CHAPTER 2

R&I, TRANSITION AND GEOECONOMICS

CHAPTER 2.1

R&D INVESTMENTS AND POLICY APPROACHES

Key questions

- What are the latest developments in research and development (R&D) investments (public and private)?
- What policy instruments can be used to support R&I?
- How have R&I policies evolved to become more transformative?

Highlights

- China has overpassed the EU for the first time in 2020 in terms of R&D intensity, and the EU R&D intensity (2.2 %) remains below that of the US (3.5 %), Japan (3.3 %) and South Korea (4.9 %).
- The R&D intensity gap between the EU and its main competitors is mostly due to a gap in private R&D investments.
- Within the EU, private R&D investment is dispersed across high-tech and mid-tech sectors.
- R&D activity in the EU is concentrated within a limited number of countries, although concentration has slightly decreased over the last decade.
- The world's top companies in terms of R&D spending tend to invest much more in R&D than governments (in terms of R&D intensity).
- Global spending on clean energy have increased between 2015 and 2022, and the EU invested more than the US but less than China in 2022.
- The total amount of government support to private R&D in the EU has decreased in 2020 by 3.4 %, due to the decrease in tax support.

Policy insights

- In recent decades, EU governments have increasingly shown a preference for tax incentives over direct subsidies to encourage private investments. This trend, however, saw a slight decrease after the COVID-19 crisis.
- The existence of a positive structural effect between the EU and US may indicate the need to promote the role of the EU in critical high-tech sectors.
- Despite lagging behind the US in total public and private Venture Capital (VC) funding, the EU surpasses Japan and Korea. The EU has the highest relative share of Government Venture Capital compared to total VC.
- Tax support, chosen for its lower administrative burden, poses challenges in monitoring and directing funds, particularly toward societal challenges. There is also a risk associated with tax competition.
- Access to financial and human capital through Government Venture Capital (GVC) has a substantial and lasting impact, but it carries a higher risk of crowding out private investments.
- EU governments increasingly use policy approaches and instruments to support R&D in line with a new frame for R&I policies: the Transformative Research and Innovation Policy (TRIP), which supports transformative change of our economies.
- Evaluating TRIP effectively demands a comprehensive approach involving systems thinking, experimentation, stakeholder involvement, and continuous monitoring. Currently, this evaluation process is still in its early stages.

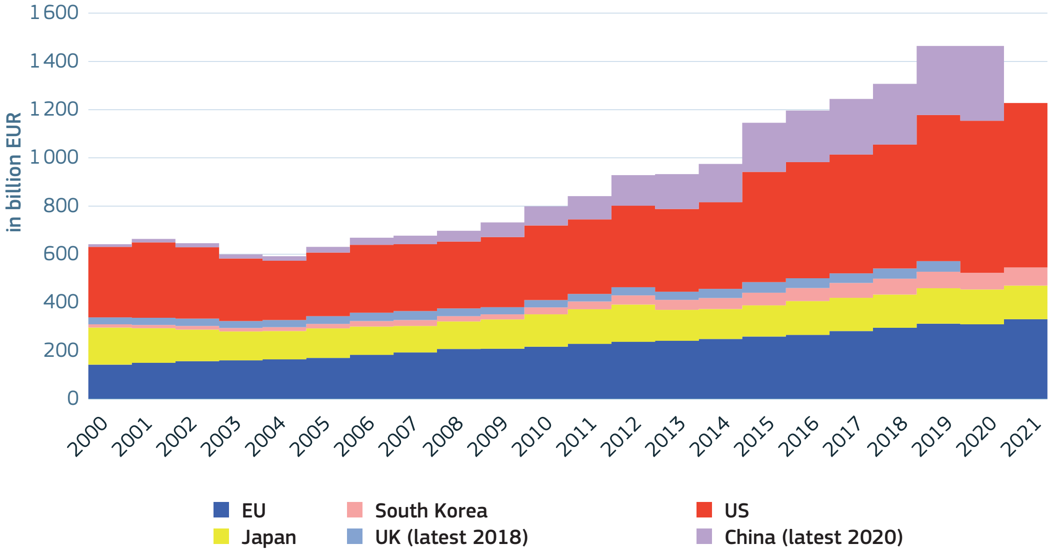
R&D investments drive economic growth by fostering innovation and the development of new technologies, products, and services. Through R&D, new industries can emerge, existing industries can be transformed, productivity can be improved and companies can stay competitive in the global marketplace, spurring job creation. R&D investments have positive spillover effects on the economy; R&D can diffuse across industries and sectors, benefiting other organizations and driving innovation in a broader sense. The first part of this chapter offers an overview of the latest trends in R&D investments in the EU, comparing them with those of its international competitors. It also disentangles these investments, analyzing their distribution across public and private sectors, various industries, and different countries.

By investing in R&D, breakthroughs can be made in areas such as healthcare, energy, environment, transportation, and communication, leading to transformative changes and societal benefits. Overall, it can help address societal challenges. Worldwide and in the EU, governments have implemented various approaches and instruments to support R&D investments and guide private R&D towards societal challenges. This includes R&D tax incentives, subsidies, innovation public procurement, or government venture capital. The second part of this chapter focuses on the evolving approach to Research and Innovation (R&I) policies, highlighting the latest trends and rationale behind the use of different R&I policy instruments in the EU and beyond.

