(3), https://doi.org/10.3390/publications7030046

Iammarino, S., Rodriguez-Pose, A. and Storper, M. (2018), Regional inequality in Europe: evidence, theory and policy implications, *Journal of Economic Geography*, 19(2), https://doi.org/10.1093/jeg/lby021.

Ioannidis, J.P.A. and Khoury, M.J. (2011), Improving validation practices in “omics” research, *Science*, 334(6060), 1230-1232, https://doi.org/10.1126/science.1211811.

Jonkers, K. and Cruz-Castro, L. (2013), Research upon return: The effect of international mobility on scientific ties, production and impact, *Research Policy*, 42 (8), 1366-1377, https://doi.org/10.1016/j.respol.2013.05.005.

Nesta (2019), Innovation mapping now.

Rybnicek, R. and Königsgruber, R. (2109), What makes industry-university collaboration succeed? A systematic review of the literature, *Journal of Business Economics*, 2019, 89 (2), 221.

Sansone, S., McQuilton, P., Rocca-Serra, P. et al. (2019), FAIRsharing as a community approach to standards, repositories and policies, *Nat Biotechnol*, 37, 358–367. https://doi.org/10.1038/s41587-019-0080-8.

Scheliga, K. and Friesike, S. (2014), Putting open science into practice: a social dilemma?, *First Monday*, 19 (9), https://doi.org/10.5210/fm.v19i9.5381.

Tennant, J.P., Waldner, F., Jacques, D., Masuzzo, P., Collister, L.B. and Hartgerink, C., (2016), The academic, economic and societal impacts of Open Access: an evidence-based review, F1000Res; 5: 632: https://doi.org/doi:10.12688/f1000research.8460.3

Veugelers, R. (2017), Countering European brain drain, *Science*, 356(6339), 695-696, https://doi.org/10.1126/science.aan3920.

Wagner, C. S. and Jonkers, K. (2017), Open countries have strong science, *Nature* 550, 7674: https://doi.org/doi:10.1038/550032a

Wagner, C.S., Whetsell, T., Baas, J. and Jonkers, K. (2018), Openness and Impact of Leading Scientific Countries, *Frontiers in Research Metrics and Analytics*, https://doi.org/10.3389/frma.2018.00010.

Wilkinson, M. Sansone, S-A., Schultes,E. Doorn, P. Bonino da Silva Santos,L., Dumontierc, M. (2018), A design framework and exemplar metrics for FAIRness, Scientific Data 5, 180118. https://doi.org/10.1038/sdata.2018.118.

CHAPTER 6.3

INNOVATION OUTPUT AND KNOWLEDGE VALORISATION[1]

KEY FIGURES

48 %
of EU companies were considered innovative

1 in 5
worldwide PCT patent applications come from the EU

9x better
performance on average for the top 10 EU economies in PCT patent applications

101.2
EU Innovation Output Indicator, below Japan and the United States

1 Valorisation in the context of the EU Framework Programmes is referred to as exploitation.

What can we learn?

- The **EU is falling short in the Innovation Output Indicator compared to Japan and the United States**. **The economic impacts** seen as an outcome of innovation are not only related to innovation capacity but also **to the structure of the economy**, which explains the differences between countries.
- **Japan and China have increased** their share in PCT patent applications while **EU and US shares have dropped significantly** since 2000. In relative terms, the **EU lags behind South Korea, Japan and the United States**.
- **In PCT patent applications, there is still an innovation divide in the EU**, with north-western Europe performing well and south-eastern Europe performing poorly.
- The **EU is leading technological progress in the fields of energy, climate and environment and food and bioeconomy**.
- Nearly **half of the enterprises in the EU were considered innovative**, with higher shares for **product and/or process innovation**.

What does it mean for policy?

- The EU needs to **support European IP policy and culture, foster science-industry interaction** and **engage citizens, local communities and policymakers** in a **knowledge-valorisation policy** for societal, environmental and economic impact. In addition to improving innovation systems, the EU must **encourage structural reforms** that **upgrade Member States' technology profiles**.
- To tackle the current innovation divide, the EU needs to **support poorly performing countries** to improve their innovation systems, **facilitate knowledge circulation** among EU countries and **incentivise the creation** of innovation-intensive sectors in the economy.

1. Innovation output in Europe is lagging

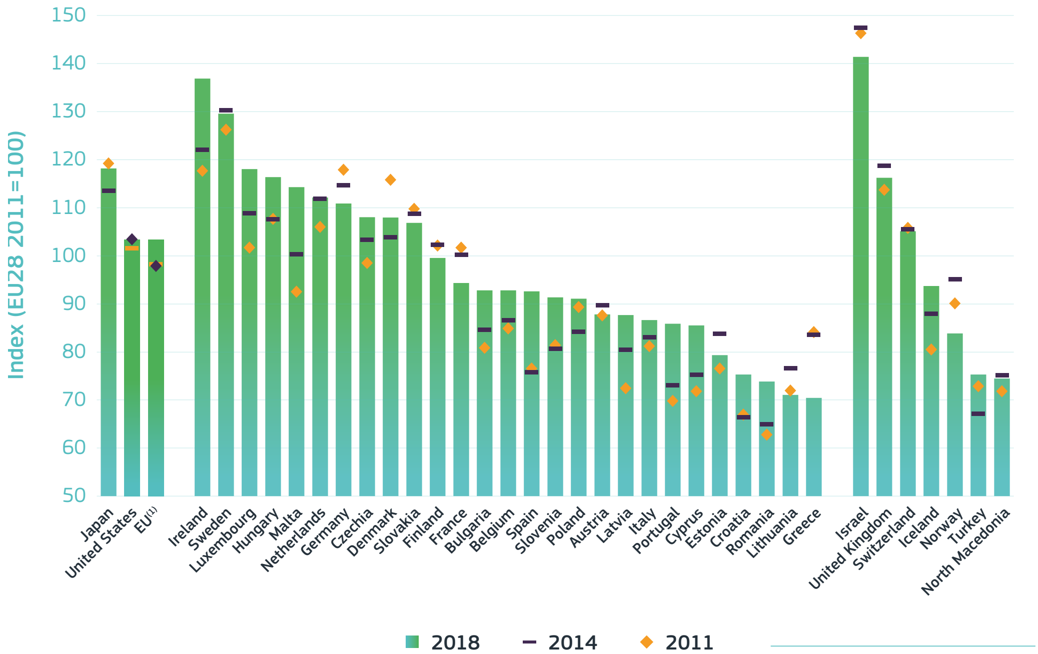
According to the European Commission's Innovation Output Indicator (IOI), the EU lags behind Japan and the United States in terms of innovation output, mainly due to its poor performance in PCT patent applications, with very slow progress in recent years[2]. The composite indicator aggregates four components to measure innovation output (patents, employment in knowledge-intensive activities, trade in knowledge-based goods and services, and innovativeness of high-growth enterprises). These figures differ from the latest results from the European Innovation Scoreboard (EIS) in which the EU surpasses the United States for the first time. However, in addition to these four components, the EIS includes several other dimensions such as investments and framework conditions. Even though the EU is not performing well as a whole, some EU Member States, such as Sweden, the Netherlands and Denmark, show identical or better performances than international competitors in several innovation indexes. For instance, the top 10 in the latest Global Innovation Index[3] includes 5 EU Member States, with Sweden as the best EU performer. In the latest EIS, Sweden, followed by Finland, Denmark and the Netherlands, are the innovation leaders.

Within the EU, Ireland is the best performer, followed by Sweden, Luxembourg and Hungary. Conversely, with its performance worsening, Greece is at the bottom end of the Index, followed by Lithuania and Romania. To some extent, the Innovation Output Indicator confirms the innovation divide between north-western and south-eastern Europe (Figure 6.3-1). However, countries such as Hungary, Malta and Czechia, which show high shares of both medium and high-tech products in total exports and employment in fast-growing enterprises in innovative sectors, are remarkable exceptions. In terms of progress, innovation output has improved in most EU countries. Countries such as Malta and Portugal have improved considerably over time as a result of significant increases in patent applications and innovative high-growth enterprises, while innovation output has declined substantially in Greece due to deterioration in knowledge-intensive services exports and the innovativeness of high-growth enterprises. The mixed progress across the EU indicates that the innovation divide is not diminishing, even though the performance of some innovation leaders, such has Finland, Germany and Denmark, has also dropped.

2 For the last release of the Innovation Output Indicator see Vertesy and Damioli (2020).

3 Cornell University, INSEAD, and WIPO (2019); The Global Innovation Index 2019.

Figure 6.3-1 Innovation output indicator (EU28, 2011 = 100), 2011, 2014 and 2018



Science, research and innovation performance of the EU 2020

Source: European Commission, DG Joint Research Centre (Vértesy and Damioli, 2020)

Note: [(1)]EU: Two sets of values are available: values for worldwide comparison and values for European comparison. The values for worldwide comparison are shown on the graph. The value for European comparison for 2018 is 101.7.

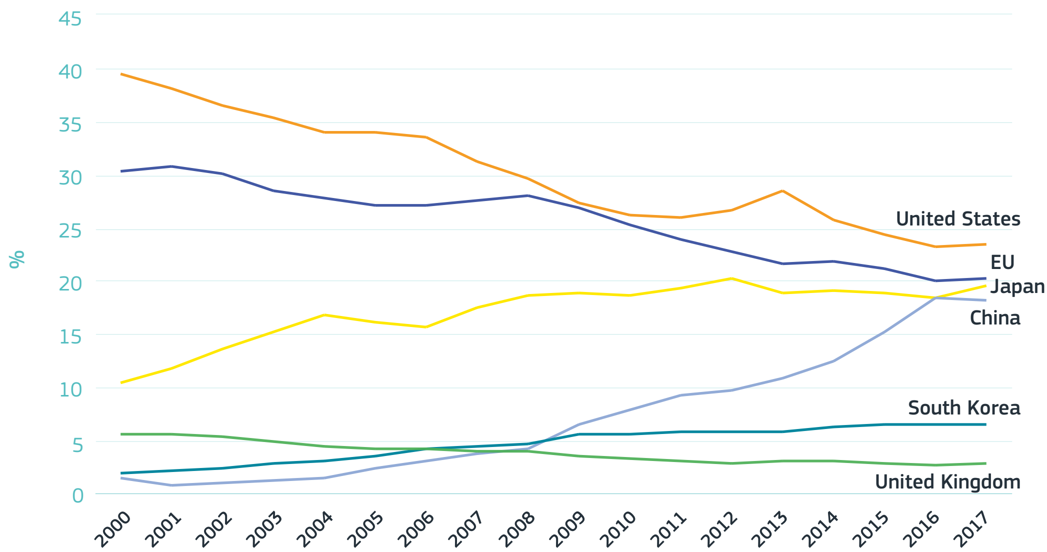
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-1.xlsx

2. Intellectual property in Europe: a mixed picture

To a certain extent, technological innovation resulting from investment in R&I is reflected in the patenting activities of R&I actors. In 2017, the EU accounted for 20% of worldwide PCT[4] patent applications, a decline from its 30% share in 2000 (Figure 6.3-2). While the share of PCT patent applications has been growing quickly in East Asian countries, mainly in Japan and China, in Western countries, such as the United States, the EU and the United Kingdom, the share has been declining. In 2016, China, in particular, became a powerhouse in international patent applications, having caught up quickly by growing at an annual rate of roughly 22% between 2000 and 2017. Even though the United States remains the world leader in PCT patent applications, its share declined significantly from 40% in 2000 to 23.5% in 2017. When comparing these figures with research production in terms of scientific publications, it can be concluded that the EU is not capable of capturing the full value of its excellent science.

