CHAPTER 5

INVESTMENT: THE CRITICAL ROLE OF INTANGIBLES

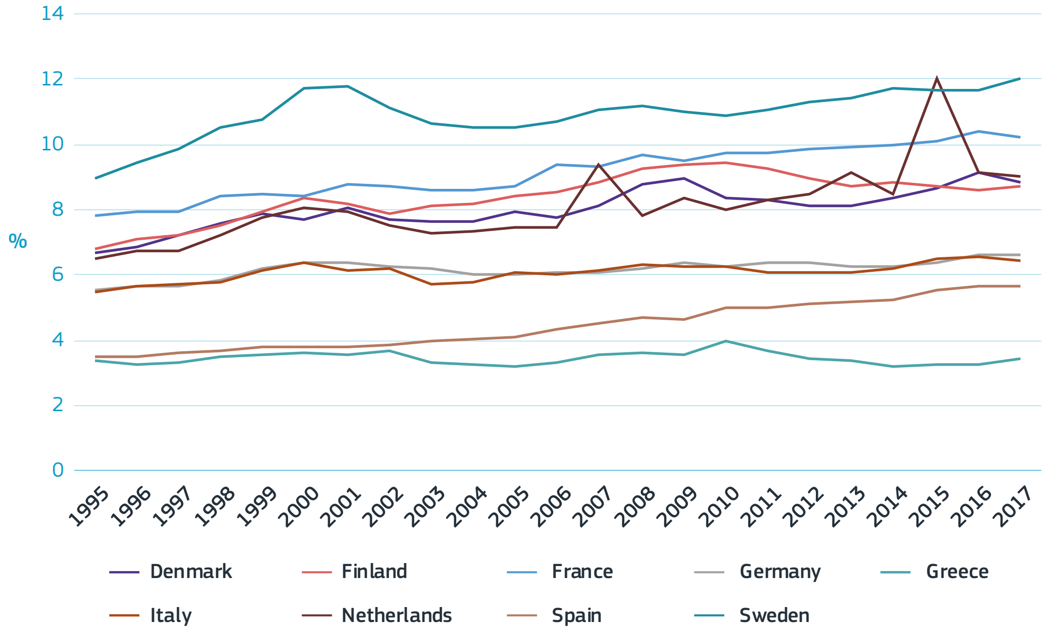
CHAPTER 5.1

INTRODUCTION: TANGIBLE AND INTANGIBLES ASSETS

The processes of production commonly require a combination of different inputs such as machines and buildings, computer hardware and software, and data and workers with digital skills. Such inputs can be classified in different ways, such as 'capital' and 'labour', as well as 'tangible' and 'intangible' assets. Investments in one asset are likely to effect the effectiveness of others, creating a complex network of complementarities and optimal mixes of strategic investments. As an example, hiring highly skilled IT workers is not very effective without the necessary investment in software and IT infrastructure.

Over the past 25 years, the investment mix has shifted towards intangible assets and the COVID-19 pandemic appears to have accelerated this shift toward a dematerialised economy (Haskel and Westlake 2017; Roth 2019, Thum-Thysen 2019). Over the last decades different Member States increased their investments in intangibles (as a share of GDP), yet there is wide heterogeneity across countries (see Figure 5.1). In 2020, the EU share of investment on software, data and IT activities has been 15% of the total investments, training of employees has been 10%, R&D has been 8% (see Figure 5.2). Yet, investments in machinery and equipment still represent a large part of the overall investment planning, with 48%, yet their typology and quantity are increasingly linked to the intangible assets of companies.

Figure 5.1-1: Investments in intangible assets (% of GDP[(1)]), 1995-2017



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit own elaboration.

Note: [(1)]data on intangible assets expressed in current prices, million units of national currency, are taken from the INTAN-Invest database. Data on GDP from Eurostat (online data code: NAMA_10_GDP) expressed in current prices, million units of national currency.

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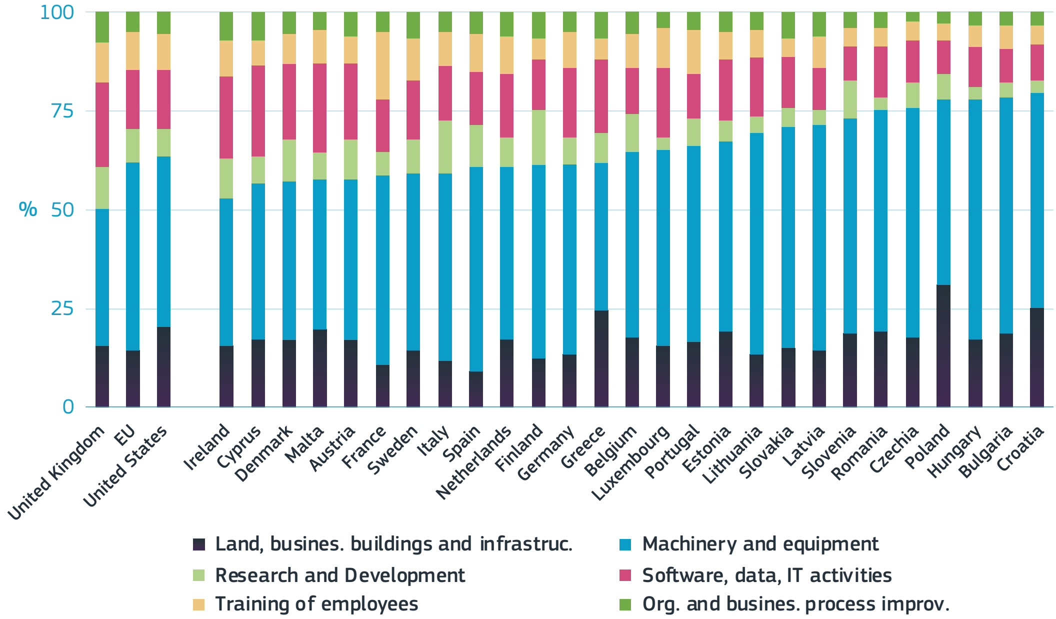
Figure 5.1-2: Average share of investment in different asset types across countries



Science, Research and Innovation Performance of the EU 2022

Source: EIB Investment Survey 2021

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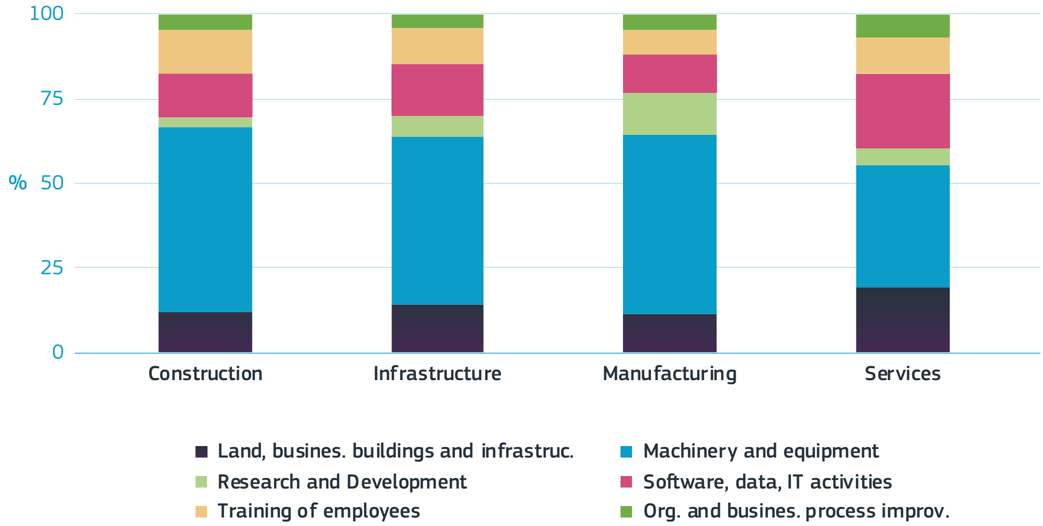
Figure 5.1-3: Average share of investment in different asset types across sectors in the EU



Science, Research and Innovation Performance of the EU 2022

Source: EIB Investment Survey 2021
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The use of tangible and intangible assets vary both across countries and across sectors. Countries that invest more (as share of the total) on intangible are Ireland, Cyprus, Denmark and Malta, while countries that spend less are Croatia, Bulgaria, Hungary and Poland. At a sectoral level, the service sector has the highest share of spending on intangibles, with the share of investment in software, data and IT services (22 %), almost doubling the spending on software by other sectors (see Figure 5.3).

Both tangible and intangible assets positively affect firms' productivity and innovative potential. In the EU, software investments contribute to 19 % of productivity growth, followed by economic competencies[1] (16 %) and innovative property[2] (8 %). Total Factor Productivity contributes to 47 % and tangible capital to 10 % of productivity growth (see Chapter 4.1 for more). Furthermore, the returns from investments in tangible and intangible are not unrelated from each other. Complementary between tangible and intangible assets play a relevant role in explaining productivity (Radhakrishnan 2017, Thum-Thysen et al. 2021), competitive advantages and innovations (Stieglitz and Heine 2007). Human capital, in particular, is necessary for firms to capture the productivity enhancing properties of new technologies (see Chapter 5.4 for more).

Regardless of the sectors, companies that invest more in intangibles grow more. Leading firms (companies in the top quartile for growth in gross value added, a measure of economic growth) invest much more in intangibles than low growers, companies in the bottom quartiles[3]. Such a pro-

1 Advertisement, market research and branding, vocational training and organisational capita
2 Research and development and design and other product developments
3 Getting tangible about intangibles: The future of growth and productivity? | McKinsey

ductivity divide is profoundly linked with the relationship between the tangible and intangible assets of the digital economy, with only top-performer companies having the ability to afford the initial non-trivial adjustment costs, organisational changes, new skills and infrastructures required to purposely succeed in the dematerialisation of the economy.

Drivers and barriers to investing in intangible and tangible are different. The regulatory framework seems to be more relevant for investments in intangibles while financial conditions and, in particular, the availability of external funding, appears to be more important for investments in tangibles. In turn, investment in intangibles is funded more from internal resources, which makes such investments arguably less dependent on bank lending rates. In addition, investment in human capital emerges as important for fostering investment in intangible assets, pointing to the need for well-integrated education systems targeting early as well as lifelong learning (Thum-Thysen 2019). Such elements may justify policy interventions, such as higher spending on the education system, R&D public investment and subsidies to firms aimed at stimulating investment in intangible assets and the creation of a knowledge-based economy.

References

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Radhakrishnan, S., Wang, H., Wang, K., & Zhu, Z. J. (2017), *R&D Investment and Firm Growth: The Role of Tangible Asset Complementarit*y, Available at SSRN 3096806.

Roth, F. (2019), *Intangible capital and labour productivity growth: A review of the literature*, Hamburg Discussion Papers in International Economics No. 4.

Thum-Thysen, A., Voigt, P., Bilbao-Osorio, B., Maier, C., & Ognyanova, D. (2019), 'Investment dynamics in Europe: Distinct drivers and barriers for investing in intangible versus tangible assets?', *Structural Change and Economic Dynamics*, 51, pp. 77-88.

Thum-Thysen, A., Voigt, P., & Weiss, C. (2021), *Reflections on Complementarities in Capital Formation and Production: Tangible and Intangible Assets across Europe* (No. 152), Directorate General Economic and Financial Affairs (DG ECFIN), European Commission.

CHAPTER 5.2

INVESTMENT IN R&D

KEY FIGURES

2.3 %
of GDP was invested in R&D in the EU in 2020

6 out of 10 euros
invested by governments in R&D was in the form of tax reliefs in the EU in 2019

7
Member States have reached their national 2020 R&D investment targets

€205 bn
was invested in R&D by the business sector in the EU in 2020

€2.73 bn
was invested in public R&D in energy efficiency, renewables, hydrogen and fuel cells, power and storage in the EU in 2020

KEY QUESTIONS WE ARE ADDRESSING

- What is the state of R&D investments and their evolution in Europe, in the Member States and compared to other international players?
- What are the key drivers, sectors and components of R&D investments in Europe?
- What are the main policy tools to support R&D in Europe?

KEY MESSAGES

What did we learn?

- R&D intensity stood at 2.3% of GDP in the EU in 2020. The EU accounts for almost 20 % of global R&D expenditure, though its share is on a declining trend.
- R&D intensity increased over 2000-2019 in 24 Member States, but significant heterogeneity persists across EU countries.
- Against the backdrop of the COVID-19 pandemic, R&D business investments in the EU decreased from EUR 208 billion in 2019 to EUR 205 billion in 2020. Due to a sharp decline in GDP, this translated into a small increase in R&D intensity to 2.32% of GDP in 2020.
- R&D tax support doubled over the past decade to reach 58% of total government support for R&D in 2019.
- The European Commission's R&I funding programmes (including Horizon 2020) were responsible for 7.2% of public funding for R&D in the EU in 2019.

What does it mean for policy?

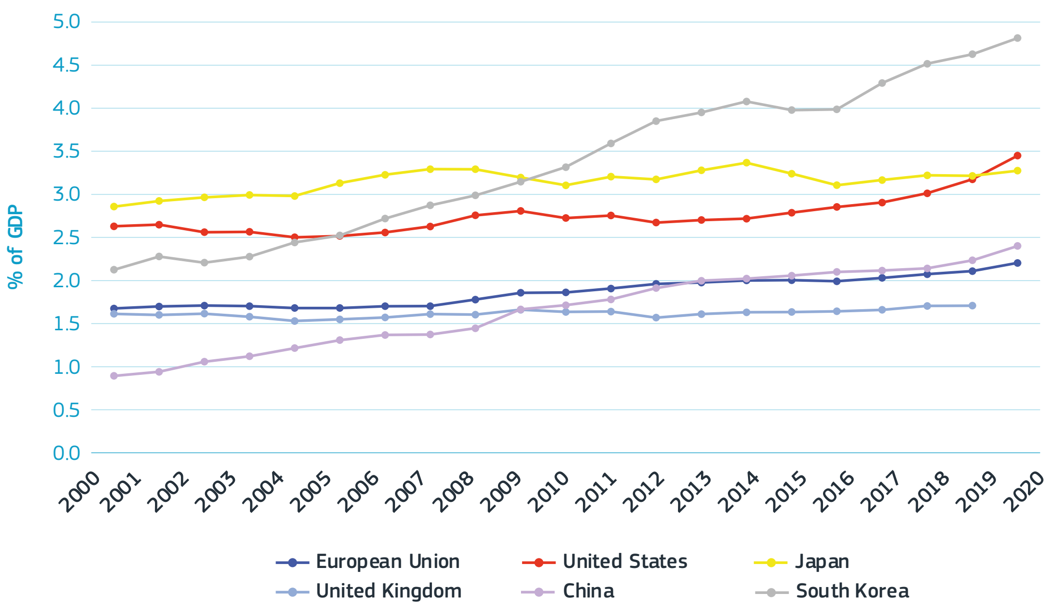
- The EU needs a transformative R&I policy to pursue the green and digital transitions and to enhance resilience against future crises. Such a policy requires directionality in national and EU investments to facilitate and coordinate the alignment of R&I investments with EU priorities.
- This coordinated reform and modernisation effort could aim to improve the effectiveness and efficiency of R&I investments as well as to leverage private investments.
- The revitalised ERA agenda under the New ERA for Research and Innovation includes a set of ambitious political objectives and R&D investment targets. The timeline and intensity of such investments as well as structural reforms of R&I systems could be adapted to the national context and national specificities. This also calls for enhanced national strategies ensuring timely delivery of those key objectives.
- Green innovation policies complement net-zero policies.

1. R&D investments in Europe: state of play

Europe has intensified its R&D investments over the past two decades, but there remains a gap in terms of R&D intensity compared to some of its main competitors. Figure 5.2-2 highlights that the EU R&D intensity increased from 1.81% of GDP to 2.32% of GDP over 2000-2020, but in 2020 still below the US (3,45%), Japan (3,27%), and South Korea (4,81%). China experienced steady growth, reaching the EU level in 2020 (2.32%).

The scientific and technological divide between the more advanced Member States and the rest (i.e. central European and southern countries) is largely the result of lower public R&D investment and of how this funding is allocated. R&D spending is highly concentrated in the EU. In 2020, only three Member States were responsible for 50% of total R&D investments in the EU, and eight for 85% (Figure 5.2-3). The distribution is, however, more dispersed across the EU than a decade ago (the same first three Member States had a share of 61% in 2010). Several Member States have increased their share in EU-wide R&D spending over 2010-2020, but there is still a clear divide between these leading countries and the rest of the EU.

Figure 5.2-1: R&D intensity (R&D expenditure as % of GDP), 2000 - 2020



Source: OECD (Main Science and Technology Indicators)
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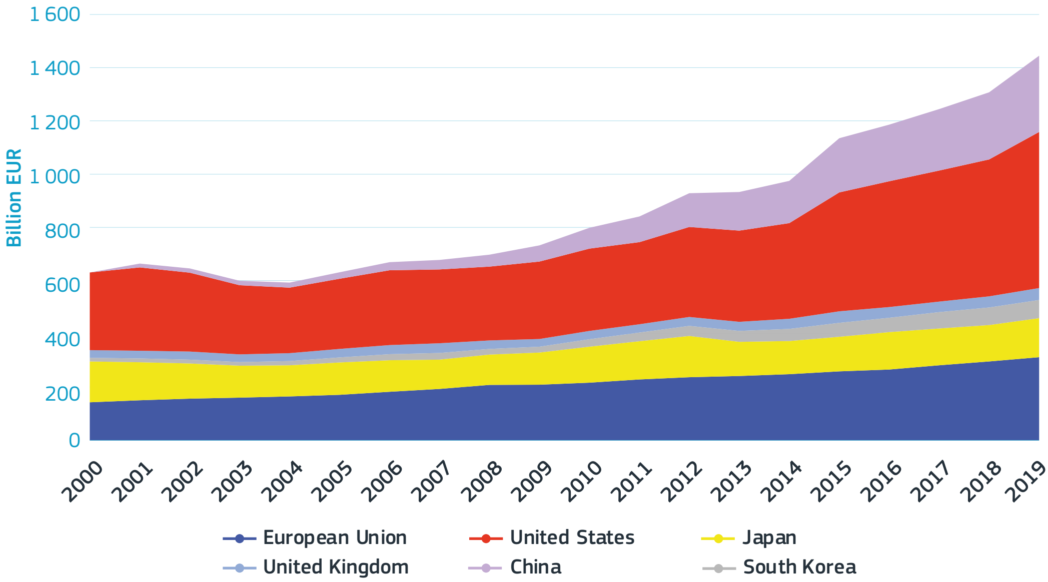
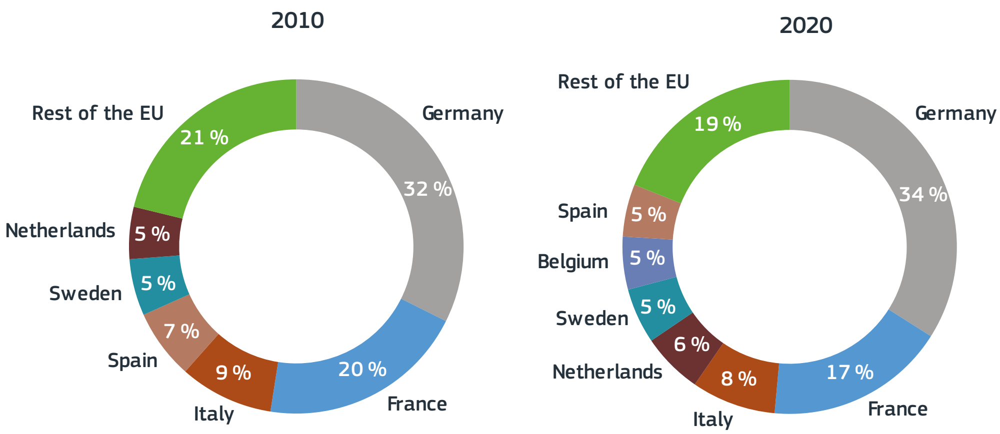
Figure 5.2-2: R&D investments in billion euro, 2000-2019



Science, Research and Innovation Performance of the EU 2022

Source: Eurostat (online data code: rd_e_gerdtot)
Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-2-2.xlsx

Figure 5.2-3: Distribution (%) of gross expenditure in R&D (GERD) within the EU, 2010 and 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdtot)
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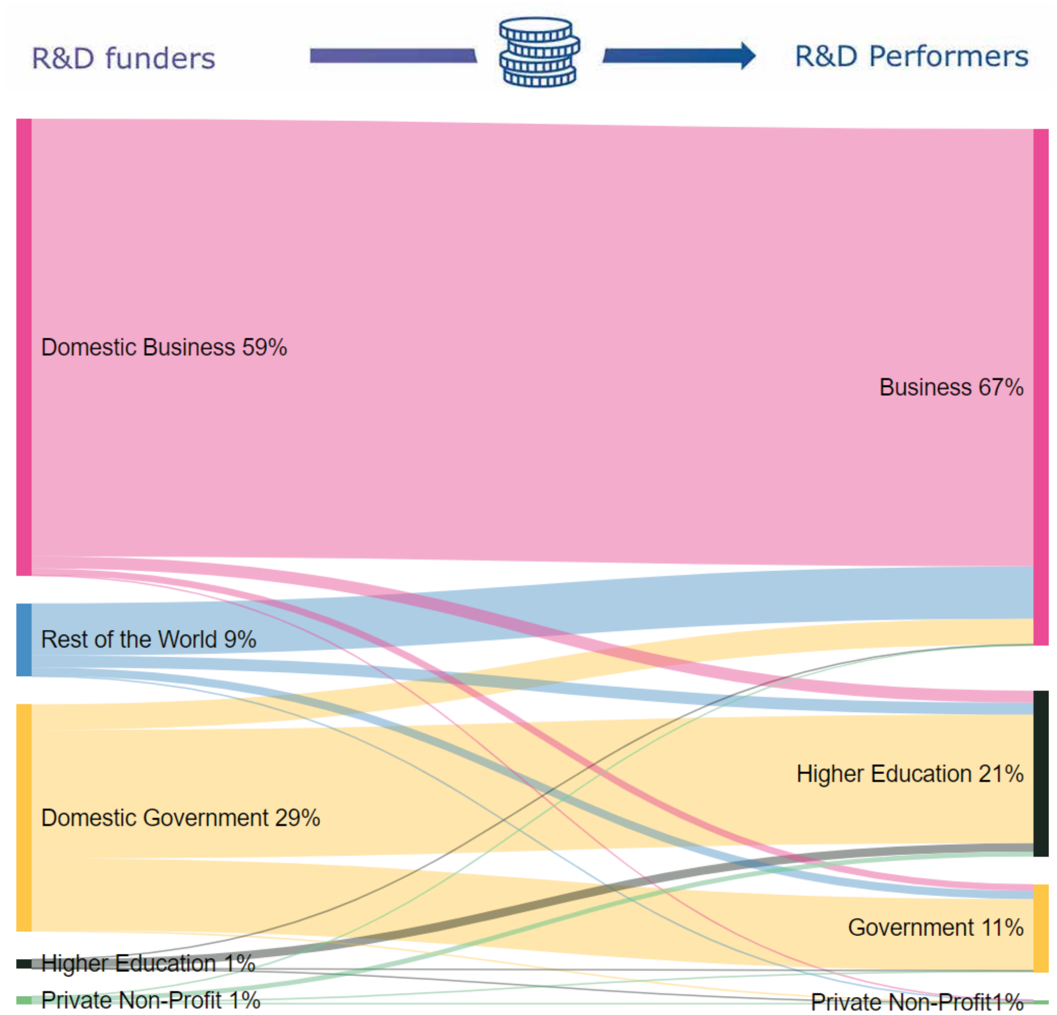
Governments finance about 30% of R&D expenditure in the EU and the private sector slightly less than 60% (Figure 5.2-4, for 2019). About two-thirds of these investments are carried out by the private sector, about 20% by universities and higher education institutes, and about 11% by the government directly. Public R&D investments are primarily directed towards creating an excellent public science base (composed of higher education institutions and other public organisations performing R&I), which will generate the knowledge and talent needed by innovative firms and will leverage and benefit private investments, notably in the more innovative and dynamic industries (Dosi and Stiglitz, 2014; Mazzucato, 2013; Archibugi and Filippetti, 2018). The quality of the public science base of Member States is directly linked to the level of public R&D investments and the effectiveness of the latter. During the recent pandemic, the research community repeatedly advocated stronger public support to ensure the sustainability of long-term research projects, increasing the resilience and the preparedness of societies when facing similar threats in the future.

The EU has a much lower rate of R&D investments from the business sector than its international competitors. Figure 5.2-5 shows that the business sector funds 59% of R&D investments in the EU, while it funds 63% in the USA, 76% in China, 77% in South Korea and 79% in Japan. With respective shares of 21% and 23% of R&D investments, the higher education sector is much more involved in the EU and in the UK than it is in the USA and Japan (both 12%) or in China and in South Korea (both 8%). It is also interesting to note that China has the highest share of R&D investment performed by the government (16%), followed by the EU with 11%.

Figure 5.2-4: R&D funders and performers in the EU in 2019



Science, Research and Innovation Performance of the EU 2022

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

Note: In the Rest of the World, 3 of the 9% is funded by the public sector (European Commission and international organisations) and about 1.2% of these go to the higher education sectors.

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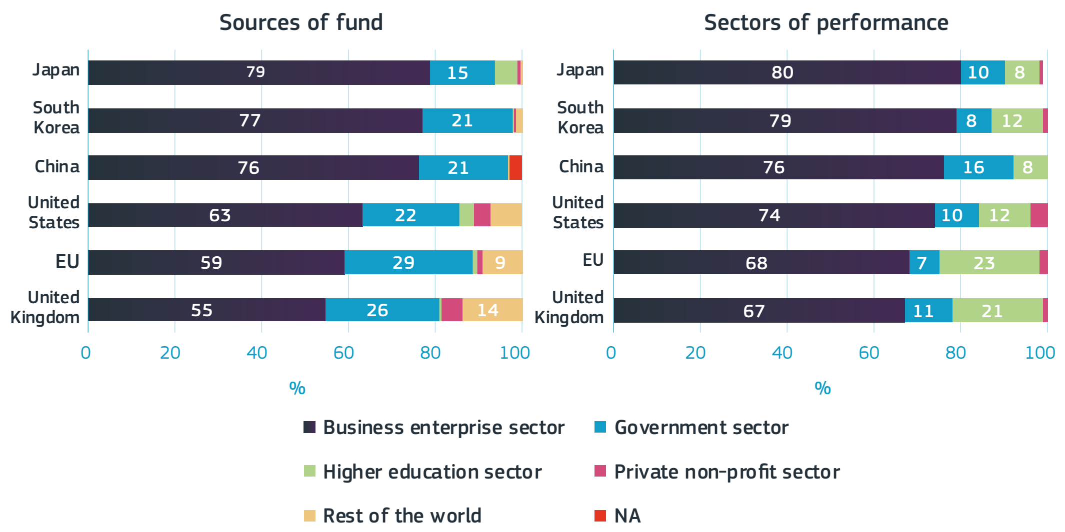
Figure 5.2-5: Gross Expenditure in R&D (GERD) by source of funds and sectors of performance per country/region, 2019



Science, Research and Innovation Performance of the EU 2022

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

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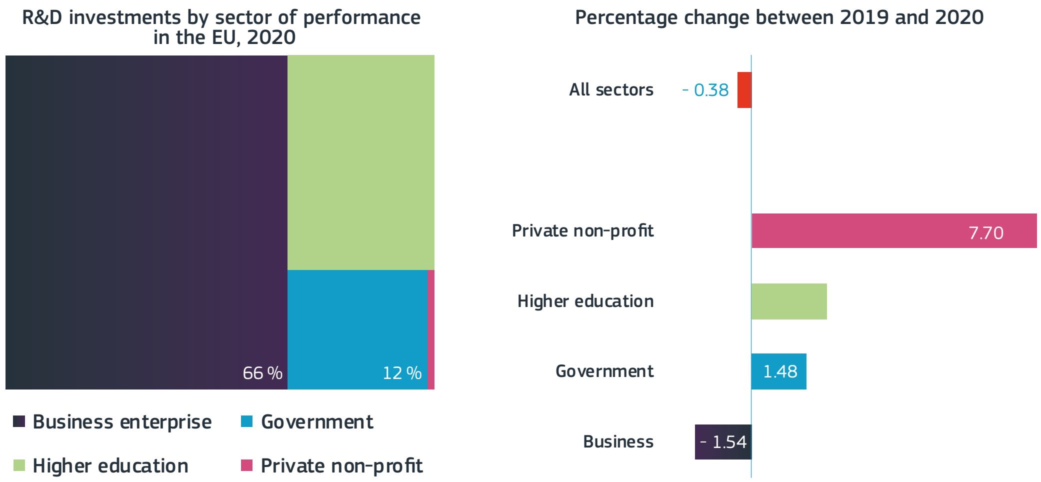
The COVID-19 pandemic has led to a decrease in R&D investments in the EU. In 2020, for the first time since 2010, business R&D investments decreased in the EU from EUR 208 billion in 2019 to EUR 205 billion in 2020 (Figure 5.2-6). In contrast, performance in the public sector has increased, from EUR 102 billion in 2019 to EUR 104 billion in 2020 (the government sector by 2.3% and higher education by 2.04%). The private non-profit sector experienced the highest growth rate, with a 7.7% increase from 2019 to 2020. As the business sector is the main R&D performer, **the overall effect is a decrease in R&D investments in 2020 compared to the 2019 level.** However, it is worth noting that due to the decline in GDP linked to the COVID-19 pandemic, EU total R&D intensity increased to 2.32% of GDP in 2020.

Figure 5.2-6: R&D investments by sector of performance in the EU in 2020 and percentage change between 2019 and 2020



Science, Research and Innovation Performance of the EU 2022

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

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Box 5.2-1 Business R&D investment and sectoral composition

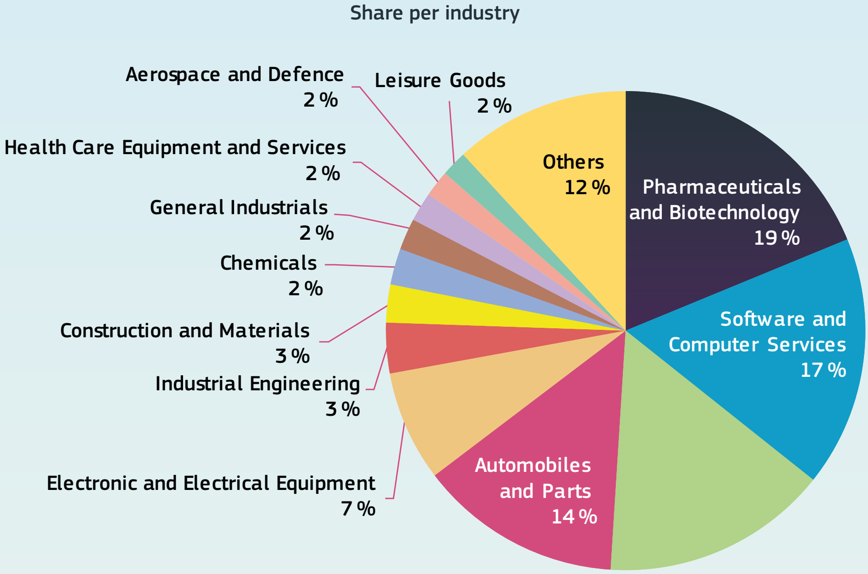
Analysis based on the 2021 EU Industrial R&D Investment Scoreboard (European Commission, 2021d)

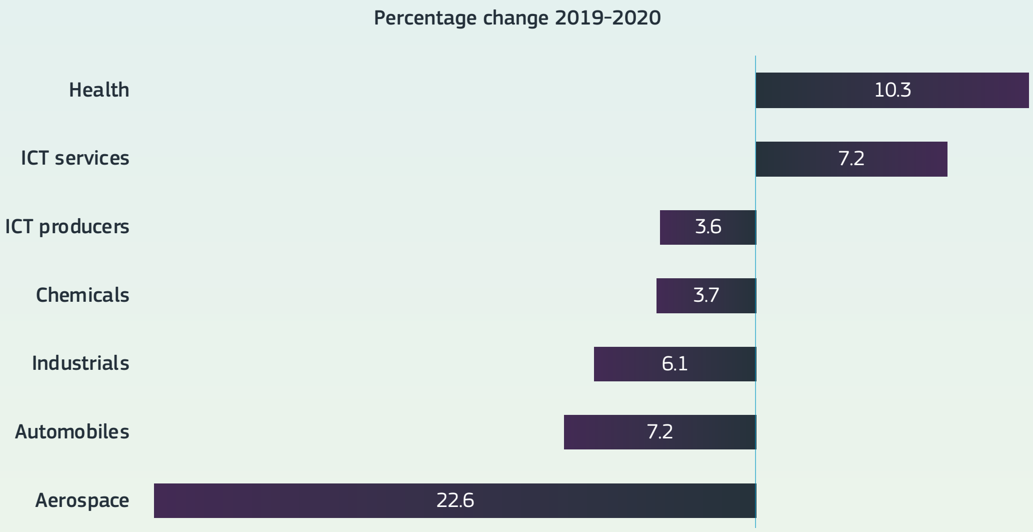
Despite the COVID-19 pandemic, worldwide investment in R&D continued to increase significantly in 2020, but at a much slower pace than the year before[1]. In 2019, the world top 2 500 R&D business investors increased their investment by 9.2 % compared to 2018, whereas in 2020 they invested EUR 909.8 billion in R&D, 6.0 % more than in 2019 (2021 EU Industrial R&D Investment Scoreboard). Still, according to the 2021 EU Industrial R&D Investments Scoreboard, **business R&D investments for the top 2 500 R&D investors proved to be one of the most resilient factors during the crisis**. Most of the other performance indicators were more strongly affected by the pandemic, particularly operating profits, net sales and capital expenditure. R&D investments are less pro-cyclical than other performance indicators for several reasons, one being that it can be cheaper for companies to invest in R&D during a recession (the opportunity-cost effect). It may also underline the important role R&D investment plays in tackling major societal challenges and in maintaining the competitive position of companies in order to reap post-crisis opportunities.