1. Investments in R&D

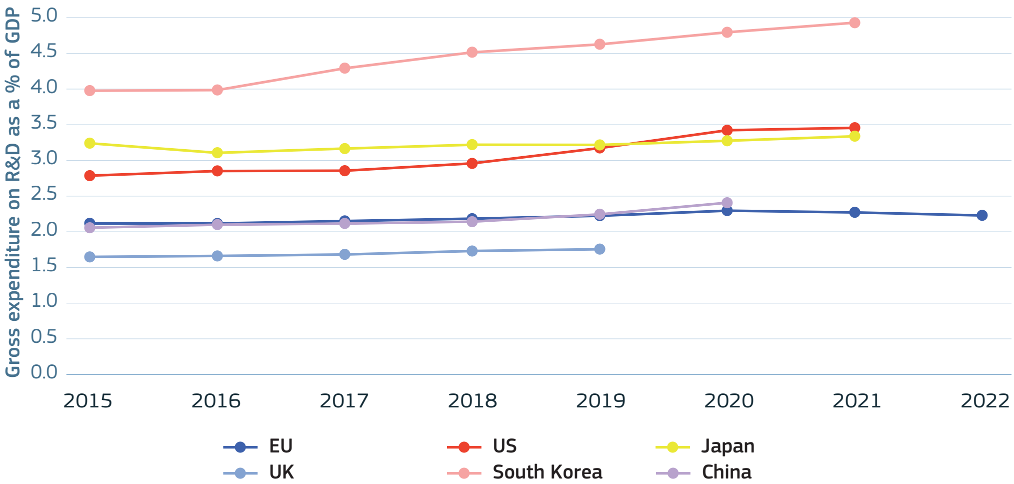
The EU has increased its R&D investments over the past two decades, yet a gap remains compared to some of its main competitors. The EU's relative weight in this global R&D landscape is decreasing (Figure 2.1-1). In 2021, EU R&D intensity (2.3 %, and 2.2 % in 2022) was below that of the US (3.5 %), Japan (3.3 %) and South Korea (4.9 %) (Figure 2.1-2). China experienced steady growth, surpassing the EU level in 2020 for the first time (2.4 %).

Figure 2.1-1 R&D expenditure in billion EUR, 2000-2021



Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Eurostat (online data code: rd_e_gerdtot).
Note: The UK value of 2020 is a prediction based on the annual compound growth rate from 2014-2019.

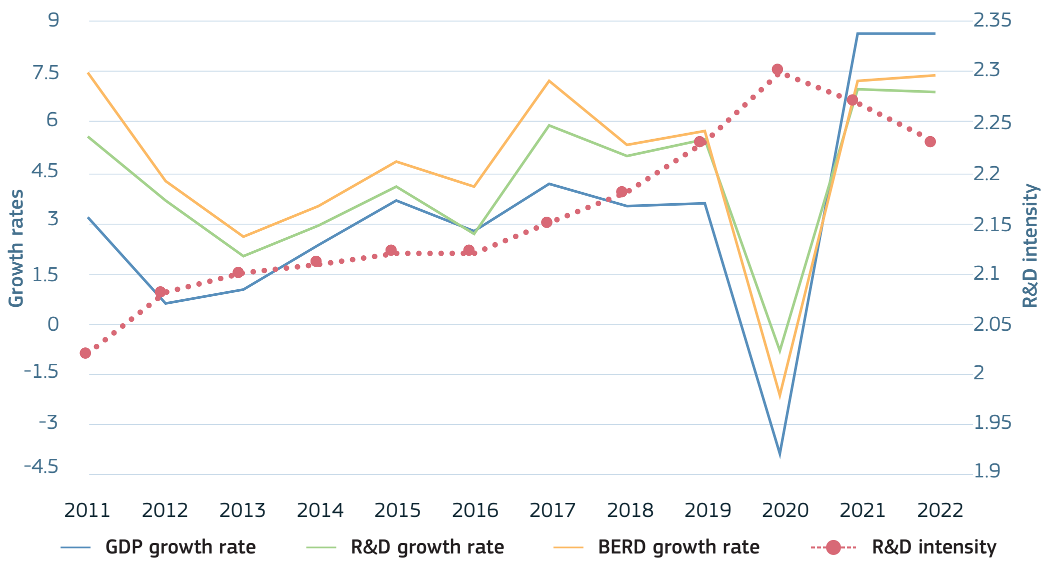
Figure 2.1-2 Gross expenditure on R&D as a percentage of GDP (R&D intensity), 2015-2022



Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Eurostat (online data code: rd_e_gerdtot).

In 2020, the EU's R&D expenditure decreased less than GDP but still declined, driven by the private sector, while, in 2021, R&D intensity decreased with R&D investments increasing less than GDP (Figure 2.1-3). R&D activities tend to be pro-cyclical (Barlevy, 2007; Fatas, 2000; Rafferty, 2003; Comin & Gertler, 2006), moving in tandem with economic growth: R&D declines during recessions and increases during economic booms (Fabrizio and Tsolmon, 2014; Barlevy, 2007; Sedgley et al., 2019; Aghion et al., 2012).