4 Patent Cooperation Treaty.

Figure 6.3-2 World shares (%) of PCT patent applications[(1)], 2000-2017



Source: OECD (Patents by technology)

Note: [(1)]Patent applications filed under the PCT, at international phase, designating the European Patent Office (EPO). Patent counts are based on the priority date, the inventor's country of residence and fractional counts.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-2.xlsx

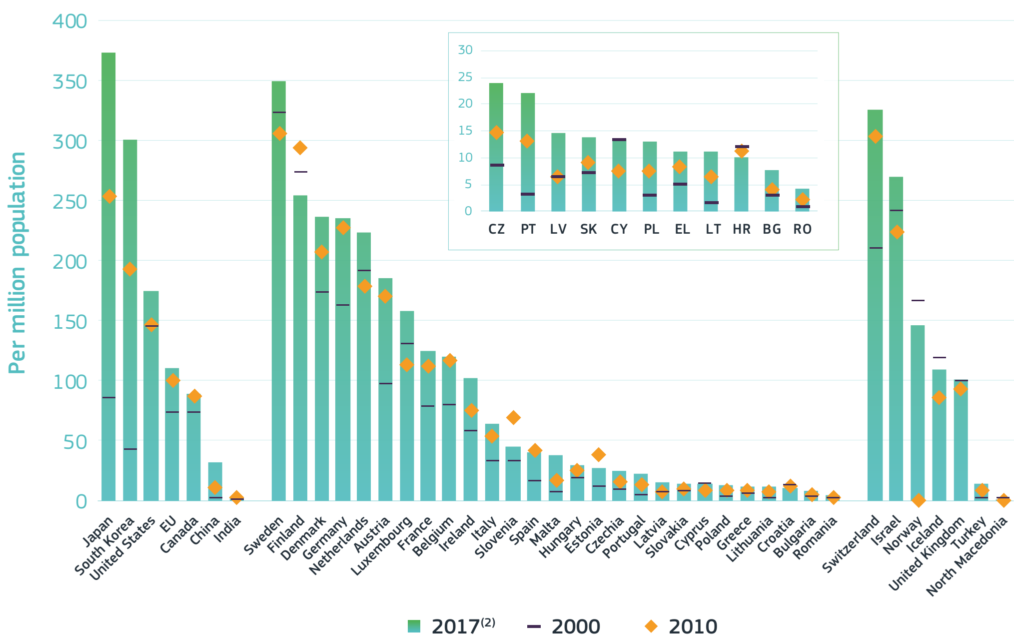
In per capita terms, however, China's performance is well below that of the United States, the EU and advanced Asian economies. When normalised by population, PCT patent applications in Japan and South Korea improved remarkably over time (Figure 6.3-3). In 2000, while South Korea was behind the United States, Europe and Canada, in 2017 it was well ahead of those countries. In recent years, the EU's performance has been quite stable, with an increasing gap with Japan, South Korea and the United States, but remaining ahead of Canada.

Within the EU, performances vary considerably across Member States, reinforcing the persistent innovation divide. While north and western Europe mainly perform well, eastern and southern Europe's performance is poor. Nonetheless, it is important to highlight that several factors explain the differences in performance, i.e. patenting is linked, among other factors, to the share of manufacturing in value added (as manufacturing companies tend to patent more than service-sector companies[5]), to the high-tech orientation of the manufacturing sector, to the share of ICT and research-related services as against other types of services, to the enterprises' size distribution in a country (as larger enterprises tend to have higher patent propensity), and to the location of company's headquarters, as patenting tends to be carried out in countries with legislation which favours patent activity. Between 2000 and 2017, with the exception of Croatia and Finland, all the other EU countries have seen their performance improving. On the negative side, Finland stands out as its performance

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

has worsened substantially. This might be associated with the weak performance of Nokia which is the most important patent applicant[6] in the country. On the other hand, countries like Portugal, Lithuania and Malta have seen two-digit compound growth rates over the same period. As possible explanations, in the case of Portugal, incentives for patent applications, such as the creation of a patent box in 2014, seemed to have boosted patent applications, mainly from the higher education sector[7,8]. Similarly, in the case of Lithuania, several measures to promote the protection of IP rights seemed to have boosted patent applications[9]. Other countries, such as Ireland and Austria, also show significant improvements.

Figure 6.3-3 PCT patent applications[(1)] per million population, 2000, 2010 and 2017



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on OECD (Patents by technology), Eurostat and World Bank data

Notes: [(1)]Patent applications filed under the PCT, at the international phase, designating the European Patent Office (EPO). Patent counts are based on the priority date, the inventor's country of residence and fractional counts. [(2)]MK: 2016.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-3.xlsx

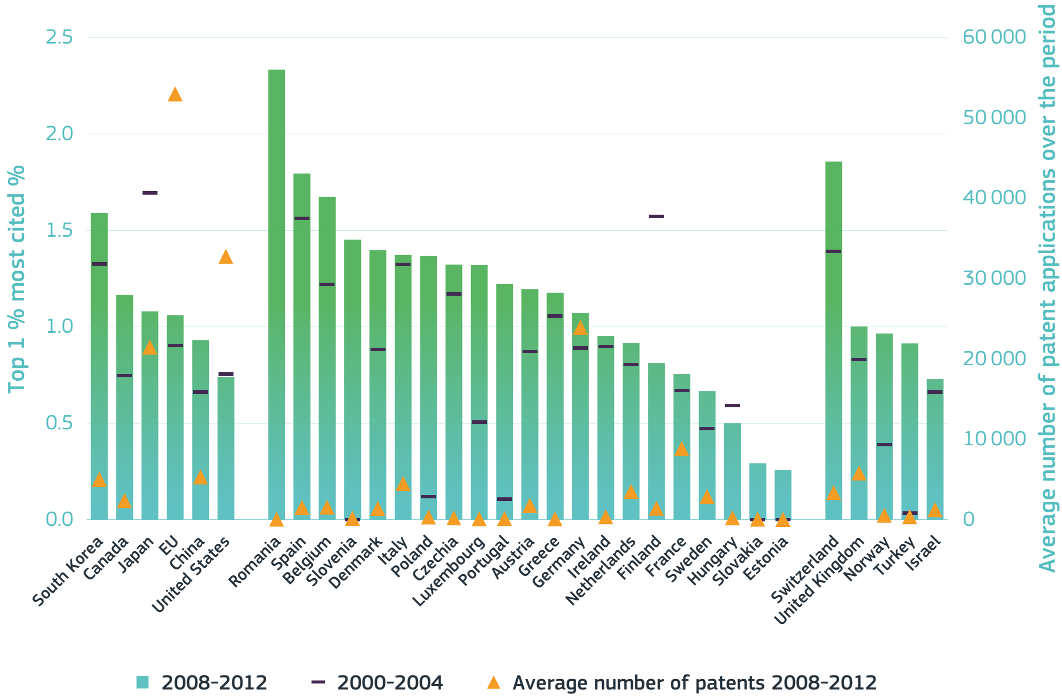
6 ETLA - Research Institute of the Finnish Economy (2010), Nokia and Finland in a Sea of Change.

7 European Commission (2015), RIO country report 2015: Portugal.

8 European Commission (2014), a Study on R&D Tax Incentives.

9 European Commission (2015), RIO country report 2015: Lithuania.

Figure 6.3-4 Top 1% most-cited patent applications filed with the EPO, average over 2000-2004 and 2008-2012, and average number of patent applications over 2008-2012



Science, research and innovation performance of the EU 2020

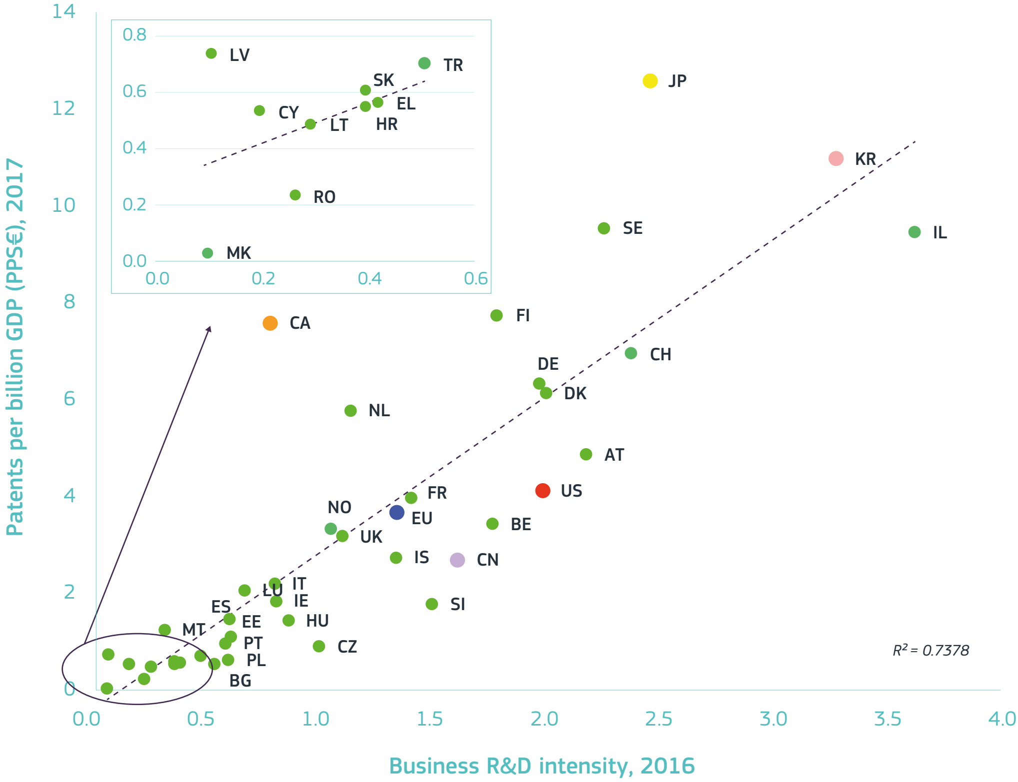
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: Data produced by Science-Metrix using data from EPO Patstat Spring 2019 database. A minimum of 30 patent applications for a given country and period are required to calculate a score. Fractional counting method was used. Five-year window used in the calculation. Data is calculated with five-year average to reduce volatility.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-4.xlsx

As a measure of patent quality, the top 1 % most-cited patent applications filed with the EPO shows South Korea, followed by Canada and Japan, ahead of the EU. On the other hand, the EU is ahead of China and the United States. Japan, which was the best performer at the beginning of the century, has declined significantly (Figure 6.3-4). Within the EU, Romania tops the ranking, followed by Spain and Belgium. At the bottom, Estonia, Slovakia and Hungary are the worst performers. Over time, only Finland has shown a decline, which is probably due to over reliance on Nokia, as mentioned above. Romania, Slovenia, Poland and Portugal have made the most improvements since the period 2000-2004. The results show a lack of innovation divide, with modest innovators such as Romania or Poland performing well, and lead innovators such has Sweden and Finland performing poorly. However, the absolute number of patents can have an impact on the results, with smaller amounts inflating the indicator and contributing to more volatility. For instance, during the period 2000-2004, Romania had fewer than 30 patents, which is the minimum necessary to calculate the score.

Figure 6.3-5 Patent applications[1] per billion GDP (PPS€), 2017[2] and business R&D intensity, 2016[3]



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on OECD (Patents by technology), Eurostat and Unesco data

Notes: [1]Patent applications filed under the PCT, at the international phase, designating the European Patent Office (EPO). Patent counts are based on the priority date, the inventor's country of residence and fractional counts. [2]IL, MK: 2016. [3]CH: 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-5.xlsx

Japan and Canada are the most efficient in translating their business R&D investments into technological progress. They have high patent intensities when compared to their levels of business expenditure in R&D intensities, and are outperforming the EU, the United States and China. By assuming business investment in R&D as knowledge input and patents as knowledge output, patents can be considered as a return on investing in R&D[10]. In fact, as shown in Figure 6.3-5, there is a positive correlation between business R&D intensity and patent intensity. Compared to the United States, for a similar level of patent intensity, the EU uses less business investment in R&D. However, according to the latest Industrial R&D Investment Scoreboard[11], the top US R&D performers are companies in

10 Maastricht University and UNU-MERIT (2019), R&D, innovation and productivity.

11 European Commission (2018), The 2019 EU Industrial R&D Investment Scoreboard.

the ICT sector, while in the EU, the top R&D performers are companies in the automotive and pharmaceutical sectors, which are more patent intensive. This might explain the differences between the United States and EU. Within the EU, according to the European Innovation Scoreboard, the most innovative economies, such as Sweden, Finland and the Netherlands, are also the countries with very high levels of patent intensity in relation to their levels of BERD intensity. On the other hand, Slovenia, Austria and Czechia, despite their relatively high levels of business expenditure in R&D, do not translate this into patent applications.

In order to assess how innovation is contributing to addressing sustainability and the challenges our society is currently facing, one can look at the evolution of patent activity in areas such as the bioeconomy and food security, climate and environment, energy, security, transport and health.

As regarding PCT patent applications by societal challenges[12], as defined under the Horizon 2020 Framework Programme, the total number of patent applications increased over time in all fields. However, not all of them follow the same path. After a significant increase up to 2012, the energy sector has shown a decline in recent years, albeit caused by a methodological issue[13]. Transport, which was the third most-patented field until 2010, overtook the food and bioeconomy sector with more than 22 000 patent applications in 2016, reducing the gap with health. Health remains the most-patented field over the period. Both sectors have a high patent propensity[14], reflecting their high number of patents compared to other fields. Even though the field of climate has a persistently low number of patents, this has more than doubled and, in 2016, accounted for almost 2 000 patents. Positive variations in the transport (+233 %), energy (+239 %), security (+209 %) and climate (+133 %) sectors show how fields like climate change, environment and resilience have moved significantly higher in the global political agenda (Figure 6.3-6)[15].

When considering the geographical differences, both the EU and the United States have been losing ground in patent applications in the societal challenges field, while Japan, South Korea and China, in particular, have become more important. In fact, only in bioeconomy and health do the EU and United States combined still represent more than 50 % of patent applications. The United States is the leader in the health, bioeconomy and security sectors, while the EU leads in the fields of energy, climate and transport. Besides its growing importance in all fields, China has becoming particularly strong in energy and security, while Japan has remained strong in the bioeconomy and transport.