The decrease in R&D investments in Europe is mainly linked to a difference in the sectoral composition of European industry compared to the US and Chinese industrial landscapes. While most major R&D investors in the ICT and health industries across the world, including in Europe, exhibited growth in R&D investments, firms in other industries, especially in transport equipment and industrials, experienced a large reduction in R&D investment (OECD, 2021). As shown in Figure 5.2-7, the largest R&D investors with their headquarters in the EU operate in the automotive, chemicals and industrial sectors, which were severely hit by the crisis. For this reason, business R&D investments by the top R&D investors declined in absolute terms in 2020. These differences in sectoral composition may explain why R&D investments in the EU have declined more than in the USA or in China.

1 This result is based on the EU Industrial R&D Investment Scoreboard, which captures companies' activities regardless of their location (i.e. of the parent companies and their subsidiaries) and not only investments made by companies and subsidiaries based in the EU. At the world level, inward and outward flows in companies compensate each other to a certain extent, which makes this approach coherent.

Figure 5.2-7: R&D private investments by industry in the EU for the top EU R&D investing companies amongst the top 2500 R&D investors worldwide, 2020





Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on European Investment Scoreboard 2021

Note: The sectoral distributions are calculated using only the R&D investments of the top 401 R&D investors that have their headquarters in the EU.

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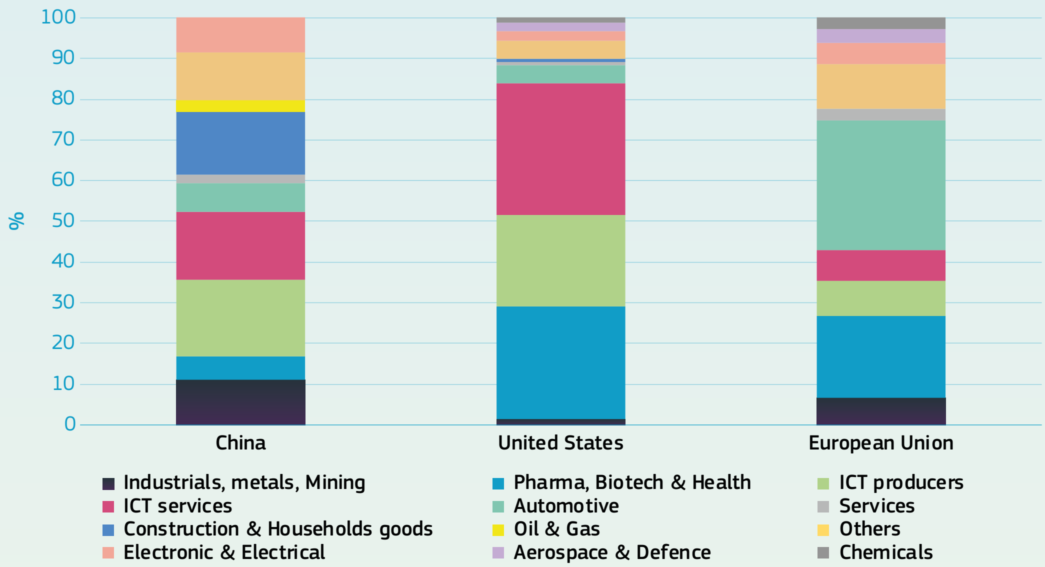
The sectoral composition of the European economy can also explain, to some extent, the lower business R&D intensity in the EU compared to its main competitors. **Figure 5.2-8 shows that less than 50 % of EU corporate R&D expenditures is in the high R&D-intensity sectors** (e.g. ICT producers, ICT services, health industries) and **around 40 % in the medium-high R&D-intensity sectors** (e.g. automobiles and other transport)[2]. Conversely, 80 % of R&D investment by US companies (and more than half of Chinese business R&D investment) is in the high R&D-intensity sectors. Over the past 10 years, the USA and China have increased their specialisation in ICT sectors, and the US increased its proportion in the health sector. In terms of R&D intensity, in 2019, China already caught up to the European level. According to R&D-investment trend for the top investors worldwide, we might expect China to leapfrog the EU in terms of business R&D investment within two to three years (2021 EU Industrial R&D Investment Scoreboard).

Figure 5.2-8: Sectoral distribution of R&D investment by country/region, considering the top 2500 R&D investors worldwide, 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on European Investment Scoreboard 2021

Note: The sectoral distributions are calculated using only the R&D investments of the top 2 500 R&D investing companies worldwide, distributed according to the location of their headquarters (China, USA, EU) and not the country/regions of the world where investments are carried out.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-2-8.xlsx

2 Based on the 2019 EU Industrial R&D Investment Scoreboard (Hernández et al., 2019) which covers more than 90 % of business spending on R&D (BERD) worldwide.

2. R&D investments dynamics at national level

The headline target of investing 3% of GDP in R&D has provided a stimulus to the EU R&I, growth and competitiveness policy. This target was set at the 2002 Barcelona European Council[3] and subsequently confirmed in the Europe 2020 strategy (European Commission, 2010). Most Member States[4] defined national R&D intensity targets for 2020, taking into consideration their R&I-system maturity and their industrial specialisation. **Although the EU did not fulfil its R&D investment ambition in 2020** (Figure 5.2-9), **the headline target is an essential compass** that can help to accelerate the transition towards an environmentally, socially and economically sustainable Europe. Hence, continuation of the EU-wide 3% R&D investment target and joint reflection with Member States on the performance of R&D systems compared to the national targets[5] is crucial, including in the context of the New ERA for Research and Innovation (Razic et al., 2021). **In 2020, the EU would have needed to invest an additional EUR 91 billion to reach the 3% target,** the equivalent of the budget of an entire European Commission framework programme for R&I. The gap declined from 2019 to 2020, however this was not due to an increase in R&D investments but to the decrease in GDP.[6]

R&D investments by Member States remain uneven, with important differences across countries. R&D intensity at national level varies from 0.5% to 3.5% of GDP, with the highest values observed in the northern and western parts of the EU (Table 5.2-1). R&D activity is concentrated into a limited number of countries. Most R&D is performed in Germany (34%), France (17.5%) and Italy (8.1%) (data refer to 2020). Germany alone still accounts for almost the same amount of R&D spending as 23 Member States combined. Trends in R&D intensity are very diverse between Member States. **R&D intensity increased over 2000-2019 in 24 Member States, but significant heterogeneity persists across European countries** (Table 5.2-1). Only eight Member States stand above the EU average intensity (Sweden, Austria, Germany, Denmark, Belgium, France, Finland and the Netherlands). Besides, **only seven Member States have reached their 2020 targets**. However, it is worth noting that in 2019, only two Member States had already reached their 2020 targets (Germany and Cyprus). The other five may have therefore reached their targets because of the decline in GDP.

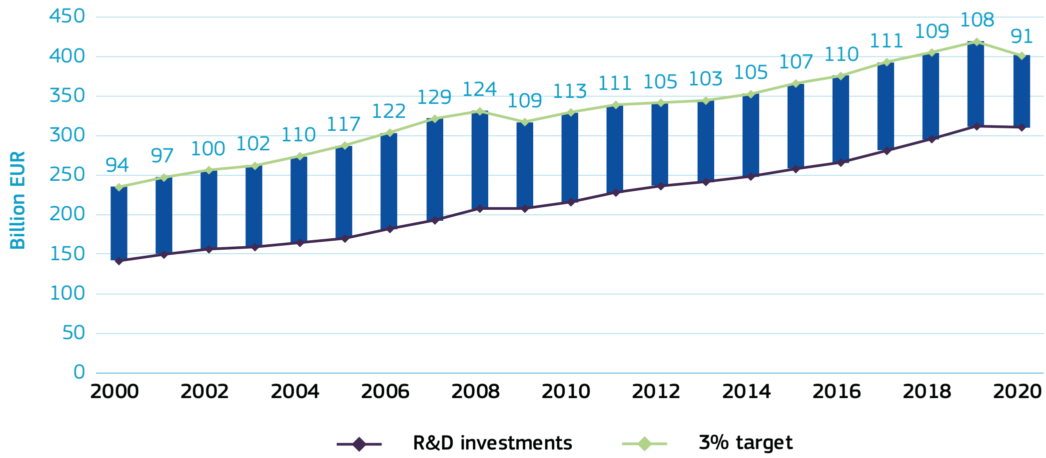
3 Presidency Conclusions, Barcelona 15 and 16 March 2002, SN 100/1/02 REV 1

4 Czechia defined a target for its public R&D intensity only.

5 https://op.europa.eu/en/publication-detail/-/publication/4adfd6f8-b2cf-11eb-8aca-01aa75ed71a1/language-en/format-PDF/source-212299297 R&D investment targets and reforms - Publications Office of the EU (europa.eu)

6 In 2020, the EU recorded a 6.1% decrease in GDP as the initial impact of the COVID-19 crisis was felt. This decrease was considerably larger than the decrease in activity in 2009 during the global financial and economic crisis.

Figure 5.2-9: **R&D investment gap in the EU, 2000-2020**



Science, Research and Innovation Performance of the EU 2022

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

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Table 5.2-1: Situation of each Member State with regard to its national R&D intensity target

	R&D intensity 2020 (% of GDP)	R&D 2020 target (% of GDP)	Compound annual growth 2010-2020 (%) (4)	Gap to reach the target in m euros
Sweden	3.5	4.0	1.01	2 356
Belgium	3.48	3.0	5.37	Target reached in 2020
Austria	3.2	3.76	1.62	2 119
Germany	3.14	3.0(5)	1.39	Target reached in 2019
Denmark	3.03	3.0	0.37	Target reached in 2020
Finland	2.94	4.0	-2.3	2 509
France	2.35	3.0	0.78	14 855
EU	2.32	3.0	1.65	91 000
Netherlands	2.29	2.5	0.89	1 646
Slovenia	2.15	3.0	-1.29	400
Czechia	1.99	(*new 2030 target:* 3.0%)	4.14	
Estonia	1.79	3.0	1.28	324
Hungary	1.61	1.8	2.46	263
Portugal	1.6	2.7-3.3(3)	0.42	2 200
Italy	1.53	1.53	2.36	Target reached in 2020
Greece	1.5	1.3	9.5	Target reached in 2020
Spain	1.41	2.0	0.33	6 671
Poland	1.39	1.7	6.82	1 613
Croatia	1.25	1.4	5.44	76
Ireland	1.23	1.9 (1)	-2.55	2 862
Lithuania	1.16	1.9	3.96	Target reached in 2020
Luxembourg	1.13	2.3-2.6(2)	-0.73	752
Slovakia	0.91	1.2	4.13	266
Bulgaria	0.85	1.5	4.25	397
Cyprus	0.82	0.5	6.35	Target reached in 2019
Latvia	0.69	1.5	1.37	238
Malta	0.65	2.0	1.08	176
Romania	0.47	2.0	-0.65	3 352

Science, Research and Innovation Performance of the EU 2022

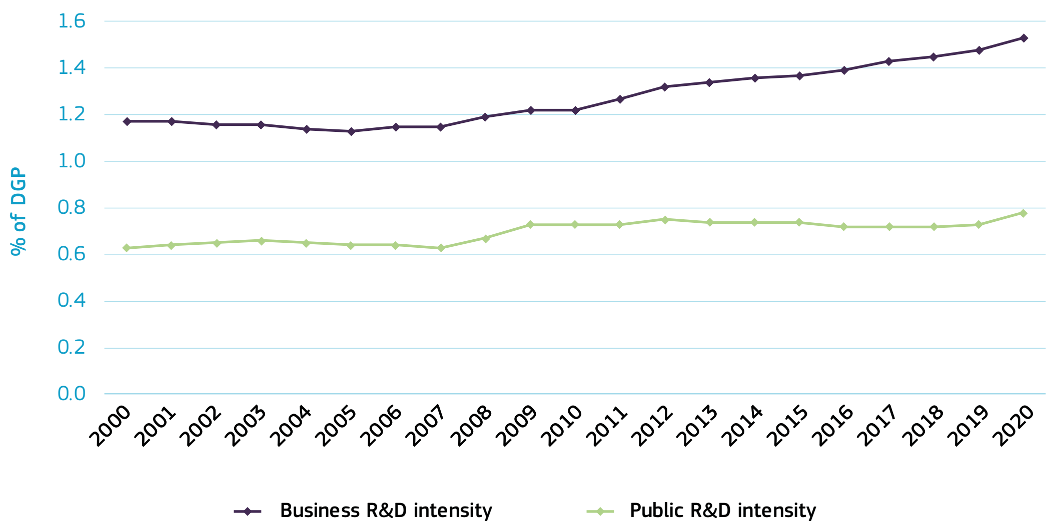
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, adapted from Ruzika et al., 2021

Note: (1)IE: The national target of 2.5% of GNP has been estimated to be equal to 2.0% of GDP. (2)LU: A 2020 target of 2.45% was assumed. (3)PT: A 2020 target of 3.0% was assumed. (4)IT, LU, HU, NL, RO, SI: Breaks in series occur between 2010 and 2020; when there is a break in series the growth calculation takes into account annual growth before the break in series and annual growth after the break in series. (5)DE: new 2025 target of 3.5%. CZ: new 2030 target of 3.0%.

Following the COVID-19 pandemic, the decline in business R&D expenditure over 2019-2020 was driven by only six countries: Germany, Czechia, Italy, Luxembourg, Austria and Romania. **The other 21 EU Member States saw their expenditure increase in 2020**, with the highest increases observed in Lithuania, Latvia and Portugal. However, six Member States still recorded a business R&D intensity below 1% of GDP in 2020: Romania, Malta, Latvia, Cyprus, Bulgaria and Slovakia. These differences in investment translate into gaps in scientific excellence and innovation output. For example, indicators for science quality (top cited scientific publications) also demonstrate a persistent innovation gap across the EU (see Chapter 2.2 – Zoom in). In the context of the new ERA, the European Commission has proposed a new 1.25% EU GDP public R&D target, to be achieved by 2030 in a coordinated manner through public national R&D targets. This will leverage and incentivise private investment in R&D.

The public sector is a main source of funding in countries where conditions for business R&D investment are still insufficiently attractive. Conversely, in the most research-intensive countries, the business sector is the predominant source of funding (Figure 5.2-12). Adding up investments from national governments and the EU, we find exceptionally high shares of publicly funded R&D in Latvia, Cyprus and Lithuania. The public sector is also the predominant investor in Greece, Luxembourg, Romania, Portugal, Slovakia and Spain. In the more research-intensive Member States (Germany, Sweden, Belgium, Denmark, Finland

Figure 5.2-10: Evolution of Business R&D and Public[(1)] R&D as % of GDP in the EU, 2000-2020



Science, Research and Innovation Performance of the EU 2022

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

Note: [(1)]Public R&D is defined as the sum of Government and Higher Education sectors

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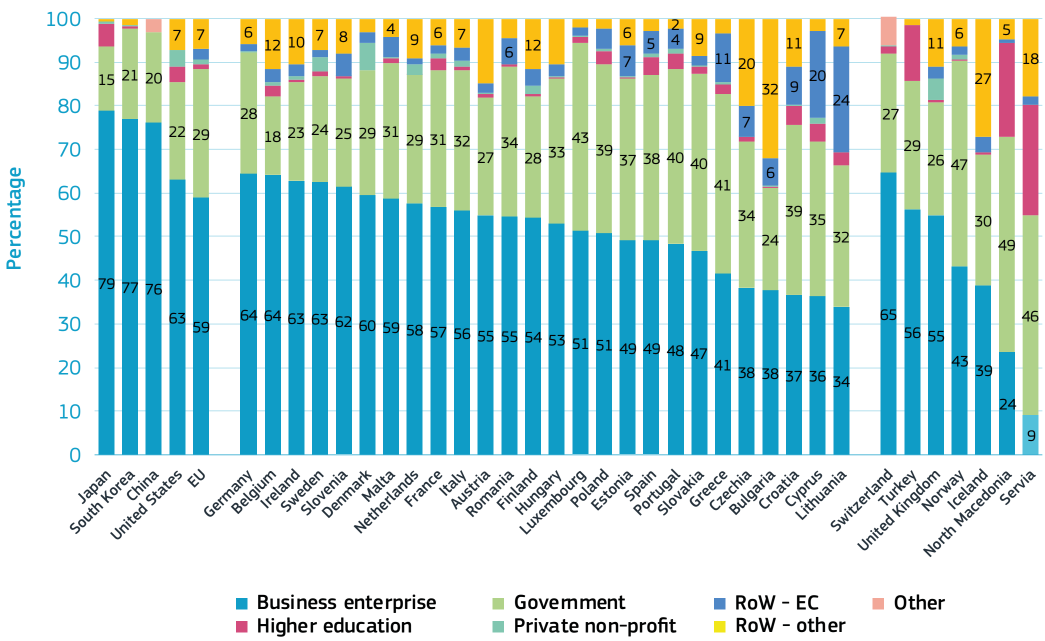
and Slovenia), the business sector is the predominant source of funds. In those countries, the R&I funding from the business sector is comparable to that in the United States (62 %), although significantly lower than in South Korea, China and Japan, where businesses finance more than 75 % of R&D.

Businesses are more inclined to invest in R&D in countries with a high quality of public administration, sufficient availability of high-skilled workers and solid research infrastructure. Hence how much the private sector invests in a particular country relies largely on the return it can expect and therefore on the framework conditions in place. Figure 5.2-11 shows the sources of R&D funding broken down into business enterprise, domestic government, rest of the world and other sources.

Investments in R&D carried out by the public sector over 2010-2020 increased at an annual growth rate above the EU average (0.7 %) in Member States with high levels of public R&D intensity (Belgium, Austria, Germany, Denmark) and in Member States with low public-investment in R&D intensity (Cyprus, Malta, Slovakia, Lithuania, Croatia), (Figure 5.2-12). **For the first group, this improved their position as leaders in the field; for the second this allowed some convergence across the EU.** In contrast, some Member States with strong public R&D intensity (Finland, Sweden, Estonia) witnessed a stabilisation or reduction in public R&D spending over 2010-2020. Persistent weak public R&D investments for countries characterised by a declining annual growth rate between 2010 and 2020 and low levels of R&D

Figure 5.2-11: Source of R&D funds by country, 2019[(1)]



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

Note: [(1)]UK, US: Year 2018.

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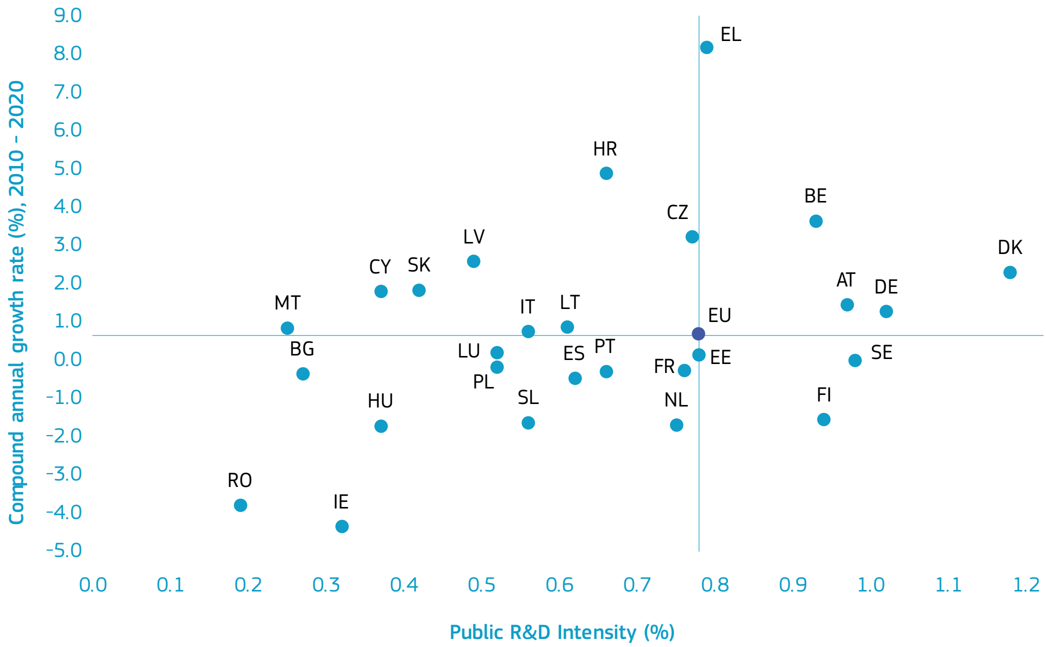
intensities (Bulgaria, Hungary, Romania, Ireland, Poland, Slovenia, Spain, Portugal, France and the Netherlands) may limit their prospects of improving the performance of their public science base. This, in turn, may severally hamper the technological upgrade of their private sector and slow down their catch-up towards countries with higher levels of productivity. For the more advanced Member States, public investment in R&D is critical to being at the technological frontier and generating the knowledge and skills needed to fully reap the benefits of the digital and green transitions. It is worth noting that several Member States that in 2020 had an R&D intensity below the EU average increased their R&D investments between 2010 and 2020 (Croatia, Lithuania, Slovakia, Cyprus, Italy, Greece, Latvia and Cyprus), in particular over 2018-2020, which has likely helped some of them to reach their 2020 targets (Italy, Greece, Latvia and Cyprus). However, this result should also be interpreted in light of the decrease in GDP over 2019-2020.

Even though the EU has one of the highest public R&D intensities worldwide, some countries still need to develop their public science base substantially for this base to play a role in their transition from an economy based on cost competitiveness[7] to an innovation-driven one. This will require not only more public R&D investments, but also

Figure 5.2-12: Public[(1)] R&D intensity, 2020 and compounded annual growth rate (%), 2010-2020



Science, Research and Innovation Performance of the EU 2022

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

Note: [(1)]Public investments are the sum of government and higher education investments.

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7 competition to reduce unit costs

significant structural reforms in the national and regional R&I systems (e.g. improving the excellence of the science base, and stronger links between business and science) to ensure that these investments are efficient and effective to bring in more private R&D investment.

Over 2010-2020, most Member States characterised by low business R&D investments have experienced a relatively strong increase in private R&D spending (Cyprus, Poland, Greece, Latvia, Bulgaria, Slovakia, Croatia, Romania, Hungary, Czechia and Italy), **allowing some convergence across the EU** (Figure 5.2-13). However, the declining R&D intensity observed over 2010-2020 in many Member States with already low-to-median business R&D spending (Lithuania, Luxembourg, Ireland, Malta, Spain) is particularly worrisome. In contrast, some Member States still have scope to improve private R&D spending, such as Luxembourg, Malta, Lithuania, Spain, Greece and Ireland. Several Member States are characterised by relatively high R&D intensity in their business sector but have decreased their business R&D investments (Slovenia, Denmark, Finland, Germany, Austria and Sweden). **Only Belgium and the Netherlands have intensified their business R&D investments at a relatively high growth rate over 2010-2020**.

Figure 5.2-13: Business R&D intensity, 2020 and compounded annual growth rate (%), 2010-2020

Science, Research and Innovation Performance of the EU 2022

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

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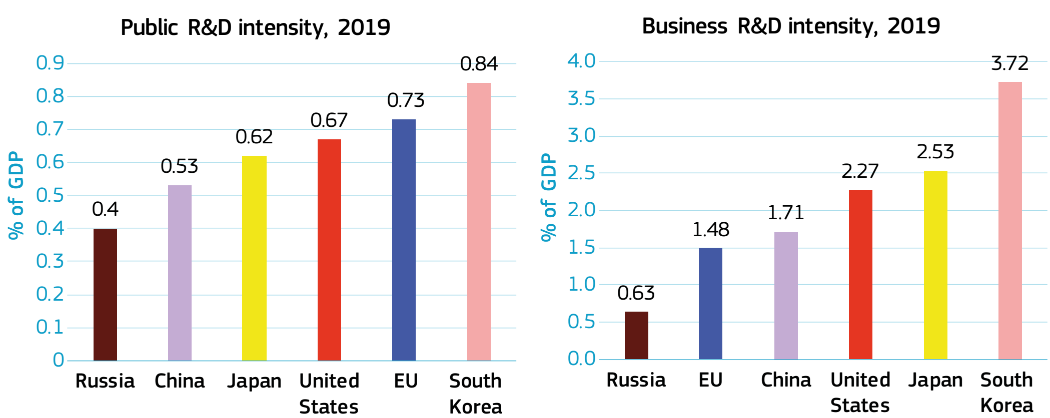
Stimulating private R&D investment is critical but remains a challenge. Compared to its main competitors, EU R&D investment is especially low in terms of private investments (Borunsky et al., 2020; Figure 5.2-14). Businesses that intend to invest in R&D typically face various obstacles, possibly resulting in underinvestment. These obstacles are high risks, high sunk costs, market uncertainty, lack of full appropriability of results and financing constraints (European Commission, 2017). Due to positive externalities from R&D investments, the social rate of return on these investments is about two to three times higher than the private return for the company making the investment (Frontier Economics, 2014; Coe and Helpman, 1995; Kao et al., 1999). This discrepancy calls for public support. Furthermore, R&D efforts are increasingly concentrated in a limited number of firms, while innovation expenditure in SMEs is faltering, leading to a productivity gap between technology leaders and other firms.

R&D tax incentives, used to stimulate business R&D investments, surpassed direct funding in the EU. R&D tax support doubled over ten years, from 26% of total government support to business in 2006 to 58% in 2019 (OECD, 2021). The EU level of R&D tax incentives (% of total government budget for R&D investments) is higher than in China, Canada, the United States and South Korea, in which respectively 55%, 53%, 48% and 43% of the total government support to R&D is given through tax incentives, but below the rate of Japan (82%). In the EU, the number of countries offering R&D tax relief increased from 12 in 2000 to 20 in 2019 (Figure 5.2-15).

R&D tax policies, such as tax relief, increase firms' R&D activities (Hall & Van Reenen, 2000; OECD, 2016; Hall, 2019). Direct funding involves discretionary (and potentially costly) choices on the part of governments on which R&D projects and firms to support (Hall, 2020). In contrast, most R&D tax incentives are mar-

Figure 5.2-14: Public and private R&D investments as % of GDP in country/regions, 2019



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-2-14.xlsx ket-based instruments that provide more broad-based support. These comply with state-aid and international competition rules, and promise lower administrative and compliance costs (Appelt et al., 2020). Literature suggests **that R&D tax incentives are effective in raising R&D investment by business**. Its effect on experimental development is almost twice as large as its effect on research (OECD, 2020). However, **even if tax incentives are market-based, they might render tax (incentive) systems overly complex if not designed properly, which ultimately reduces their effectiveness and distorts the business climate. Direct funding usually provides better directionality to R&D** (European Commission, 2021b) and higher social returns, but also brings a high administrative burden for national authorities and therefore greater costs. Finally, direct and indirect governmental support have similar effectiveness (each euro of either direct or tax support leads to around 1.4 euro of R&D on average) but may serve different policy objectives. Therefore it is important to have a balanced policy mix (European Commission, 2021c).

Trends in forgone tax revenues are very diverse among Member States. In some Member States, tax incentives represent over or close to 80% of total government support for business R&D: 89% in Malta, 85% in Ireland, 83% in Portugal and Lithuania, and 80% in Italy (2019 or closest-year data, Figure 5.2-15). These high levels reflect a shift in the business R&D support policy mix towards R&D tax incentives that is observable in many EU countries.

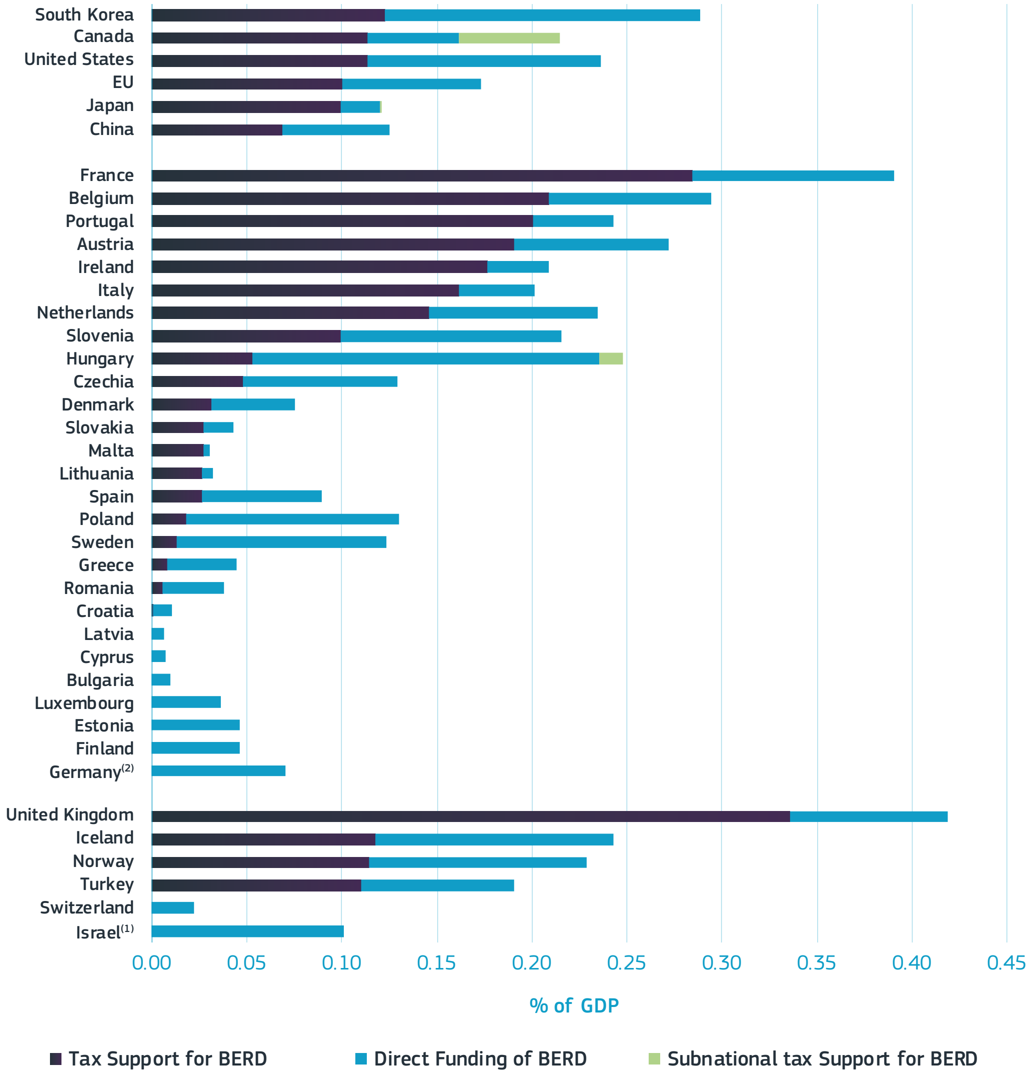
Furthermore, the combined support for R&D (direct and tax) is relatively high in France, Belgium, Austria, Hungary and the Netherlands, ranging between roughly 0.23% and 0.40% of GDP. On the other hand, combined support is very low in Bulgaria, Croatia, Cyprus and Latvia (around 0.01% of GDP) and exclusively through direct support. **The EU average support to R&D is about 0.1% and 0.07% of GDP for tax incentives and direct funding, respectively**, in 2019. Other Member States have introduced R&D tax incentives only recently, such as Germany in 2020 and Finland in 2021. Yet another group uses R&D tax incentives only to a limited extent, while still offering relatively high direct support to private R&D investments, such as Hungary (0.18% of GPD), Poland (0.11% of GDP) or Sweden (0.11%).