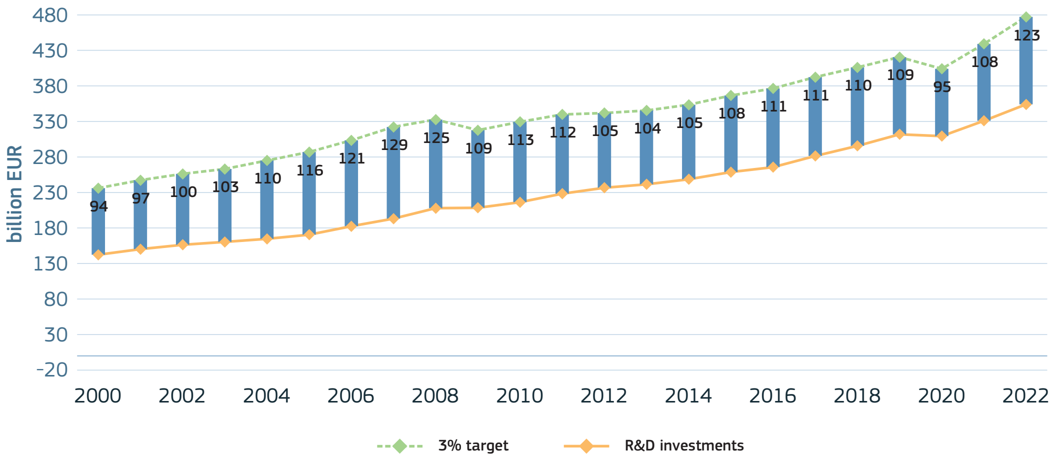
Figure 2.1-3 Annual growth rates and R&D intensity in the EU, 2011-2022



Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Eurostat (online data code: rd_e_gerdtot).
Note: BERD stands for business enterprise R&D expenditure.

In 2022, the EU would have needed to invest an additional EUR 123 billion to reach the 3% target, more than the budget of an entire 7-year European Commission framework programme for R&I (Figure 2.1-4). It is also worth noting that the decline of the gap from 2019 to 2020 is not due to an increase in R&D investments but to the decrease in GDP that followed the COVID-19 pandemic.

Figure 2.1-4 R&D investment gap in the EU in billion EUR, 2000-2022

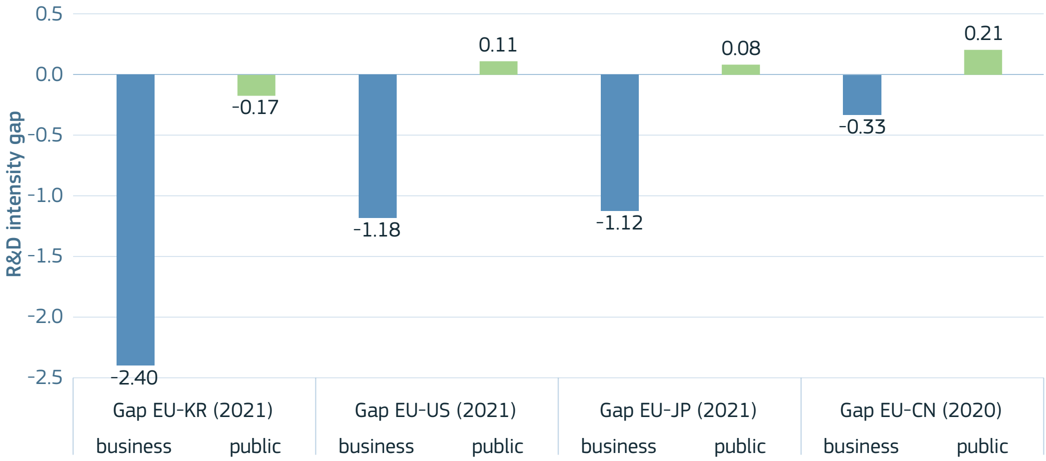


Science, research and innovation performance of the EU 2024

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

The R&D intensity gap between the EU and its main competitors is due to a gap in private R&D investments. In 2021, the R&D intensity of the EU in the public sector, gathering government and higher education, was higher than that of Japan, the US and China (2020), whereas it was lower in the private sector (Figure 2.1-5). Only South Korea had a higher public R&D intensity than the EU.

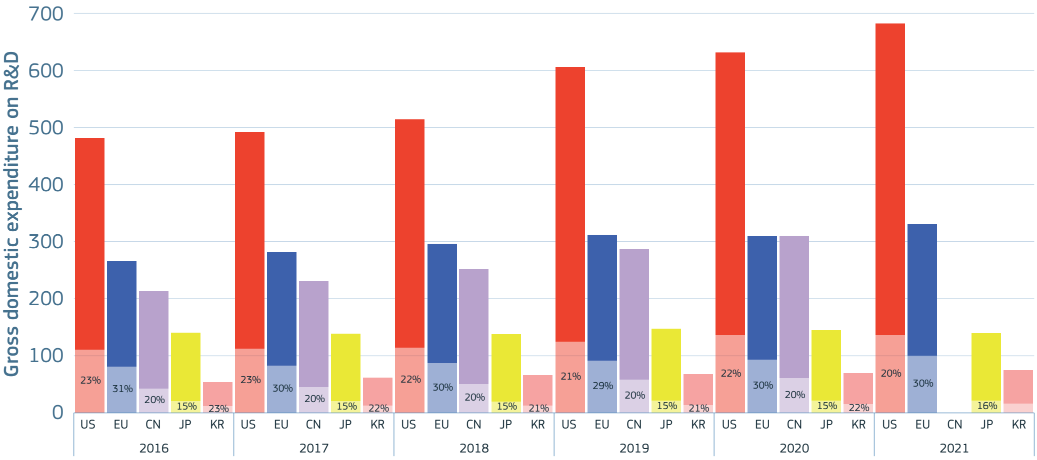
Figure 2.1-5 Public and private R&D intensity gaps between the US, Japan, China, South Korea and the EU, 2021 or latest year available



Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's own elaboration based on Eurostat dataset.
Note: Public R&D intensity is defined using R&D investments funded by national government and higher education sectors and does not include funding from other public sources, such as the European Commission and international organisations.