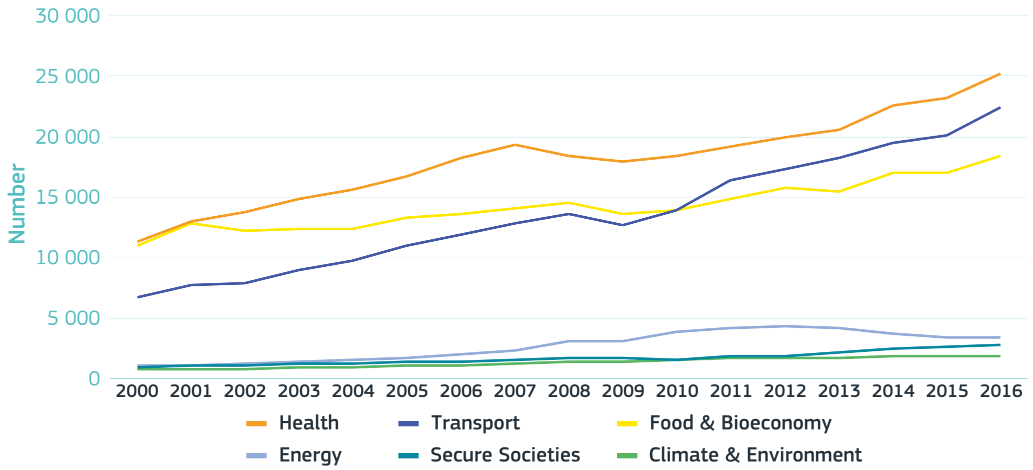
12 https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges

13 The decline is only due to the classification of the energy SGC, namely the Y-classification. A disadvantage of the Y-classification is that the CPC (Cooperative Patent Classification), on which it is based, is not provided for patents until the patents pending via the PCT process are transferred to the national phase. This is only the case 30 months after registration. The current margin in the figures is therefore even further back than in purely IPC-based patent searches. European Commission (2017), Final report on the collection of patents and business indicators by economic sector: Societal Grand Challenges and Key Enabling Technologies.

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

15 European Commission (2019), Reflection Paper - Towards a Sustainable Europe by 2030.

Figure 6.3-6 Total number of PCT patent applications by Societal Challenge, 2000-2016



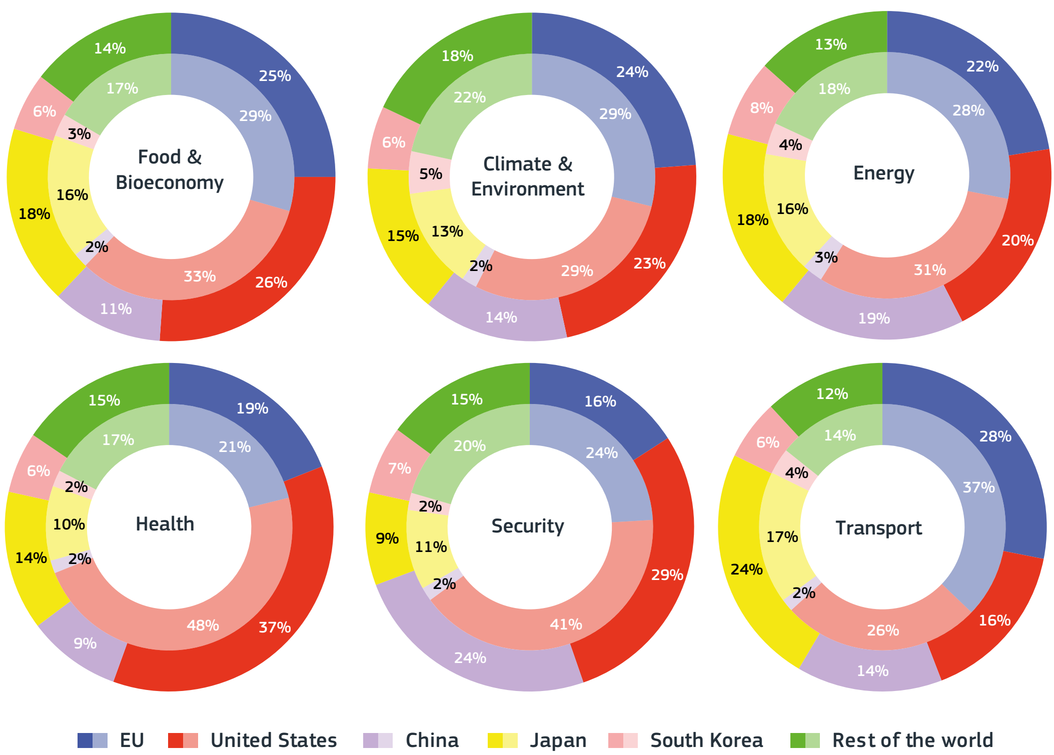
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: Data produced by Science-Metrix using data from the European Patent Office Patstat Spring 2019 database.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-6.xlsx

Figure 6.3-7 Share of PCT patent applications by Societal Challenges, 2016 (exterior) versus 2006 (interior)



Science, research and innovation performance of the EU 2020

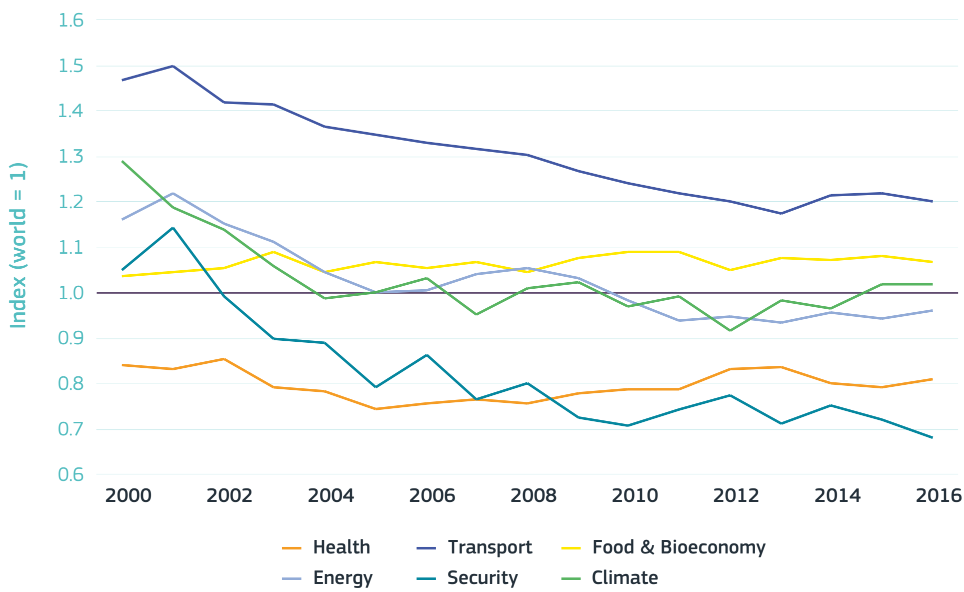
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: Data produced by Science-Metrix using data from the European Patent Office Patstat Spring 2019 database.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-7.xlsx

Compared to the rest of the world, the EU is more specialised in patenting in the fields of transport and food and bioeconomy, and less specialised in the health and security sectors. However, this can also be explained by the strong and patent-intensive automotive sector in some European countries. Over time, the EU has undergone significant changes (Figure 6.3-8). While in 2000, the EU was more specialised than the rest of the world in all fields except health, in 2016, only transport, food and the bioeconomy and climate, which have recovered slightly in recent years, were above the world average. In addition, the greatest negative variation was in the fields of security and climate. When comparing the performance with scientific publications, the EU is clearly stronger in the food and bioeconomy sector, with specialisation indexes above its main competitors in both scientific publications and patent applications.

Figure 6.3-8 EU Specialisation Index[1] by Societal Grand Challenge (vs. rest of the world), 2000-2016



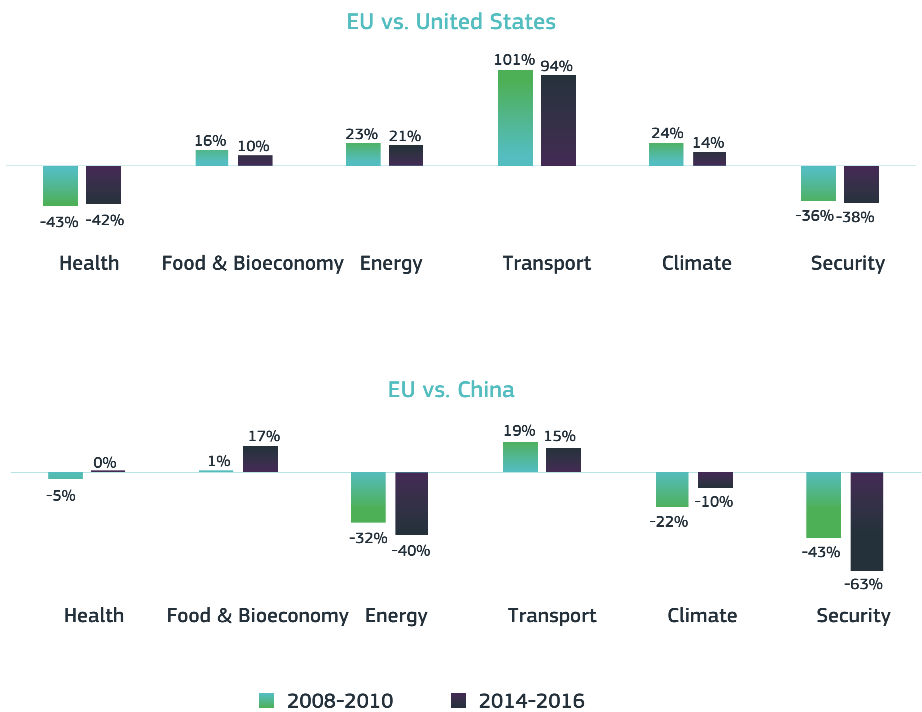
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: Data produced Science-Metrix using data from the European Patent Office Patstat Spring 2019 database. [1]Specialisation refers to the Intensity in the EU for a given societal challenge relative to the intensity in the world for the same research area. Fractional counts and date of application used. [2]World average = 1.0.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-8.xlsx

The EU is stronger in both transport and food and bioeconomy than the United States and China but weaker in security. Compared to the United States, the EU also patents more in the climate and energy fields (Figure 6.3-9). These results are also in line with the specialisation indexes in scientific publications in the same fields. In the health sector, however, the United States is significantly more specialised than the EU in both patenting and publishing. Compared to China, the EU has a very small advantage in the field of health, in addition to a very strong performance in terms of scientific publications. As regards the security and energy sectors, the EU not only shows lower specialisation than China, but its position has also deteriorated over time. In the field of climate, the EU has recovered in comparison with China, but worsened when compared to the United States.

Figure 6.3-9 EU Specialisation Index[1] by societal grand challenge (vs. United States and China), three-year average period



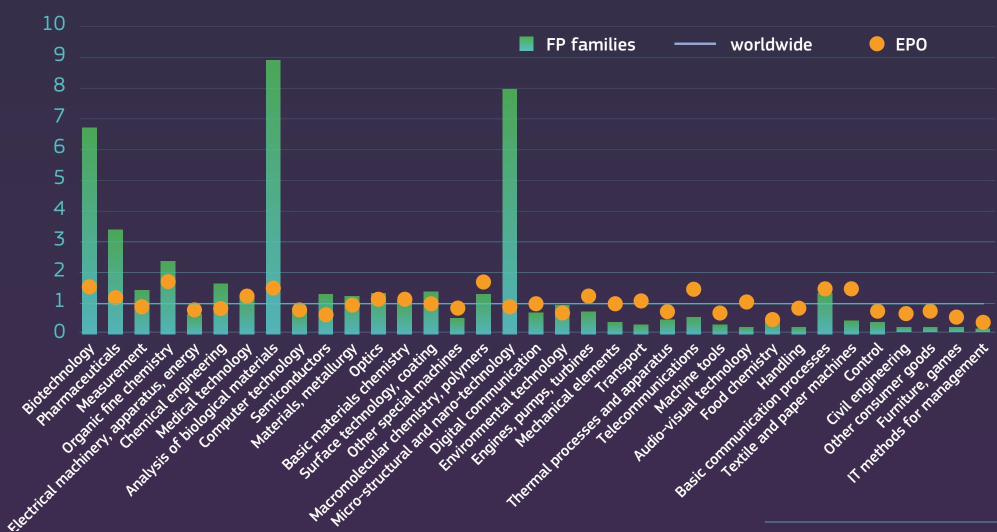
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit
Note: Data produced by Science-Metrix using data from the European Patent Office Patstat Spring 2019 database.
[1]Specialisation refers to the Intensity in EU for a given societal challenge, relative to the intensity of the United States and China for the same research area. Fractional counts and date of application used.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-9.xlsx

BOX 6.3-1 What type of inventions are self-reportedly patented as a result of the Framework Programme?