The increasing importance of R&D tax incentives has translated into a significant increase in the number of firms receiving R&D tax support over the last decade (OECD, 2021). Figure 5.2-16 demonstrates that **SMEs account for most R&D tax relief recipients in the EU**, ranging from around 50% in Belgium[8] to 98% in Lithuania. It is noteworthy that self-employed individuals feature among R&D tax relief recipients in Slovakia, Sweden and the Netherlands, though they account for fewer than 10% of tax relief recipients. **The distribution of R&D tax support is, however, heavily skewed towards large firms, which account for the bulk of R&D in most economies**. Large companies receive high percentages of R&D tax relief, ranging from 12% in Lithuania to 80% in Belgium (Figure 5.2-16).

While the support for R&D is essential, giving preferential treatment to SMEs via tax incentives might encourage them to limit their growth to keep the incentives alive (i.e. a harmful tax-avoidance strategy) (Evers et al., 2015; Almunia and Rodriguez, 2018; Sterlacchini and Venturini, 2018).

8 The low percentage for Belgium can be partly explained by the definition of SMEs, which is more restrictive in this country compared to others in the EU. In Belgium, SMEs are defined as enterprises that, in the last two years, have not exceeded an average annual number of employees below 50, revenue under EUR 9 million or a balance sheet under EUR 4.5 million whereas in most EU MS, SMEs are defined as having 1-249 employees.

Figure 5.2-15: Tax support and direct government funding for business R&D (as a % of GDP), 2019



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on OECD Measuring Tax Support for R&D and Innovation: Indicators - OECD

Note: (1)The percentage represent the percentage of tax incentives over total government support for R&D in the corresponding country. (2)Germany has introduced tax incentives in 2020.

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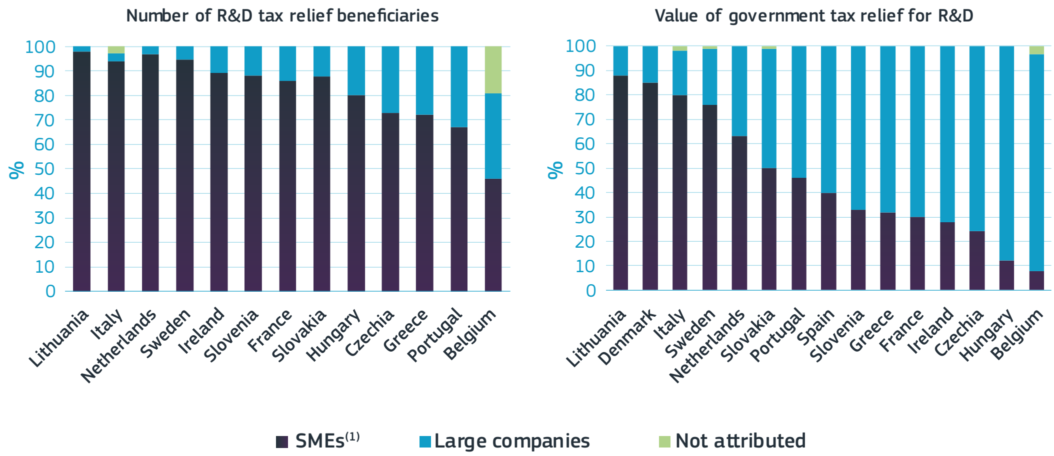
Figure 5.2-16: Number of R&D tax relief beneficiaries and value of government tax relief for R&D in selected EU Member States, 2019



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on OECD Measuring Tax Support for R&D and Innovation: Indicators - OECD

Note: (1)SMEs are defined as companies with number of employees between 1-249, except for HU, LI, NL, ES where SMEs are defined as firms with less than 250 employees and an annual turnover that does not exceed EUR 50 million or an annual balance sheet that does not exceed EUR 43 million; BE where they are defined as enterprises that, in the last two years, do not exceed an average annual number of employees below 50 or a revenue under EUR 9 million or a balance sheet under EUR 4.5 million; SI where they are defined as firms with 1-249 employees, a balance sheet total less than EUR 20 000 000 and a net turnover less than EUR 40 000 000; and SE where SMEs are defined as firms with 10-249 employees.

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Box 5.2-2: The OECD R&D tax incentives database, selected extracts from the 2021 edition

Since 2007, the OECD has continuously worked to collect international evidence on R&D tax incentives and has developed experimental methodologies and data infrastructure that have received considerable interest and become widely used in the policy, statistical and academic arenas. This progress in the measurement of expenditure-based R&D tax incentives is the result of 10 years of close collaboration with a network of official experts from OECD countries and partner economies. In recent years, such efforts have been intensified with support from the EU's Horizon 2020 programme, which has contributed to an increased frequency of data collection and extended coverage and analysis. This work has been supported by the OECD R&D tax incentives network, which comprises delegates from the OECD Working Party of National Experts on Science, Technology and Innovation (NESTI) and Working Party No. 2 on Tax Policy and Statistics (WP2), among other national experts on R&D tax incentives.

The annual OECD R&D tax incentives data collection has been collecting information on R&D tax relief beneficiaries since 2016 and further extended its scope in 2020 to additionally collect information on the amount of qualifying R&D expenditures. At the same time, the number of countries reporting beneficiary figures has increased steadily over the last years, reaching 36 in 2021. We present below some selected parts of the 2021 OECD R&D tax incentives database report, drawing on the 2021 OECD R&D tax incentives data collection.

R&D and eligible activities

Definitions of R&D or other types of expenditures eligible for tax relief differ across jurisdictions and with respect to the OECD Frascati Manual definition (OECD, 2015a), but most countries attempt to be consistent with the manual. Only a few countries extend tax relief beyond R&D to other innovation activities, and when they do, it is typically under much stricter and less generous terms. R&D in the social sciences are sometimes excluded, possibly because of the difficulty in distinguishing these from market research and related activities. The tax relief is often more closely targeted at the financial cost of R&D to the firm (expense), regardless of who carries out the R&D, than the cost of the R&D activity incurred within the firm (i.e. intramural R&D, regardless of who funds the work).

Some R&D tax incentive schemes explicitly target specific types of R&D costs. Overall, there is a general preference for considering costs relating to labour and other current expenditures as within the scope of eligible R&D costs. R&D personnel costs account for the largest share of intramural R&D costs. In principle, the focus on R&D personnel incentivises investment in human resources based in the domestic economy. Acquisition of capital assets to be used for R&D is less typically supported as assets may be subsequently disposed of or used for other purposes.

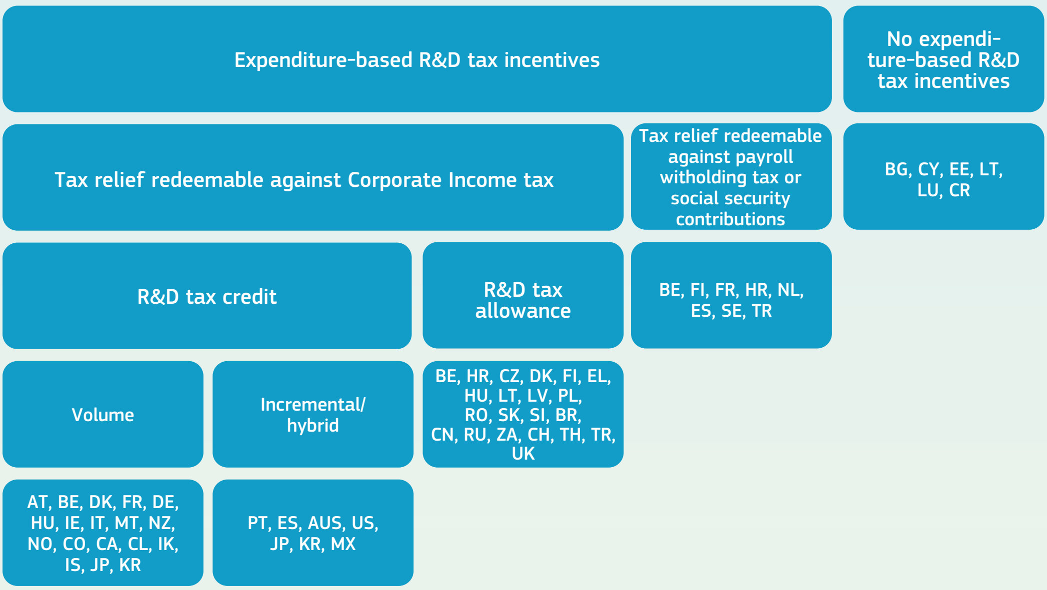
Types of tax instrument

Any form of tax relief can be provided as an allowance, exemption, deduction or credit.

- Tax allowances, exemptions and deductions effectively subtract from the tax base before the tax liability is computed, reducing the taxable amount before assessing the tax.
- A tax credit is an amount subtracted directly from the tax liability due from the beneficiary unit after the liability has been computed.

The choice between credits and allowances is largely a formal one, as they can be converted into each other to be made equivalent. However, the value of the tax benefit will react differently to changes in the tax rate, as the value of R&D tax allowances is directly linked to the level of the corporate income tax rate.

Figure 5.2-17: **Different types of R&D tax relief**



Source: Adapted from the OECD (2021), "OECD R&D tax incentives database report, 2021 edition", December 2021, https://www.oecd.org/sti/rd-tax-stats-database.pdf

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Directionality and R&D tax reliefs

Although tax incentives are generally seen as a more market-based, non-discretionary alternative to direct support for R&D, a number of countries target R&D tax incentives to particular types of firms, industries or activities. Targeted relief measures may be motivated by evidence or the belief that some groups of firms with observable characteristics, e.g. firm size or age, can be more responsive to a given unit of financial support. Tax provisions may give more favourable treatment to SMEs and young firms in the form of more generous rates of tax support or refund provisions that are exclusively available to these firms. Likewise, in the 2021 OECD R&D tax incentives data collection, a few countries reported having special, temporary or emergency tax relief provision for R&D in specific priority areas such as green or energy related R&D. These include:

- Italy. A higher tax credit rate is available for technological innovation for 4.0 innovation (national strategy) or the ecological transition.

- Portugal. Expenses related to making eco-design products are increased by 10% upon submission and approval of the project by the Portuguese Environment Agency.

- Spain. A higher tax credit rate currently applies to expenses in technological innovation activities for new or relevant improvements in production processes in the value chain of the automotive industry in Spain.

3. Public intervention for directed R&D investments?

In the past decade, the rationale for government intervention in R&I has shifted from a predominantly market or system-failure argument to a system or transformative-change approach. Public interventions seek to channel innovation efforts and support towards addressing societal challenges. There is a strong rationale for policy that seeks to increase the amount of innovation in the economy. First, knowledge spillovers for clean innovations are over 40 % greater than their high-carbon counterparts in the energy production and transport sectors (Dechezleprêtre et al., 2014). Second, R&I are subject to path dependences: investments in early-stage clean technologies are generally perceived as riskier than the more traditional alternatives (Gaddy et al., 2017), leading to tighter financing constraints. Finally, clean products can be more expensive for consumers. Unlike digital technologies, for which people are ready to pay more for state-of-the-art products, consumers are not necessarily willing to pay more for clean products as the beneficial effects are less direct for them. A key implication is that socially and environmentally related technologies may not be able to overtake dirty technologies without government intervention that can shift the economy onto a clean and inclusive equilibrium path (Stern and Valero, 2021).

In this context, providing a degree of directionality to national and EU R&D investments will ultimately help to deliver on EU priorities[9], notably the green and digital transitions, to strengthen resilience and to maintain Europe's competitive edge.

Furthermore, the analytical basis for the 2030 Climate Target Plan and Fit for 55 shows that the decarbonisation pathway is feasible, but that the full roll-out of these technologies represents a significant investment challenge (an increase of almost EUR 400 billion per year in investment needs compared to investments in the previous decade).

EU public and private investment in R&D in climate mitigation activities has grown, but at a slow pace over the last five years (EIB, 2021). Overall, the United States has experienced a higher increase and remains the world leader in climate-related R&D. Due to a very high increase, China overtook the EU in 2018 and has a significant lead in 2019. In the EU, energy-related automotive R&D grew steadily for several years and stabilised in 2018 and 2019 (EIB, 2021). This might be due to a decrease in car sales and the imperative to invest in new models and improve manufacturing supply chains.

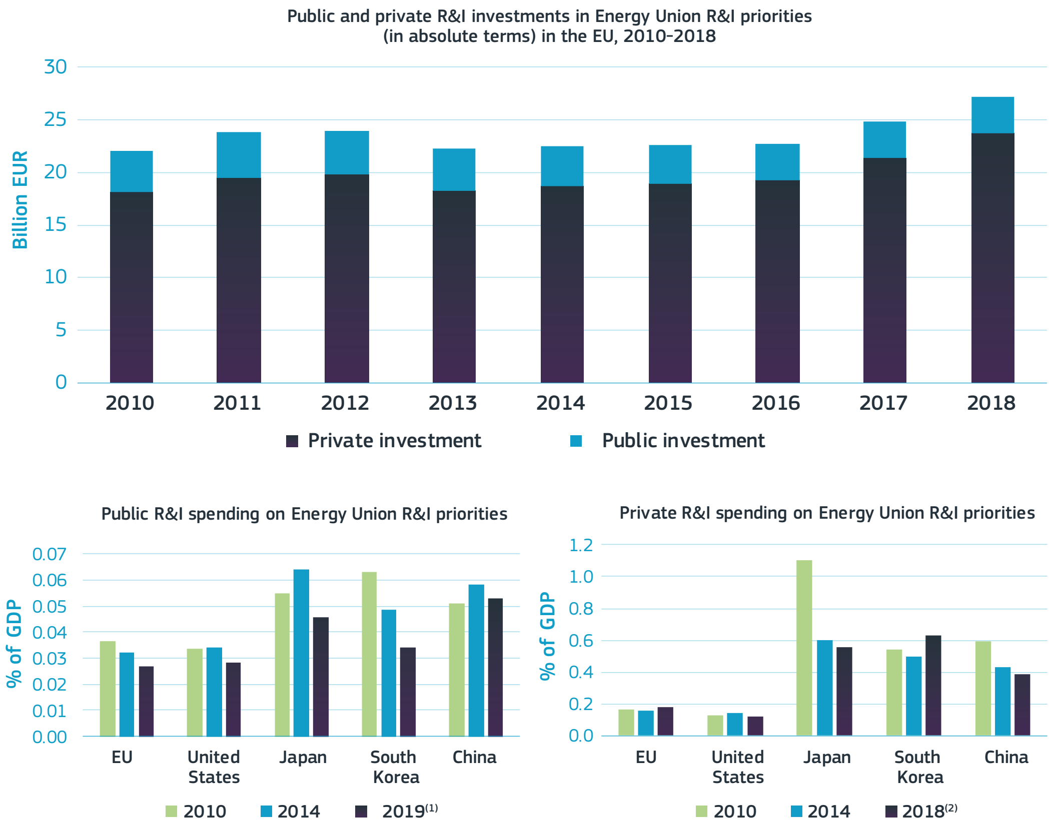
Public and private investments in R&I prioritised by the Energy Union have increased in absolute terms 2014-2018 (European Commission, 2015). After the economic crisis of 2008, public investments went into decline for half a decade, showing signs of recovery only after 2014 (Figure 5.2-18). Since then, EU Member States have invested on average EUR 3.5 billion per year, but spending is still lower than that observed a decade ago. Besides, this increase in public and private investments in the total Energy Union R&I priorities has not kept pace with increases in GDP or R&I spending in other sectors.

9 See Council Conclusions on the New European Research Area, 1 December 2020 https://data.consilium.europa.eu/doc/document/ST-13567-2020-INIT/en/pdf

Measured as a share of GDP, the EU investment rate (0.027 %) is currently the lowest of all major global economies, just below the USA, although levels seem to be decreasing or stable for all economies. In addition, the **EU private sector experienced a 7 % reduction in overall energy R&I spending in 2020, possibly due to the COVID-19 pandemic.** Only spending in renewable energy R&I specifically was more resilient and continued to grow (European Commission, 2021b).

In the EU, public R&D investments in energy have switched from nuclear to a more diversified mix, including a high share dedicated to renewables and energy efficiency. Figure 5.2-19 shows that over the past forty years, EU public investment in energy R&D has become progressively more diverse. Nuclear power, which accounted for 78 % of the total in Europe in 1977, has declined over the years to 29 % in 2020. **R&D budgets for fossil fuels, which were at**

Figure 5.2-18: Public and private R&I investment in Energy Union R&I priorities (absolute terms and as % of GDP) in the EU and major economies



Science, Research and Innovation Performance of the EU 2022

Source: European Commission. Joint Research Centre (2021e), based on International Energy Agency (2021) and their own work

Note: (1)Public R&I data for China and Italy (in EU total) refer to 2018. (2)Private R&I data for 2018 are provisional.

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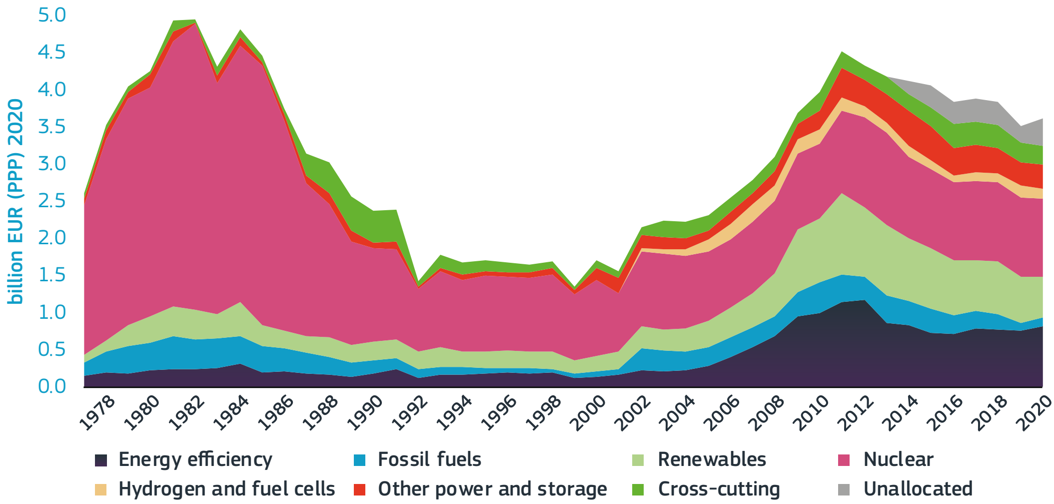
their highest in the 1980s, have declined since 2013 and budgets for both energy efficiency and renewables expanded significantly faster during the 2000s. Besides, in 2019, around 80% of worldwide public R&D spending on energy was dedicated to low-carbon technologies – energy efficiency, CCUS, renewables, nuclear, hydrogen, energy storage and cross-cutting issues such as smart grids. However, budgets for hydrogen and tfuel cells maintained their share at 3-4% for 2000-2020. In addition, increasing amounts of public R&D spending went to low-carbon technologies (IEA, 2021).

Energy – low-carbon energy in particular – represents a high share of the total public R&D investment in many EU countries, but less than in other major economies, such as in the USA or Japan (Figure 5.2-20). After the USA (35%) and Japan (15%), France has the highest share of such investments in the EU, at 9%. **In 2020, through Horizon 2020, the EU spent a fifth of its total R&D budget on power and storage technologies, making it the largest spender worldwide for this category.** More generally, sustainable development is one of the general objectives of the EU R&I programme. More than 80% of the Horizon 2020 investment addressed at least one SDG (European Commission, 2020).

Figure 5.2-19: Public R&D investments in energy in the EU[(1)], 1977-2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on International Energy Agency

Note: [(1)]Only 20 of the 27 Member States were taken into account: AT, BE, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LI, LU, PL, PT, SK, ES, SE. It does not include the European Union R&D FP budget.

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Figure 5.2-20: Public energy R&D budgets for selected countries and Horizon 2020 budget of the European Union, 2020[1] (% of total energy budgets)

Source: International Energy Agency, 2021

Notes: [1]The amounts shown are based on 2020 energy R&D budgets for: Belgium, Canada, Czechia, Denmark, Estonia, Germany, Hungary, Mexico, Norway, Poland, Portugal, Slovakia, Sweden, Switzerland, the United States and the European Union. The amounts shown are based on 2019 energy RD&D budgets for: Australia, Austria, Finland, France, Ireland, the Netherlands, New Zealand, Spain and the United Kingdom. For the other countries, data refer to 2018. [2]Data for the United States were estimated by IEA Secretariat. [3]European Union refers to the European Union budget under Horizon 2020, and not to the sum of national budgets of European Union member countries. [4]the Rest of the countries correspond to all other IEA countries (https://www.iea.org/countries).

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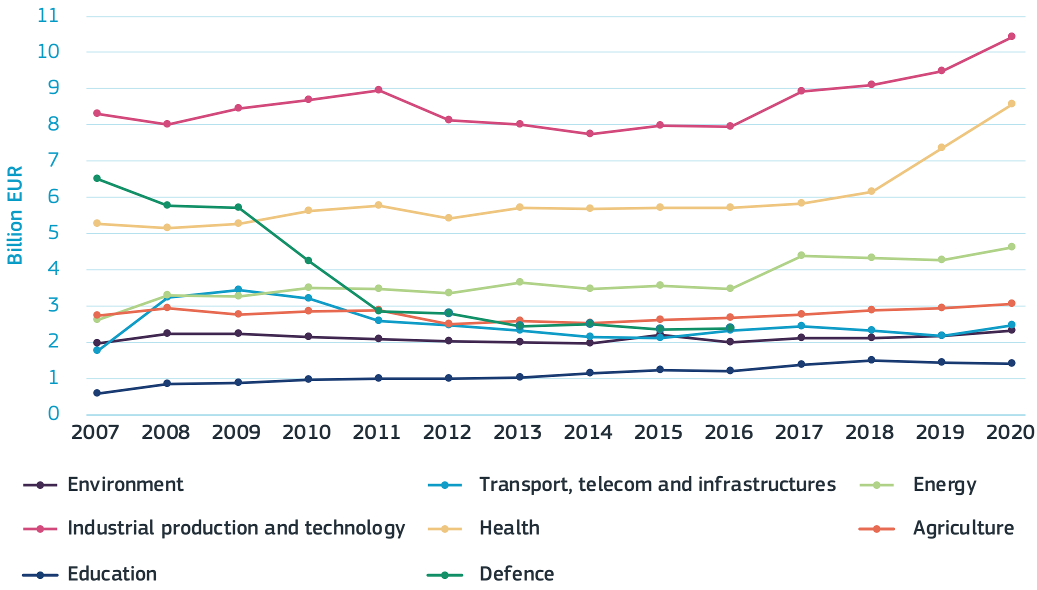
Member States are slowly steering their public national budget allocations for R&D towards societal and environmental challenges. Figure 5.2-21 shows an increase in health, industrial production, technology and energy-related government budget allocations for R&D (GBARD) at the European level. Growth in the budget allocations for total civil and environment R&D investment are more modest. Transport and communications increased mainly from 2007 to 2009, but then slowly decreased to stagnate from 2011 onwards. In contrast, the R&D budget for defence has decreased significantly in recent years.

Figure 5.2-21: Evolution of government budget allocation for R&D by socio-economic objectives in the EU, 2007-2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Eurostat (online data code: gba_nabsfin07)

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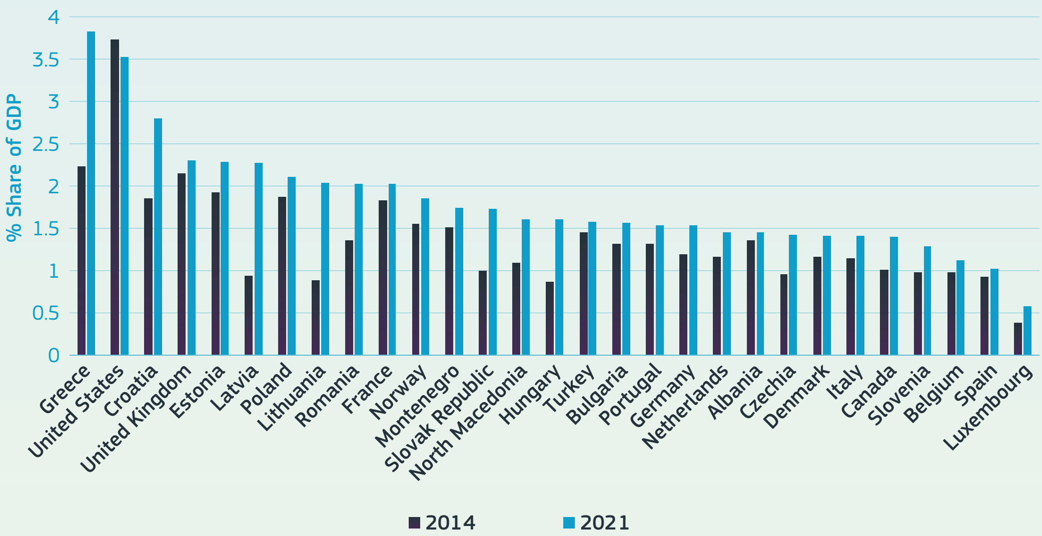
Box 5.2-3: R&D investments in defence

The invasion of Ukraine by Russia in February 2022 naturally brings the defence industry, and related R&D, to centre stage. In 2020, the five biggest spenders on defence were the United States, China, India, Russia and the United Kingdom, representing together 62% of world military spending. Among these countries, China showed a significant increase of 76% in its military expenditure over 2011-2020 (Lopes da Silva et al., 2021). The NATO guidelines suggest that member countries should spend 2% of their GDP on defence. This 2% guideline is met today by the USA, UK and eight EU Member States (NATO, 2021): Greece (the highest share amongst the NATO members, with 3.8% of GDP), Croatia, Estonia, Latvia, Poland, Lithuania, Romania and France (Figure 5.2-22). Since 2014, the share of GDP invested in defence has increased for all NATO member countries, except the USA. The Russian war against Ukraine may also reinforce this trend. For example, announcements in Germany include a special defence fund that can boost German defence spending from around 1.5% of GDP to at least 2% (*The Economist*, 2022b).

Figure 5.2-22: Defence expenditure as a share of GDP, 2014 and 2021



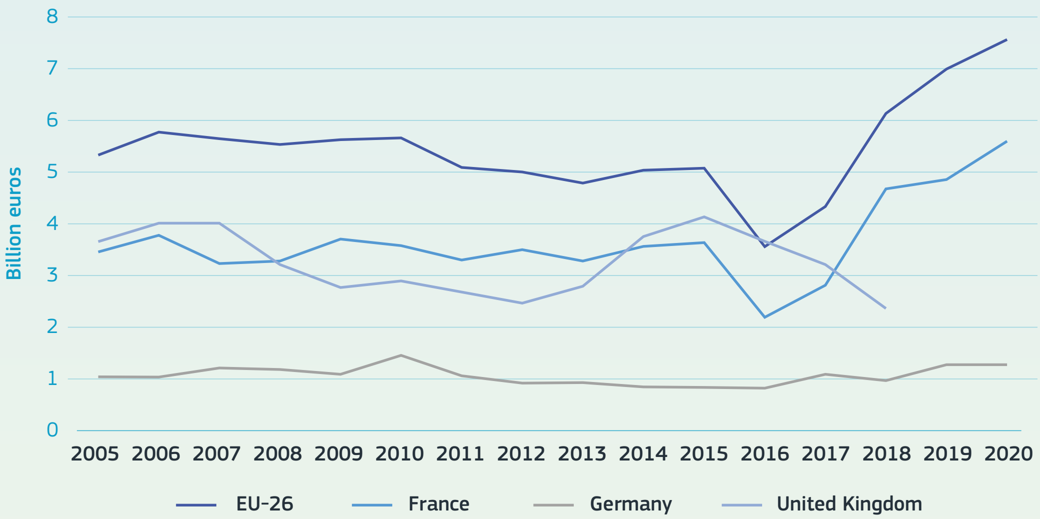
Science, Research and Innovation Performance of the EU 2022

Source: NATO
Note: (1)Figures for 2021 are estimates.
Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-2-22.xlsx

Spending on defence R&D in Europe is low. Compared to the other largest OECD economies, the United States spends a much greater share of GDP on defence R&D (Congressional Research Service, 2020). In the EU, most countries spend little on defence R&D, with the exception of France. The EU budget for defence R&D (without Denmark) amounted to EUR 7.6 billion in 2020[10], which includes 91% from both France (EUR 5.6 billion) and Germany (EUR 1.3 billion). The total amount of defence R&D in the EU was stable over 2005-2015, then increased significantly after 2016, mainly driven by increased French expenditure (Figure 5.2-23). EU expenditure on research and technology[11] corresponds to 1.25% of total defence expenditure in 2020, which is below the 2% benchmark of the European Defence Agency.

Compared to traditional civil sectors, the defence sector has specific characteristics, such as cost escalation over time of defence equipment and higher R&D costs (EC, 2018b). The cost escalation is a long-term trend for a sector that is driven by intense technological competition at the technology frontier, which is vastly expensive (Hove and Lillekvelland, 2016). The ratio of R&D costs to recurring costs of defence programmes is considered several times higher than the corresponding ratio for civil programmes (EP, 2016). These factors can limit the launch of new defence programmes, especially making them out of reach of single EU Member States, and can impact the competitiveness and innovation capacity of the EU industry. Furthermore, the defence market does not follow the conventional rules and business

Figure 5.2-23: Defence R&D Expenditure (in billion EUR), 2005-2020



Science, Research and Innovation Performance of the EU 2022

Source: European Defence Agency

Note: [(1)]EU-26 includes EU countries other than Denmark. Figures include any R&D programmes up to the point where expenditure for production of equipment starts to be incurred.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-2-23.xlsx

10 Source: European Defence Agency

11 Expenditure for basic research, applied research and technology demonstration for defence purposes. It is a subset of R&D expenditures, which includes any R&D programmes up to the point where expenditure for production of equipment starts to be incurred (source: European Defence Agency).

models of more traditional markets: demand is almost entirely driven by Member States and their defence budgets, and the sector is strictly regulated. Therefore, the industry is not expected to spontaneously launch self-funded defence R&D projects and rather works on demand for a state (EC, 2018b).

Hence, **R&I in the defence sector hinges on public demand** (Moura, 2011; EC, 2018b). Several recent policy developments related to defence R&I can be observed. Of particular importance is the diminishing dichotomy between the civilian and the defence sector. At the EU level, the European Defence Fund supports defence research with a budget of close to EUR 8 billion over 2021-2027, while Horizon Europe has an exclusive focus on civil applications (Table 5.2-2 for an overview of programmes and instruments related to defence and security R&I). In its 2022 communication on the roadmap on critical technologies for security and defence (EC, 2022b), the Commission highlights that these technologies increasingly originate in the civilian domain and use critical components of a dual-use nature. Against this backdrop, it has announced the preparation of an approach for encouraging dual-use R&I across EU programmes and instruments. In a recent declaration[12] drawing lessons from the ongoing military aggression against Ukraine, EU leaders also stressed the importance of investing more and better in defence capabilities and innovative technologies. It was agreed to substantially increase defence expenditure, foster synergies between civilian, defence and space R&I, and invest in critical and emerging technologies and innovation for security and defence.