Despite not having the highest public spending among all major economies in absolute terms, with the US leading, it is important to note that R&I funding by the public sector is relatively higher in the EU compared to other countries (Figure 2.1-6). Within the EU, the percentage of government-funded R&I is around 30% of the total R&I funding. In contrast, other countries have lower percentages of government-funded R&I, such as China and the US, both at 20%, and Japan even lower at 16% of total R&I funding. These figures are also reflected in the percentages funded by the private sector, with China, Japan and South Korea ranging between 75% and 80%, while the EU is below 60%.

Figure 2.1-6 Gross domestic expenditure on R&D (GERD) – government (light colour) and non-government (other, dark colour) funds, in billion EUR, 2016-2021

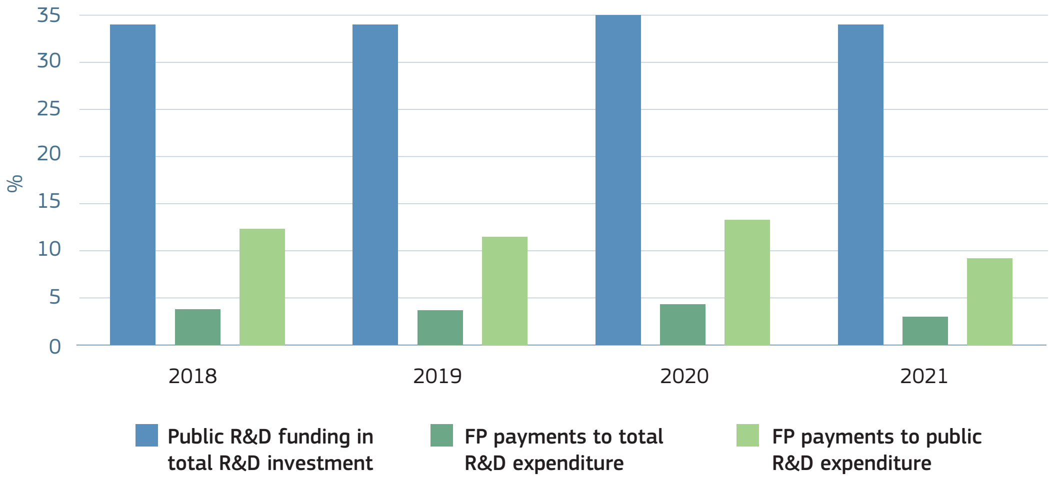


Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Eurostat (online data code: rd_e_gerdtot).
Note: The labels are the shares of gross expenditure on R&D funded by the national government.

For the EU as a whole, the majority of R&I investments are financed by the Member States themselves. Member States adopt their individual approaches to funding R&I activities, primarily through annual budget allocations to national agencies or dedicated R&I programmes and funds.

Overall, the European FP for R&I funding constituted 9.2 % of public R&I funding and 3.0% of the total R&I funding in Europe in 2021 (Figure 2.1-7). The share of FP payments in the European public and total R&I funding was slightly higher in previous years, representing between 11.5% - 13.3% in the European public R&I funding and around 3.7% - 4.3% in the European total R&I funding. The significance of public R&D funding in the total R&D investment remained more or less stable around an average of 33.5% between 2018 and 2021.

Figure 2.1-7 The contribution of the Framework Programme for R&I as a percentage of total and public R&D expenditure, 2018-2021