The majority of the FP self-reported inventions (patent families) are patented in health-related areas such as biotechnology, pharmaceuticals, organic chemistry or medical technology. Only a limited number of inventions relate to environmental technology.

The highest share of FP self-reported inventions (patent families) is related to biotechnology[16] 14% of all self-reported inventions). This is almost 6 times higher than the worldwide average (2.1% of world patents are in biotechnology). Pharmaceutical inventions follow with around 9% of FP inventions, almost 4 times more than the global average (2.7% of world patents are in this class) and 3 times more than inventions registered at the EPO in this class (3.4% of all EPO patents). Organic fine chemistry FP inventions are also visibly better represented than the overall world picture (a more than twofold increase from 6.1% of FP inventions to 2.6% in world patents) and in line with the percentage of EPO patents in the same class. Inventions in the analysis of biological materials class, as well as nanotechnology FP inventions seem to be over-represented in the FP compared to the percentage of patents in these classes worldwide. At the same time, the Framework Programmes produce proportionately fewer patents than what is observed worldwide in the electrical machinery and energy class, as well as in computer technology, digital communication, telecommunication, transport and environmental technology classes, among others.

Figure 6.3-10 Technological specialisation index of FP main patents, EPO published in 2009-2018 (worldwide=1)



Science, research and innovation performance of the EU 2020

Source: Upcoming Monitoring Flash #4 Patents in FP, DG R&I based on ORBIS Intellectual Property (IP), CORDA and own calculations. The analysis covers self-reported patents from more than 50,000 FP7 and Horizon 2020 projects funded until 2019.

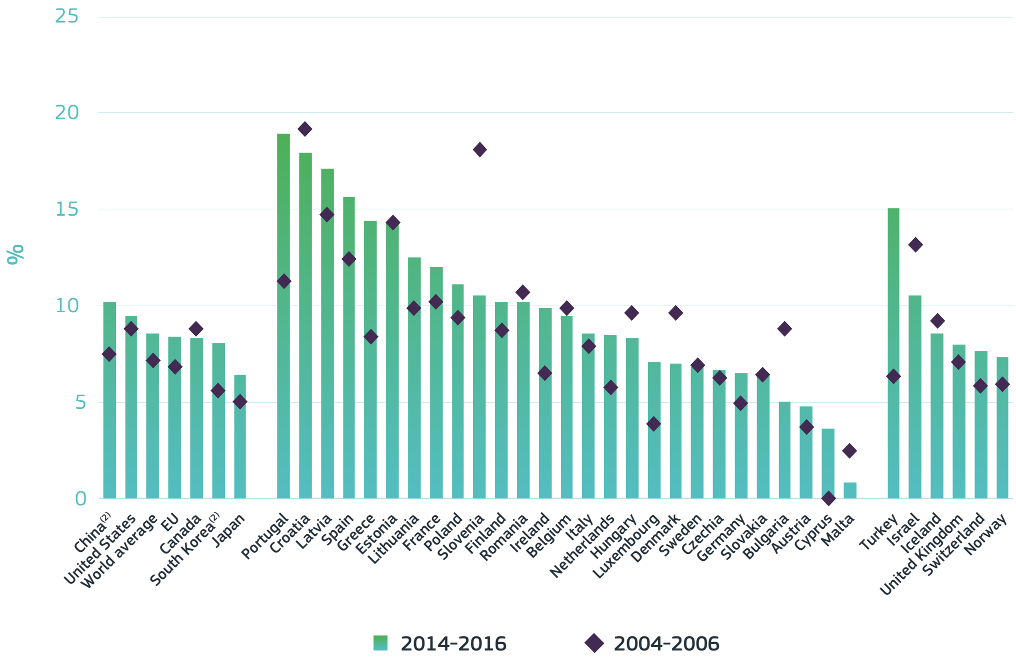
Note: Values are normalised so that worldwide percentage of patents in each WIPO technology class equals 1. A value of 2 indicates a percentage (of FP or EPO patents) twice as high as the worldwide percentage of patents in that class.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-10.xlsx

16 Note that WIPO technology classes are counted only for the main patent of each FP foreground patent family, due to data constraints. Worldwide figures are, nevertheless, at patent-level, rather than patent family (invention) level. Given that the patents covering an invention are very similar, one can assume that they are registered in the same WIPO class.

China, followed by the United States, shows a slightly higher share of female applicants on patent applications than the EU. However, the EU performed marginally better than Canada, South Korea and Japan, and just below the world average with a share of 8.4 % during the period 2014-2016. Together with climate, environment and inequality, gender equality has become more relevant in the political agenda in recent years[17]. Therefore, it is important to analyse the contribution women have made to technological progress as patent applicants. Even though the share of female applicants in patent applications to the European Patent Office is small, performances vary significantly across Europe. Portugal then Croatia, Latvia and Spain display the highest shares, at over 15 %, while Malta then Cyprus and Austria display the lowest shares, at below 5 % for the period 2014-2016. Between the two periods presented, most countries have shown an improvement in the share of female applicants, with a particular emphasis on Portugal, Greece and Turkey. Conversely, Slovenia, Israel and Denmark saw a decline.

Figure 6.3-11 Share of female applicants on patent applications filed with the EPO by country (%), 2004-2006 and 2014-2016[(1)]



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: Data produced by Science-Metrix using data from the European Patent Office Patstat Spring 2019 database. Gender was assigned to applicant names using the NamSor API. [(1)]Due to high volatily over time, an average of three-year period was used. The fractional counting method was used. [(2)]Data for China and South Korea has a high margin of error, thus results should be interpreted with caution.

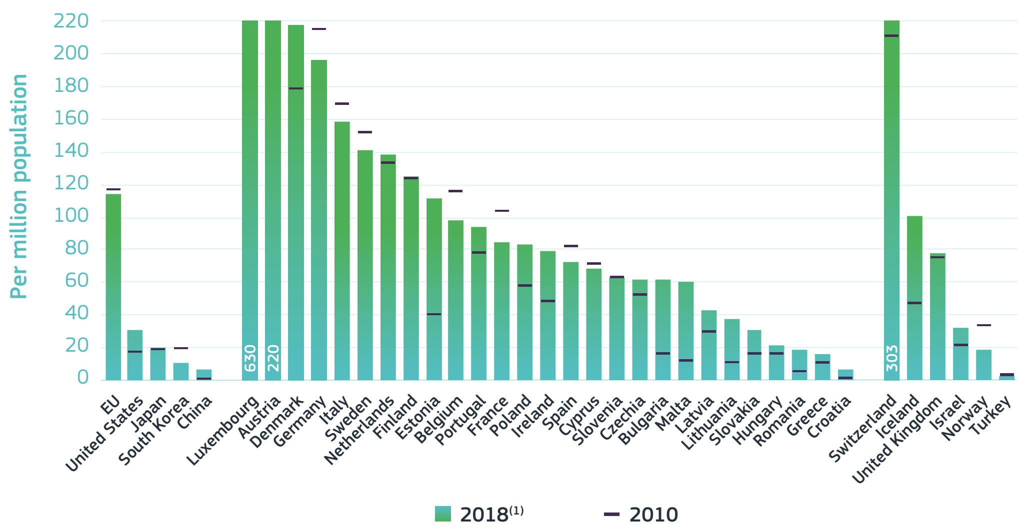
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-11.xlsx

17 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Union of Equality: Gender Equality Strategy 2020-2025.

Over time, the EU has shown significant improvements in the case of trademarks, while achieving a stable performance in community designs. By looking at per capita community designs and trademarks[18] as a proxy for assessing patterns of innovation outside of the traditional exploitation of R&I results (Figures 6.3-12 and 6.3-13), the EU extensively outperforms the United States, Japan, South Korea and China.

Within Europe, the innovation divide is less striking in trademarks and community design applications than in patent applications. Countries like Cyprus and Estonia, which perform poorly in patent applications, rank particularly high in these types of IP applications. In addition, countries such as Lithuania and Bulgaria have shown significant improvements in recent years. These patterns might be the result of initial reforms in incentive systems and framework conditions. However, good performances in small countries like Luxembourg and Malta might be the result of legislation, easy procedures and attractive taxation systems rather than investment in innovation or more innovative companies. Despite the good performance of some less-innovative economies, countries performing traditionally well in innovation, like Denmark or Sweden, not only lead patent applications but also other types of IP applications. On the other hand, countries like Romania or Greece with less-attractive innovation systems perform poorly in both types of intellectual property rights.

Figure 6.3-12 Community design applications to the EU Intellectual Property Office (EUIPO) per million population, 2010 and 2018



Science, research and innovation performance of the EU 2020

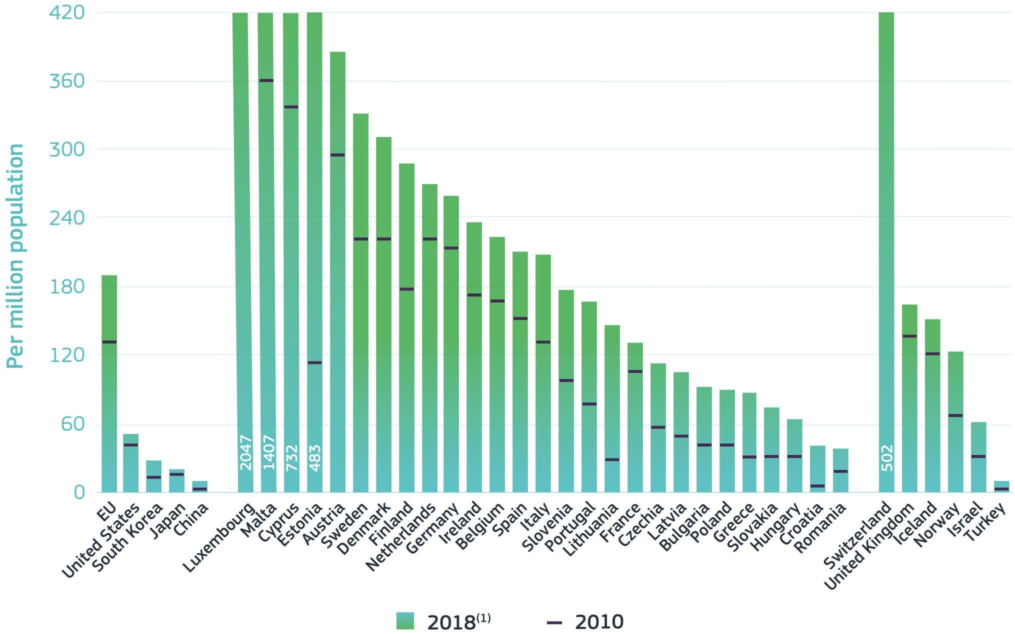
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on data produced by Science-Metrix using data from the EUIPO database, Eurostat and World Bank data

Note: (1)US, KR, JP, CN: 2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-12.xlsx

18 Design 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. A trademark is a distinctive sign that identifies certain goods or services such as those provided by a specific person or organisation and distinguishes them from those of other organisations. Trademarks can be words, pictures, stylised words, logos, a colour or colour combination, a shape, a sound or a combination of those signs.

Figure 6.3-13 Trademark applications to the EU Intellectual Property Office (EUIPO) per million population, 2010 and 2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on data produced by Science-Metrix using data from the EUIPO database, Eurostat and World Bank data

Note: (1)US, KR, JP, CN: 2017.

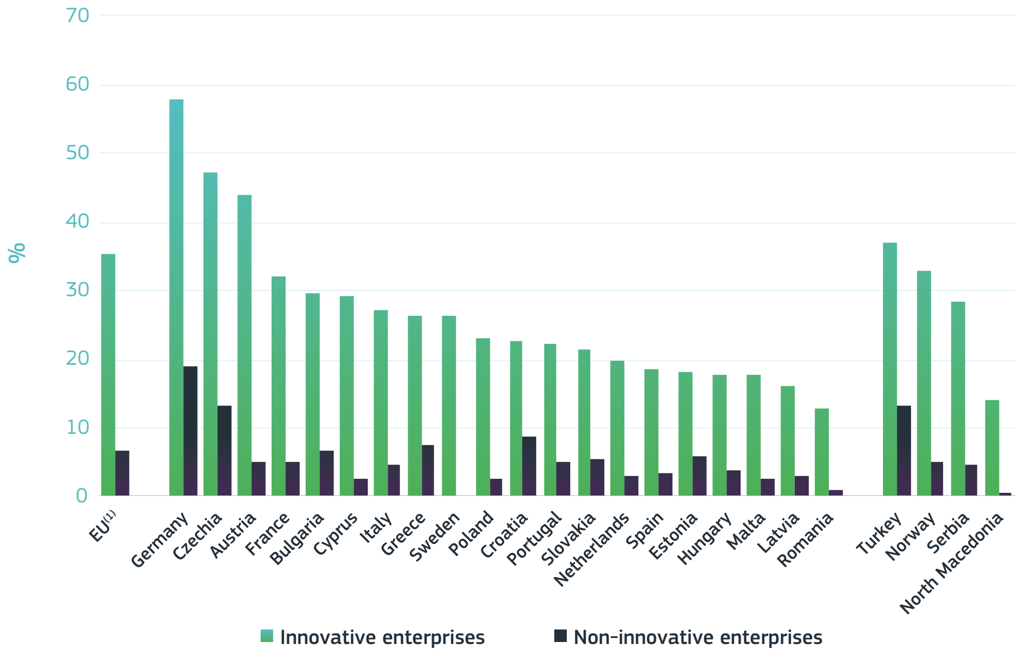
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-13.xlsx

Innovative companies use significantly more IPRs than non-innovative companies. Intellectual property rights are one of the main tools used by companies to extract a benefit from investment in R&I and to protect their innovations[19]. The extent to which IPRs are used among innovative companies diverges among EU countries. As shown in Figure 6.3-14, in Germany, almost 60 % of innovative companies use IPRs, whereas in Romania, the share is just above 10 %. Moreover, there are certain differences between innovation leaders and modest innovators; for example, a substantial share of innovative enterprises in Bulgaria and Czechia use IPRs, while the shares of innovative enterprises using IPRs are lower in the Netherlands and Estonia. Differences in the dominant economic sector can explain the results. In countries with higher shares, IPR-intensive sectors, such as automotive, software and equipment manufacturing, dominate the share of innovative enterprises, while in countries with lower shares, the dominant sectors are primarily services such as wholesale and retail trade, which are not IPR-intensive sectors. In addition, country-specific policies on IPRs, such as incentives and enforcement of IPR, can contribute to higher shares. For instance, in 2014, Czechia introduced a programme that supported expenses on IPR protection in businesses[20].