Table 5.2-2: EU programmes and instruments supporting R&I on critical technologies relevant to security and defence

Programme/instrument	Link to defence and security
European Defence Fund	EUR 8 bn to defence R&I
Horizon Europe	EUR 1.6 bn 'Civil security for Society' cluster to address challenges to border control, to counter cybercrime and to improve disaster-resilience and security of critical infrastructure; Critical technologies also supported under other clusters (e.g. 'Digital, Industry and Space' cluster); Complementary activities under Excellent Science, the European Innovation Council, the European Institute of Innovation and Technology and European partnerships.
Digital Europe Programme (DEP)	Deployment activities related to cybersecurity, AI and supercomputing
Cybersecurity Industrial, Technology and Research Competence Centre and the Network of Coordination Centres	These will adopt a strategic agenda on cyber investments feeding into Horizon Europe and DEP. Synergies between civilian and defence technologies and dual-use applications may be explored through links to EDF in line with applicable rules.
European structural and investment funds	The funds can be used in support of the European Defence Technological and Industrial Base
Other	Other relevant EU programmes, funds and instruments include the Space Programme, CEF, InvestEU Programme, the Recovery and Resilience Facility (RRF), the LIFE Programme, public-private partnerships, blending facilities

Source: Authors' elaboration based on the communication on the roadmap on critical technologies for security and defence (European Commission, 2022b)

12 https://www.consilium.europa.eu/media/54773/20220311-versailles-declaration-en.pdf

At the European level, R&I funding programmes – in particular Horizon 2020 – have fully integrated the principle of directionality. It aims to focus on the areas with the greatest potential to deliver on the SDGs, and it maintains the 35% target for climate action in Horizon 2020. As a new feature, it implements EU-wide R&I Missions (European Commission, 2017; 2018) with ambitious goals to tackle major societal challenges for Europe (climate change, healthy oceans, climate-neutral and smart cities, and soil health and food). Partly inspired by the Apollo 11 mission to put a man on the moon, the mission-oriented approach allows challenges to be transformed into concrete, measurable and achievable targets while mobilising and engaging citizens, policymakers and a broad range of actors well beyond the usual R&I stakeholders. The Missions are expected to be an instrument for delivering European public goods and transforming Europe into a greener, healthier and more resilient continent.

The European R&I funding programmes, including Horizon 2020, are responsible for 7.2% of public R&I funding in 2019 in Europe and a significantly higher percentage when looking only at competitive funding (Figure 5.2-24). Horizon 2020 contributed to 0.1% of the EU R&D intensity, estimated at 2.23% in 2019[13]. Each euro invested in the programme mobilised an additional 0.25 euro of public and private investment in R&I projects for a total of EUR 16.9 billion[14]. An estimated additional EUR 9.5 billion was also leveraged by the EU framework programme research teams (EUR 4.2 billion) and as private follow-up investments attracted by EIC accelerator portfolio companies (EUR 5.3 billion).

Over 2014-2030, Horizon 2020 is expected to bring GDP gains of EUR 400-600 billion: each EUR of Horizon 2020 investment brings a GDP increase of EUR 6.0-8.5[15]. Furthermore, **European Union budgets have substantially increased over the last programming periods.** Together with the European structural and investment funds, the European Commission is an important source of R&D funding in many Member States. It represents a high share of the total R&D expenditure in some Member States, such as Latvia, Lithuania, Cyprus.

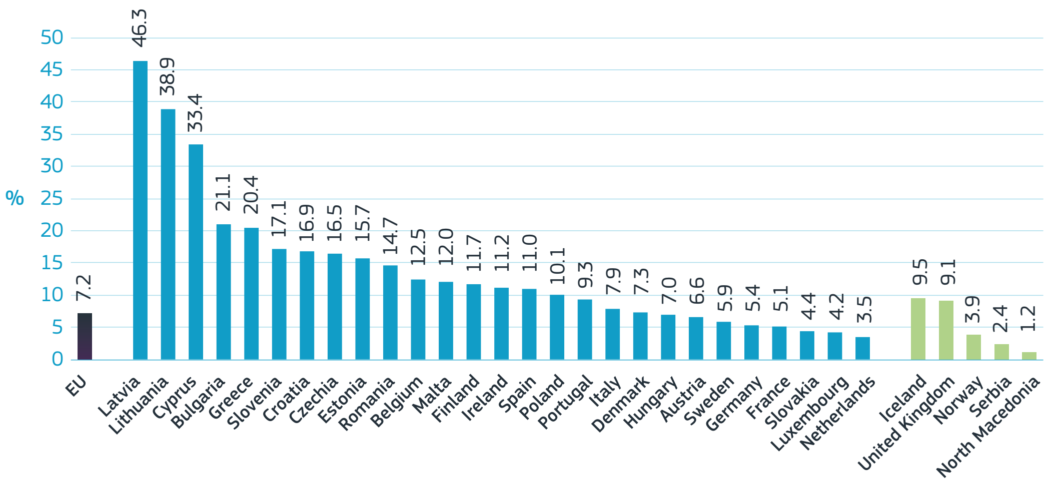
Amongst the different instruments designed under Horizon Europe, the EU Missions embody the paradigm shift that this Commission has committed itself to deliver. In September 2020, Europe's leading experts submitted a set of mission proposals that aim to find solutions for saving more lives from cancer, making Europe climate resilient, restoring our ocean and waters, achieving 100 climate-neutral cities, and ensuring 75% of EU Member State soils are healthy by 2030. These missions are directly relevant to the delivery of the European Green Deal, a Europe Fit for the Digital Age, and a sustainable recovery (Table 5.2-3). They are at the very core of an economy that works for people and our European way of life. The implementation of these solutions goes far beyond the remit of R&I and can have direct impact on the delivery of a range of policies and portfolios across the Commission.

13 Source: CORDIS, EUROSTAT

14 Horizon Dashboard

15 Interim evaluation of Horizon 2020

Figure 5.2-24: R&D expenditure financed by the European Commission(3) as % of total R&D expenditure financed by the public sector(1), 2019(2)



Science, Research and Innovation Performance of the EU 2022

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

Note: (1)Public sector is defined as the sum of GOV, RoW European Commission and international organisations (using the GERD by source of funds). (2)UK:Year 2018. (3)The European Commission budget calculated in this figure represents mainly the budget for the Framework programme for R&I, and may not report the total of the budget dedicated to R&D from the European Structural funds under the correspoding category.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-2-24.xlsx

The Horizon Europe Partnerships and the Horizon Policy Support Facility are also expected to drive EU-wide transformations towards a greener, socially relevant and digitally enabled society and economy, and will directly support the priorities of the Commission. Partnerships trigger additional private and public R&I investments, resources and activities around EU priorities. Horizon 2020 already supports 26 partnerships. Several partnerships are directly relevant for achieving the European Green Deal. The partnerships culminate in large coalitions and provide experimental platforms to test and develop innovative solutions for societal challenges and industrial transformation. As of December 2021, 49 partnerships are foreseen under the first strategic plan (2021-2024) of Horizon Europe. The **Horizon Policy Support Facility** (in operation since 2015) **provides policy advice** to Member States and Associated Countries (to Horizon 2020) **in the design, implementation and evaluation of R&I reforms** to improve the quality and impact of their R&I systems, investments and policies.

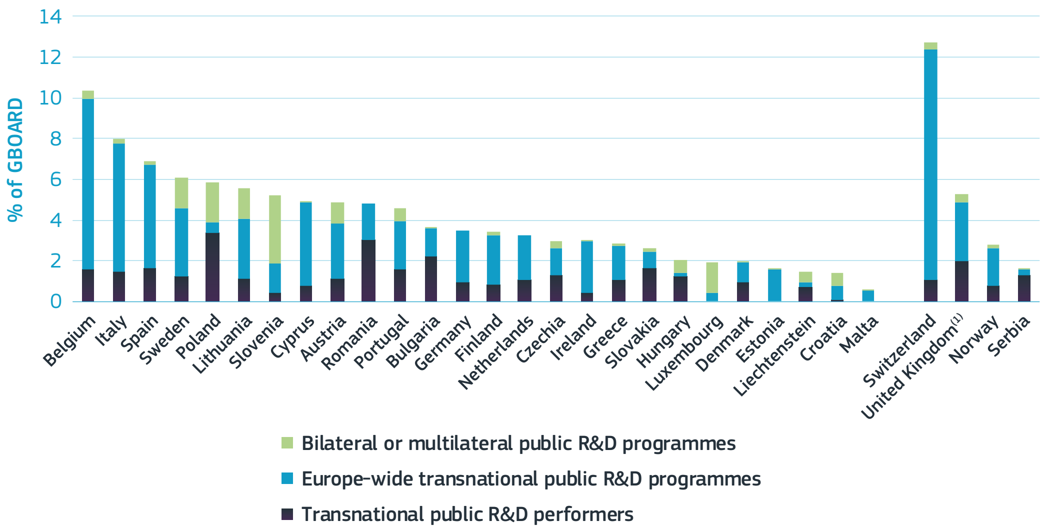
Table 5.2-3: Mapping of the Missions and European policy objectives

	Adaptation to climate change	Ocean, seas and waters	Climate-neutral and smart cities	Soil health and food	Cancer
Energy transition, mobility and housing		√	√		
Circular economy	√	√	√	√	
Jobs and skills in the local economy	√	√	√	√	√
Air quality	√	√	√	√	
Sustainable land use			√	√	
Climate adaptation and mitigation	√	√	√	√	
Digital transition	√		√		√
Urban poverty and inclusion of migrants and refugees		√	√	√	√
Territorial Agenda, post-2020 Urban Agenda and Interreg	√	√	√	√	√
Artificial intelligence		√		√	√
European data strategy	√	√	√	√	√
European industrial strategy	√		√	√	
High-performing computing	√	√			√
Digital transformation of businesses			√	√	
Connectivity	√	√	√	√	√
Digital skills	√	√	√	√	
Climate action (including Climate Pact and adaptation)	√	√	√	√	√
Biodiversity	√	√		√	
Farm to Fork	√	√		√	√
Sustainable industry	√	√	√	√	√
Clean energy	√	√	√		
Sustainable mobility	√	√	√		
Eliminating pollution	√	√	√	√	√
New European Bauhaus	√		√		

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on a publication by César Dro (DG R&I), Kathrin Kapfinger (DG R&I) and Ruzica Rakic (DG R&I)

The European Research Area is a multi-level governance initiative launched in 2000 to create a single, borderless market for research, innovation and technology across the EU and also embed the principle of directionality. It helps countries to cooperate more effectively, by strongly aligning their research policies and programmes. Furthermore, the ERA aims to reduce fragmentation of regulatory and administrative frameworks[16]. The ERA, together with the 3% Barcelona target and the accompanying action plan, was part of the Lisbon Strategy, which aimed to turn the EU into the most competitive and dynamic knowledge-based economy of the world. **Under the ERA transition forum launched in 2021, the European Commission proposed that national public funding to a transnationally coordinated R&D target would replace the 5% target for joint R&D investments**. This target would include EU funding under the Structural Funds. In 2019, the EU average was 4.25% of the total government budget for R&D (GBARD) allocated to transnationally coordinated R&D activities (Figure 5.2-25). Member States would all perform inside the bracket of a **minimum of 0.61% and a maximum of 8.85%** of total GBARD in 2019. A possible EU orientation indicator for the future Pact for R&I could be realistically set at **10% of total GBARD by 2030**, as both ambitious and attainable. It would in fact require the **doubling of efforts for cross-border European R&D** investments.

Figure 5.2-25: National public funding to transnationally coordinated R&D by source as a % of GBARD, 2020



Science, Research and Innovation Performance of the EU 2022

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

Note: [(1)]Data for UK is 2019

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-2-25.xlsx

16 Council Resolution of 15 June 2000 on establishing a European area of research and innovation, Lisbon European Council conclusions (24/3/2000)

The recovery and resilience facility scheme proposed by the Commission will also support directed R&D. According to the Single Market Report 2022, **around 40%** of the total allocation in Member States' Recovery and Resilience Plans **is related to measures supporting climate objectives, and more than 26% on the digital transition**. The horizontal R&I investments include a variety of cross-cutting measures such as strengthening of innovation ecosystems, upgrading research infrastructures, grants for researchers, support for business innovation, including start-ups and SMEs, and facilitation of public-private R&I cooperation. **The thematic R&I investments are targeted at specific areas**, such as **energy** (15% of total R&I expenditure, including, e.g., development of hydrogen solutions), **environment** (5%, e.g. supporting public and business environmental R&I or research in innovative green technologies), **transport/smart mobility** (4%, e.g. for development of electro-mobility), and the circular economy (3%, e.g. for development of re-use and recycling technologies). **R&I investments in digital technologies account for approximately 24% of total R&I expenditure** and include, for instance, development of advanced technologies (microprocessors, cloud, quantum computing, etc.), cybersecurity, 5G, and digital technologies of a more horizontal impact. Another important area of R&I investments is **health** (5% of total R&I expenditure). These investments include, for example, the development of alternative production processes for nuclear medicine for cancer treatment and the establishment of a centre for precision medicine.

Furthermore, **most Recovery and Resilience Plans includes R&D expenditure-based measures to boost R&I investment**. All approved Recovery and Resilience Plans[17] include measures related to R&I. This represents a total of 224 measures (55 reforms and 169 investments) for a budget of around EUR44.4 billion[18]. The amount of R&I investment in the Recovery and Resilience Plans represents typically between 4% and 13% of the Recovery and Resilience Facility grant allocation of a country, with a few outliers below or above this range and an average of about 10%. Investments range from ensuring access to finance for young innovative firms[19], to innovation diffusion and take up amongst SMEs[20]. In fifteen Recovery and Resilience Plans[21], innovation by firms, in particular SMEs, is also supported via reforms such as enhanced R&D tax-incentive schemes, new legal frameworks tailored to the needs of start-ups, innovative SMEs and social entrepreneurs (e.g. a new 'Austrian Limited' company form) and revision of innovation support instruments to make them more accessible to SMEs (e.g. the 'Widening the innovation base' reform in Belgium). Several Member States have also included investments to support Horizon Europe Partnerships and the funding of projects receiving a Seal of Excellence (i.e. projects which were judged to deserve funding under Horizon Europe but could not be financed due to budget limitations).

17 The recovery and resilience plans of the following 22 Member States have been approved so far: Austria, Belgium, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Ireland, Italy, Germany, Greece, Latvia, Lithuania, Luxemburg, Malta, Portugal, Romania, Slovakia, Slovenia, and Spain.

18 This amount corresponds to the total estimated costs of all measures addressing research, development and innovation priorities, including those directly related to the green or digital transitions.

19 BG, CZ, EL, ES, HR, IT, CY, LT, RO, SK

20 CZ, DK, DE, IE, EL, FR, HR, IT, CY, AT, PL, PT, RO, SK, SE

21 AT, BE, BG, CZ, DK, DE, EL, ES, HR, CY, LV, LT, PL, PT, RO

R&I projects and initiatives at the regional level that meet European priorities are also supported through European Cohesion Policy. In 2021-2027, the first of the EU Cohesion Policy objectives was 'a more competitive and smarter Europe through innovation and support to small and medium-sized businesses'. This objective is the main priority of the European Regional Development Fund. ESF Social Innovation+ is another initiative and aims to facilitate the transfer and upscaling of innovative solutions to societal challenges. Administered through indirect management (i.e. implemented by an ESF agency on behalf of the European Commission), ESF Social Innovation+ has a budget of EUR 197 million for the 2021-2027 programming period[22]. In past programming periods, European Structural and Investment Funds have directly supported millions of projects, many of which are R&D projects[23]. **Several other EU policy programmes, initiatives and funds also support R&D projects with directionality, such as LIFE**. Since 2018, the LIFE programme has been instrumental in supporting green innovations and cleantech solutions across Europe. As well as funding up to 55 % of each project, the LIFE financial instrument helps with the commercialisation of innovative solutions, easing their entry into the market[24].

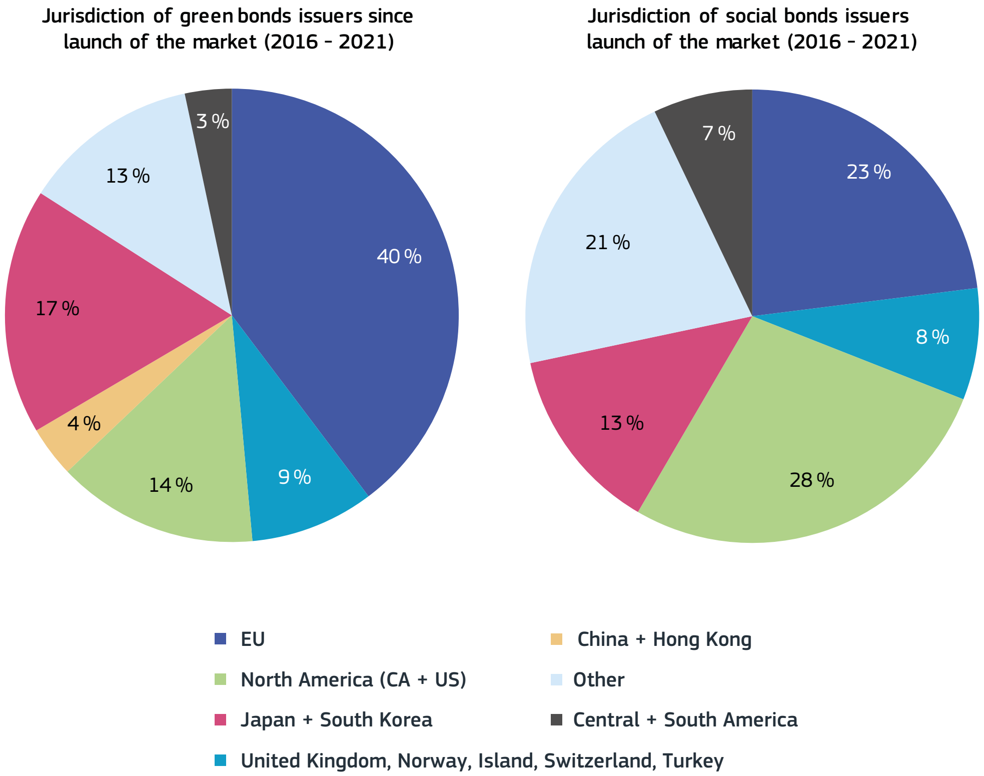
The EU sustainable finance framework has been revised to foster private sustainable and responsible investments, including R&D investments. The 2020 EU taxonomy establishes a list of environmentally sustainable economic activities and should create security for investors, protect private investors from greenwashing, help companies to become more climate-friendly, mitigate market fragmentation and help to shift investments.

In 2021, the European Commission also proposed a regulation for a European green bond standard (EU-GBS) to facilitate the issuance of green bonds by enhancing the transparency, comparability and credibility of the green bond market for both borrowers and investors. Lately, **green and social bonds have been playing an increasing role in financing green and social innovation** (Figure 5.2-26). Their issuance in comparison to total bond issuance has been growing steadily since their inception, both in terms of contracts and volumes. For example, **green bonds worldwide, expressed as a percentage of total bond issuance, doubled in terms of volume and almost quadrupled in terms of the number of deals between 2018 and 2019** (European Commission, 2021d). The market for green bonds has experienced exponential growth since its inception in 2007 and witnessed a high growth rate between 2014 and 2020 (from EUR 31.1 billion to EUR 245 billion).

Social impact bonds, which are typically implemented by social and solidarity-economy entities, have started to emerge over the last decade, both for domestic initiatives and in the framework of international development cooperation. **Recent estimates identify 221 social impact bonds that have been implemented in 37 countries, mostly related to employment and social welfare objectives** (Brookings, 2022). Europe is in the lead worldwide for the issuance of these bonds.

22 ESF Social Innovation+ | European Social Fund Plus (europa.eu)
23 Maps - Regional Policy - European Commission (europa.eu)
24 LIFE close-to-market projects (europa.eu)

Figure 5.2-26: Jurisdiction of green and social bonds issuers since launch of the market (2016-2021)



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on International Capital Markets Associations

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4. Conclusions: boosting directed R&D investments

With just over 2% of its GDP in R&D, the EU has not achieved its 2020 3% target. It is underinvesting in R&D compared to its main competitors, especially in terms of private investments, while Asian countries, in particular China and South Korea, are investing at a rate that is eclipsing both the EU and the United States. If this continues, Europe risks being outpaced irreversibly.

The **EU is well-positioned in some sectors, such as mobility and chemicals, but less in others, notably the highly R&D-intensive sectors, such as health and ICT. Considering the impacts of the COVID-19 pandemic**, which has hit mobility and manufacturing sectors hard but positively impacted health and ICT services sectors, this unbalanced situation may jeopardise its competitiveness in the future.

EU public and private investment in R&D are steering towards societal and environmental challenges, but at a slow pace. Member States use direct support funding, often directed, to increase the EU science and technological base. However, they also use more and more tax relief schemes to foster private R&D investments, with some also featuring some degree of directionality towards sustainable challenges and others focusing on supporting SMEs or young start-ups.

At the European level, **one of the main public investment instruments in Europe is the EU's R&I framework programme**. Horizon Europe, the 2021-2027 framework programme, with its increased budget of almost EUR 95.5 billion, will continue to create new knowledge and solutions to attain the SDGs. It provides even **greater directionality through its mission-oriented approach** (on, for example, climate change, healthy oceans, climate-neutral and smart cities, and soil health and food) and European partnerships. **The European Cohesion policy and structural funds,** and several other EU policy programmes, initiatives and funds, **also support R&D projects with directionality**. Finally, most Member States **include measures to boost R&D investments in their Recovery and Resilience Plans.**

Europe requires **coordinated reform and a modernisation effort** that could be aimed at ensuring the effectiveness and efficiency of increased R&D investments as well as incentivising and leveraging private investments in the future: **investments and reforms must go hand in hand**. The timeline and intensity for such investments as well as structural reforms of the R&I systems could be clearly adapted to the national context and national specificities (e.g. economic structure, structure of the R&I system) in the Member States, in particular as regards the absorption capacity in terms of increased funding and the pace of the modernisation of the R&I sector. This also calls for enhanced **national strategies** that ensure a timely delivery on those key objectives.

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CHAPTER 5.3

THE ICT SECTOR AND DIGITALISATION

KEY FIGURES

€63 billion of value added in the EU ICT sector	**4.2 %** share of the ICT sector in total GDP	**6 million** workers employed in the EU ICT sector

13 % share of EU firms using big data analytics	**5.4 %** R&D intensity in the EU ICT sector

KEY QUESTIONS WE ARE ADDRESSING

- How is the EU ICT sector performing compared to that of other major economies?
- Where does the EU stand in terms of the digital divide and the integration of digital technologies?
- How does the EU perform in terms of ICT innovation?

KEY MESSAGES

What did we learn?

- The COVID-19 pandemic has accelerated the digitalisation process in the EU but has also exacerbated the digital divide between EU firms, regions and countries.
- The boost to digitalisation after the pandemic has not been sufficient to reduce the gap between the EU and its international competitors.
- Overall, the EU lags behind the USA and China in terms of digital patent applications across several industries, although it remains strong in the automotive sector and in the field of climate change.

What does it mean for policy?

- Increasing asymmetries across EU Member States put the European convergence process in jeopardy.
- R&I policy plays a critical role in supporting the EU digital transition, enabling the development and deployment of digital innovations throughout the EU.
- The digital transition has changed the way the society interacts and operates, calling for increasing efforts to protect and safeguard European citizens' rights and freedoms.

The rapid development of ICT over the last few decades has set in motion an irreversible change in how business is done. The way firms adopt and use ICT determines their ability to cope with the challenges of modern times. Further developing the ICT sector in the EU is critical to increasing competitiveness by allowing European enterprises to take part in global digital supply chains.

ICT plays a central role in promoting innovation and growth across EU countries. The ICT sector is a key determinant of the competitive power of knowledge-based economies as it is a magnet for investors and constitutes a natural environment for innovation (OECD, 2020).

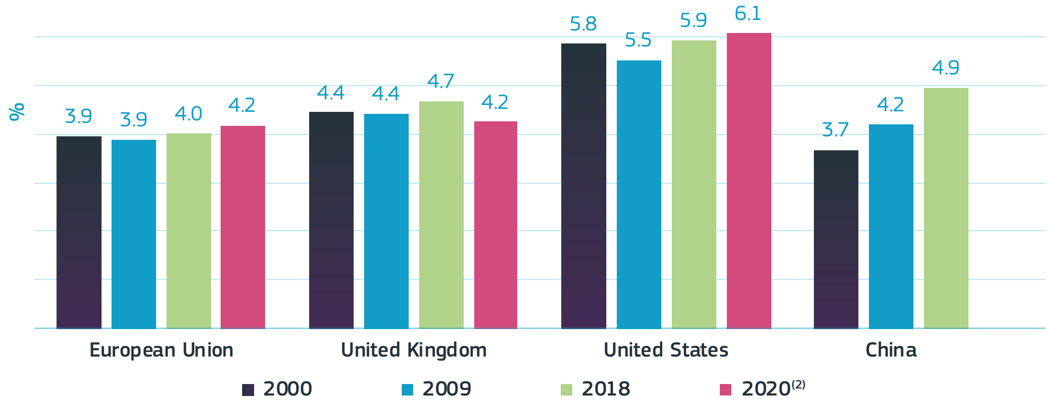
Furthermore, the impacts of the digital transformation are irreversibly transforming the world of work. The non-rival nature of digital innovations has an impact on firms' production technologies, which are often characterised by relatively high fixed costs of development and low (close to zero) marginal costs. Also, digitalisation entails strong network effects that can play an important role in the uptake of digital technologies by end users. Both factors play a role in understanding why the ICT-producing sector is strongly concentrated, with a few dominant tech and digital giants.

1. The ICT sector in the EU

A strong ICT sector[1] enables EU businesses to compete in globalised markets. The European Commission has placed the development of the ICT sector at the heart of its policy agenda. By including 'a Europe fit for the digital age' among its core priorities, the European Commission creates a concrete and comprehensive digital strategy. In this regard, monitoring the evolution of the ICT-producing sector is essential to identify potential sources of innovation and to effectively implement EU and national policy action[2].

The value added of the EU ICT sector has increased by more than 70% in absolute term, over 2000-2020. In 2019, the value added of the sector stood at EUR 607 billion, a slight increase compared to 2018. The ICT sector stagnated in 2020, due to the COVID-19 crisis, with a value added of EUR 603 billion.

Figure 5.3-1: ICT(1) sector value added as % of GDP by world region, 2000, 2009, 2018, 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit, based on DESI Report 2021 - ICT Sector and Its R&D performance, PREDICT Project; Eurostat (online data code: nama_10_gdp); OECD Database

Note: (1)Data for the ICT sector are aggregated using the operational definition of the ICT sector as defined in the PREDICT project, which does not include the following industries: manufacture of magnetic and optical media (268) and ICT trade industries (465). The operational definition enables the EU to be compared with non-EU countries. (2)US and UK data on GDP for 2020 are taken from OECD Database.

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1 In this chapter, the ICT sector is defined according to the definition provided by the OECD and based on the Statistical Classification of Economic Activities in the European Community (NACE) Rev.2 (2008) nomenclature. Specifically, data are aggregated using the comprehensive definition of the ICT sector from the PREDICT project, when not specified otherwise.

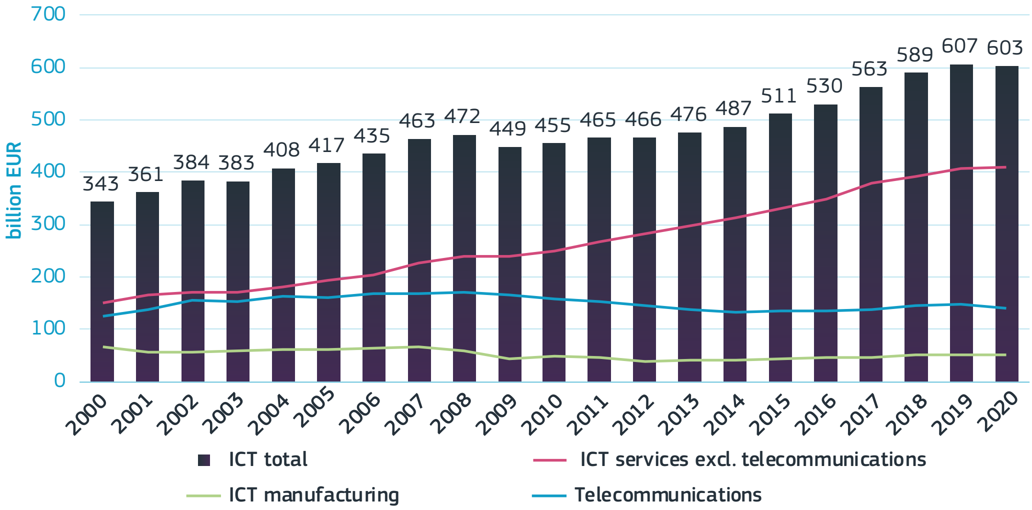
2 Commission Staff Working Document 'Annual Single Market Report 2021' (SWD(2021) 351 final)

Nevertheless, the value added of the ICT sector in the EU as a share of total GDP has been stagnating around 4% over the last decades. When compared to its main international competitors, in 2020 the contribution of the ICT sector to the European economy was lower than in the USA (4.2% against 6.1%) and the same as in the UK (Figure 5.3-1). Nevertheless, when looking at the evolution over time, the share of the ICT sector in national GDP has also been stagnating in the UK and the USA. Although the ICT sector grew by 46% and 74% in the two countries respectively in absolute terms (DESI, 2021a), its weight in national GDP increased only marginally over 2000-2020 in the USA, while it decreased in the UK over the same period. China represents an important exception as the contribution of the ICT sector to Chinese GDP grew significantly over time, increasing from 3.7% in 2000 to 4.9% in 2018.

The performance of the EU ICT sector is not homogeneous across ICT subsectors. ICT services (excluding telecommunications) were the key driver of the overall positive trend of the sector over time. Between 2000 and 2020, it was the only subsector that experienced a significant increase, moving from EUR 151 billion value added in 2000 to EUR 411 billion in 2020. Furthermore, this subsector was the only one reporting a positive performance after the outbreak of the COVID-19 pandemic (Figure 5.3-2). In contrast, both telecommunications and ICT manufacturing experienced a decline 2006-2018 and stagnated thereafter.

Germany, France, Italy, Spain and the Netherlands together accounted for 65% of value added in the EU ICT sector (in 2020). Germany reported the highest valued added in the ICT sector across EU countries, with EUR 142 billion in 2020. France ranked

Figure 5.3-2: ICT sector value added in billion EUR, 2006-2020



Source: DESI Report 2021 - ICT Sector and Its R&D performance, PREDICT Project

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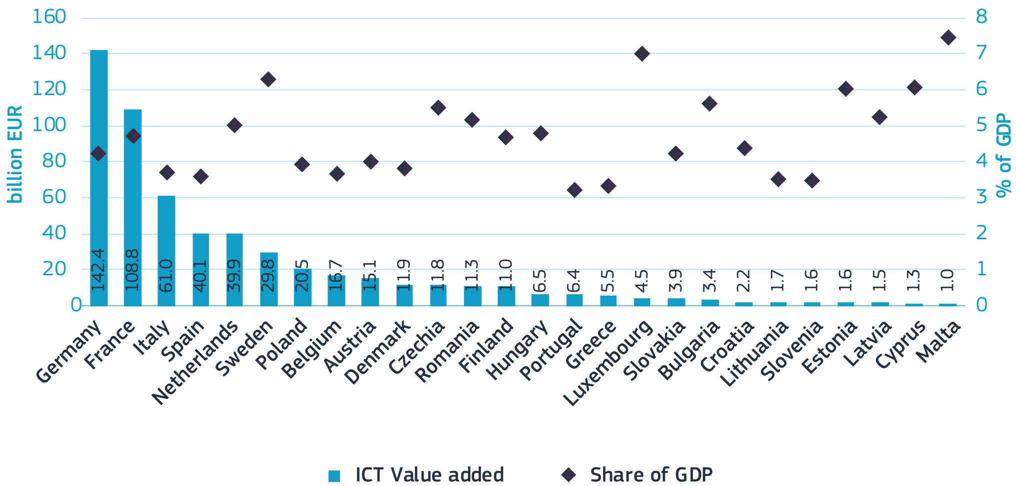
second with EUR 109 billion. Italy, Spain and the Netherlands followed with an ICT value added ranging between EUR 61 billion and EUR 40 billion (Figure 5.3-3).

In terms of GDP contribution, the EU countries with high ICT share were Malta (7.5%), Luxembourg (7.0%) and Sweden (6.3%). Eastern European countries such as Romania, Hungary and Latvia also reported a large contribution of the ICT sector to their GDP, with a share of around 5%.

The EU ICT sector employed over 6 million people in 2020, continuing the upward trend started in the 2000s. The ICT services (excluding telecommunications) subsector accounted for the highest share of ICT employment in 2020, with about 4.7 million employees. It is also the only subsector in which employment has been increasing over a long period (2006-2020). This is in line with the earlier finding of its prominent role for the overall performance of the ICT sector. The telecommunications and ICT manufacturing subsectors experienced a decline in the number of people employed over the same period. The decrease was more significant in the ICT manufacturing segment, which reported a 35.5% drop between 2006 and 2020, from 817 million to 527 million employees.