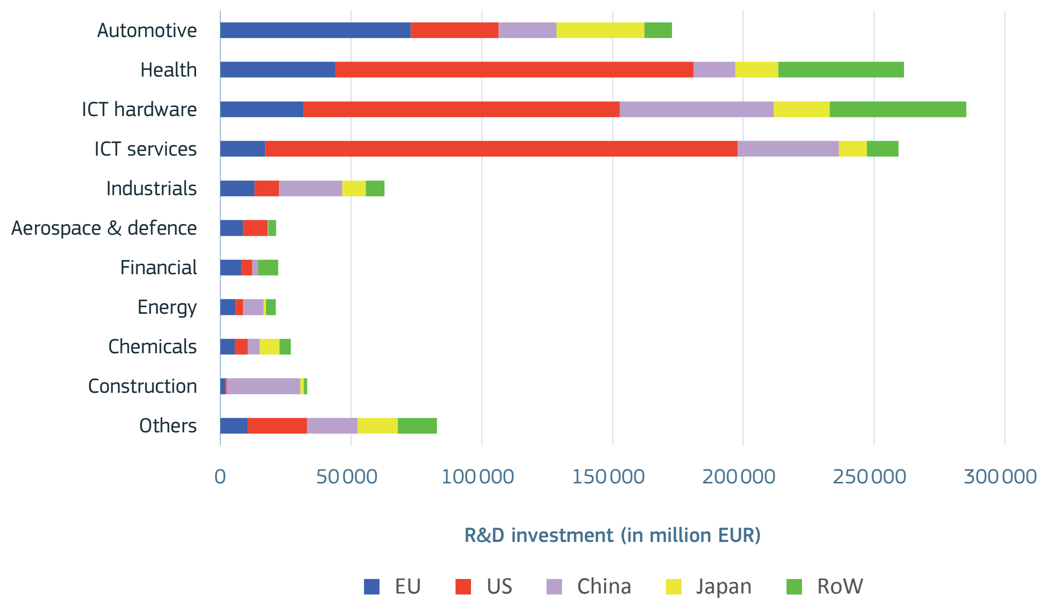


Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's own elaboration based on Eurostat.
Notes: The contribution of FP is defined as the payments made under Horizon 2020 and Horizon Europe as reported in the consolidated annual accounts of the EU. As the UK is considered as a Member State for all pre-2021 programmes, payments may also comprise payments to the UK. The R&D expenditures of the public sector are defined as the sum of GERD with national governments, the European Commission and international organisations as source of funds.

Comparing the EU R&D to the US, Japan and China, dissimilarities in the sectoral composition of the regions' economy can often explain differences in private R&D investment (Figure 2.1-8). Following a similar approach to Moncada-Paternò-Castello et al. (2016), private R&D investment (BERD) can be decomposed across industrial sectors. Comparing the EU R&D to the US, Japan and China, differences in private R&D investment can be explained by dissimilarities in the sectoral composition of the regions' economy (Figure 2.1-8). Within the US, investment in R&D is largely driven by R&D in high-tech sectors such as health, ICT hardware and ICT services, which account for approximately 85% of all US private R&D investment (Figure 2.1-9).

Within the EU, China and Japan, private R&D investment is less concentrated in high-tech sectors, but is more dispersed in comparison to the US. EU private R&D investment seems to be largely driven by R&D in the mid-tech automotive sector, yet substantial investments are also made in the high-tech health and ICT hardware sector. Overall, R&D investment in mid-tech sectors accounts for approximately 43% of EU private R&D investment, while high-tech sectors account for around 46%. Japan follows a very similar trend, with mid-tech sectors accounting for approximately 37% and high-tech sectors for 54% of total private R&D. Private R&D investment in China is even more dispersed across high-tech, mid-tech and low-tech sectors. While a substantial amount of Chinese private R&D investment is taking place in the high-tech ICT services and hardware sector, substantial investments are also made in the mid-tech industrials sector and the low-tech construction sector. As a result, high-tech sectors make up approximately 49% of total private R&D investment, in comparison to 24% and 27% for mid-tech and low-tech, respectively.

Figure 2.1-8 **Sectoral composition of private R&D investment in million EUR, 2022**

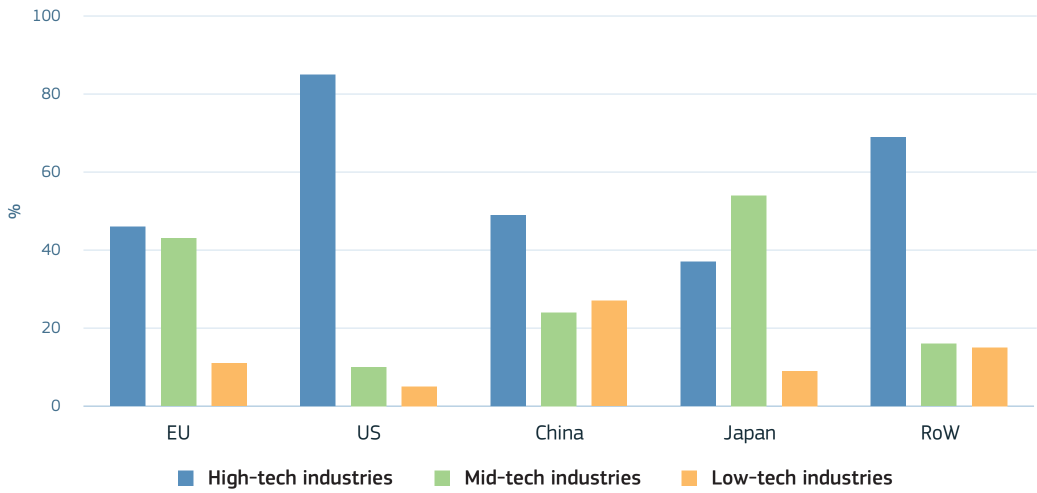


Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on data from the 2023 EU Industrial R&D Investment Scoreboard.

Note: Due to the scope of the scoreboard, the 'EU' data represents 17 Member States.

Figure 2.1-9 Private R&D investment by region and sector type (high-tech, mid-tech, low-tech), 2022



Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on data from the 2023 EU Industrial R&D Investment Scoreboard.
Note: Due to the scope of the scoreboard, the 'EU' data represents 17 Member States.