19 European Union Intellectual Property Office (2017), Protecting innovation through trade secrets and patents: determinants for European Union firms.

20 EC-OECD STIP COMPASS, https://stip.oecd.org/stip.html

Figure 6.3-14 Share of innovative and non-innovative enterprises (%) that used intellectual property rights (IPRs), 2016



Science, research and innovation performance of the EU 2020

Source: Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_ipr)

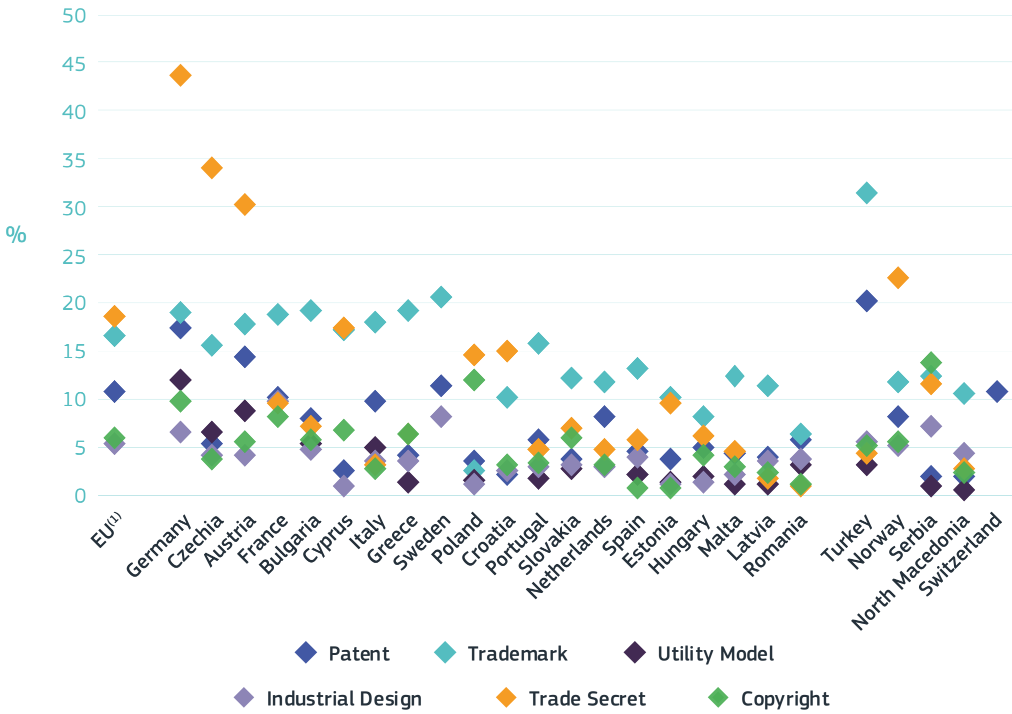
Note: (1)EU value estimated with the available 20 EU countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-14.xlsx

The most commonly used IPR by innovative companies in the EU are trade secrets and trademarks and, to a lesser extent, patents, as shown in Figure 6.3-15. These figures are in line with the very high numbers shown in Figure 6.3-12 and 13 in which trademarks are used much more than patents and community designs. In fact, while patents are used mainly for products and to protect innovations that are new to the market, trade secrets and trademarks can be applied in both products/services and processes and also in innovations new to a firm[21], thereby increasing the scope of these types of IP for innovation protection. By type of IPR, Germany, followed by Austria and Czechia, show the highest shares for trade secrets in the EU; Sweden, followed by Bulgaria and Germany, show the highest shares for trademarks; and Germany, followed by Austria and Sweden, show the highest shares for patents. As for utility models, industrial design and copyright, the top countries are Germany, France and Poland, respectively. Once again, differences in the dominant economic sector to which innovative companies belong and variations in IPR legislation can explain the results. Nonetheless, the highest shares are concentrated in the more innovative countries such as Sweden, Germany and Austria.

21 European Union Intellectual Property office (2017), Protecting innovation through trade secrets and patents: determinants for European Union firms.

Figure 6.3-15 Share of innovative enterprises (%) by intellectual property rights (IPRs) and licensing in the enterprise, 2016



Source: Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_ipr)

Note: [1]EU value estimated with the available 20 EU countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-15.xlsx

3. An unequal landscape of innovative enterprises

The share of innovative enterprises in an economy also illustrates its innovativeness. By definition, and according to the Community Innovation Survey of 2016, enterprises are considered innovative if they carried out innovation activities during the period 2014-2016, including ongoing and abandoned activities, i.e. regardless of whether the innovation activity resulted in implementation of an innovation[22].

In 2016, 48 % of EU enterprises reported innovation activities in the period 2014-2016, a decline of 5.7 percentage points since 2010. Even though innovation performance has improved over time, according to the latest European Innovation Scoreboard[23], half of the EU countries have also shown a decline in the share of innovative enterprises. On the negative side, countries such as Germany, Romania and Poland stand out with a significant decline in the share of innovative enterprises (Figure 6.3-16). Conversely, Lithuania shows a significant improvement when compared to 2010. Belgium is the EU country with the highest share of innovative companies (almost 70 %), followed by Portugal and Finland. Among all countries, Switzerland and Norway are the best performers with shares above 70 %. On the downside, Romania, Poland, Bulgaria and Hungary have the lowest shares of innovative companies (less than 30 %). Looking at the figures, the share of innovative enterprises demonstrates the innovation divide between north-western and south-eastern Europe, with some exceptions such as Portugal, Greece and Italy. Portugal, for instance, reports a relatively high share of innovative enterprises, mainly driven by a very high share of innovative SMEs in combination with a relatively high share of public support to business R&D investment and a good performance of SME investment in R&D. In addition, the share of innovative companies is connected with countries' economic structures. The higher share of SMEs in medium-high, high-tech manufacturing and knowledge-intensive services (such as ICT and finance) is likely to translate into a higher share of innovative enterprises which, for instance, might explain the results from Belgium and Luxembourg.

In terms of company size, with more resources to invest in R&D, large companies are naturally more innovative than SMEs. However, the gap in both shares varies across countries (Figure 6.3-17). More-innovative countries, such as Luxembourg, the Netherlands, Finland, Belgium and Denmark show not only a lower gap but also high shares of innovative SMEs and innovative big companies which, as mentioned previously, is partly explained by the economic structure. Portugal comes out on top with a high share of innovative SMEs and the lowest gap. On the contrary, eastern European and less-innovative countries like Romania, Bulgaria[24], Slovenia, Poland and Slovakia, where business structures are dominated by few large multinational companies that control most of the business investment in R&D, have the lowest shares of innovative SMEs as well as the largest gaps between large enterprises and SMEs.

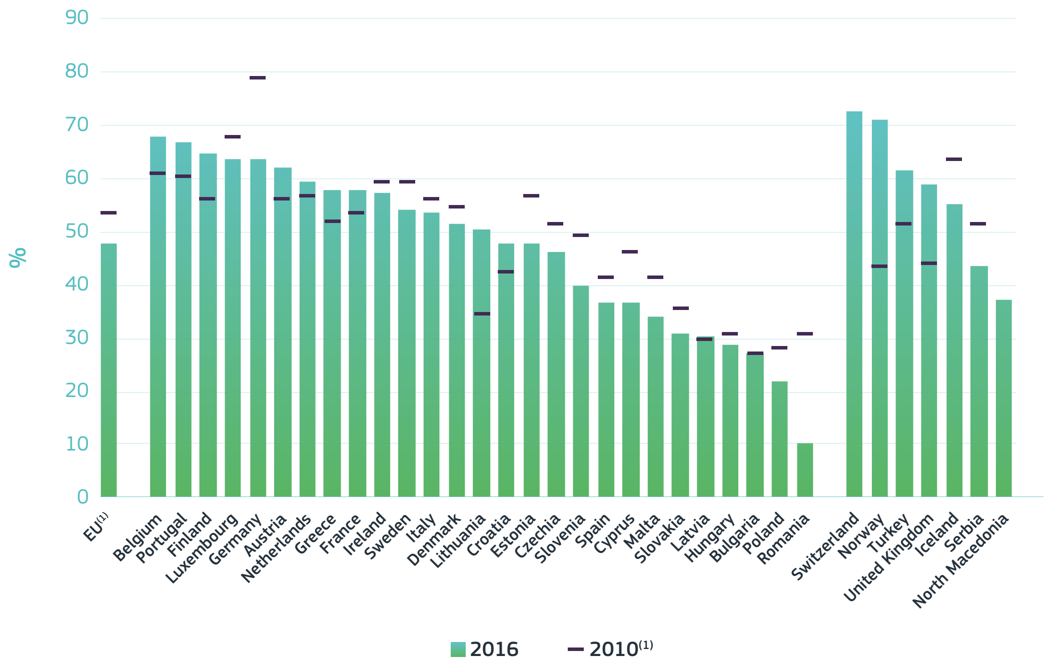
22 The concepts are in line with those recommended by the Oslo Manual (2005, 3rd edition) which is the internationally recognised standard methodology for collecting innovation statistics.

23 European Commission (2019), European Innovation Scoreboard 2019.

24 European Commission (2019). European Semester – Country Report.

As regards the different types of innovation activities, the share of innovative enterprises in product and process innovation is generally higher than in organisational and marketing innovation. This is an important result because it means that companies are investing more in new or significantly improved products and/or services rather than promoting existing ones.

Figure 6.3-16 Innovative enterprises as % of total number of enterprises, 2010 and 2016



Source: Eurostat - Community Innovation Survey 2016 and 2010 (online data code: inn_cis10_type and inn_cis7_type)

Note: [1]EU estimated and not including EL. EL: 2012.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-16.xlsx

Figure 6.3-17 Share of innovative enterprises by size, 2016

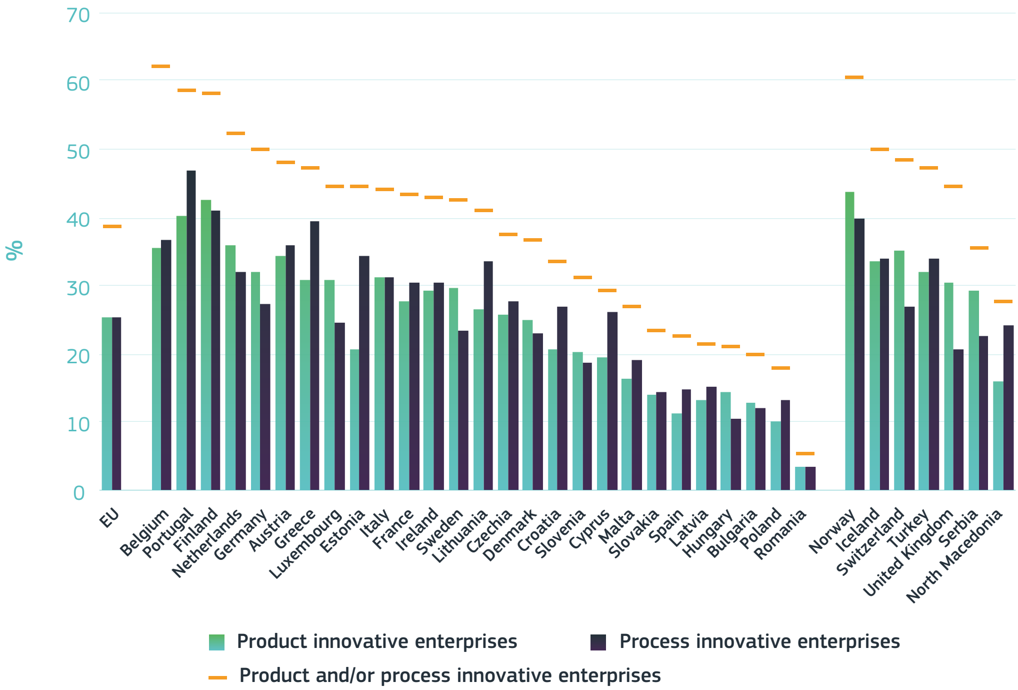
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_type)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-17.xlsx

In geographical terms, there is generally a divide between leading innovative countries performing better in both types of innovation and less-innovative countries performing poorly equally in both types of innovation. However, some exceptions, such as Portugal and Greece, stand out with high shares and both types (Figures 6.3-18 and 6.3-19). In addition, countries such as the Netherlands, Estonia, Belgium and Finland perform much better in product and process innovation than in organisational and marketing innovation. In more detail, the majority of countries perform better in organisational than marketing innovation and tend to do better in process rather than product innovation. However, because product innovation requires more and better resources, leading innovative countries such as Finland, the Netherlands, Denmark and Sweden show higher shares in product innovation as against process innovation.