The government budget allocation to R&D (GBARD) in the ICT sector has remained relatively constant over the last decade. The allocation increased between 2017 and 2019, when the ICT GBARD increased from EUR 5.8 billion to EUR 6.4 billion (Figure 5.3-5).

Figure 5.3-3: ICT[1] value added in billion EUR and as % of GDP by EU Member State, 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on DESI 2021 – the EU ICT sector and its R&D performance, PREDICT Project; Eurostat [nama_10_gdp]

Note: [1]Data for the ICT sector are aggregated according to ICT sector comprehensive definition, as defined by the PREDICT project; Data for IE not available for 2020.

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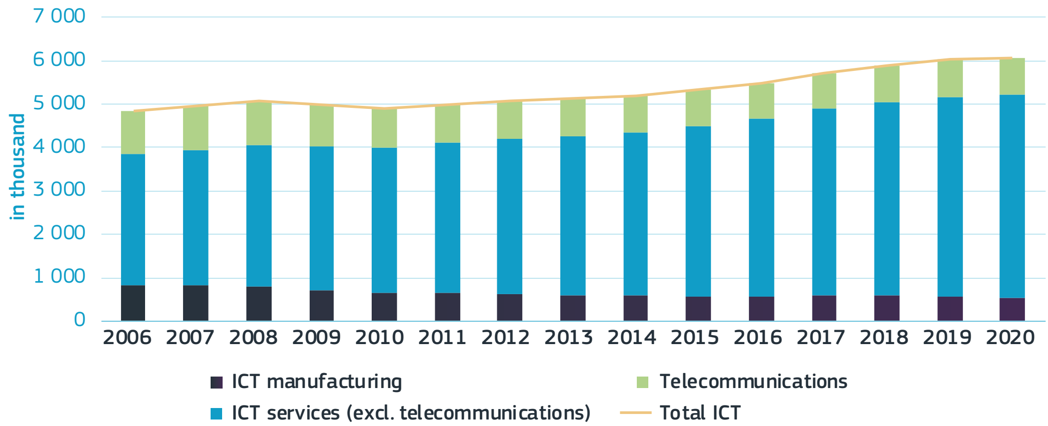
Figure 5.3-4: Employment in the ICT[1] sector broken down by manufacturing and services in the EU, 2006-2020



Science, Research and Innovation Performance of the EU 2022

Source: DESI 2021 – the EU ICT sector and its R&D performance, PREDICT project

Note: [1]Data for the ICT sector are aggregated according to the comprehensive definition of the sector from the PREDICT project. Data for Ireland not available for 2020.

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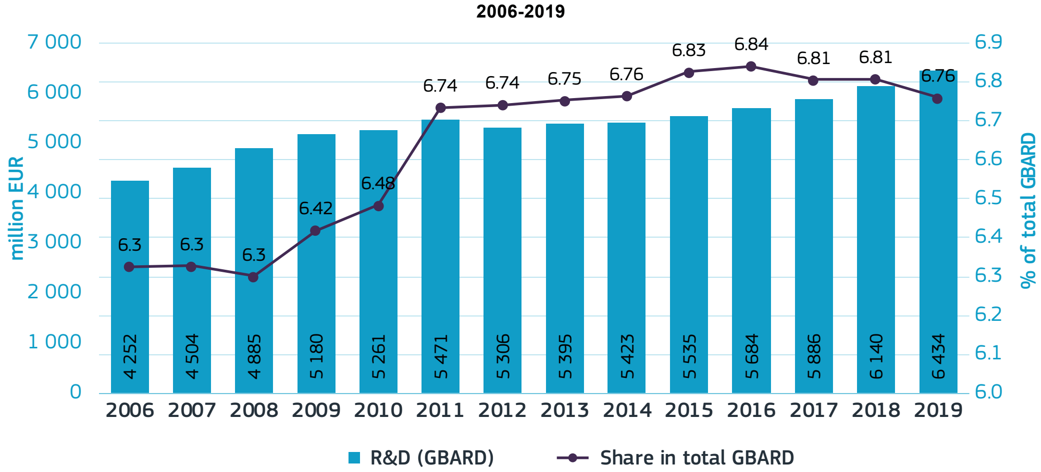
Similarly, the share of GBARD in the ICT sector in total public funding for R&D has remained relatively constant over time, ranging between 6.7% and 6.8% over 2011-2019 (Figure 5.3-5).

In contrast, the share of business R&D expenditure (BERD) in the EU ICT sector over total BERD has decreased over the past decade. Although ICT BERD in the EU has increased over time in absolute terms, its contribution to total BERD has declined over time. In 2006, the share of ICT BERD in total EU R&D expenditure by business enterprises was around 18.6%, whereas in 2020 the share was about 15.3% (Figure 5.3-6).

The R&D intensity[3] of the EU ICT sector was around 5.2% in 2020, well below the EU's main international competitors. South Korea has the most R&D-intensive sector, with a BERD/value added ratio of 20.4% in 2020, followed by the USA with 9.8%. Japan and China also report a higher R&D intensity than the EU, i.e. 7.3% and 6.2%, respectively. In contrast, the UK is lagging behind the EU, with an R&D intensity of 3.6% in 2020.

3 R&D Intensity is measured as BERD over value added.

Figure 5.3-5: Government Budget Allocation to R&D (GBARD) in the ICT[(1)] sector in the EU, 2006-2019



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit, based on DESI Report 2021 - ICT Sector and Its R&D performance, PREDICT Project; Eurostat (online data code: gba_nabsfin07).

Note: [(1)]Data for the ICT sector are aggregated according to ICT sector comprehensive definition, as defined by the PREDICT project.

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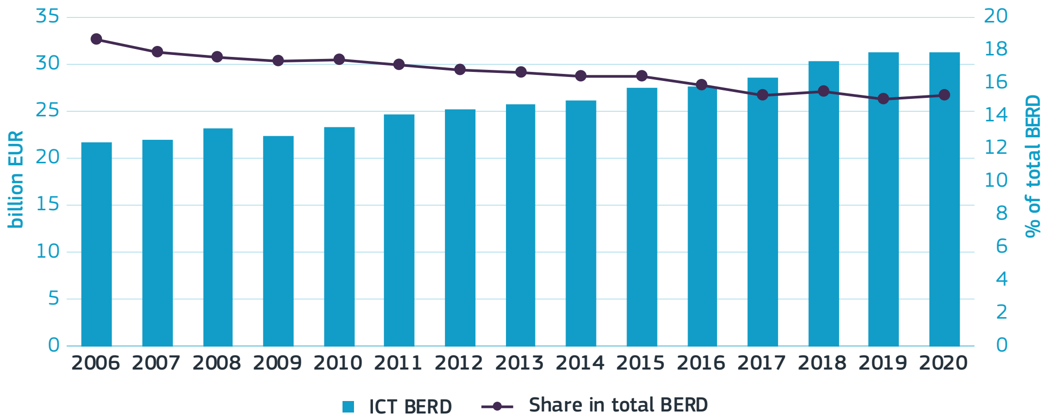
Figure 5.3-6: Business R&D expenditure (BERD) in the ICT[(1)] sector in the EU, 2006-2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – ¬Common R&I Strategy and Foresight Service – Chief Economist Unit, based on DESI 2021 – the EU ICT sector and its R&D performance, PREDICT project; Eurostat [online data code: rd_e_berdindr2]

Note: [(1)]Data for the ICT sector are aggregated according to the comprehensive definition of the sector from the PREDICT project.

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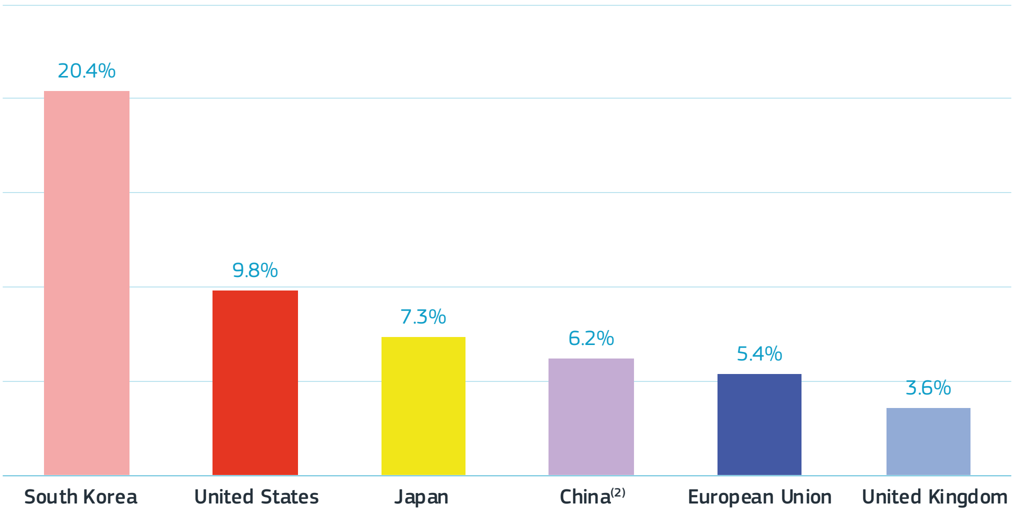
Figure 5.3-7: R&I Intensity in the ICT[1] sector per world region, 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit, based on DESI Report 2021 - ICT Sector and Its R&D performance, PREDICT Project.

Note: [1]Data for the ICT sector are aggregated using the operational definition of the ICT sector as defined in the PREDICT project, which does not include the following industries: manufacture of magnetic and optical media (268) and ICT trade industries (465). The operational definition enables the EU to be compared with non-EU countries. [2]CN: year 2018

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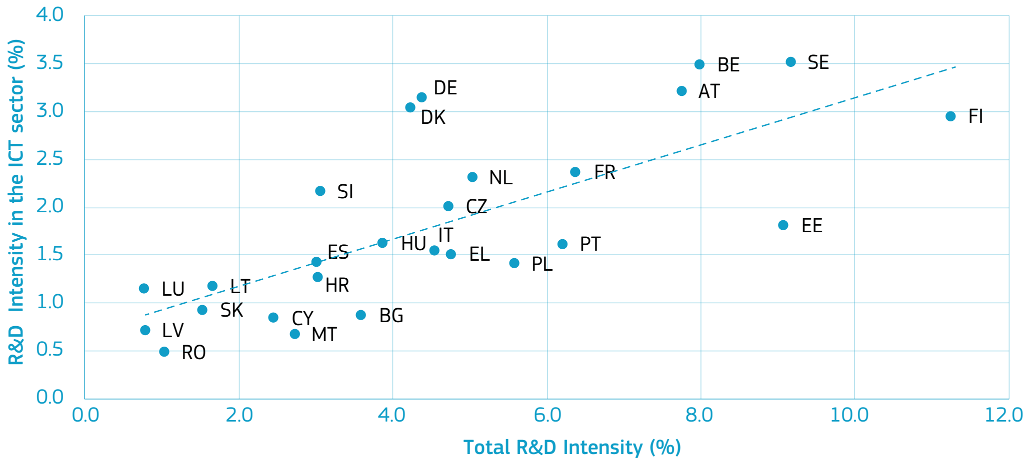
Finland, Sweden and Estonia report the highest R&D intensity in the ICT sector. Finland also confirmed its role as an innovation leader in 2020, with an R&D intensity in the ICT sector equal to 11 %. Sweden followed with 9 %, continuing its strong performance (DESI, 2021a). Estonia reported the same R&D intensity as Sweden, showing an improvement compared to the 6 % registered in 2018 (DESI, 2021a). Other strong performers were Belgium and Austria, also both with an R&D intensity close to 8 %. Countries such as the Netherlands, Czechia and Italy performed very closely to the EU average, while the R&D intensity in ICT was only about 1 % in Romania, Latvia and Luxembourg (Figure 5.3-8).

Interestingly, the Member States reporting the highest R&D intensity in the ICT sector also performed very well in terms of national R&D intensity[4]. In 2020, Sweden and Belgium reported the highest total R&D intensity in the EU (3.5 % for both). Other countries with a high R&D intensity were Austria (3.2 %) and Finland (2.9 %) (Figure 5.3-8).

4 Total R&D intensity is calculated as the percentage of R&D expenditure over GDP.

Figure 5.3-8: Total R&D Intensity vs R&D intensity in the ICT[1] sector by EU Member States, 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit, based on DESI Report 2021 - ICT Sector and Its R&D performance, PREDICT Project; Eurostat (online data code: rd_e_berdindr2).

Note: [1]Data for the ICT sector are aggregated according to ICT sector comprehensive definition, as defined by the PREDICT project.

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2. The EU digital divide

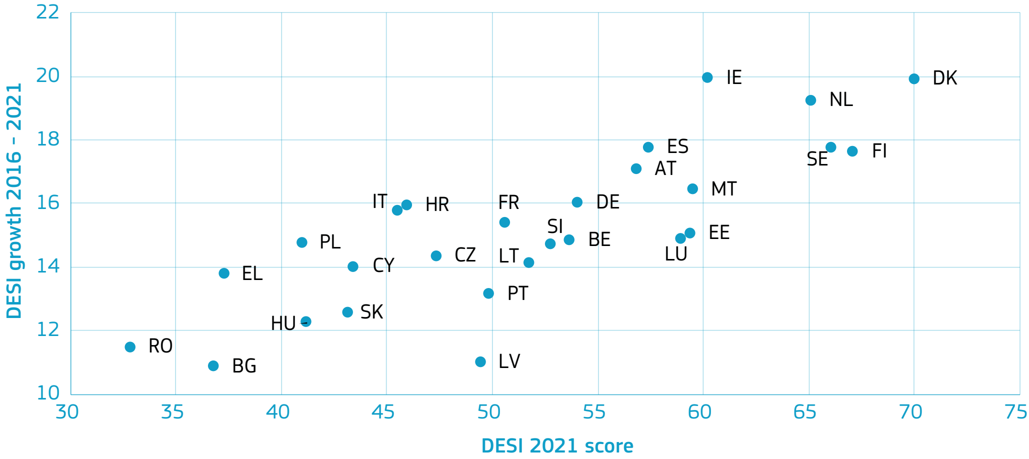
Digitalisation goes beyond the ICT sector. The digital transition affects different aspects of society, as it influences the way people work and live and how businesses operate. For instance, the diffusion of ever more sophisticated digital technologies calls for workers' re- and up-skilling to cope with the challenges of the digital age (see chapter 4.3 – Skills in the digital era). Furthermore, the massive shift to remote teleworking after the outbreak of COVID-19 allowed firms to ensure a certain degree of business continuity, thereby partially counteracting the disruptive effects of the pandemic (see chapter 1 – COVID-19, recovery and resilience).

Digitalisation has accelerated the pace at which R&I activities are performed. The increasing automation levels, use of big data analytics, Internet of Things (IoT) and AI have increased researchers' productivity capacity, which also contributes to the opening of new research fields. The rapid uptake of digital technologies across several industrial sectors has enabled the creation of new and more efficient business processes and products, allowing for a broad set of new applications and breakthrough innovations (European Commission, 2021). Digitalisation has also intensified the spread and application of knowledge by boosting open innovation and opening access to larger talent pools. Furthermore, digitalisation has increased the speed at which technology proliferates, and changed firms' innovation strategies. This is especially true for consumer-driven innovations, linked not only to the faster spread of digital business-to-consumer activities, but also to the increase in consumer participation in firms' innovation processes (European Commission, 2021).

Despite the high proliferation of digital tools, the digital divide is increasing. The digital divide refers to the gap between individuals and economic actors who have access to ICT and are able to take part in the information society, and those who are excluded from these digital services. Digital literacy is not homogeneous across EU Member States, and substantial differences also remain within countries between more industrialised and rural areas, as well as across different age groups (see chapter 4.3 – Skills in the digital era).

Digital performance varies widely across EU countries. The DESI provides an overview of the digital performance of EU countries, allowing a distinction to be made between digital innovators and those Member States still lagging behind in terms of digital performance (DESI, 2021b). Between 2015 and 2020, Ireland and

Figure 5.3-9: EU Member States' progress in their digital performance, DESI index 2016-2021



Science, Research and Innovation Performance of the EU 2022

Source: DESI 2021 – the EU ICT sector and its R&D performance.
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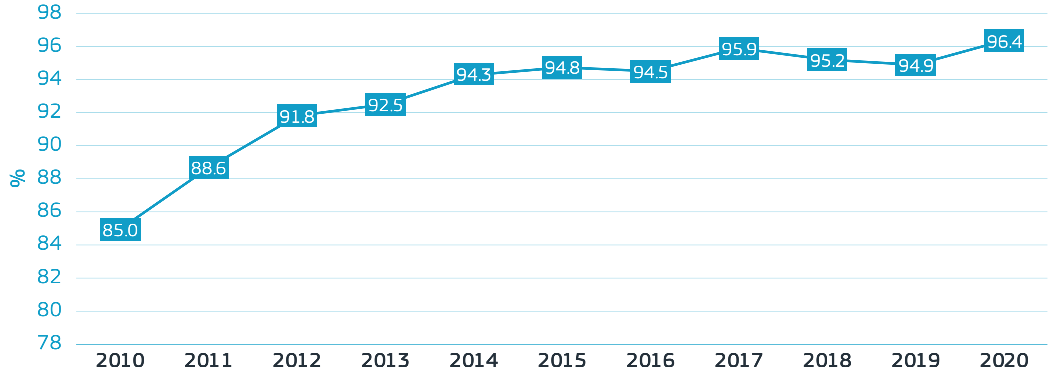
Denmark advanced well in making their economies fit for the digital age. The Netherlands, Spain, Sweden and Finland also reported an improvement in their digital performance over the same time span (Figure 5.3-9). Denmark, Finland, Sweden and the Netherlands were also the main digital innovators in the EU in 2020, according to the DESI ranking (DESI, 2021). Ireland, Malta and Estonia performed quite well in terms of DESI ranking, while Greece, Bulgaria and Romania lagged significantly behind the rest of the EU countries. Bulgaria and Romania showed only slow progress over the last five years.

Almost all firms in the EU have a broadband connection. The number of European enterprises with a broadband connection has increased steadily over time. In 2020, 96.4% of firms in the EU had a broadband connection at their disposal, compared to 85% in 2010 (Figure 5.3-10). With the acceleration of the digital transition, businesses are progressively relying on digital technologies to carry out their activities. Nowadays, access to internet is an integral part of the way of doing business worldwide (OECD, 2020).

Nevertheless, divergences persist across Member States in terms of the number of employees using computers with internet access. Looking at the share of employees able to work with an internet-connected device provides a better overview of the extent to which ICTs have been embedded in EU businesses (OECD, 2020). Sweden, Finland and Denmark report the highest share of employees using computers with internet access, ranging between 83.3% and 77.4% (Figure 5.3-11). Greece, Hungary, Latvia and Portugal report shares well below 50%.

5 The 2016 and 2021 DESI indexes refer respectively to data for 2015 and 2020

Figure 5.3-10: Share of businesses with a broadband connection in the EU, 2010 - 2020 (includes both fixed and mobile)



Science, Research and Innovation Performance of the EU 2022

Source: OECD ICT Access and Usage by Businesses Database, December 2021

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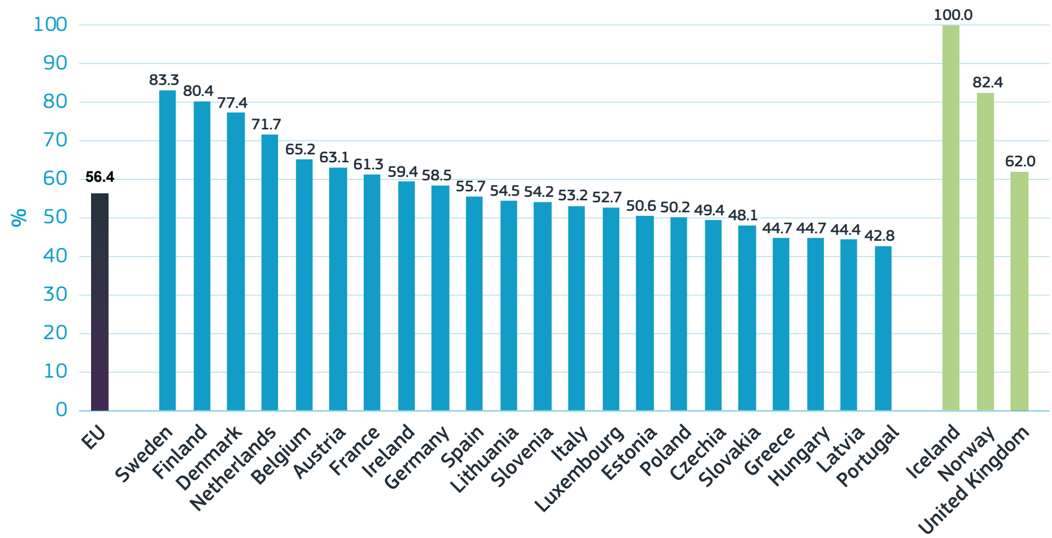
Figure 5.3-11: Share of employed persons using computers with internet access, 2020



Science, Research and Innovation Performance of the EU 2022

Source: ICT Access and Usage by Businesses' database, OECD, accessed December 2021

Note: Data available for 22 EU Member States.

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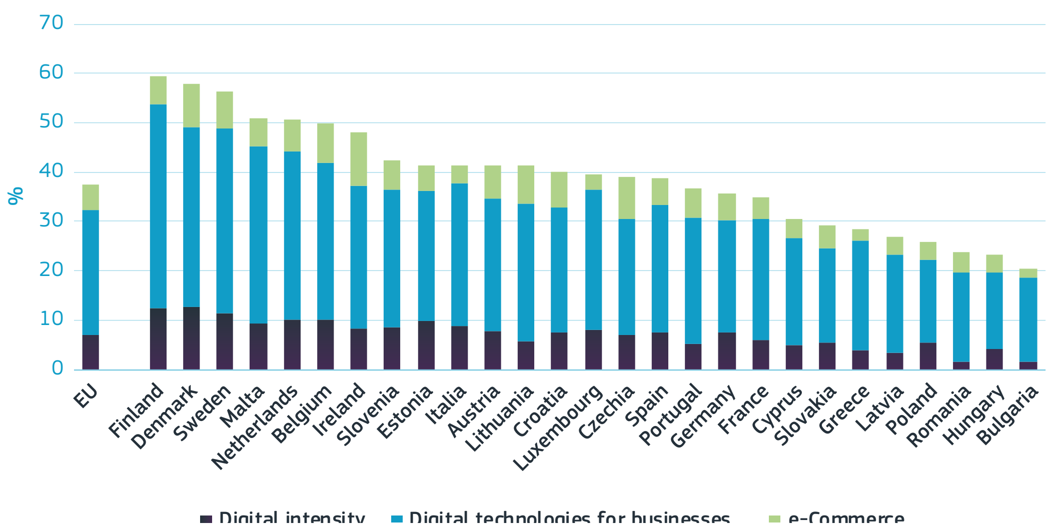
3. The adoption of digital technologies in the EU – implications of the COVID-19 crisis

Speeding-up the digitalisation of the EU economy is at the heart of the EU policy agenda. In the Communication '2030 Digital Compass: the European way for the Digital Decade', the European Commission set out its objectives for the digital transformation by 2030. Key ingredients of the EU strategy for a human-centred, sustainable and more prosperous digital future are digital sovereignty in an open and interconnected world and increasing the empowerment of people and businesses. In this regard, increasing the adoption of digital technologies in the EU economy is essential to meeting EU objectives and successfully tackling the challenges of the digital age.

EU firms are struggling to catch up with US and Chinese companies, which are the global frontrunners in terms of digital technologies. The rapid change of the global innovation landscape poses important challenges to the EU's digital ambitions. The share of firms that adopted at least one digital technology in 2019 among EU manufacturing firms was 66 %, against 78 % in the USA (EIB, 2020).

The degree of adoption of digital technologies varies significantly across EU Member States. Finland, Denmark and Sweden are the top performers in terms of integration of digital technologies, with a score well above 50 (DESI, 2021). Bulgaria, Hungary and Romania report the lowest levels of adoption (Figure 5.3-12).

Figure 5.3-12: **Adoption of digital technologies in the EU, 2021**



Source: Digital Economy and Society Index 2021, European Commission

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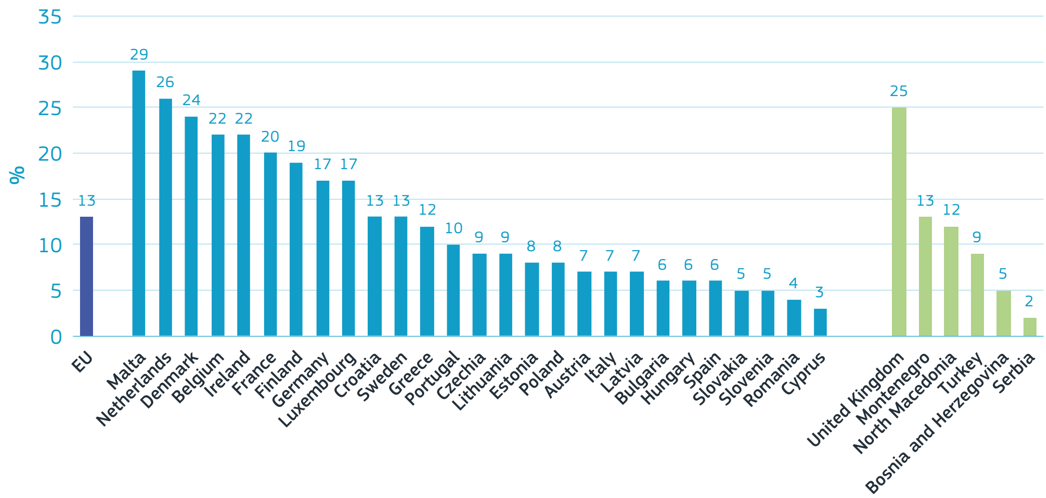
Differences across the EU also exist in terms of big data uptake. More than 20% of firms in Malta, the Netherlands, Denmark, Belgium and Ireland use big data analytics, whereas this share is below 5% in Slovenia and Cyprus (2020 data) (Figure 5.3-13).

The COVID-19 crisis has accelerated the digitalisation of EU businesses, with large enterprises taking the lead. Digital technologies such as cloud computing and big data analytics gained importance during the COVID-19 crisis. According to a recent survey, 46% of EU firms decided to integrate more digital services in their businesses because of COVID-19 (EIB, 2022). Micro and small firms reported a more modest reaction to the COVID-19 crisis as compared to companies of bigger size. Only 36% of micro firms took action to become more digitalised, against 54% of large firms. As of 2020, more than 60% of large-sized firms in the EU use cloud computing services within their businesses, as opposed to 46% and 33% of medium and small firms, respectively. Similarly, the use of big data is less diffuse in medium (19%) and small (11%) companies, while large companies show a higher uptake (31%). The same pattern is observed across other digital technologies, such as 3D printing and IoT (Figure 5.3-14).

Figure 5.3-13: Share of enterprises performing big data analysis(1), 2020



Source: Eurostat [online data code: isoc_eb_bd]

Note: (1)Share calculated as number of enterprises analysing big data internally (from any source) in total enterprises (i.e., all enterprises, without financial sector, 10 or more employees and self-employed persons)

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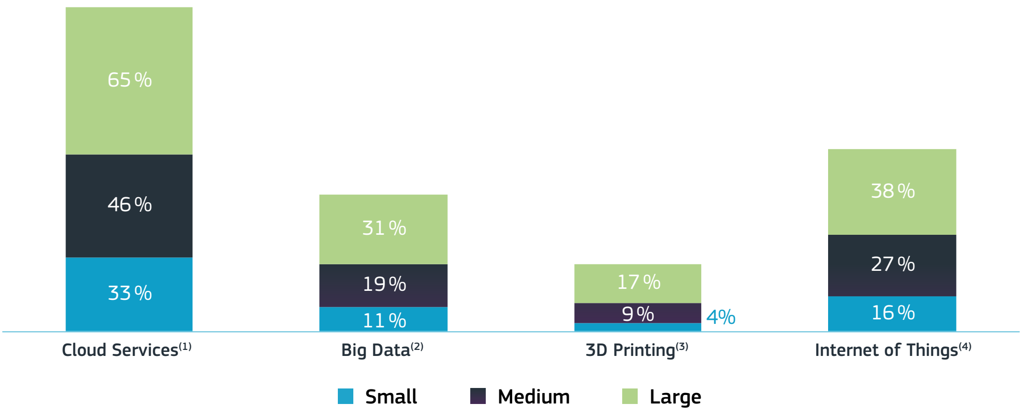
Figure 5.3-14: Share of enterprises using digital technologies in the EU per firm size, 2020



Science, Research and Innovation Performance of the EU 2022

Source: Eurostat (online data codes: isoc_cicce_use, isoc_eb_bd, isoc_eb_p3d, isoc_eb_iot)
Note: [(1)]Cloud Service – share calculated as number of enterprises relying on cloud computing services used over the internet. [(2)]Big Data - share calculated as number of enterprises analyzing big data internally (from any source) in total enterprises. [(3)]3D Printing - share calculated as number of enterprises using 3D printing. [(4)]IoT – share calculated as number of enterprises using interconnected devices or systems that can be monitored or remotely controlled via the internet (Internet of Things).
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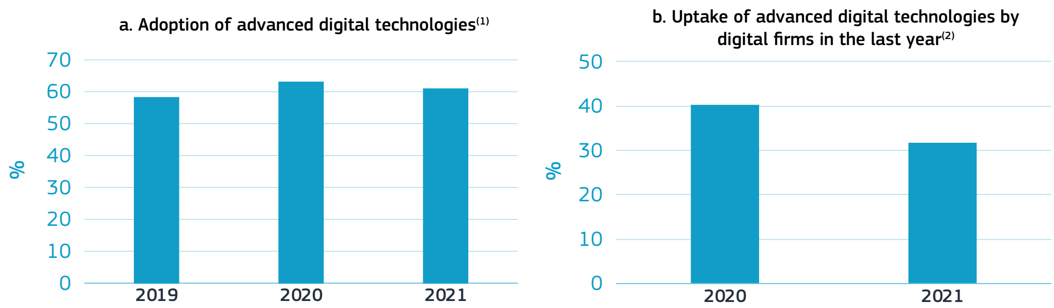
There are important inter-sectoral differences in the effects of the COVID-19 pandemic on EU firms' digitalisation. Companies operating in the services industry put more effort in the digitalisation of their businesses. As a response to the pandemic, 49% of firms in this industry indicated that they had invested more in digitalisation, compared to 32% of companies active in the construction industry (EIB, 2022).

In addition, the digital progress triggered by the COVID-19 pandemic differed across technologies. In the wake of the COVID-19 crisis, firms invested more in basic digital technologies, leaving aside the adoption of new and more advanced digital technologies (e.g. 3D printing, advanced robotics, IoT, big data analytics and AI) (EIB, 2022). The rate of adoption of advanced digital technologies increased between 2019 and 2020, from 58% to 63%, but mildly contracted to 61% in 2021 (Figure 5.3-15a). Furthermore, the adoption rate of advanced technologies by digital firms dropped considerably over 2020-2021 (Figure 5.3-15b), suggesting that **firms' investment choices triggered by the pandemic were mostly directed towards meeting their immediate needs, while more complex investment projects were given less priority** (EIB, 2022).