Sectoral differences in R&D spending can be explained via both 'structural' effects (i.e., related to the size of the sector in relation to other sectors within the economy (Figure 2.1-10)) and 'intrinsic' effects (i.e., effects related to the R&D investment of firms within a particular sector (Figure 2.1-11)). In 2022, the private R&D intensity gap between the EU and the US was positive overall, implying that, within the majority of sectors, the US demonstrated a higher R&D intensity compared to the EU. The opposite situation can be observed for the private R&D intensity gap between the EU and China or Japan. A more in-depth analysis into the different sectors reveals that, in comparison to the US, the EU demonstrates a higher R&D intensity for the mid-tech automotive sector and a lower R&D intensity for the high-tech health, ICT services and ICT hardware sectors. Following this observation, it is possible to conclude that high-tech sectors in the US invest more in R&D, not only due to their extensive size, but also due to higher R&D intensity. This implies the existence of a positive structural effect between the EU and US: sectors that are considered to be more substantial in the EU/US economy than in the US/EU economy, are also considerably more R&D-intensive. This finding is in line with that of Moncada-Paternò-Castello et al. (2016), who identify a positive and more pronounced structural effect between the US and the EU. It is also in line with recent estimations made within Fuest et al., (2024) which concluded that structural factors account for about 60% of the difference, while intrinsic factors account for the remaining 40%.

Japan and China are mainly characterized by positive structural effects with the EU, with the exception of ICT hardware. While R&D investments in this sector are of larger importance to the overall Chinese and Japanese economy, R&D intensity in this sector is higher in the EU. A similar observation can be made for the EU health sector, i.e., despite its overall higher importance to the EU economy, Japan is characterized by higher levels of R&D intensity in the health sector.

Figure 2.1-10 Share of private R&D investment by sector and region, 2022

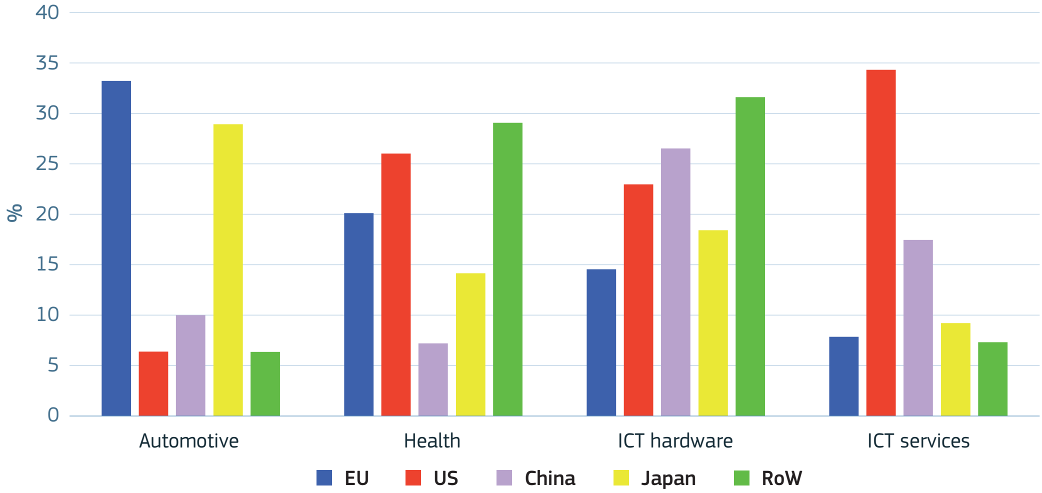
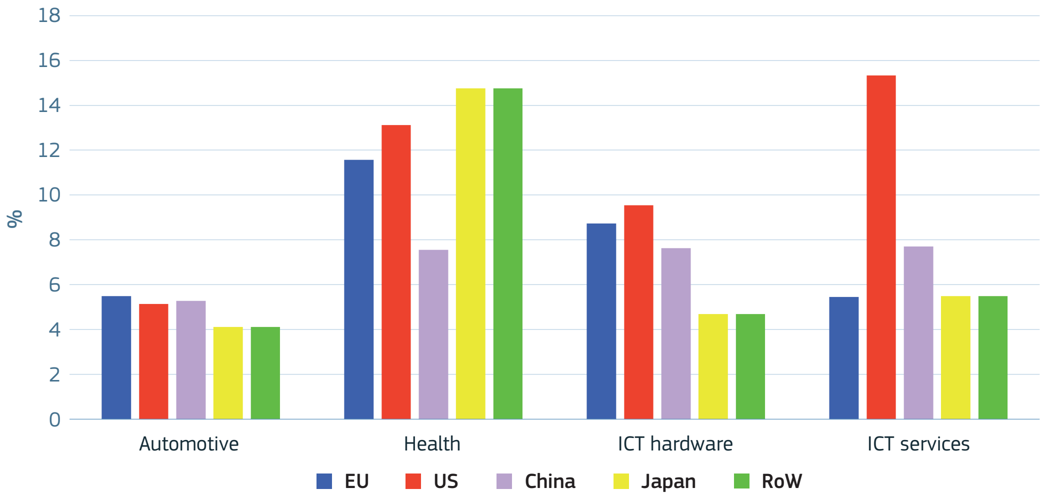


Figure 2.1-11 R&D intensity by sector and region, 2022



Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on data from the 2023 EU Industrial R&D Investment Scoreboard.
Note: Due to the scope of the scoreboard, the 'EU' data represents 17 Member States.

The existence of a mainly positive structural effect between the EU and other regions could indicate the need for policies that promote the role of the EU in critical high-tech sectors. To this extent, policy could focus on improving the innovation ecosystem (e.g., access to finance and improvement of business conditions) as well as providing more directionality in R&D (e.g., via mission-oriented policies). Nevertheless, further in-depth analysis would be required to fully understand all the underlying factors that may drive these relationships.