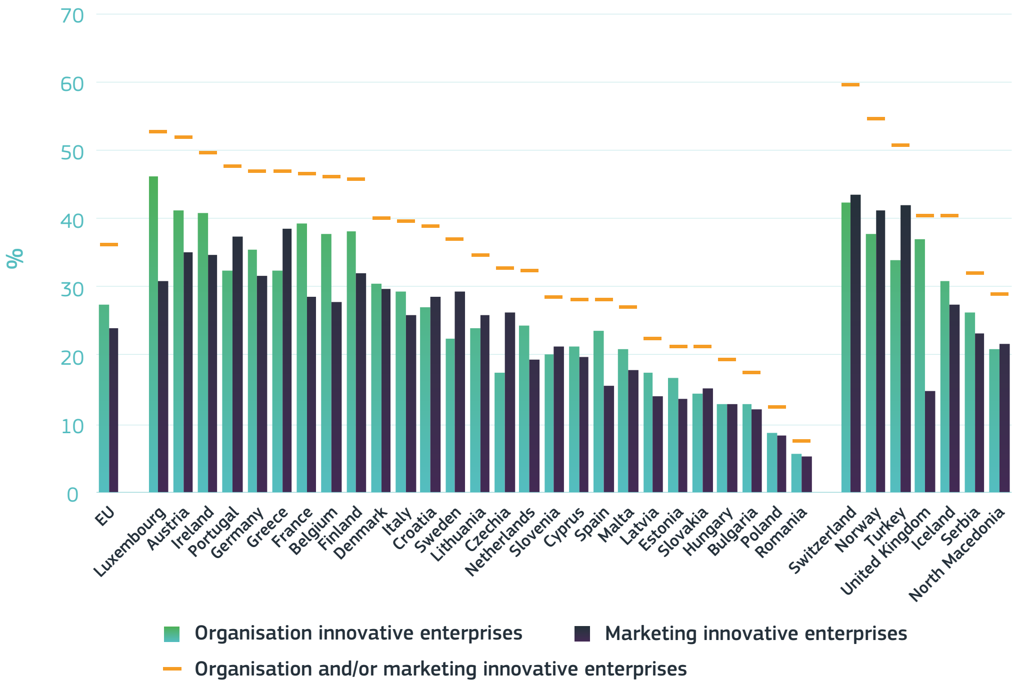
Figure 6.3-18 Innovative enterprises by type of innovation activity as % of total enterprises, 2016



Source: Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_type)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-18.xlsx

Figure 6.3-19 Innovative enterprises by type of innovation activity as % of total enterprises, 2016



Science, research and innovation performance of the EU 2020

Source: Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_type)

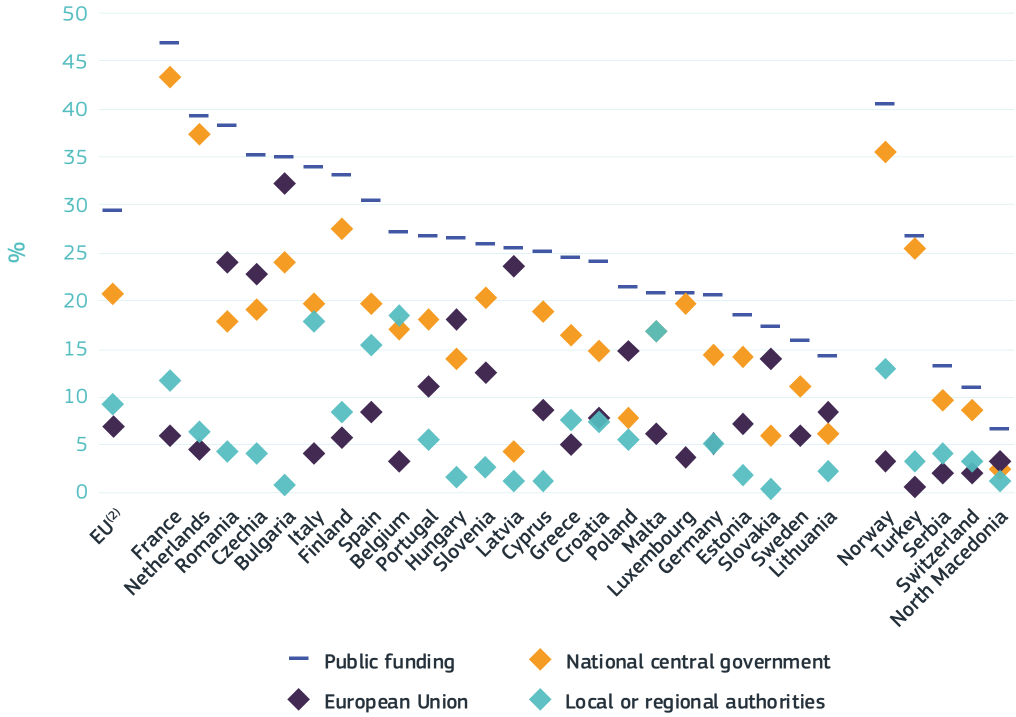
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-19.xlsx

At the EU level, approximately 30% of product- and/or process-innovative enterprises received public funding for their innovation activities during the period 2014-2016. Public funding is an important tool to support business innovation activities, either through tax incentives or direct public support[25]. Figure 6.3-20 shows there is no clear innovation divide between the most- and least-innovative countries. For instance, France reports the highest share of product and process innovation enterprises that have received public funding, followed by the Netherlands and Romania. However, the source of funding diverges. While enterprises in countries with better innovation capacities and more public support for business investment in R&D, such as France, the Netherlands, Finland and Luxembourg, show relatively higher shares of funding from national sources, in less-developed public innovation systems, like Bulgaria, Czechia, Romania, Latvia and Slovakia, companies tend to use relatively more funding from the EU. Furthermore, these figures show that companies might look for public support to fund their innovation activities either as the result of a well-developed public investment system, when the highest share comes from national sources, or because of poor framework conditions that are

25 European Commission (2017), The economic rationale for public R&I funding and its impact.

unable to secure business investment in R&D, when the highest share comes from external sources. As a consequence of deprived national investment systems, the results confirm the importance of European funding in helping innovative companies to fund their activities , especially in the countries that are more distant from the technological frontier.

Figure 6.3-20 Share of product and/or process-innovative enterprises[(1)] (%) that received public funding for innovation activities by source of funding, 2016



Science, research and innovation performance of the EU 2020

Source: Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_pub)

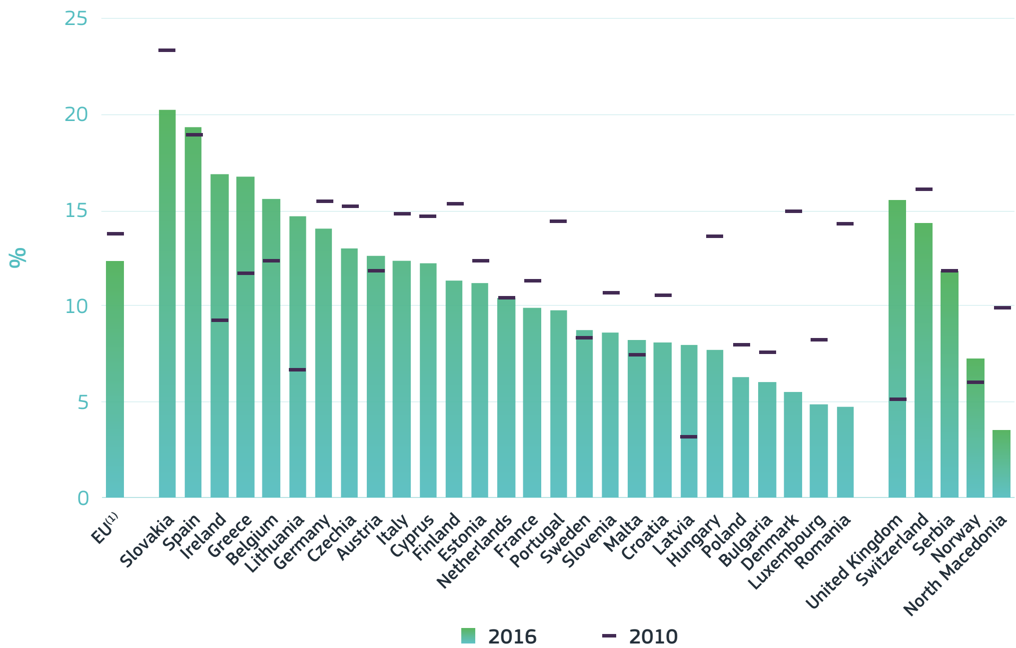
Notes: [(1)]Public funding includes financial support via tax credits or deductions, grants, subsidised loans, and loan guarantees. [(2)]EU value estimated with the available 24 EU countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-20.xlsx

4. The economic impact of innovation illustrates diverse national economic structures

In 2016, innovation turnover in the EU, measured as sales of new-to-market and new-to-firm innovations, was 12.4% of total turnover. Even though in absolute terms, innovation turnover increased by 7%, the share is slightly lower than in 2010. In addition, the share of innovation turnover fell in 17 of the 27 EU countries. The decrease is particularly significant in Denmark, Romania and Hungary (Figure 6.3-21). On the other hand, a few countries have shown big improvements, such as Ireland, Latvia and Lithuania. Slovakia, followed by Spain and Ireland, show the highest shares of innovation turnover while Romania, Luxembourg and Denmark display the lowest shares. In Denmark, the result seems to be linked to a high concentration of a few very large R&D-intensive industries, especially in the pharmaceutical sector. Similarly, a concentration of a few very large R&D-intensive industries in Luxembourg's services sector might explain its low share. Therefore, these figures indicate that innovation turnover does not seem to be aligned to the share of innovative enterprises or the country's innovation capacity. However, it is important to note that, while data on company shares includes several types of innovation and are dominated by the high number of SMEs, as regards turnover, larger companies play a bigger role, especially multinational companies that import innovations from the headquarter country. Countries with a relatively large high-tech and medium-high-tech manufacturing sector also tend to show higher innovation turnover.

Figure 6.3-21 Sales of new-to-market and new-to-firm innovations as % of total turnover, 2010 and 2016



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat - Community Innovation Survey 2016 and 2010 (online data code: inn_cis10_prodt and inn_cis7_prod) and European Innovation Scoreboard 2019

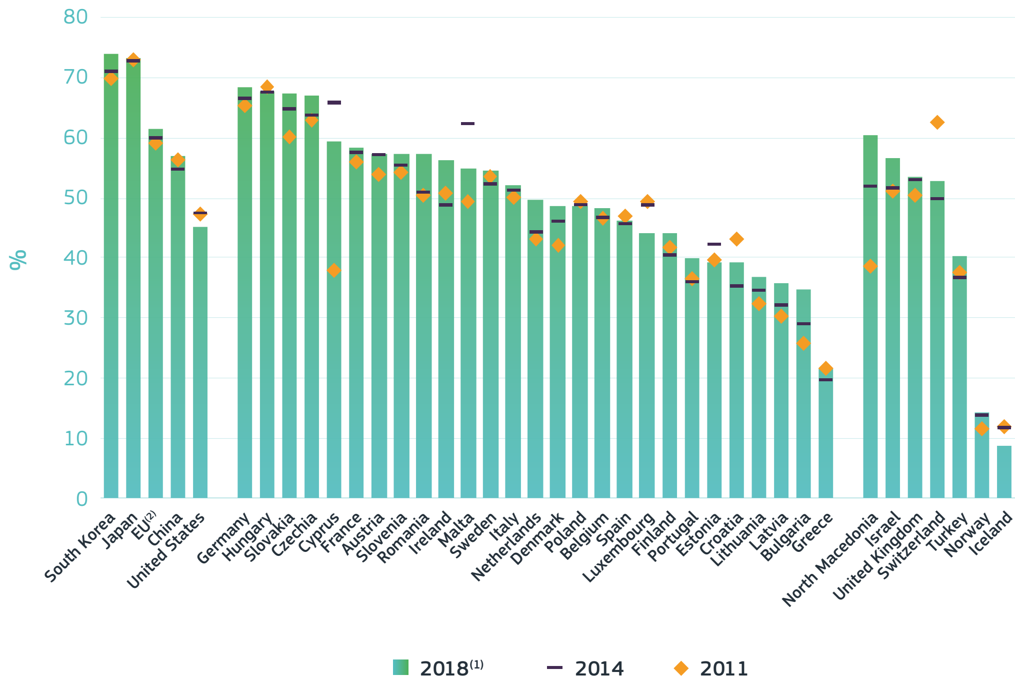
Note: (1)EU value was estimated.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-21.xlsx

As regards the export share of medium- and high-tech products, South Korea and Japan, with strong ICT hardware and automotive industries, show the best performance. While the EU lags behind those two countries, it performs better than China and the United States. As key drivers of economic growth and productivity, medium- and high-technology products might reflect a country's ability to commercialise the results of R&D in international markets.