Figure 5.3-15: Share of firms adopting advanced digital technologies in the EU, 2019-2021



Science, Research and Innovation Performance of the EU 2022

Source: EIBIS (2019, 2020, 2021), firms in EU.
Note: (1)A firm is identified as having adopted an "advanced digital technology" if at least one digital technology specific to its sector was implemented in parts of the business and/or if the entire business is organised around at least one digital technology. Firms are weighted using value added. (2)The question on whether any new digital technology was introduced in the last year was not asked in EIBIS 2019. Firms are weighted using value added.
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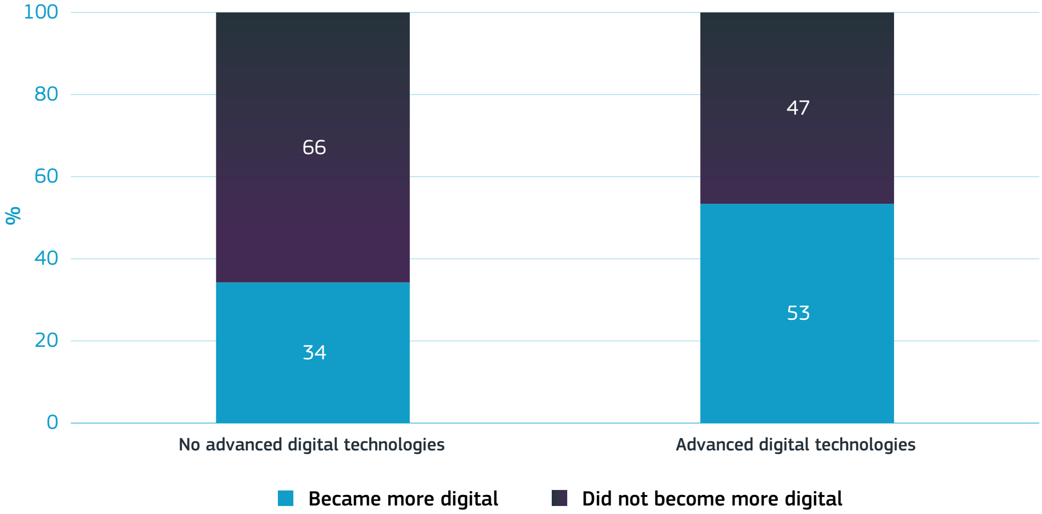
The COVID-19 pandemic acted as a catalyst for digitalisation, especially in firms already implementing digital technologies as part of their businesses (EIB, 2022). Already well-performing firms further strengthened their position, while digital laggards continued to fall behind (EIB, 2022). As such, the COVID-19 appears to have widened the digital gap between EU firms. Only 34% of EU firms increased their adoption of basic digital technologies in response to the COVID-19 pandemic, while the share of those reporting no digital progress was over 40%. Nevertheless, 53% of firms already using advanced digital technologies further invested in their digitalisation as a result of the pandemic (Figure 5.3-16).

Figure 5.3-16: EU firms[1] investing in the digitalization process as a response to the COVID-19 pandemic



Science, Research and Innovation Performance of the EU 2022

Source: EIBIS (2021), firms in EU.
Note: [1]Firms are weighted with value added.
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This digital acceleration experienced after the outbreak of the pandemic has been insufficient to catch up with the USA, where 58 % of firms adopted digital technologies in response to the pandemic (against the 46 % reported in the EU). The gap also remains or has even widened further in terms of the adoption of advanced digital technologies. In the USA, around 66 % of firms have already incorporated advanced digital technologies as a result of the pandemic, compared to 61 % in the EU (EIB, 2022).

Box 5.3-1: Technological uptake and sustainability

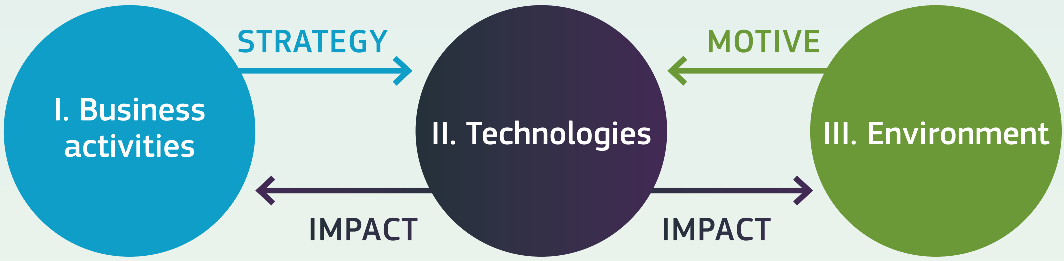
Digitalisation and green transition are strongly interlinked. The adoption of digital tools may help to reduce the economy's carbon footprint. At the same time, it is key to ensure that digital technologies become more energy efficient to allow a smart and sustainable use of resources[6]. In this regard, it is important to understand what factors drive firms' digital uptake and environmental goals.

Firms' technological uptake is mainly driven by their business strategy. Firms choose the technologies based on their set of objectives, including in terms of sustainability (Ipsos and iCite, 2021).

Firms adopt new technologies mainly to improve their products and services. According to a recent survey, ICT uptake is mainly driven by business decisions, as the most common motivations for the use of AI and cloud computing are 'improving product or services' (reported by 82% of respondents) and 'reducing operating costs' (70%) (Ipsos and iCite, 2021).

Nevertheless, around 60% of EU enterprises reported 'reducing the environmental footprint' as a main motivation for their ICT uptake. To pursue their environmental goals, 60% of EU enterprises have adopted collaborative platforms, 58% use AI and 55% use cloud computing and cloud storage (Figure 5.3-18).

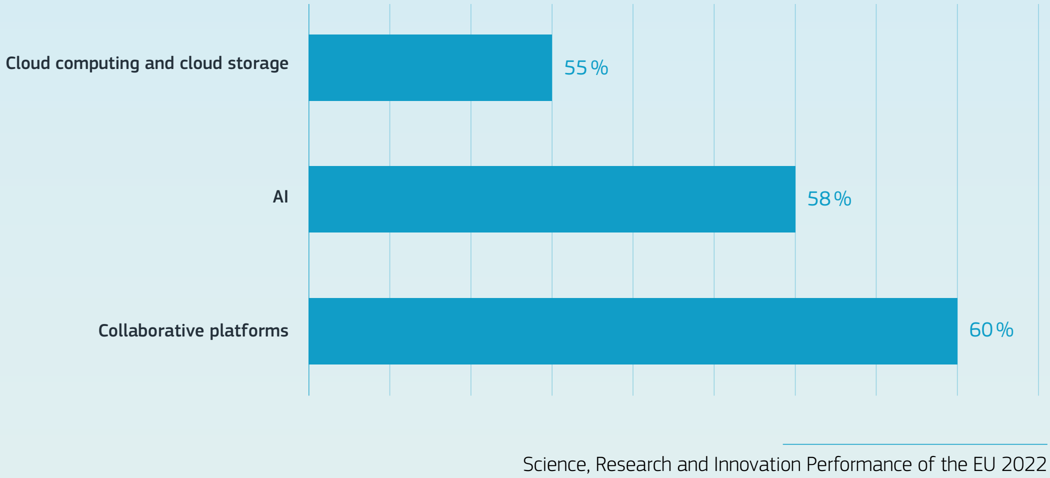
Figure 5.3-17: Technology uptake and firms' environmental footprint



Source: Ipsos and iCite, 2021
Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-3-17.xlsx

6 Commission Communication 'Annual Sustainable Growth Survey 2022' (COM(2021) 740 final)

Figure 5.3-18: Green motivation behind the ICT uptake of EU firms, by technology type



Source: Ipsos and iCite, 2021
Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-3-18.xlsx

ICTs particularly helped in facilitating teleworking. When looking at the actual contribution of ICT to environmental actions, 83% of firms reported the facilitation of teleworking as the main environmental action undertaken through the adoption of ICTs. The reduction of business travel follows, with 78%. Given that the survey was carried out in the aftermath of the COVID-19 outbreak, the results are significantly driven by the pandemic context. Nevertheless, they confirm that the adoption of ICT technologies was crucial to allowing business continuity under the imposed restrictions (DESI, 2021b). Of the respondents, 73% also declared that digital technologies helped to reduce the use of materials, equipment or consumables, as well as to produce less waste (72%) or to use less energy (70%) (Ipsos and iCite, 2021).

There exists a positive relationship between firms' digital intensity and their green performance. On average, 81% of EU firms agreed that digital technologies indirectly impact their environmental footprint, while 60% agreed that their environmental goals influence their choice to adopt ICT. Nevertheless, replies varied according to firms' levels of digitalisation. While the relationship between digital technologies and firms' environmental footprint is confirmed by 87% of highly digitalised firms, this figure drops to 68% for firms with lower levels of digitalisation. Similarly, 65% of highly digitalised enterprises reported that their environmental objectives influenced their choice of digital technologies, against 52% of less digitalised companies (Ipsos and iCite, 2021).

The ability of EU businesses to continue to integrate digital technologies will play a key role in boosting their productivity performance. To deliver on the digital transition, it is essential to increase investments in digital technologies as well as in R&I activities in the ICT sector. Such an effort is required not only to catch up with other major economies but also to avoid a further exacerbation of the digital divide within the EU.

The Recovery and Resilience Plans adopted by EU Member States aim to contribute EUR 117 billion to the digital transformation, trying to reduce the digital investment gap with other major economies. EUR 17 billion is allocated to the development of digital innovation, including advanced digital technologies such as AI and high-performance computing. Important efforts are also put into the digitalisation of the public sector (with EUR 43 billion allocated to the digital transformation of public services) and the business sector (EUR 24 billion)[7].

Horizon Europe plays a key role in enabling the deployment, uptake and rollout of digital R&I activities. Compared to Horizon 2020, the new R&I framework programme is characterised by a significant increase in the budget for digital R&I activities. Additionally, the new Missions embedded in Horizon Europe will allow delivery on common European objectives and can act as an accelerator for the digital transition.

7 Commission Communication 'Annual Sustainable Growth Survey 2022' (COM(2021) 740 final)

Box 5.3-2. The role of the RRF and Horizon Europe in the digital transition

Recovery and Resilience Facility

The Recovery and Resilience Facility (RRF) represents the largest component of Next Generation EU (NGEU), the new set of EU instruments designed to tackle the impacts of the COVID-19 pandemic and to support the recovery of the EU economy. **Digitalisation is a main priority of the RFF**. EU Member States benefitting from the RRF are required to allocate and spend at least 20% of the resources available on digitalisation and related impacts.

The reforms and investments proposed by Member States in their national plans have exceeded the intended target, with total digital expenditure of about 26%. The planned allocation to digital transformation varies significantly across Member States (Figure 5.3-19). Italy and Spain, the EU Member States receiving the largest amount of RFF funds in absolute terms, are allocating 25% and 30%, respectively. Croatia, which received the largest share of RFF funds as a percentage of GDP, reports an allocation of about 20%. Another Member State receiving a considerable share of RFF resources in GDP terms is Greece, which plans to allocate around 23% of its RFF resources to digitalisation overall. Similarly, the reforms and investments proposed by the Member States have also allowed them to exceed the target for climate change (37%). As reported in Figure 5.3-19, the expenditures allocated to the green transition at EU level amount to 40% of the RRF.

Horizon Europe

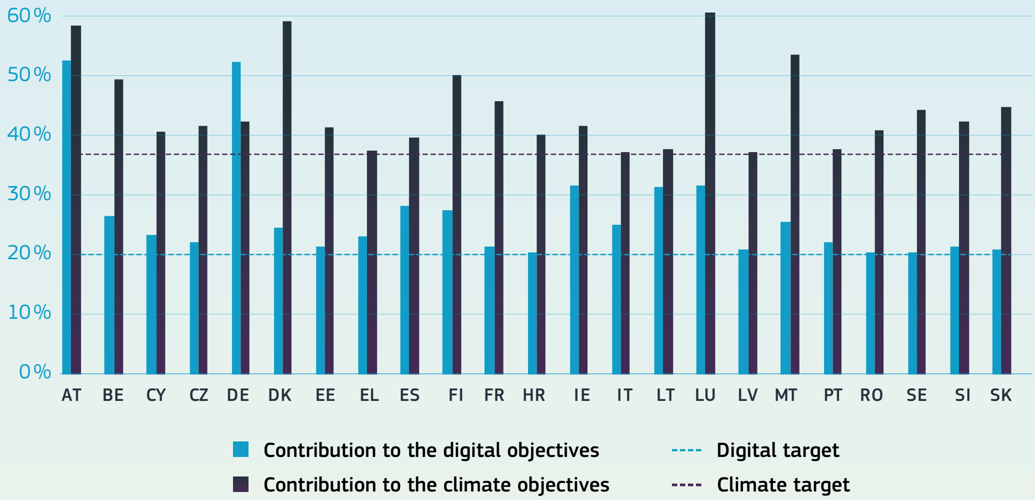
It is expected **that around 35% of Horizon Europe funding will support projects on digitalisation**[8].

The new R&I framework programme Horizon Europe includes a dedicated sub-programme focusing on 'Digital, Industry and Space' (Cluster 4 – Pillar II). The overarching objective of the **EUR 15.3 billion budget for Cluster 4** is to foster European competitiveness and technological leadership by building an efficient, digital, low-carbon and circular economy[9].

Cluster 4 is expected to support R&I activities in key enabling technologies, e.g. artificial intelligence and robotics, high-performance computing, big data, and 6G technology, to enable a faster and more profound digital and industrial transformation across Europe. Similarly, support for the application of digital technologies is also embedded in the other Horizon Europe clusters, as well as in the EIC. In this regard, the new framework programme aims to foster the adoption of digital technologies in all key strategic areas, including health, transport and energy.

8 https://digital-strategy.ec.europa.eu/en/activities/funding-digital
9 https://op.europa.eu/en/publication-detail/-/publication/1f107d76-acbe-11eb-9767-01aa75ed71a1

Figure 5.3-19: Share of RRP estimated expenditure towards climate and digital objectives



Science, Research and Innovation Performance of the EU 2022

Source: Recovery and Resilience Scoreboard https://ec.europa.eu/economy_finance/recovery-and-resilience-scoreboard/index.html?lang=en

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-3-19.xlsx

4. AI and other advanced digital technologies

Platforms and advanced robotics are the most widely adopted digital technologies in the EU. The types of advanced digital technologies adopted by EU firms after the onset of the pandemic remained the same as in the pre-COVID-19 period. Furthermore, the rate at which advanced digital technologies were adopted did not significantly change as a result of COVID-19. Exceptions were IoT technologies, whose implementation decreased in the aftermath of the pandemic, and drones, which experienced an increase in 2021 (EIB, 2022).

AI[10] technology is one of the most path-breaking technologies currently available, able to produce significant economic and social impacts. Given its general-purpose nature, AI has the ability to impact transversally across different sectors. AI is therefore also expected to play an essential role in the twin transition (EIB, 2021), and in achieving the Sustainable Development Goals (SDGs). Furthermore, the European Commission places the acceleration of the adoption of AI technologies at the heart of its strategy to establish EU global technological leadership[11]. The 2021 Coordinated Plan on Artificial Intelligence lays out the actions to be undertaken by EU Member States to accelerate AI investments and reduce fragmentation within the EU Single Market[12].

Accelerating investment in AI technologies is essential to facilitate the uptake of new digital solutions. The EU still significantly underperforms in this regard compared to other major economies. AI investment in EU shows a positive trend over 2015-2020 (Figure 5.3-21).

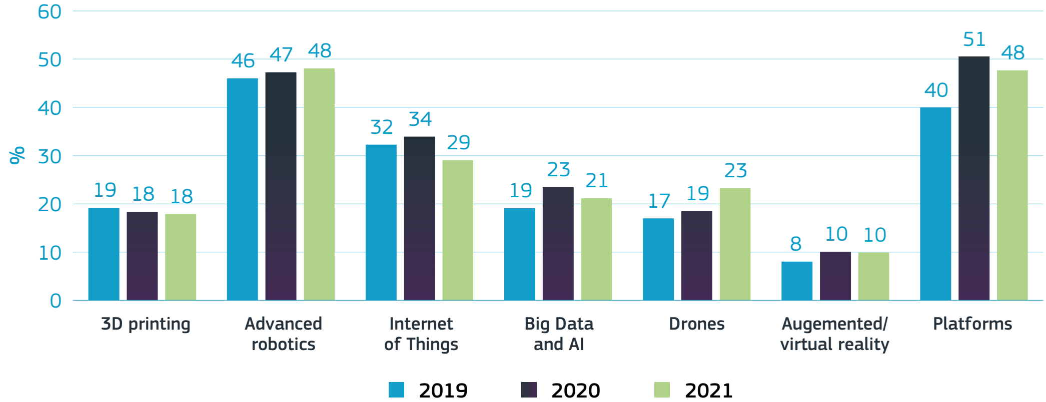
Nevertheless, the increase is not sufficient to close the gap with the USA and China. The USA is clearly leading in terms of private investment in AI, amounting to USD 23.6 billion in 2020. AI private investment in China was less than half of US private investment levels in 2020, presumably due to the fact that Chinese AI investment largely comes from the public sector (Zhang et al., 2021).

10 The European Commission High-Level Expert Group on Artificial Intelligence defines AI as ‘systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals.’ ‘A definition of AI: main capabilities and scientific disciplines’, High-Level Expert Group on Artificial Intelligence

11 Commission communication ‘Coordinated Plan on Artificial Intelligence’ (COM(2018)795 final)

12 Commission communication ‘Fostering a European approach to Artificial Intelligence’ (COM(2021) 205 final).

Figure 5.3-20: Share of EU firms adopting digital technologies, per technology type and year



Science, Research and Innovation Performance of the EU 2022

Source: EIBIS (2019, 2020, 2021), firms in EU.
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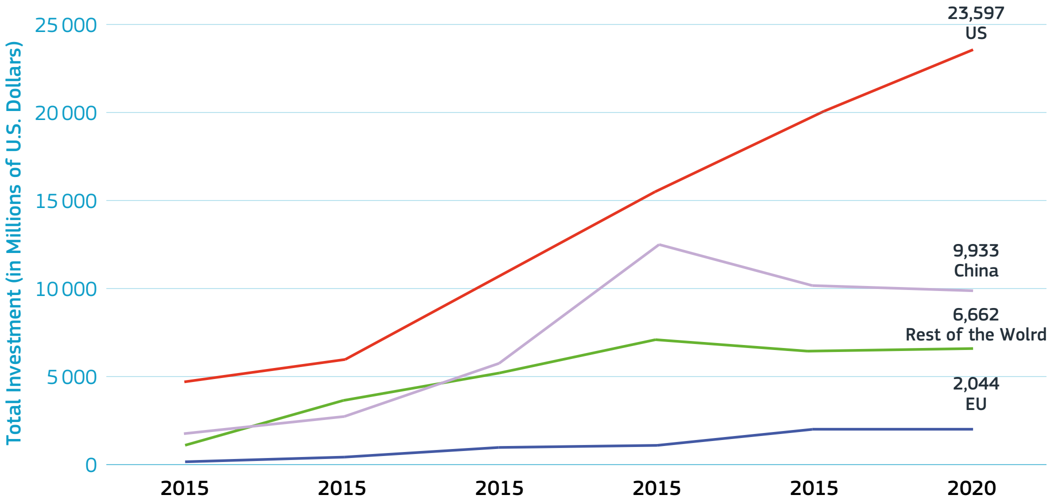
Figure 5.3-21: Private investment in AI by world region, 2015-2020



Science, Research and Innovation Performance of the EU 2022

Source: Zhang et al. (2021), based on CAPIQ, Crunchbase and NetBase Quid (2020)
Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-3-21.xlsx

The opportunities presented by AI technologies can be further enhanced by combining AI applications with other emerging technologies, such as blockchain[13]. The combined application of these advanced technologies allows for a better integration of supply chain systems and new business models leveraging shorter distance and time to market. The possibility for the EU to take up a strong position in the new digital race will strongly hinge on its ability to adapt to new market conditions through a deep integration of these emerging technologies across businesses and sectors (Veugelers et al., 2019).

The EU still lags behind other major economies in terms of number of enterprises with blockchain technologies. When looking at the number of SMEs using blockchain technologies, the EU ranks third, with 242 enterprises, after the USA and China (with 542 and 406 SMEs, respectively). The UK, Canada and Japan follow with 104, 39 and 15 blockchain SMEs, respectively (EIB, 2021). The picture changes when accounting for the size of the workforce in each geographical area. The USA keeps its leading position with 3.3 blockchain SMEs per 1 million workers, while EU takes the fourth position with a density of 1.1, after UK (3.1) and Canada (1.9) (Figure 5.3-22).

The EU is also not among the best performers in the field of high-performance computing (HPC)[14]. The largest number of applicants of quantum computing are headquartered in the United States, followed by Japan, Canada, and only then Europe (Travagnin, 2019). The demand for HPC will significantly increase in the coming years (DESI, 2020a).

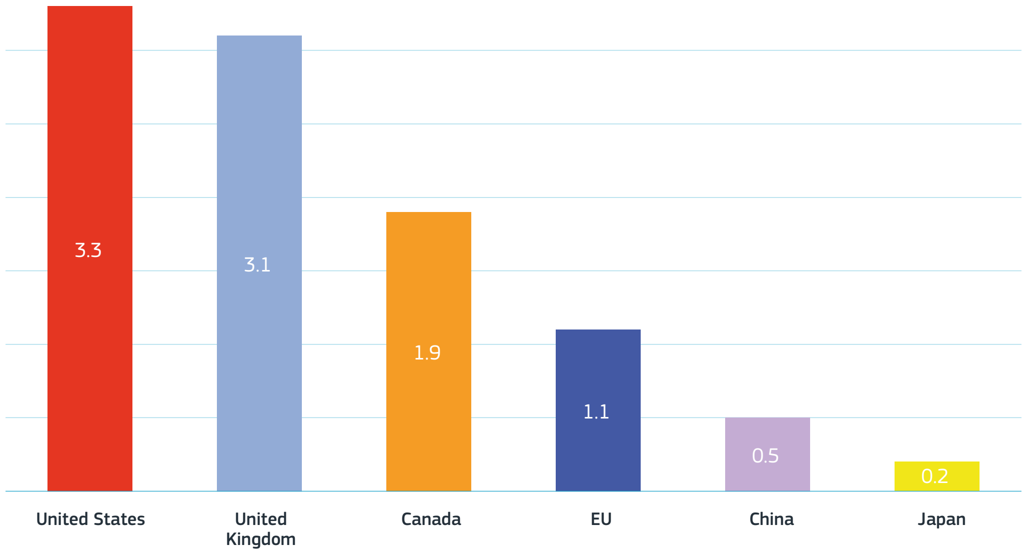
HPC will help with understanding and responding to several socioeconomic challenges, ranging from digital models to tackle climate change to data processing in the health field. Revenues from the global HPC market are expected to grow from around USD 27 billion in 2018 to almost USD 40 billion in 2022 (DESI, 2020b).

Europe lags behind in terms of supercomputing infrastructure. Only one of the world's top 10 supercomputers was in the EU as of September 2019 (DESI, 2020b). In terms of the world top 500 supercomputers, the EU ranked third in the 2019 global ranking, with a share of 15% (Figure 5.3-23). China dominates the international scene, with 228 of the top 500 systems installed (46%), followed by the USA with 117 installations (23%) (DESI, 2020b).

13 Blockchain is defined as 'a technology that allows people and organisations to reach agreement on and permanently record transactions and information in a transparent way without a central authority', 'Blockchain Strategy', Shaping Europe's digital future, European Commission.

14 HPC, also known as supercomputing, is used to solve highly complex computational or data-intensive problems (DESI, 2020b).

Figure 5.3-22: Number of blockchain SMEs in major economies per million workers, April 2020



Science, Research and Innovation Performance of the EU 2022

Source: EIB (2021), based on Crunchbase data and World Bank data

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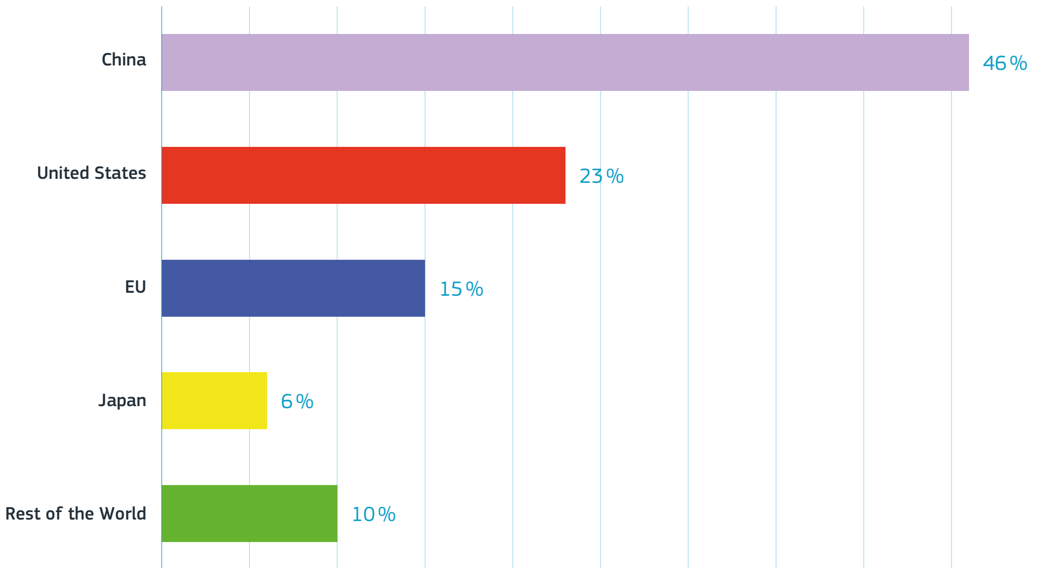
Figure 5.3-23: World share of the Top 500 supercomputers per world region, 2019



Science, Research and Innovation Performance of the EU 2022

Source: DESI (2020), based on Top500.org list.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-3-23.xlsx

It is important that the EU increases its efforts in HPC technologies. Quantum computing markets are expected to considerably grow in the next ten years (Rasanen et al., 2021). As such, the EU should not miss the opportunities coming from this strategic field and should put increasing efforts into the commercialisation of HPC-related technologies. **It is important to strengthen academia-business partnerships, improving the EU's ability to translate academic excellence into viable market solutions**. In doing so, the EU must leverage its vibrant start-up ecosystem, supporting high-growth enterprises that are best placed to become innovation leaders in advanced technology fields. In this regard, **unicorn companies have the potential to play a key role**, as they present sufficient size and innovation capabilities to compete successfully on the global market (Rasanen et al., 2021). As such, unicorn companies **can act as a conduit to foster a stronger EU-based quantum ecosystem**, reducing the gap with Asia and the USA (Rasanen et al., 2021).

See more in chapter 11 – Artificial intelligence for social good: the way forward

The chapter investigates the interlinkages between the data and AI revolution and sustainable development. The author provides a comprehensive overview of both opportunities and challenges related to AI within the context of the 17 SDGs, discussing how data-driven AI methods are able to help addressing the SDGs, and the limitations they pose that might hinder the realisation of such potential.

5. Digitalisation vs digital innovation

EU firms adopting more advanced digital technologies typically invest more in R&D and innovation (EIB, 2022). In contrast, less-digital companies are less likely to allocate resources to the development of new products, processes or services.

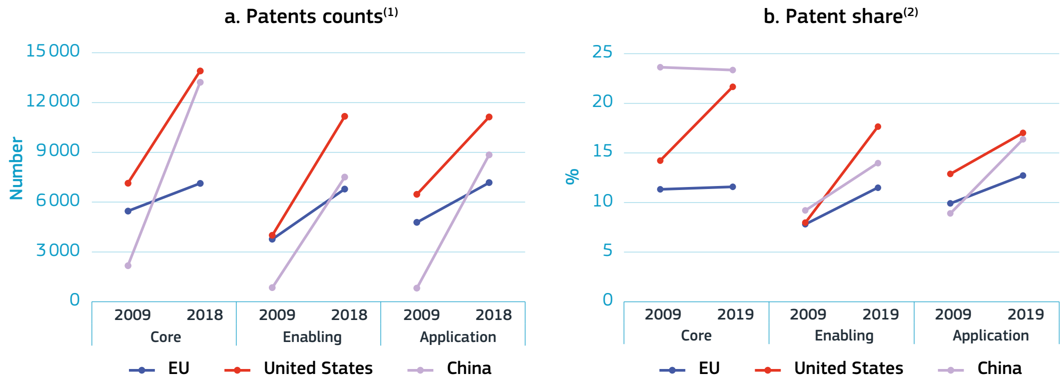
The EU lags behind the USA and China in terms of patent applications in digital technologies. In what follows, digital patent applications are classified according to the methodology proposed by EPO (2017) and based on Industry 4.0 domains. Digital patents are grouped under three domains: core technologies, enabling technologies and application domains[15]. According to this classification, the EU's share in digital patents has remained stable since 2012, while the US share has increased over time, thereby widening the gap between the two economies (EIB, 2022). Although the EU is still ahead of China, Chinese investments in new digital technologies have significantly accelerated over the past ten years (EIB, 2022).

The US and China outperform the EU in all three domains of digital innovations. While the USA consistently dominated the international scene between 2009 and 2018, China improved its performance over the same period, overtaking the EU in 2018 (Figure 5.3-24a). In terms of share of total domestic patent production, China performs particularly well in the domains of enabling technologies and application domains, whereas US patent applications are mainly concentrated in core and enabling technologies (Figure 5.3-24b). The gap between the EU and the USA and China is particularly large in the field of core technologies.

Nevertheless, the EU remains a leading innovator in the automotive sector and in fields related to climate change. The EU ranks first in terms of digital patents in vehicle applications, a category including technologies related to autonomous driving and vehicle fleet navigation devices (EIB, 2022). Nevertheless, both the USA and China are improving their performance in these fields, calling for further efforts at EU level to maintain this leading position. Furthermore, the EU significantly outperforms the USA and China in the development of technologies to tackle the challenges of the green transition, although there has been some stagnation in recent years (EIB, 2022). Furthermore, the EU reports more than half the number of Chinese patents in digital automotive technologies, and also significantly outperforms the USA in this field (EIB, 2022). Given the strategic role played by the automotive sector in the race towards carbon neutrality, it is essential for the EU to continue to strengthen its global position in this area, maintaining its technological leadership (for more information on EU technological sovereignty, see Chapter 2.1 – Zoom out: technology and global leadership).

15 Core technologies represent the basic building blocks upon which the technologies of the fourth industrial revolution are built. Enabling technologies are further built upon and complement the core technologies. The category 'application domains' captures those technologies that are ready to be put on the market, and represents the final applications of digital technologies (EIB, 2022).

Figure 5.3-24: Patent counts and share of patents in the United States, China and the EU, by digital domain



Science, Research and Innovation Performance of the EU 2022

Source: PATSTAT (PCT) data prepared in collaboration with ECOOM

Note: [1]The figure shows the count of digital patents for the three different digital domains. [2]The figure shows the shares of digital patents for the three different digital domains over the respective total domestic patent portfolio.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-3-24.xlsx

The EU performs less well in the field of healthcare technologies. Before 2019, the global increase in patent applications related to healthcare technologies was mostly driven by US performance (EIB, 2022). With the onset of the COVID-19 crisis, healthcare patent applications increased significantly worldwide. Although this increase in healthcare innovations did not immediately focus on digital technologies, the latter proved to be critical to relieving healthcare systems worldwide from the pressure of the pandemic (EIB, 2022). For example, digital technologies enabled the sharing of healthcare research and data, essential to the development of the COVID-19 vaccines. Furthermore, there is significant potential for the development of more sophisticated healthcare applications making use of advanced digital technologies, such as AI and robotics (EIB, 2022).

6. Conclusions: addressing the challenges of the digital age

The COVID-19 crisis has accelerated structural changes in firms. With the outbreak of the pandemic, digital technologies have become imperative to ensuring economic resilience. EU firms have become more digitalised, showing good capabilities for adapting to the changed economic circumstances. Investments in digital technologies undertaken after the spread of COVID-19 mostly focused on basic digital applications. As a response to the pandemic, EU firms mostly increased their uptake of less sophisticated digital technologies necessary to meet their basic needs to ensure business continuity. The adoption of advanced digital technologies did not increase at the same pace.

Nevertheless, the already existing digital divide has continued to increase. COVID-19 has exacerbated the differences between and within EU countries. Top digital innovators in the EU have continued to improve their performance, further distancing the digital laggards. Similarly, already digitalised firms further increased their uptake of digital technologies, making it more difficult for less digitalised companies to catch up (EIB, 2022). **The widening asymmetries between and within EU regions and countries represent an important challenge**. The uneven adoption of digital technologies across EU companies has put European convergence at jeopardy (EIB, 2022). Although increasing the digital uptake was one of the main strategies adopted by all European firms as a reaction to COVID-19, companies in lower-income countries showed a weaker response (EIB, 2022). In this regard, the support issued via the RFF will help to strengthen EU economic convergence, supporting the structural transformation of the EU economy, especially in lagging Member States.

R&I policy is critical to delivering the digital transition. The successful digitalisation of the EU economy requires a better transformation of R&I results into market viable solutions, as well as a more entrepreneurial-minded R&I policy. To tackle the challenges of the digital age, the EU needs to strengthen the interlinkages between public and private sectors, building partnerships able to support individuals and organisations willing to bring about the necessary technological, economical and societal transformations.

The digital transition also has the potential to support the EU decarbonisation process. The key EU policy priorities linked to the digital and green transition, the European Green Deal and 'a Europe fit for the digital age' are closely intertwined and have the potential to mutually reinvigorate each other. The decarbonisation of the EU economy needs to leverage on the availability of digital technologies to speed up the transition. At the same time, it is essential that the digitalisation process is undertaken in a sustainable way. **Digital technologies have to be green**, and initiatives to speed-up the digital progress need to account for the environmental footprint of digital technologies **to ensure full synergies and complementarity between EU priorities**.