Box 2.1-1 The development of R&D intensity in the Industrial R&D Investment Scoreboard: the role of reallocation between firms and the importance of the ICT services sector

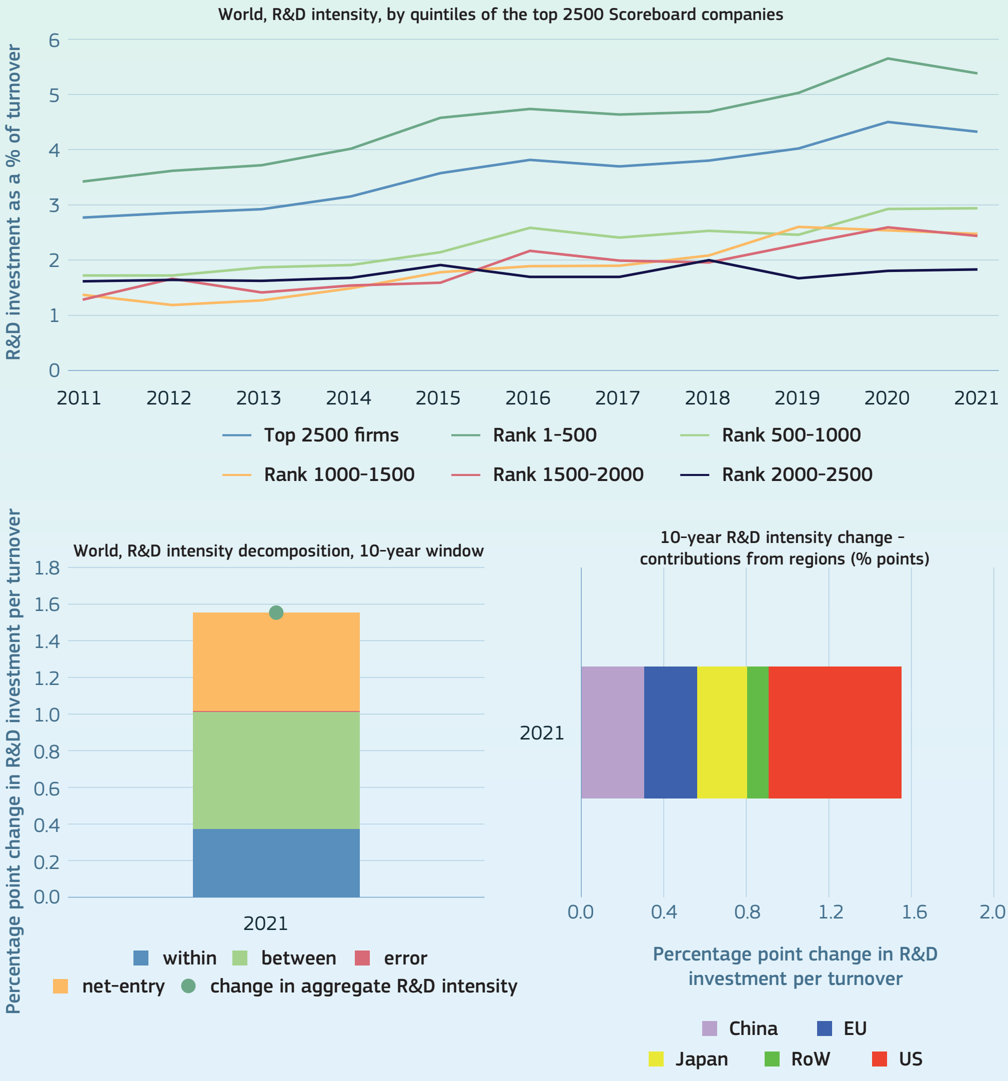
Peter Bauer and Francesco Rentocchini, Joint Research Centre, Industrial Strategy, Skills and Technology Transfer Unit.

R&D intensity is a widely used indicator of R&D efforts. We define R&D intensity as R&D expenditure over turnover of the top 2 500 R&D investors of the world from the Industrial R&D Investment Scoreboard. R&D expenditure and turnover are adjusted by purchasing power parity to take into account the different price levels of different countries.

We analyse the development of R&D intensity over time and the differences of its growth across countries (regions) and sectors. We focus on changes over a 10-year window, from 2011 until 2021. Changes in aggregate R&D intensity are decomposed to within-firm term, between-firm term, entry term and exit term. The within-firm term expresses the change of aggregate intensity coming from the change at firm-level intensities. The between-firm term is the changes to the shares of firms in aggregate turnover, indexed by the deviation of average firm-level intensity from the aggregate average intensity. Thus, this term is larger if more R&D-intensive firms tend to grow, and smaller if more R&D-intensive firms tend to shrink. The entry and exit terms express the effect of entering and exiting firms on aggregate intensity. An entering firm contributes positively (negatively) if its intensity is higher (lower) than the average aggregate intensity, and an exiting firm contributes positively (negatively) if its intensity is lower (higher) than the average aggregate intensity. The sum of the entry and exit term is called the net-entry term. The between-firm term and the net-entry term together comprise the reallocation effect on the change of aggregate R&D intensity.

First, we notice that R&D intensity tends to be greater for higher ranked companies, and there is an increasing gap during the period 2011-2021 between the leading and following firms in terms of R&D intensity. Then, analysis of world-level changes of R&D intensity reveals that the increase during the last 10 years comes mainly from reallocation between firms, especially the gaining of shares in the turnover of high R&D-intensive firms. This is a sign of allocative efficiency, as it shows that firms with high R&D intensity tend to grow faster. Contributions from different regions to world-level intensity show that 40 % of the increase was driven by the US, while China, the EU and Japan contributed similarly.