Within Europe, Germany, with its strong R&D-intensive automotive and equipment industries, shows the best performance. Central and eastern Europe, in particular Hungary, Slovakia and Czechia, also report very good performances as a result of their foreign affiliate companies' strong automotive, machinery and pharmaceutical exporting sectors. Over time, most countries have improved their shares of medium- and high-tech exports, particularly Bulgaria and Cyprus (Figure 6.3-22). Certain leading innovation countries, such as Finland which has a very strong R&D-intensive industry in the ICT hardware sector, is not able to translate the investment into exports of internationally competitive high-tech products. However, as with the innovation turnover indicator, the

Figure 6.3-22 Exports of medium- and high-technology products as % of total product exports, 2011, 2014 and 2018



Source: European Commission, DG Joint Research Centre based on Eurostat, Comext 'DS-018995' and UN Comtrade (Vértesy and Damioli, 2020, Figure 4)

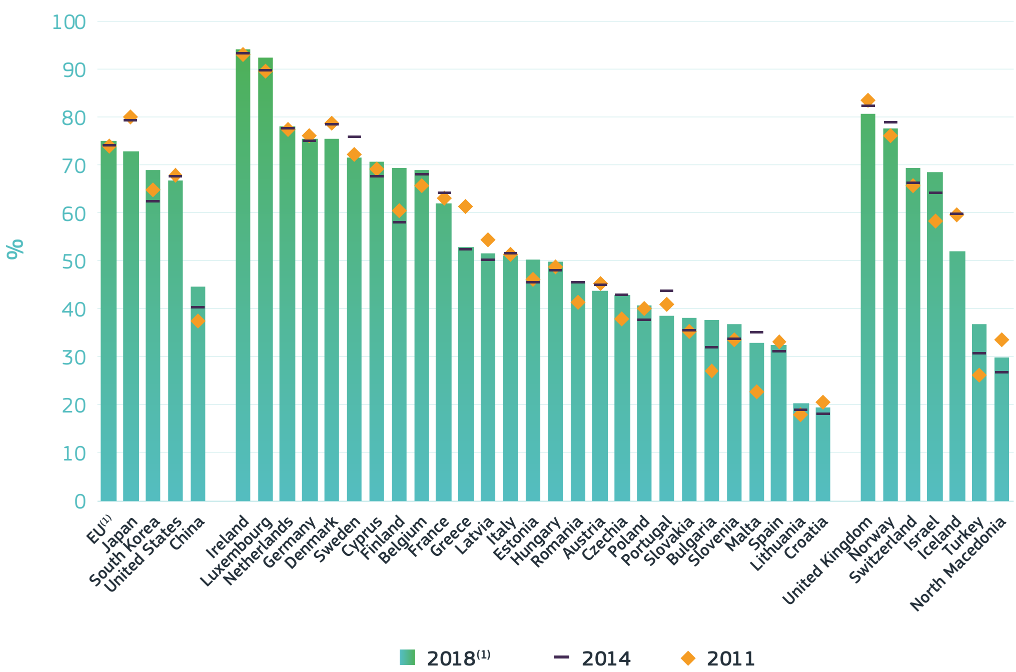
Note: (1)CN, KR, NO: 2017. (2)Two sets of values are available: values for worldwide comparison that exclude foreign trade between EU countries and values for European comparison that include it. The values for worldwide comparison are shown on the graph. The value for EU comparison for 2018 is 56.6.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-22.xlsx

results seem to be linked more closely to the country's economic structure (i.e. the weight that certain sectors have in the economy), rather than its innovation capacity.

The EU shows the highest share of knowledge-intensive service exports, ahead of Japan, South Korea, the United States and China. Within the EU, countries with a high share of R&D-intensive financial and ICT services in their economies, like Ireland and Luxembourg, are leading the EU (Figure 6.3-23). On the other hand, those with a high share of tourism-related services, such as Spain, Croatia and Malta, tend to perform poorly in this indicator, notwithstanding their R&D investment in professional, scientific and technical services. Contrary to the previous indicators, the share of KIS exports seems to be in line not only with the country's economic structure but also with its innovation capacity. Leading innovative countries, such as the Netherlands, Sweden, Denmark and Finland, perform very well while less-innovative countries, such as Lithuania, Slovakia and Bulgaria, perform poorly. This might be an indication that digitalisation and new technologies are changing the way innovation is happening, with investments in R&D and innovation more easily translated into competitive innovative services than innovative goods.

Figure 6.3-23 Exports of knowledge-intensive services as % of total services exports, 2011, 2014 and 2018



Science, research and innovation performance of the EU 2020

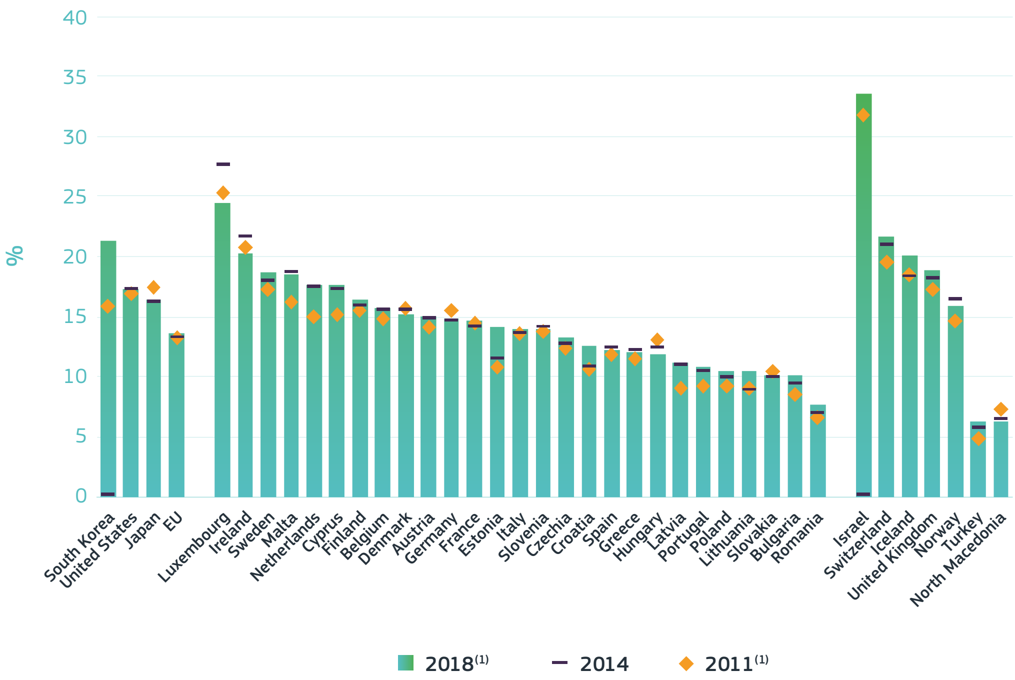
Source: European Commission, DG Joint Research Centre based on Eurostat (bop_its6_det), OECD (TISP_EBOPS2010) and ITC (Vértesy and Damioli, 2020, Figure 5)

Note: (1)Two sets of values are available: values for worldwide comparison that exclude foreign trade between EU countries and values for European comparison that include it. The values for worldwide comparison are shown on the graph. The value for EU comparison for 2018 is 68.4.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-23.xlsx

In terms of employment in knowledge-intensive activities[26], which measures the economic impact of R&I activities towards the creation of new high-skilled jobs, the United States, Japan and South Korea outperform the EU. Within the EU, this performance indicator reflects the innovation divide between north-western Europe and south-eastern Europe, with some exceptions such as Malta, Cyprus and Estonia which have seen their shares increase over time due to their growing R&D investments in ICT and professional and scientific services (Figure 6.3-24). Once again, economic structure plays an important role: Luxembourg and Ireland, which have a high share of financial services and ICT services, respectively, top the ranking in the EU.

Figure 6.3-24 Employment in knowledge-intensive activities in business industries as % of total employment, 2011, 2014 and 2018



Science, research and innovation performance of the EU 2020

Source: European Commission, DG Joint Research Centre based on Eurostat (htec_kia_emp2) Japan Statistical Office, US BLS CBP and OECD (Vértesy and Damioli, 2020, Figure 3)

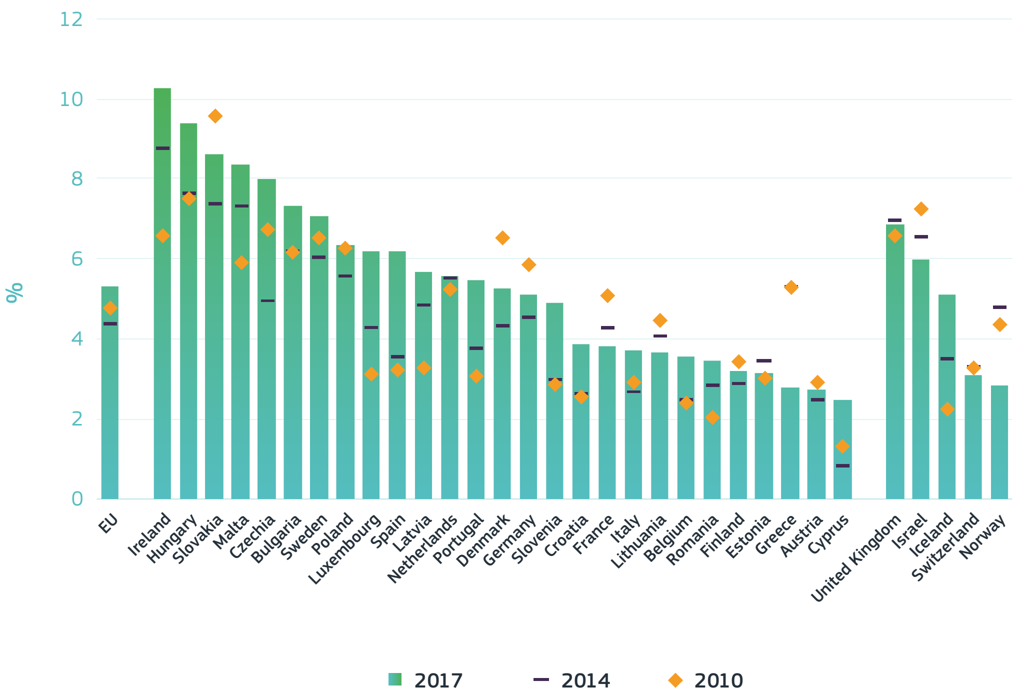
Note: (1)KR, IL: 2015. KR: 2009.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-24.xlsx

26 By definition, an activity is classified as knowledge-intensive if the tertiary educated people employed represent more than 33 % of total employment in that activity.

The last component of the Innovation Output Indicator builds on the dynamism of fast-growing enterprises in the most-innovative sectors and tries to capture countries' capacity to respond to new needs and emerging demands. At the EU level, there is no clear innovation divide, with good performances among both the most-innovative and least-innovative countries. Ireland, followed by Hungary and Slovakia, show the highest shares (Figure 6.3-25). However, while the shares in Ireland reflect its strength in the knowledge-intensive services sector, in Hungary and Slovakia they are reflected in the medium-high-technology manufacturing sector. In addition, these countries have shown high rates of economic growth in recent years, which subsequently has contributed to strong employment growth. On the downside, Cyprus, Austria and Greece show the lowest shares. Over time, Slovenia, Luxembourg and Spain have seen the biggest improvements.

Figure 6.3-25 Employment in fast-growing enterprises in the top 50% most innovative sectors as a percentage of total employment, 2010, 2014 and 2017



Source: European Commission, DG Joint Research Centre based on Eurostat (online data code: bd_9pm_r2) (Vértesy and Damioli, 2020, Figure 6)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-25.xlsx

BOX 6.3-2 Innovation beyond its economic impacts and the importance of social innovation

Beyond the impacts of innovation in job creation, new products and markets, and sustainable economic growth, impacts can also be seen in a more social context, such as through engagement with citizens and local communities, reflecting the importance of social innovation.