Furthermore, digital technologies have become increasingly integrated into the way the whole of society interacts and exchanges information. **To build a strong, human-centred and inclusive digital Europe, it is necessary to put European citizens at the centre of the digitalisation process**. In its Communication *Establishing a European Declaration on Digital rights and principles for the Digital Decade*, the European Commission reinforces its commitment to build an empowering digital society in which no one is left behind. The Communication proposes a set of principles to guide European action towards achieving its digital targets. The EU digital transformation must be shaped according to European values and law, while ensuring an effective regulatory framework able to safeguard European citizens' rights and freedoms (see Chapter 7.2 – Other framework conditions) (European Commission, 2022).

Horizon Europe encompasses all these elements. Overall, the EU is still lagging behind its main international competitors in terms of share of digital applications, although remaining strong in some strategic industries (see Chapter 2.1 – Zoom out: technology and global leadership). The new R&I framework programme is characterised by a substantial increase in spending resources devoted to digital R&I activities to ensure that the EU remains at the forefront of global R&I in digital technologies. **Horizon Europe has a key role to play in enabling the deployment, uptake and roll-out of R&I activities in digital**, while supporting a human-centred and ethical development of digital technologies **with the potential to enable and facilitate the transition towards a climate-neutral and circular economy.**

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CHAPTER 5.4

INVESTMENT IN HUMAN CAPITAL

KEY FIGURES

11.4 %
growth in the share of ICT tertiary graduates in the EU 2017-2019

41 %
of 25-34-year-olds in the EU have successfully completed tertiary studies

57 %
of tertiary graduates in the EU are women

1.2 %
of GDP in the EU is spent on tertiary education

KEY QUESTIONS WE ARE ADDRESSING

- How does human capital improve innovation and productivity?
- How are European countries performing in term of human capital?
- How does the EU perform compared to its main international competitors?
- How has COVID-19 impacted human-capital formation?

KEY MESSAGES

What did we learn?

- Human capital is an important contributor toward the propensity of firms to innovate and the economic performance of countries.
- Most tertiary graduates are women, yet they are underrepresented in ICT and engineering studies.
- Adult participation in learning, R&D personnel and researchers, the share of tertiary graduates among youth, and ICT graduates are rising across the EU, while NEETs are decreasing.
- In the EU, the total public and private expenditure on education as a percentage of GDP is higher than in Japan, yet still lower than in the United States, South Korea and the United Kingdom.
- The COVID-19 pandemic has negatively impacted the formation of human capital, particularly among students from disadvantaged socioeconomic backgrounds.

What does it mean for policy?

- Human capital policies are crucial to increase European innovation capacity.
- Educational policies targeted at students from disadvantaged socioeconomic backgrounds will be fundamental in the post-pandemic era.
- Involving more private contributions in tertiary education, to ensure a smart mix of public and private financing that does not compromise equality of opportunity, could provide the additional resources needed for the EU to compete with its international competitors.
- Further policies that aim to reduce the gender divide between scientific and humanities fields may be considered.

1. Human capital as a driver of innovation

Human capital is a crucial driver of innovation. Indeed, labour productivity and the probability of an industry to innovate are shaped by the investment of its workforce in different types of training (formal and informal), its cognitive skills (literacy and numeracy), its non-cognitive skills (soft skills), and its ICT and STEM skills (Cammeraat et al., 2021). Human capital explains much of the productivity differences and variation in growth performance across European countries (Gennaioli et al., 2013; Madsen, 2010; Baten et al., 2008).

Highly talented individuals can push forward the frontiers of knowledge if they have access to the necessary formal education, facilities and financing. A more educated and trained workforce can generate technological innovation on the job, finding solutions to old and new problems (Acemoglu and Autor, 2012). Human capital increases the 'absorptive capacity' of firms and society as a whole. Absorptive capacity is the ability to identify and make effective use of knowledge, ideas and technologies that are generated elsewhere (Cohen and Levinthal, 1989). Companies investing more in the human capital of their employees build up a greater capacity to spot innovation opportunities and learn from others, leading to higher productivity growth.

Formal education improves innovation capacity and economic performance. The tertiary education of employees is an important contributor toward firms' propensity to innovate and countries' economic performances. The level of formal education positively impacts innovation and prosperity (Griffith et al., 2004; Vandenbussche et al., 2006). However, it is not only the length of studies, but what is learnt at school or university matters: i.e. the skills learned and the quality of education (Hanushek and Woessmann, 2015).

Cognitive, non-cognitive and task-based skills (the skills that workers need to perform a job task) improve innovation capacity and economic performance (see Chapter 4.3 – Skills in the digital era). Cognitive skills (such as literacy, numeracy and problem-solving) and non-cognitive skills (such as soft skills) of workers are required for any industry to have success in the global economy (Grundke et al., 2017; Diebolt and Hippe, 2019). Cognitive and non-cognitive skills enhance technology diffusion (Messinis and Ahmed, 2013) while ICT and STEM skills enhance innovation potential (Hall, Lotti and Mairesse, 2013; Peri et al., 2015). Social skills of employees and managers and the communication culture within an organisation play an important role in determining the value of human-capital endowments. Companies with a strong human-capital base but with an ineffective communication culture are likely to waste innovation opportunities due to reduced absorptive capacity. This happens because information flows more slowly or redundantly, increasing the friction cost of obtaining the needed information.

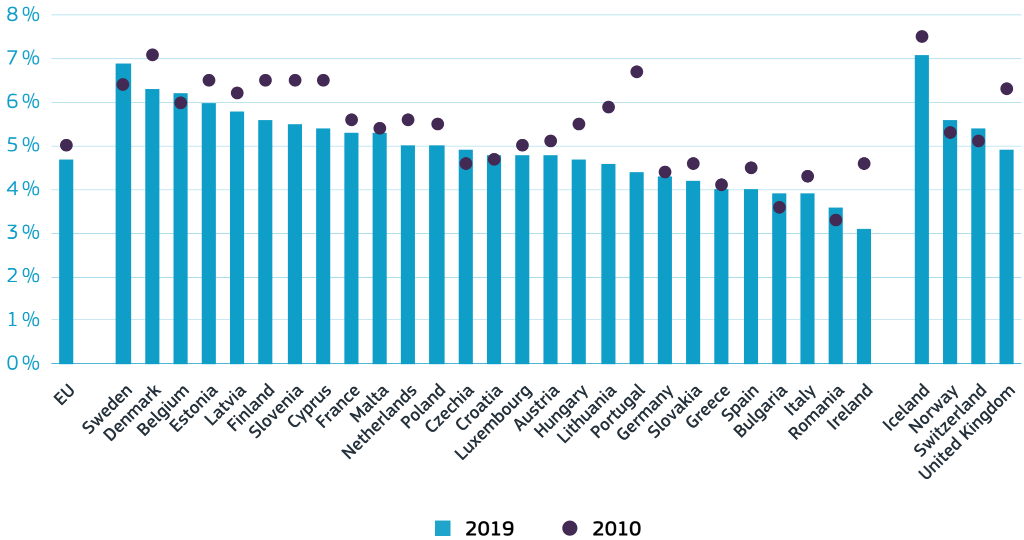
Training, re-skilling and working with others are effective ways of improving companies' human capital and propensity to innovate. Different studies find positive learning spillovers from interaction among workers (Destré, Lévy-Garboua and Sollogoub, 2008) and from training (Dearden, Reed and Van Reenen, 2006; Konings and Vanormelingen, 2015) on productivity. Furthermore, strong links have been found between training and the likelihood to innovate (González, Miles-Touya and Pazó, 2016; Dostie, 2018).

2. Education and researchers across EU Member States

General government expenditure on education as a% of GDP slightly decreased 2010-2019. Sweden, Denmark and Belgium have the highest spending in the EU, while Ireland, Romania and Italy spend the least. On average, governments spend about 5% of GDP on education in the EU. Sweden, Belgium, Norway, Czechia, Bulgaria and Romania have increased their spending on education.

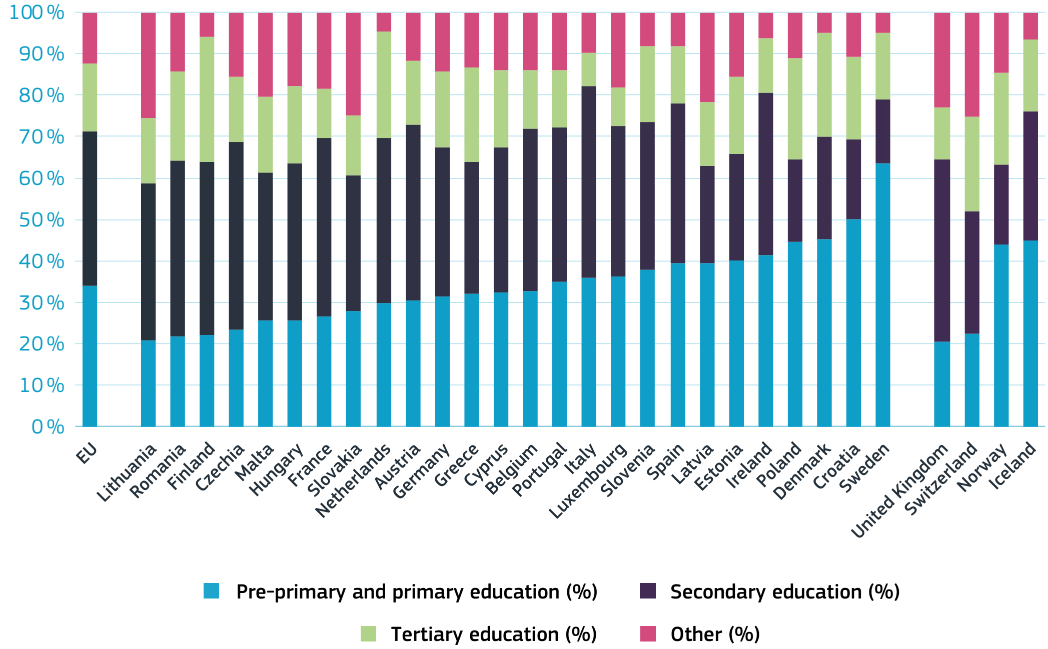
There is strong heterogeneity on how EU countries allocate their resources between the different levels of education (primary, secondary and tertiary). Sweden spends the highest share of its public expenditure on primary education (around 64%, see Figure 5.4-2). EU countries spend on average 34% of public expenditure on primary education, 37% on secondary education, 16% on tertiary education and 12% on other forms. The UK has the lowest public spending on primary education, with 21% of its education spending by the public sector going to primary education. On the other hand, the UK spends a considerably higher share on secondary education (44%), 7 percentage points more than the EU, 8 percentage points more than Germany and 29 percentage points more than Sweden.

Figure 5.4-1: **General government expenditure in education as % of GDP, 2010 and 2019**



Source: Eurostat (online data code: GOV_10A_EXP)
Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-1.xlsx

Figure 5.4-2: Share of public expenditure on education by level[(1)], 2019



Science, Research and Innovation Performance of the EU 2022

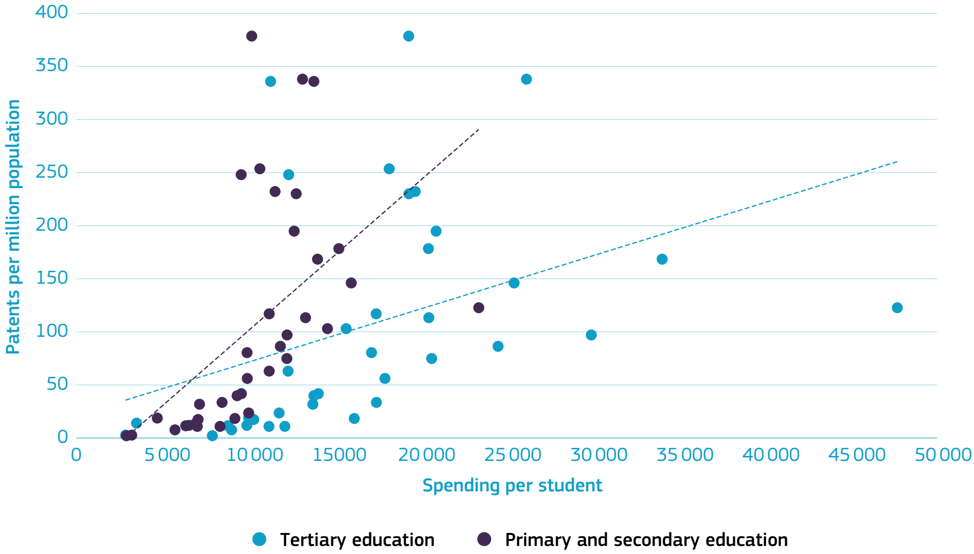
Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Eurostat (online data code: GOV_10A_EXP)

Note: [(1)]Education by level as percentage of total public expenditure in education, measured in Euro.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-2.xlsx

Expenditure on both lower and higher levels of education contribute to a country's innovation capacity and overall economic performance. The level of expenditure on education per student is positively associated with patent applications (see Figure 5.4-3) and with GDP per capita (see Figure 5.4-4). Primary and secondary education can be seen as an instrument to build up the human capital of the future, while tertiary education as an instrument to help current human capital to push the frontiers of knowledge further. For this reason, research on developing countries mostly focuses more on primary education, while studies on developed countries focus on tertiary education. Spending in education, as well as the quality of the education and the share of individuals completing formal education, are important contributors to a country's stock of human capital. High-quality primary and secondary education guarantees high-quality future human capital that is able to provide the best returns from tertiary education. In Europe, tertiary-education attainment has been found to be one of the main drivers of development and prosperity (Cuaresma, Doppelhofer and Feldkircher, 2014; Madsen, 2010).

Figure 5.4-3: Spending in education vs patenting activity[1]



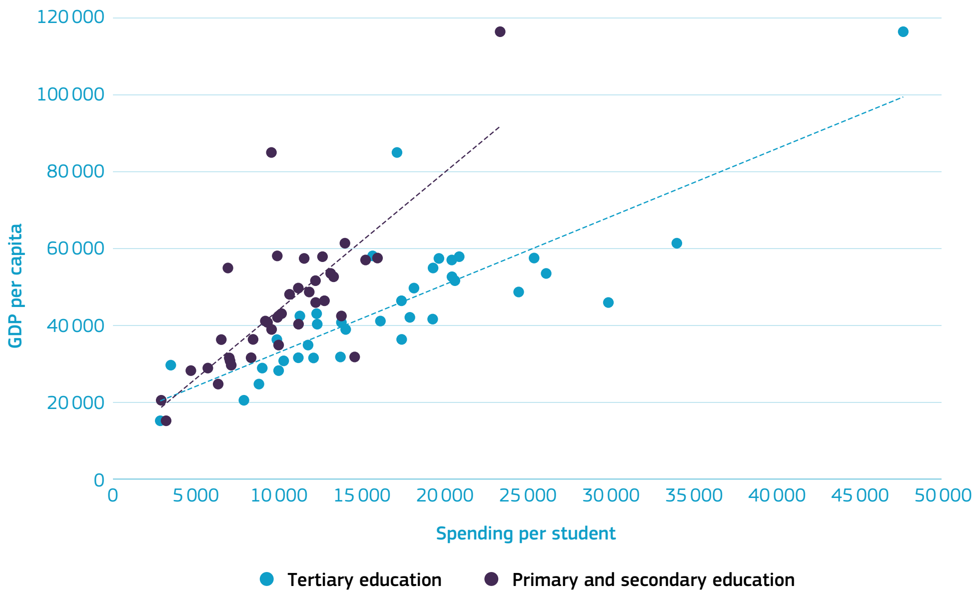
Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Education at Glance 2021, OECD Indicators and OECD (Patents by technology)

Note: [1]Plot of 37 OECD countries. Spending per students in USD PPPs. Patent are defined as patent applications filed under the PCT.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-3.xlsx

Figure 5.4-4: Spending in education vs GDP per capita[1]



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on 'Education at Glance' (2021), Indictors, OECD

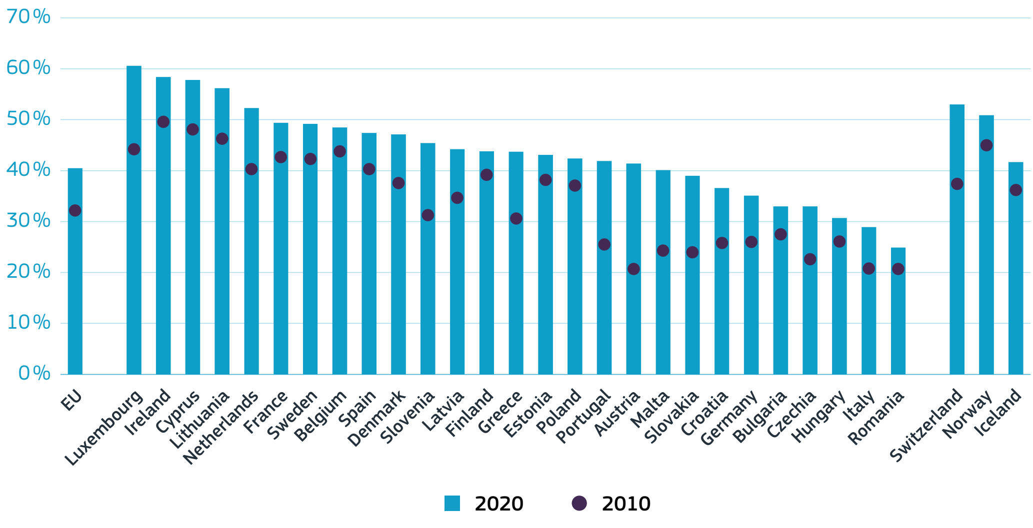
Note: [1]Plot of 37 OECD countries. Both spending per students and GDP per capita are expressed in USD PPPs.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-4.xlsx

Completion of tertiary studies increased in all EU countries from 2010 to 2020. Luxembourg has the highest share of population aged 25-35 that has completed tertiary education, with a remarkable 61% (see Figure 5.4-5). Ireland follows with 58% of the population. On average, 41% of the EU population aged 25-35 has a tertiary education degree, which is a stark increase from 32% in 2010. Romania has the lowest figure, with 25%, followed by Italy with 30%.

The influence of the digital transition is clearly observable in the tertiary graduate trend, with degrees in ICT showing the highest growth 2017-2019 (see Figure 5.4-6). The share of ICT graduates grew by 11.4% from 2017 to 2019. This is likely to be related to job-market demands. Indeed, ICT is the second most requested competence in the job market, with 25% of job postings mentioning ICT among the desired competences (see Chapter 3.3 – Skills in the digital era). However, overall, business, administration and law remains the most common degree field, with a share of 24%. Business, administration and law is also the most frequently requested competence in the job market (see Chapter 4.3 – Skills in the digital era). Engineering, manufacturing and construction is the third most common degree field, with a share of 15%. The share of tertiary graduates in arts and humanities and education degrees has been declining.

Figure 5.4-5: Share of population aged 25-34 who have successfully completed tertiary studies, 2010 and 2020



Source: Eurostat (online data code: SDG_04_20)
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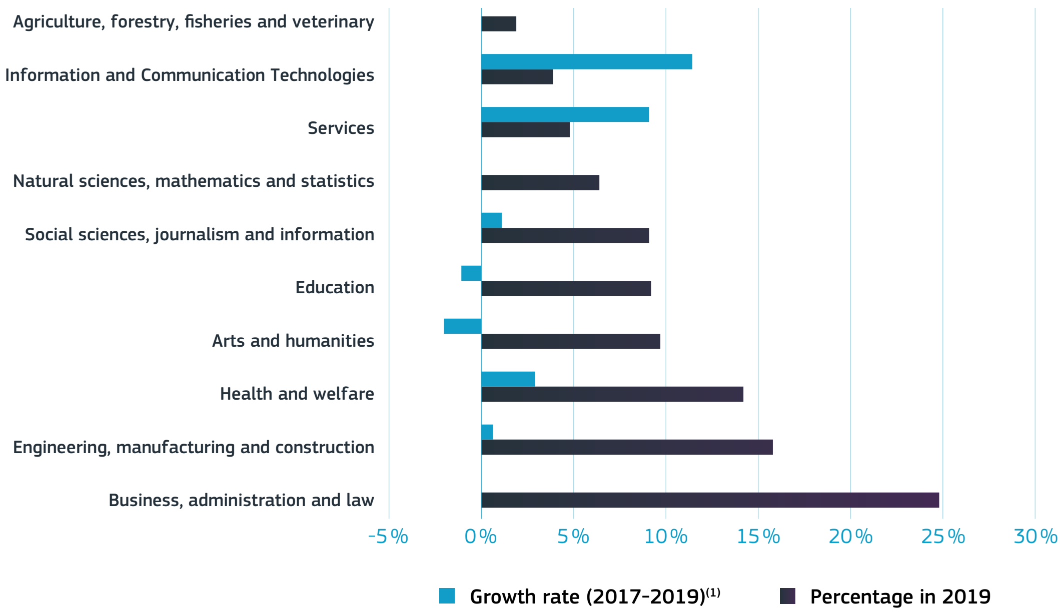
Figure 5.4-6: Share and growth of tertiary graduates by field of study in the EU



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Eurostat (online data code: EDUC_UOE_GRAD03)

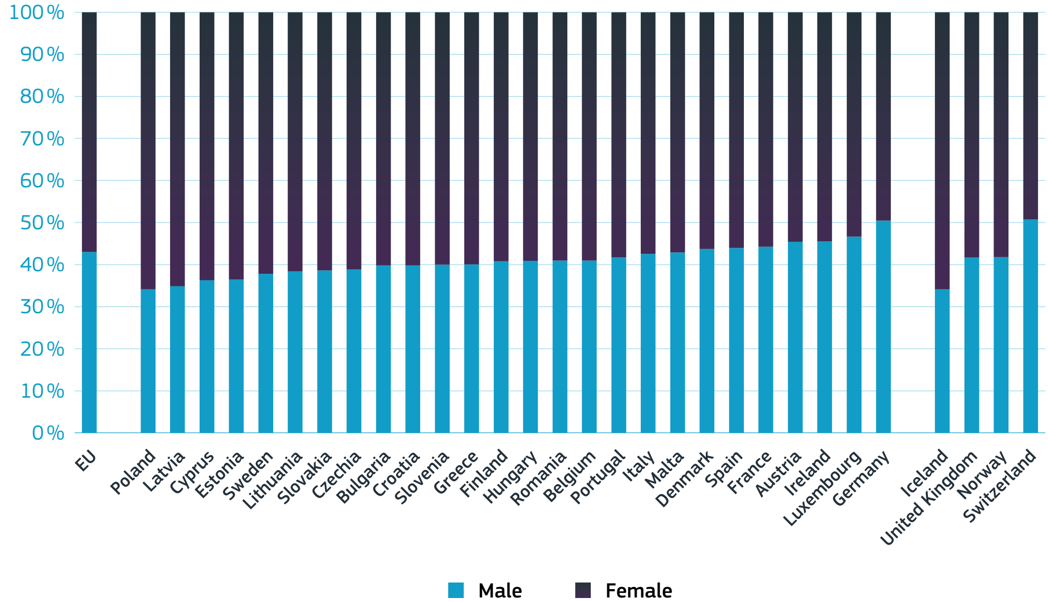
Note: (1)Growth rate from 2017 to 2019 of the percentage of graduates of a field out of the total graduates. As an example ICT graduates increased from 3.5% to 3.9%, implying a growth rate of 11.4% from 2017 to 2019.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-6.xlsx

In the EU, more than half of tertiary graduates are women. On average, 57% of EU tertiary graduates are women (see Figure 5.4-7). The EU country with the highest share of women graduates is Poland, with only 34% of male tertiary graduates. Interestingly, Germany has a 50% share split between men and women graduates.

There are still strong gender differences in the study fields chosen in the EU. Degrees in engineering, manufacturing and construction and in ICT are predominantly chosen by males, while female students are overrepresented in art and humanities, health and welfare, and education degrees (see Figure 5.4-8). Male graduates in ICT are around three times more numerous than females, and the same holds for graduates in engineering, manufacturing and construction. Female graduates in arts and humanities are double the male graduates, while women graduates in education are more than three times the male graduates in the field.

Figure 5.4-7: Share of tertiary graduates by sex, 2019

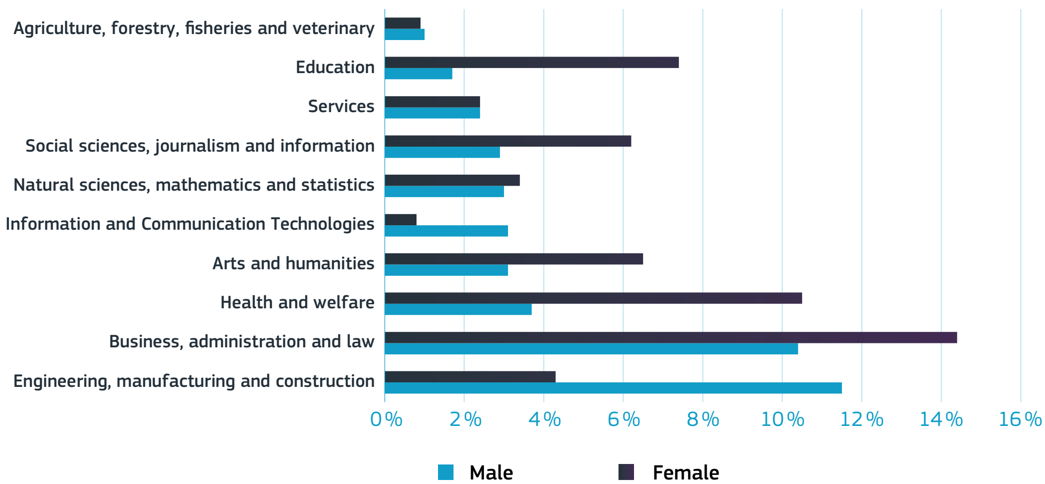


Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Eurostat (online data code: EDUC_UOE_GRAD01)

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-7.xlsx

Figure 5.4-8: Share of tertiary graduates by field of study and gender in the EU, 2019



Science, Research and Innovation Performance of the EU 2022

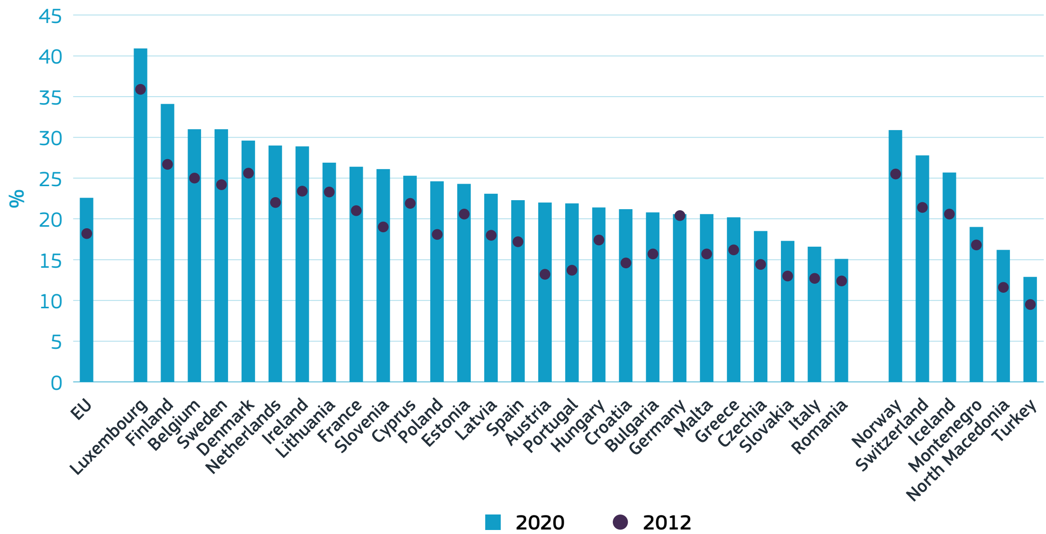
Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Eurostat (online data code: EDUC_UOE_GRAD03)

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-8.xlsx

A larger fraction of the labour force are finding employment in the science and technology sectors and has a tertiary education. On average, 23 % of EU workforce was employed in science and technology and had a tertiary degree in 2020. This share increased by around 5 percentage points from 2012 to 2020. Luxembourg tops the ranking, with around 41 % of its workforce employed in science and technology and with a tertiary education. Finland and Sweden follow just behind, with 34 % and 31 % respectively. At the bottom, we find Romania and Italy, with around 15 % and 17 % respectively.

The share of researchers in the workforce is increasing in the EU, although there is a strong variation across EU countries. The share of R&D personnel and researchers increased from 1.1 % to 1.4 % of the labour force in the EU from 2011 to 2020 (see Figure 5.4-10). In 2020, the countries with the highest share of researchers were Denmark, Belgium, Finland and Norway, while nations with the lowest share were Romania, Cyprus, Malta and Latvia. In the EU, most researchers and R&D personnel work for businesses (see Figure 5.4-11), followed by the higher education sector, the government and the private non-profit sector. The business sector accounts for more than double the numbers of researchers and R&D personnel than in the higher education sector, and more than four times the numbers in the government sector. Furthermore, in the last 10 years, the private sector has increased its number of researchers and R&D personnel the most, growing from about 1.3 million employees (in full-time equivalents) in 2013 to almost 1.8 million in 2020.