In 2018, Athens was awarded with the European Capital of Innovation prize for the way in which the capital's authorities responded to the deepening economic and refugee crisis. Athens used innovation to engage citizens, revive the local community, boost creativity and dynamism, and open the city to the world.

After major cuts in resources and greater pressure on public services, Athens revamped its policymaking processes to innovate quickly so that, along with its citizens, it could revive the local economy, build up infrastructure and rebuild the residents' confidence in their city. Inclusion and cooperation with citizens and civil society is, more than anything else, what has made this approach work. The innovation-support processes were accountable and transparent, while citizens were consulted on decisions throughout. This helped to regenerate neighbourhoods, integrate refugees, and improve education and digital access. Athens now brings groups together to improve the city rather than directing change from the top, showing that innovation enables cities to do more with less. In the end, the city has new businesses, a more attractive urban environment a revived cultural scene and better services.

As the previous Commissioner, Carlos Moedas stated: 'Athens stands out as an example that a city facing many challenges can achieve great things. Through innovation, Athens has found new purpose to turn around the economic and social crisis.'

Examples of initiatives include:

- The **POLIS2**[27] project aimed to revitalise abandoned buildings by providing small grants to residents, small enterprises, creative communities and other civil society groups and to bring life to all corners of Athens.
- The **Curing the Limbo**[28] initiative gives refugees and migrants the possibility to connect with other residents in order to learn the language, develop new skills, find employment opportunities, and engage in active citizenship.
- The **Digital Council**[29] brought together companies and educational institutions in the city to provide training on digital literacy and civic technology as well as to promote sustainable innovations like smart recycling bins

In 2019, Athens passed its title to the city of Nantes, awarded for its open and inclusive governance approach, involving citizens in 'grand debates' and discussions on major societal challenges, leading to concrete initiatives. In addition, the city has built a dynamic and thriving digital and start-up community, driving the city's innovative ecosystem and providing cutting-edge solutions to local challenges.

27 http://www.polis2.thisisathens.org/en/
28 https://www.uia-initiative.eu/en/uia-cities/athens
29 http://athenspartnership.org/news/

Nantes' flagship policies and projects include:

- 15 places to be reinvented[30]: a competitive selection of ideas submitted by citizens that resulted, for instance, in turning an unused chapel into an urban mushroom farm or creating a zero-waste awareness hub in a former art school.

- Nantes CityLab[31] helps innovators test new solutions in real life by providing physical and digital infrastructure, such as a 3D-printed social house constructed in 3 days or an autonomous shuttle powered exclusively by a solar road.

- Creative factory[32], a support system for creative and cultural industries, and the Eco-innovation factory[33], a programme that selects projects such as one which uses bicycle trailers to collect biowaste from restaurants and offices for local composting.

- **The** Nantes French Tech Capital[34] programme fosters start-ups, scale-ups, attracting talents and breakthrough technologies, and enables the coordination and promotion of the regional innovation ecosystem.

- **Ecossolies**[35] is a network that gathers private and public members to develop initiatives in the field of social and solidarity economy and promote them by awarding the best social innovation solutions, such as the Hacoopa[36] project for housing the elderly or the **Bout' à** Bout' association[37] which is reducing the impact of the used glass bottles.

- MySMARTLife[38] is an innovative European project focusing on smart solutions for urban transition.

30 https://www.nantes.fr/15lieux
31 https://twitter.com/NantesCitylab
32 https://www.creativefactory.info/
33 http://www.nantes.fr/home/actualites/ville-de-nantes/economie/2017/ecoinnovation.html
34 https://lacite-nantes.fr/nantes-labellisee-capitale-french-tech-465488.html
35 https://ecossolies.fr/
36 https://www.hacoopa.coop/decembre-2018-laureat-du-prix-de-linnovation-sociale/
37 http://www.boutabout.org/
38 https://www.mysmartlife.eu/cities/nantes/

5. The need for a stronger knowledge valorisation policy in Europe

Innovation encompasses several dimensions. As shown previously, innovation output – as defined by the composite indicator produced by the Joint Research Centre – includes four indicators: patents, employment in knowledge-intensive activities, the competitiveness of knowledge-intensive goods and services, and a measure of employment in fast-growing firms in innovative sectors (Vértesy and Damioli, 2020). The patents component includes inventions that use the knowledge generated by investing in R&D and innovation, and which can be transformed into successful technologies. Similarly, indicators for the intensity of skilled labour employment, in knowledge-intensive activities and in fast-growing firms provide an indication of an economy's orientation towards the production of goods and services with innovation added value. Finally, the trade flows associated with these commodities measure their capacity to reach global markets[39].

It is necessary to go beyond the approach of innovation output only, towards a more holistic approach in order to understand how knowledge is valorised, i.e. the process of creating value from knowledge and turning the results into sustainable solutions with economic value and societal benefits. This holistic approach should also include investments, knowledge flows, scientific performance and citizens' engagement. R&I can only play a decisive role in shaping the climate-ecological, social and economic transitions if excellent results are made available quickly and put to practical use on a large scale. This is fully in line with the Council Resolution of 29 May 2018 on 'Accelerating knowledge circulation in the EU'[40].

There is a need to reinforce knowledge valorisation in Europe. When looking at Figure 6.3-26, even though the EU outperforms the United States in terms of scientific output and number of researchers, it is surpassed in scientific quality, technological progress and the share of high-tech sectors in the economy. More worryingly, the EU lags significantly behind in terms of business-academia linkages. If Europe wants to catch up and become more competitive internationally, it needs to address its deficiencies by promoting a culture of knowledge valorisation in European R&I system, ensuring that the knowledge-based institutions know how to manage their intellectual capital and improving the links between academia, industry, citizens and policymakers.

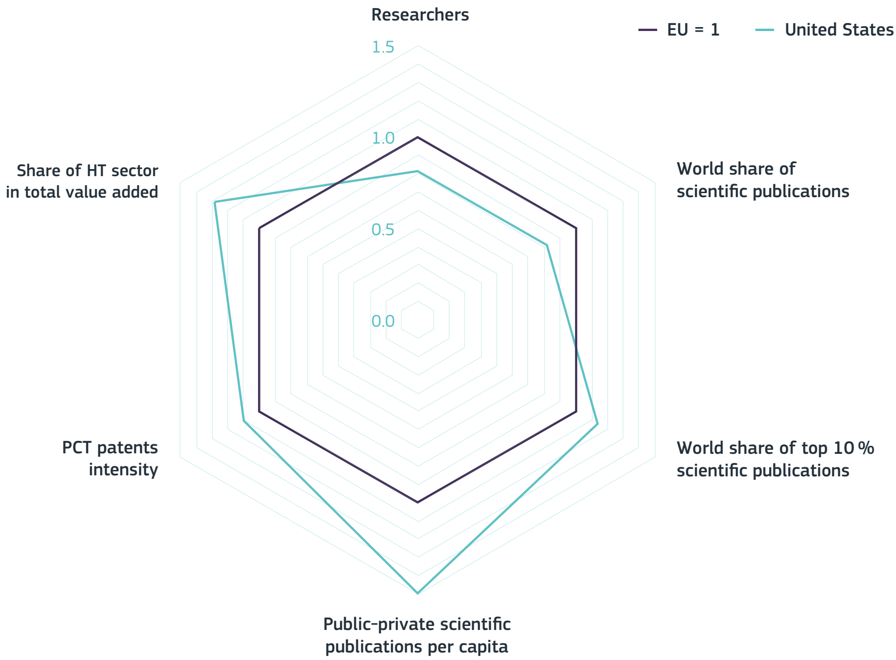
A strong valorisation policy relies on a toolbox of instruments that acknowledges different knowledge valorisation channels. Many strategies, instruments and measures have been developed at the European, national and regional level, by private and public players, to enhance knowledge transfer and valorisation. For instance:

- **Academia-industry connections** as well as 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, public-private partnerships, innovation brokers and other intermediaries, mobility programmes, knowledge clusters, startup finance schemes, etc. Digital solutions such as platforms

39 COM(2013), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

40 https://data.consilium.europa.eu/doc/document/ST-9507-2018-INIT/en/pdf

Figure 6.3-26 Knowledge-valorisation approach, latest available year



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, data produced by Science-Metrix using data from the Scopus database and OECD data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-26.xlsx

provide new opportunities for industry cross-fertilisation and for better linking the various actors in the innovation system, for instance, to connect the demand side, including end-user expectations, with the supply of innovations.

- Without **citizen engagement** even the best-designed strategies and activities for valorisation would not achieve the highest impact or sufficiently support the economic, social and ecological transition in an inclusive way – so that no community or region across Europe is left behind. A European knowledge valorisation policy also needs to ensure that it benefits all citizens, including by enabling research results and innovations to feed solutions in cities and regions across Europe that respond to their needs.

- **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. **Standardisation** facilitates the access to and spreading of new products in the market.

Examining and sharing experiences and best practices of knowledge valorisation can be a powerful way to improve national and European strategies and policies and to enhance the societal and economic uptake of research-based solutions across the Union.

6. Conclusions

This chapter shows that innovation output in the EU continues to lag behind Japan and the United States. Compared to the United States, the **EU is stronger in exporting high-tech manufacturing products and knowledge-intensive services**, but weaker in terms of qualified employment and patent applications. On the other hand, **Japan and South Korea are leading in patent applications and exports of high-tech products**. In terms of PCT patent applications, the EU and the United States have been losing their share to countries like Japan and China, while in the case of China, its growth has been particularly impressive, putting additional competitive pressure on the EU. The findings show that **if the EU wants to remain competitive and catch up with its main competitors it needs to make extra efforts, especially in supporting European IP policy, in fostering science-industry interaction and in improving its knowledge valorisation policy**.

The innovation divide within the EU remains stable. While north-western Europe performs relatively well in most of the indicators, south-eastern Europe performs relatively poorly. Despite the fact that the countries' economic structure also plays an important role in explaining the differences in innovation performance, the EU can still do more to reduce the innovation divide among its Member States by supporting the improvement of national innovation systems and facilitating knowledge circulation. Ultimately, tackling the innovation divide will help the EU as a whole to become more competitive and innovative worldwide.

The chapter also shows that **the share of innovation companies and innovation turnover fell in the EU between 2010 and 2016**. Nearly half of the companies in the EU are innovative, with higher shares for product and/or process innovation. In addition, around half of European SMEs are innovative. **Encouraging the creation of innovation-intensive sectors and upgrading the technology profiles of Member States** would definitely help the EU to have more innovative enterprises that can boost jobs and economic growth.

Last but not least, the figures show that the **EU is leading technological progress in the fields of transport, climate and energy**, where it shows the highest shares in terms of patent applications, while the United States leads in the health, bioeconomy and food and security sectors. In all fields, China has reported extraordinary increases in its share. Given the importance of innovation and technological progress in addressing the SDGs, the EU should **not only continue to invest in scientific leadership in these areas but should also promote a culture of knowledge valorisation able to benefit fully from its research results**.

7. References

Ali-Yrkkö, J. (2010), Nokia and Finland in a Sea of Change, ETLA - Research Institute of the Finnish Economy, Taloustieto Oy.

COM(2013), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

Cornell University, INSEAD, and WIPO (2019), The Global Innovation Index 2019: Creating Healthy Lives - The Future of Medical Innovation, Ithaca, Fontainebleau, and Geneva.

Dosi G., Llerena P. and Sylos Labini, M. (2006), The relationships between science, technologies and their industrial exploitation: An illustration through the myths and realities of the so-called 'European Paradox', *Research Policy* 35: 1450-1464.

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

European Commission (2014), a Study on R&D Tax Incentives.

European Commission (2019), European Innovation Scoreboard 2019.

European Commission (2019), European Semester - Country Report Bulgaria.

European Commission (2019), European Semester - Country Report Romania.

European Commission (2019), Reflection Paper - Towards a Sustainable Europe by 2030.

European Commission (2015), RIO country report 2015: Lithuania.

European Commission (2015), RIO country report 2015: Malta.

European Commission (2015), RIO country report 2015: Portugal.

European Commission (2017), The economic rationale for public R&I funding and its impact.

European Commission (2018), The 2019 EU Industrial R&D Investment Scoreboard.

European Union Intellectual Property Office (2017), Protecting innovation through trade secrets and patents: determinants for European Union firms.

Frietsch, R., Kladroba, A., Markianidou, P., Neuhäusler, P., Peter, V., Ravet, J., Rothengatter, O. and Schneider, J., Final report on the collection of patents and business indicators by economic sector: Societal Grand Challenges and Key Enabling Technologies, Publications Office of the European Union, Luxembourg, 2017: ISBN 978-92-97-76847-7, doi:10.2760/39818, JRC109299.

Mohnen, P. (2019), R&D, innovation and productivity, EU-funded project GROWINPRO Working Paper, Maastricht University and UNU-MERIT.

Vértesy, D. and Damioli, G. The Innovation Output Indicator 2019, EUR 30104 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-16413-5, doi: 10.2760/540233, JRC119969.