Figure 5.4-9: Share of workforce with tertiary education employed in science and technology[(1)], 2012 and 2020



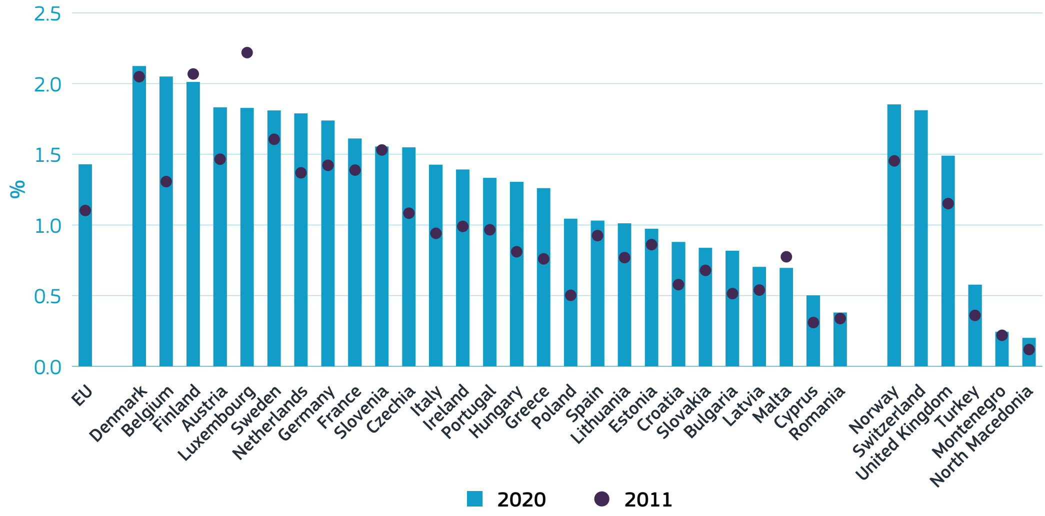
Source: Eurostat (online data code: HRST_ST_NCAT)

Note: [(1)]Percentage of the population aged 15 to 74 years in the work force with tertiary education and working in science and technology occupations.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-9.xlsx

CHAPTER 5.4

Figure 5.4-10: Share of R&D personnel and researchers in the labour force[1], 2011 and 2020



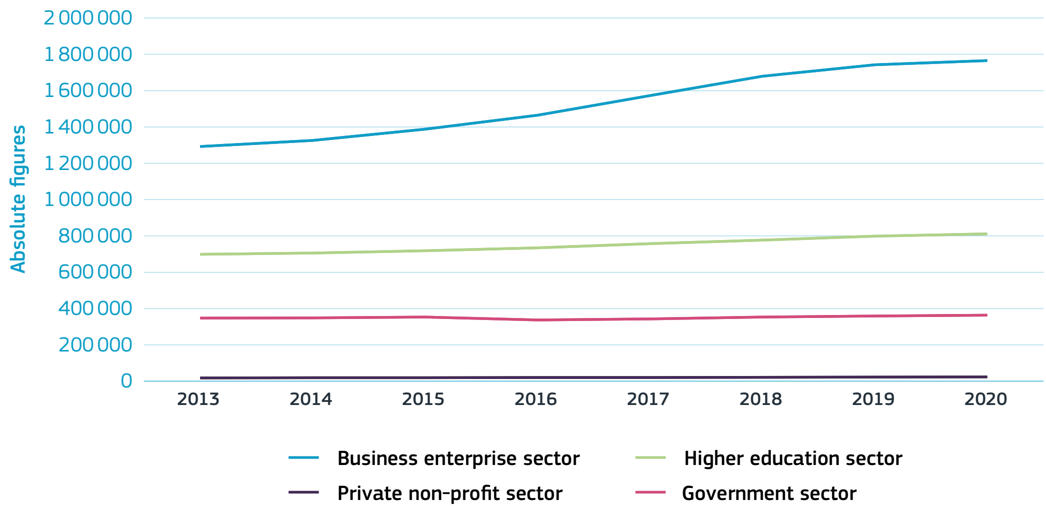
Science, Research and Innovation Performance of the EU 2022

Source: Eurostat (online data code: RD_P_PERSLF)

Note: [1]Share of R&D personnel and researchers (in full time equivalent) is measured respect to the labour force, across all sectors.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-10.xlsx

Figure 5.4-11: R&D personnel and researchers[1] in the EU by sector, 2013-2020



Science, Research and Innovation Performance of the EU 2022

Source: Eurostat (online data code: RD_P_PERSQUAL11)

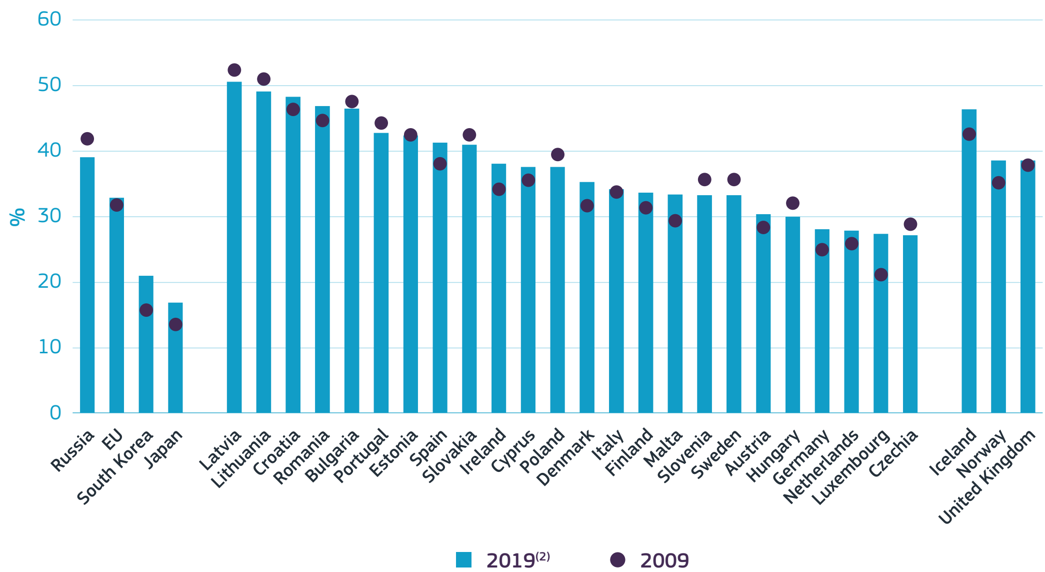
Note: [1]R&D personnel and researchers is expressed in units of full time equivalent.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-11.xlsx

The share of women researchers is slowly increasing in the EU, however wide heterogeneity exists among Member States. In the EU, 33% of researchers are women (see Figure 5.4-12). The Member State with the most women researchers is Latvia, with 51% of women researchers, while the country with the least is Czechia with 21%. The UK has 6 percentage points more female researchers than the EU. That said, such figures are likely to mask the sectorial research specialisation of the different countries. Figure 5.4-13 shows how a large majority of female researchers are in the health and care sector, while very few are in the engineering and technology sector.

The percentage of young individuals who are no longer in the education system and who are not working or enrolled in a training programme (NEETs) has been reducing in most EU countries. In 2010, the percentage of NEETs among young adults was around 15%, while in 2020 it diminished to 14% (see Figure 5.4-14). The country with the highest rate of NEETs is Italy, with a small increase from 2011 (22.5%) to 2020 (23.3%). On the other side of the distribution, the Netherlands (5.7%) and Sweden (7.2%) are the EU countries with the fewest NEETs. High percentages of NEETs not only signify wasted human capital but are also symptomatic of a generation of disillusioned youth, excluded from society, with long-term economic costs for society at large.

Figure 5.4-12: Share of women researchers(1), 2009 and 2019

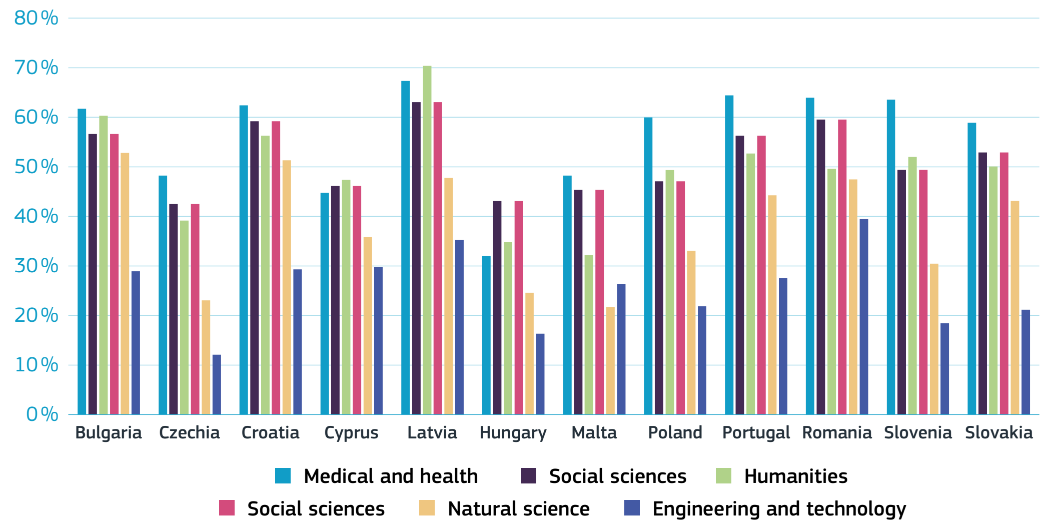


Source: Eurostat (online data code: TSC00005)

Note: (1)The share of women researchers among total researchers in head count in all institutional sectors. (2)UK, IS: year 2018

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-12.xlsx

Figure 5.4-13: Share of women researchers by field(1), 2019



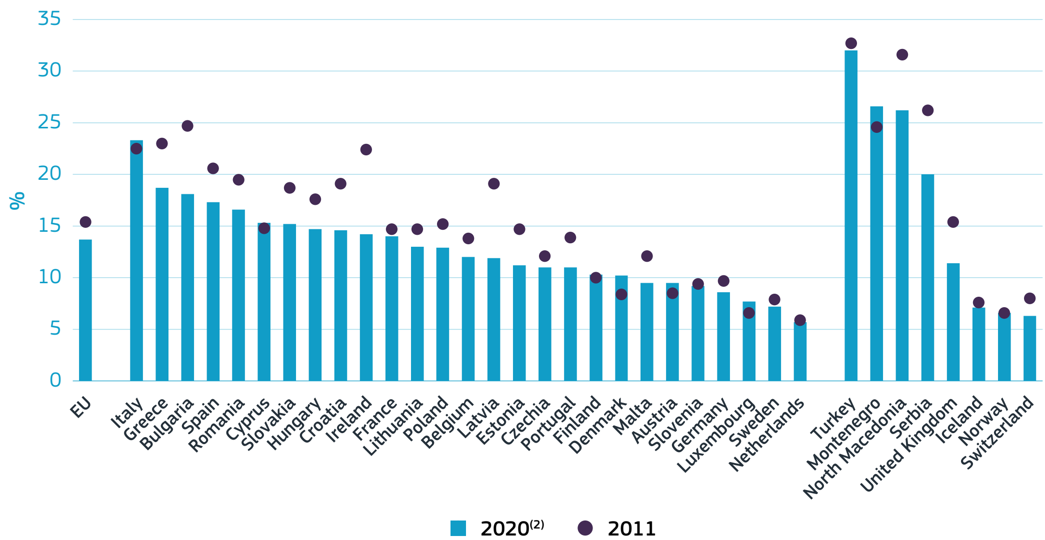
Science, Research and Innovation Performance of the EU 2022

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

Note: (1)Share of women researchers out of total researchers by field in Full-time equivalent. Data for the remaining EU countries is not available.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-13.xlsx

Figure 5.4-14: Share of young people(1) neither in employment nor in education (NEET), 2011 and 2020



Science, Research and Innovation Performance of the EU 2022

Source: Eurostat (online data code: EDAT_LFSE_20)

Note: (1)Young people aged 15-29 years in % of the total population in the same age group. (2)UK: year 2019

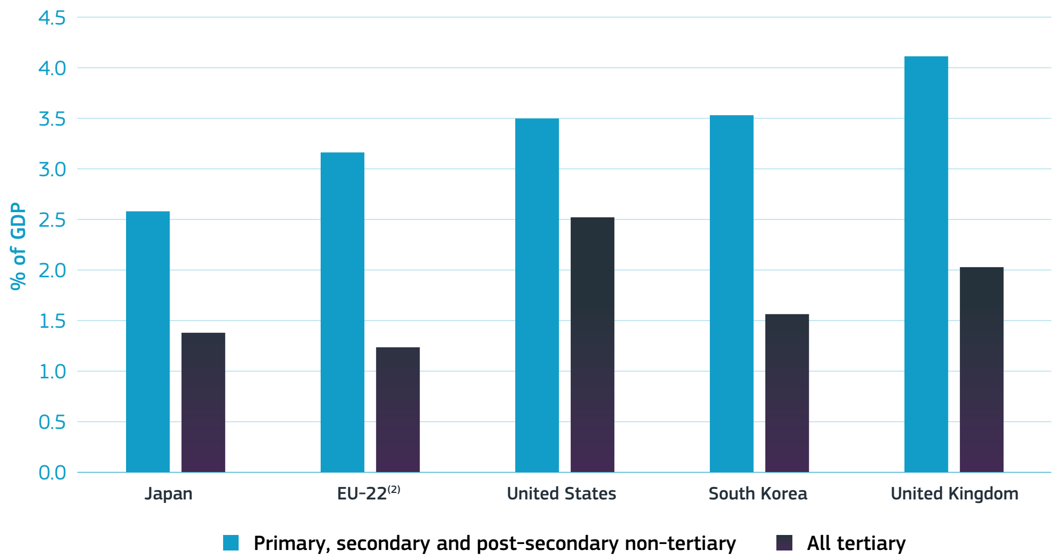
Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-14.xlsx

3. EU tertiary education figures compared to world top performers

Total public and private expenditure on education in the EU as a % of GDP is higher than in Japan, yet lower than in the United States, South Korea and the United Kingdom. The USA has the highest expenditure relative to GDP on tertiary education, followed by the UK (see Figure 5.4-15). The UK has the highest share of resources devoted to non-tertiary education, followed by South Korea. On average, EU countries spend 3.3% of GDP on non-tertiary education and 1.2% on tertiary education, less than half the level in the USA.

Private expenditure on education is relatively low in most EU countries, especially for tertiary education. Most expenditure on education in the EU is from the public sector, while other countries (particularly the USA and the UK) have a larger private contribution. The EU-22 has the highest public expenditure (% of GDP) on tertiary education. However, overall, the United States has the highest total expenditure (% of GDP) on tertiary education, followed by the United Kingdom (see Figure 5.4-16). In the USA, UK, Japan and South Korea, private contributions account for the majority of tertiary education spending. US public expenditure on tertiary education accounts for 0.9% of its GDP, while EU expenditure accounts for 1%. At the same time, US private expenditure on tertiary education accounts for 1.6% of its GDP, while in the EU this figure is only 0.2%.

Figure 5.4-15: Total (public and private) expenditure[1] on education, 2018



Science, Research and Innovation Performance of the EU 2022

Source: 'Education at a glance' (2021), Indicators, OECD.

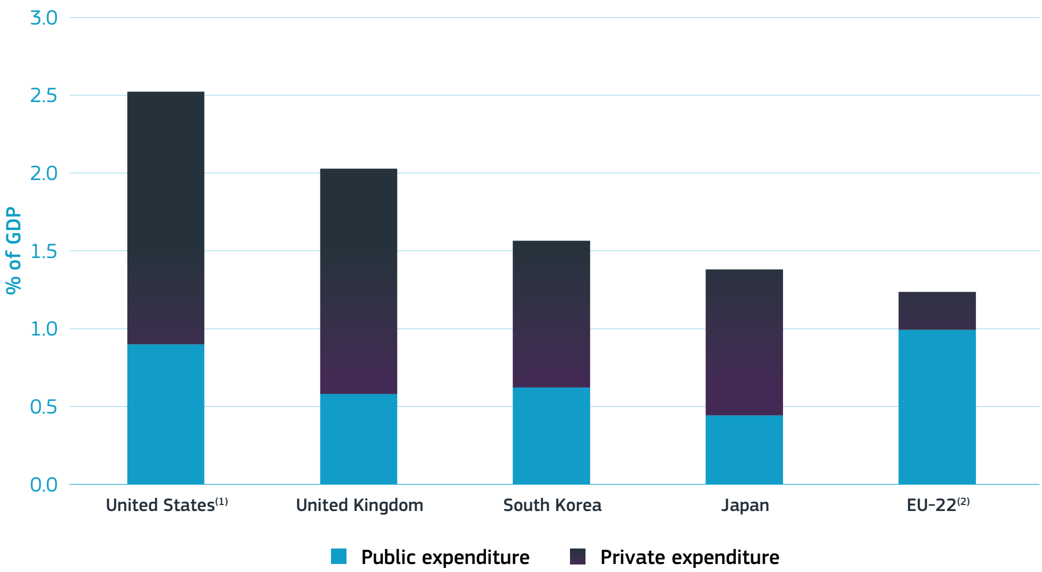
Note: [1]Total expenditure includes public, private and international sources. [2]EU-22 includes: AT, BE, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LV, LT, LU, NL, PL, PT, SK, SI, ES, SE.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-15.xlsx

China is witnessing a rapid expansion in tertiary education participation, both in absolute and relative terms. South Korea has the highest share of young adults enrolled in tertiary education, closely followed by the United States and the European Union (see Figure 5.4-17). China's share of young adults enrolled in tertiary education increased from 32 % in 2013 to 54 % in 2019. The United Kingdom's share increased from 57 % in 2013 to 66 % in 2019, and the EU's from 67 % to 75 %.

The EU is comparable with the USA and the UK in terms of numbers of researchers relative to the population, growing from 2 600 researchers per million inhabitants in 2000 to 4 500 in 2018 (see Figure 5.4-18). Yet South Korea has shown a remarkable increase over the same period, and is outperforming the EU, the USA, the UK and Japan. Despite China's overall growth, its number of researchers relative to population is still relatively low.

Figure 5.4-16: Expenditure in tertiary education, 2018

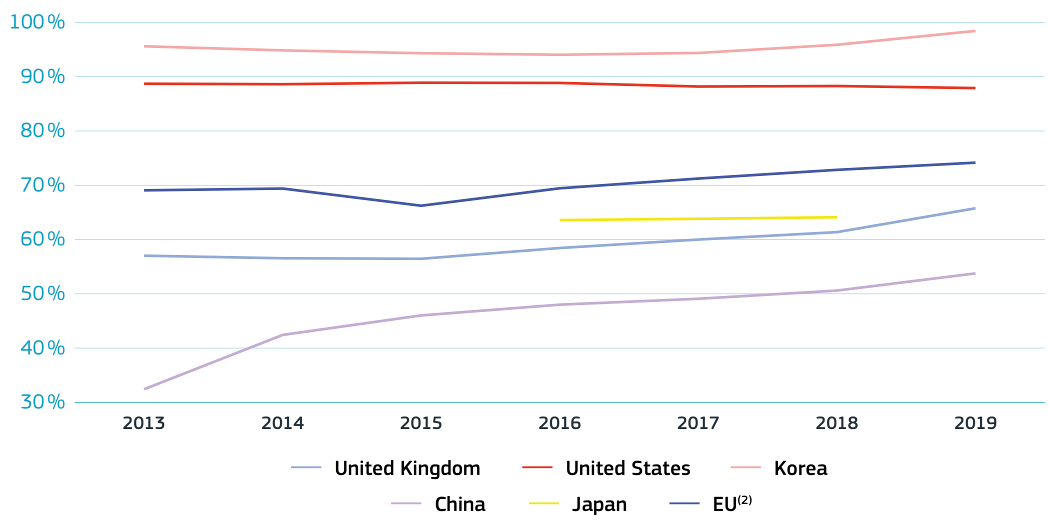


Source: 'Education at a glance' (2021), Indicators, OECD.

Note: [1]US figures are for net student loans rather than gross, thereby underestimating public transfers. [2]EU-22 includes: AT, BE, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LV, LT, LU, NL, PL, PT, SK, SI, ES, SE.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-16.xlsx

Figure 5.4-17: Gross enrolment ratio for tertiary education[1], 2013-2019



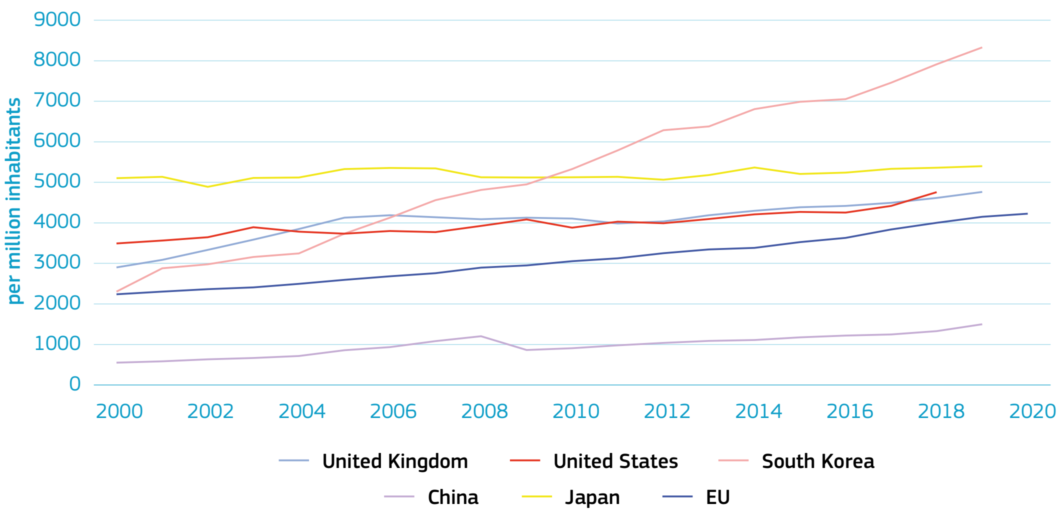
Science, Research and Innovation Performance of the EU 2022

Source: UNESCO data

Note: [1]The number of students enrolled in tertiary education is expressed as percentage of the 5-year age group immediately following upper secondary education. [2]EU average is computed as an unweighted average of gross enrolment ration for tertiary education by DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit.

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-17.xlsx

Figure 5.4-18: Researchers per million inhabitants (in FTE), 2000-2020



Science, Research and Innovation Performance of the EU 2022

Source: Eurostat (online data code: rd_p_persocc) and World Bank

Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-18.xlsx

4. The human-capital challenge posed by COVID-19

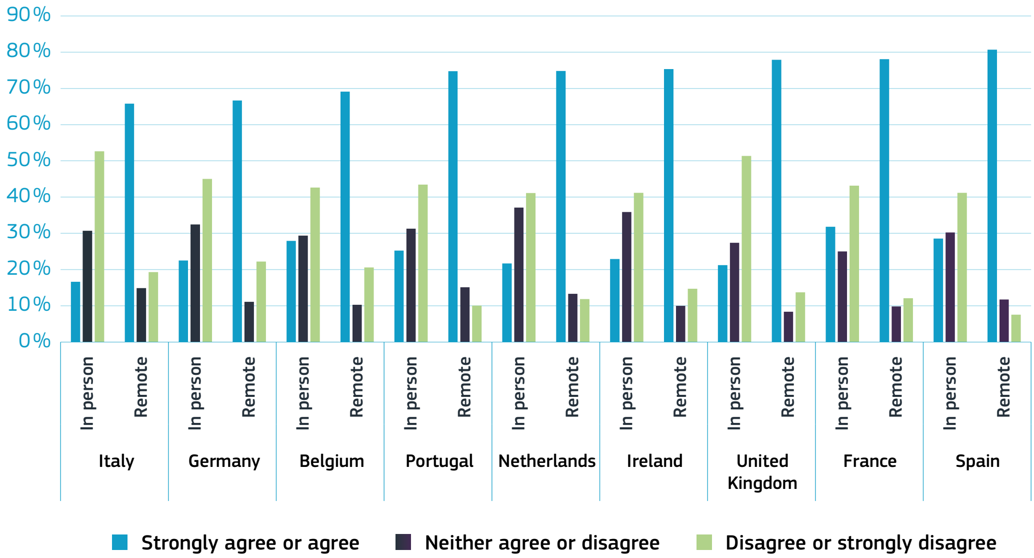
The COVID-19 pandemic has negatively impacted learning outcomes, particularly for students from disadvantaged socio-economic backgrounds (Reimers, 2022). This can cast a long shadow in terms of the human capital endowment of the population, productivity and innovation capacity[1]. Students whose education has been interrupted by the pandemic risk facing long-term losses in income. Economies with an impacted human-capital base in the workforce are likely to face lower economic growth, with substantial welfare consequences (Hanushek and Woessmann, 2020; Azevedo et al., 2021). According to UNESCO, in 'Education: From Disruption to Recovery', over 100 million additional children worldwide will fall below the minimum proficiency level in reading as a result of the COVID-19 crisis[2]. The JRC also highlighted how students from poorer socioeconomic backgrounds will likely be among the greatest losers of the COVID-19 pandemic (Di Pietro et al., 2020).

During the COVID-19 pandemic, students were shown to be more distracted during online classes compared to in-person classes (see Figure 5.4-19). In Germany, 23 % of students declared being very distracted during in-person classes, while 67 % agreed that they are very distracted during online classes. This finding is relatively homogeneous across European countries. Moving from in-person to online classes increases the percentage of students believing that they are distracted by around 49 percentage points in Italy, 41 percentage points in Belgium, 50 percentage points in Portugal, 53 percentage points in the Netherlands, 43 percentage points in France and 52 percentage points in Spain.

Disadvantaged students gain the most from in-school peer interaction and cannot rely on private tutoring at home from well-educated parents or costly private teachers. Students from poorer families may also not always have access to the facilities needed for online learning: a modern computer, a silent room and a fast internet connection (Agostinelli et al., 2022). Furthermore, schoolteachers, particularly in more rural and less-developed areas, do not always have an adequate level of digital proficiency to perform online teaching. For example, primary school closures in Belgium resulted in significant learning losses and a substantial increase in educational inequality (Maldonado and De Witte, 2020). Inequality in learning outcomes, both within and across schools, increased, and socioeconomically disadvantaged students were relatively more affected. Similarly, primary school closures during COVID-19 in the Netherlands and Germany diminished learning outcomes, particularly among students from disadvantaged homes (Engzell et al., 2021; Werner and Woessmann, 2021). Noticeably, this empirical evidence is from countries with very high level of digitalisation, suggesting that the likely effect in less digital-ready nations may be worse. Such disruptions to children's learning today, generated by COVID-19-related school closures, are likely to have a persistent and large impact on the production capacity of the economy and to harm future growth (Fernald and Ochse, 2021). At the same time, for some students, the pandemic provided an opportunity to gain more autonomy in learning, to spend more time with their families and to learn together with their families.

1 Learning loss is global – and significant, McKinsey
2 UNESCO report 2021

Figure 5.4-19: Share of students agreeing with the sentence: "I am often distracted when doing course work or attending classes"



Science, Research and Innovation Performance of the EU 2022

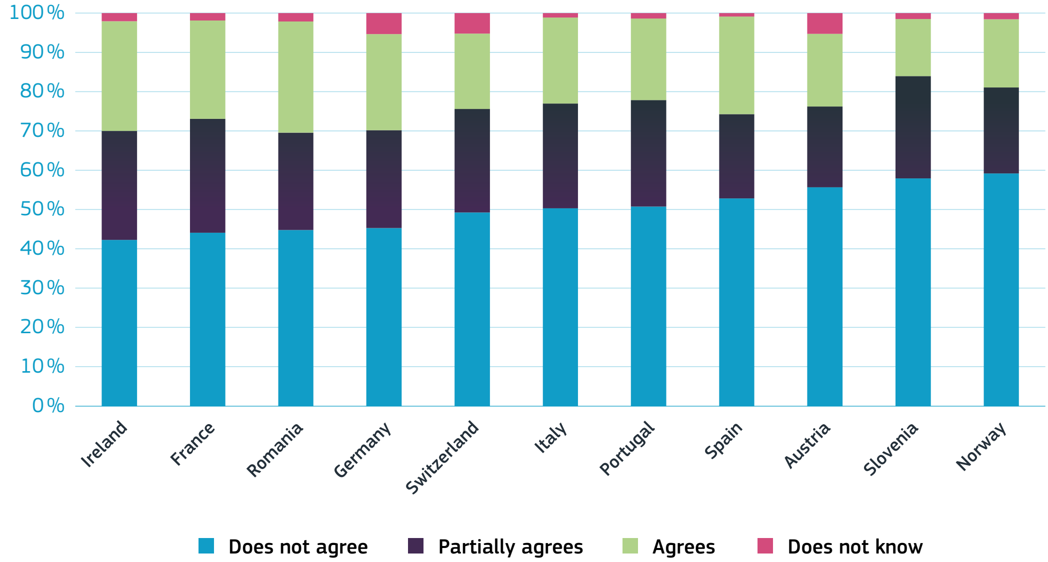
Source: Based on *Student perceptions of remote learning* (Stein, 2020), Harvard Dataverse
Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-19.xlsx

Understandably, students from disadvantaged socioeconomic backgrounds could gain the least from such an opportunity, which often translated in a 'sink-or-swim' environment (Reimers, 2022).

During COVID-19, around 50% of students in many European countries felt helpless when they had to do school activities and homework online. In France, 54% of students agreed or partially agreed with the statement 'I feel helpless when I have to do school activities and homework online' (see Figure 5.4-20). In Germany, the same group amounted to 49%, and in Ireland, 56%.

Early age education has well-known long-term impacts on future income and well-being (Dillon et al., 2017; Duflo, 2001; Elango et al., 2016). Even small losses of time

Figure 5.4-20: Share of students agreeing with the sentence: "I feel helpless when I have to do school activities and homework online"



Science, Research and Innovation Performance of the EU 2022

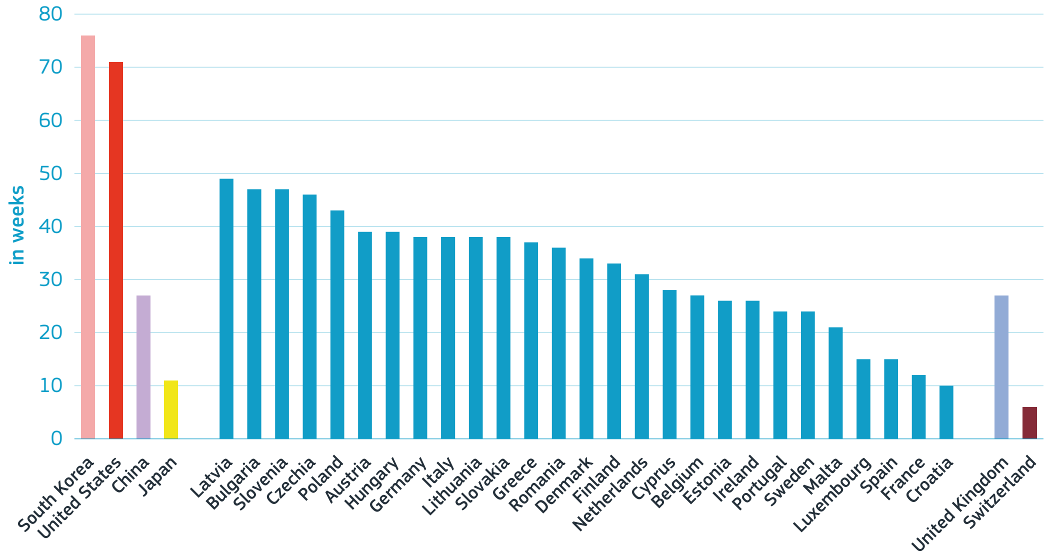
Source: Based on KiDiCoTi consortium calculations
Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-20.xlsx

spent at school can have large consequences for the development of skills and abilities (Carlsson et al., 2015; Lavy, 2015). Figure 5.4-21 shows the numbers of weeks lost by students during the pandemic. Significant losses are depicted for all countries, yet with meaningful differences. For example, in Germany and Italy, students faced 38 weeks of full or partial school closure, while in France only 12 weeks. The negative impact of COVID-19 restrictions on the student population calls for urgent implementation of corrective policies.

Students who graduated during the pandemic face higher barriers to entering the job market, which will likely lead to persistent earnings losses, particularly for less advantaged graduates. Indeed, graduating during a recession can permanently affect the long-term income and professional career of individuals (Oreopoulos, 2012). Cutler et al. (2015) found that graduation in a recessionary period permanently lowers income and health later in life.

Online teaching methods are an imperfect substitute for classroom teaching, with a negative impact on learning outcomes, particularly for disadvantaged students (Cacault et al., 2021). Cacault et al. (2021) used a randomised experiment in a public Swiss university and found that attending lectures via live streaming lowers achievement for low-ability students and increases achievement for high-ability ones.

Figure 5.4-21: Duration of FULL and PARTIAL school closures[1]



Science, Research and Innovation Performance of the EU 2022

Source: UNESCO global monitoring of school-closures data
Note: [1]Data updated until 30 November 2021
Stat. https://ec.europa.eu/assets/rtd/srip/2022/figure-5-4-21.xlsx

Figlio et al. (2013) provided experimental evidence from a US university showing that online education is not a full substitute for traditional live classroom instruction. Alpert et al. (2016) also found similar experimental evidence indicating that purely online teaching reduces learning outcomes relative to the face-to-face format. Bettinger et al. (2017) found that taking a course online, instead of in-person, reduced student success and progress in college, leading to lower grades and reducing the likelihood of remaining enrolled in the programme.

To deal with the negative consequences of school closure, education systems across Europe implemented remedial actions that have helped reducing learning disruptions. Governments allocated additional funding to cover additional costs of hygiene and sanitation of educational spaces and acquisition of IT equipment such as computers and tablets (De Witte and Smet, 2021). Countries implemented broader measures to support the digitalisation of education, improving teacher training and hiring additional teachers and tutors for pupils struggling with online and blended modes of learning. Furthermore, several EU Member States promoted the organisation of summer programmes in 2020 targeted at students from disadvantaged backgrounds, with funding to support their enrolment without cost for their families (Depping et al., 2021; Gambi and Witte, 2021; De Witte and Smet, 2021). The initial results seem to support such compensatory measures, with evidence of their capacity to halt learning losses (Gambi and de Witte, 2021).

5. Conclusions: human capital, the building block of prosperity

Investment in human capital is one of the main drivers of economic growth. The quality and quantity of formal education has long-term effects on the creativity, competence and productivity of individuals. In the knowledge economy, demand for highly skilled workers is rapidly increasing, calling for additional resources to be devoted to the education system, from primary up to tertiary education and including lifelong learning.

An increasing share of the EU population is obtaining a tertiary education. Furthermore, the share of the work force with tertiary education and working in science and technology occupations, as well as the share of researchers in the workforce, is increasing in the EU. However, there is still strong gender disparity among the fields of study, with ICT, engineering and technology dominated by male students, and humanities, health and care prevalently chosen by women.

Considering both public and private spending, the EU invests less in education than the USA, Japan, the UK and South Korea. More effort is required to unlock further public and private resources to be devoted to education, training and reskilling. On the other hand, the EU has the highest share of publicly financed education spending, reducing risks of inequalities and making the spending less sensitive to exogenous shocks.

The number of ICT graduates and employment in the ICT sector are rapidly increasing. At the same time, European companies are expanding their reskilling programmes, shifting to a model of life-long learning fitting the digital era. More and more adults are engaging with learning activities to keep themselves equipped with the right skills for their professional development.

School closures during the pandemic have resulted in learning losses, especially for disadvantaged students. Corrective policies will be needed to support students to recover these learning losses.

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