Figure 2.1-12 R&D intensities and its decomposition per within-firm term, between-firm term, entry term and exit term in 2021, and the 10-year intensity change, Scoreboard companies, 2011-2021



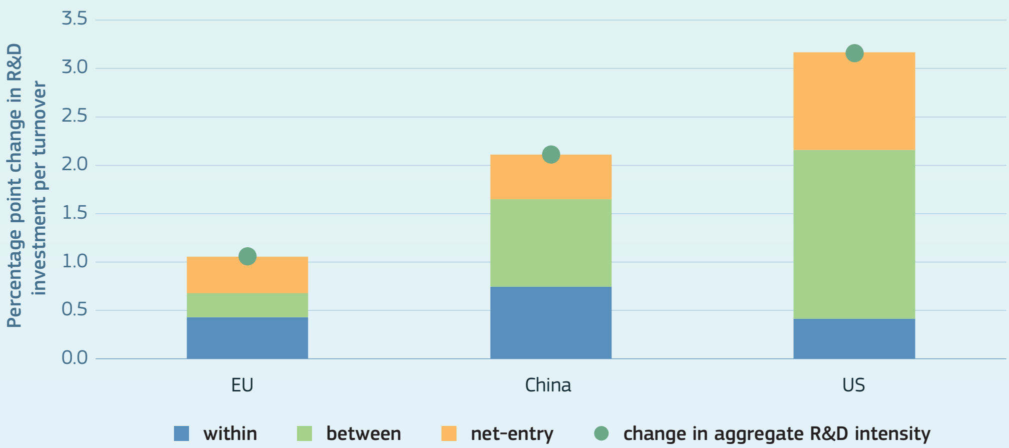
Science, research and innovation performance of the EU 2024

Source: Joint Research Centre, Industrial Strategy, Skills and Technology Transfer Unit, calculations based on the Industrial R&D Investment Scoreboard data.

Note: RoW stands for Rest of the world

Analysing regions separately, we find that R&D intensity (in terms of percentage points) increased the most in the US, followed by China and then the EU in third place. The main difference between the regions stems from the between effects, i.e. the different change in market share of high versus low R&D intensity firms in the different regions. We can assess the role of different sectors within regions. The leading position of the US in terms of R&D intensity growth in the past 10 years has been driven mainly by firms in the health and ICT service sectors that either entered into the market, or gained share at the expense of firms losing market share in less R&D-intensive sectors.

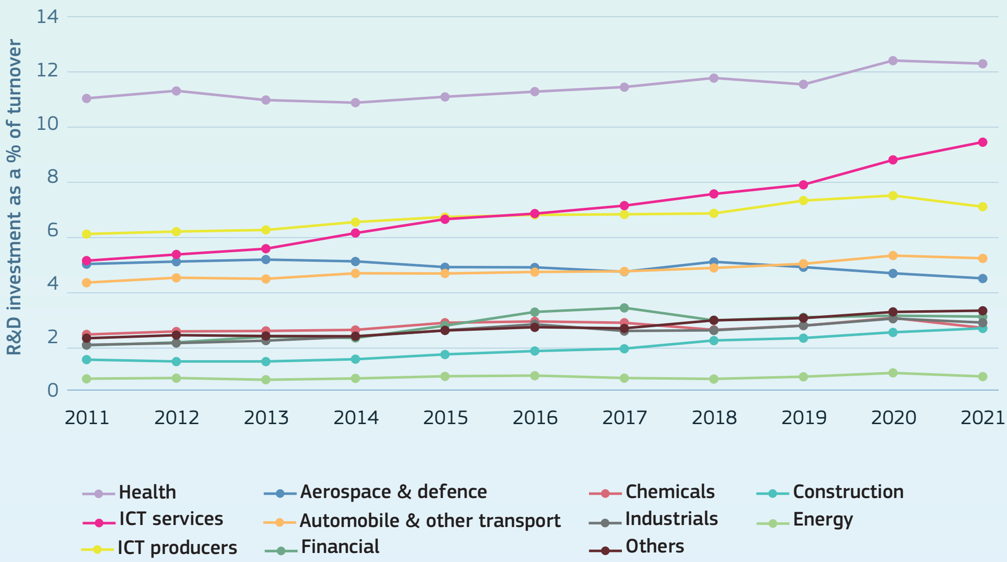
Figure 2.1-13 R&D intensity decomposition, Scoreboard companies, 2011-2021



Science, research and innovation performance of the EU 2024
Source: Joint Research Centre, Industrial Strategy, Skills and Technology Transfer Unit, calculations based on the Industrial R&D Investment Scoreboard data.

We can also analyse sectors at the world level – motivated by the global nature of many of the scoreboard companies. First, we can state that health has the highest R&D intensity historically, and it could still grow a bit in the coming 10 years. ICT producers and ICT services also have a high R&D intensity relative to the other sectors; ICT services increased its R&D intensity substantially in the past 10 years, and this increase was by far the highest among the sectors. The energy sector has a permanently low R&D intensity compared to other sectors.

Figure 2.1-14 R&D intensity per sector at world level, Scoreboard companies, 2011-2021

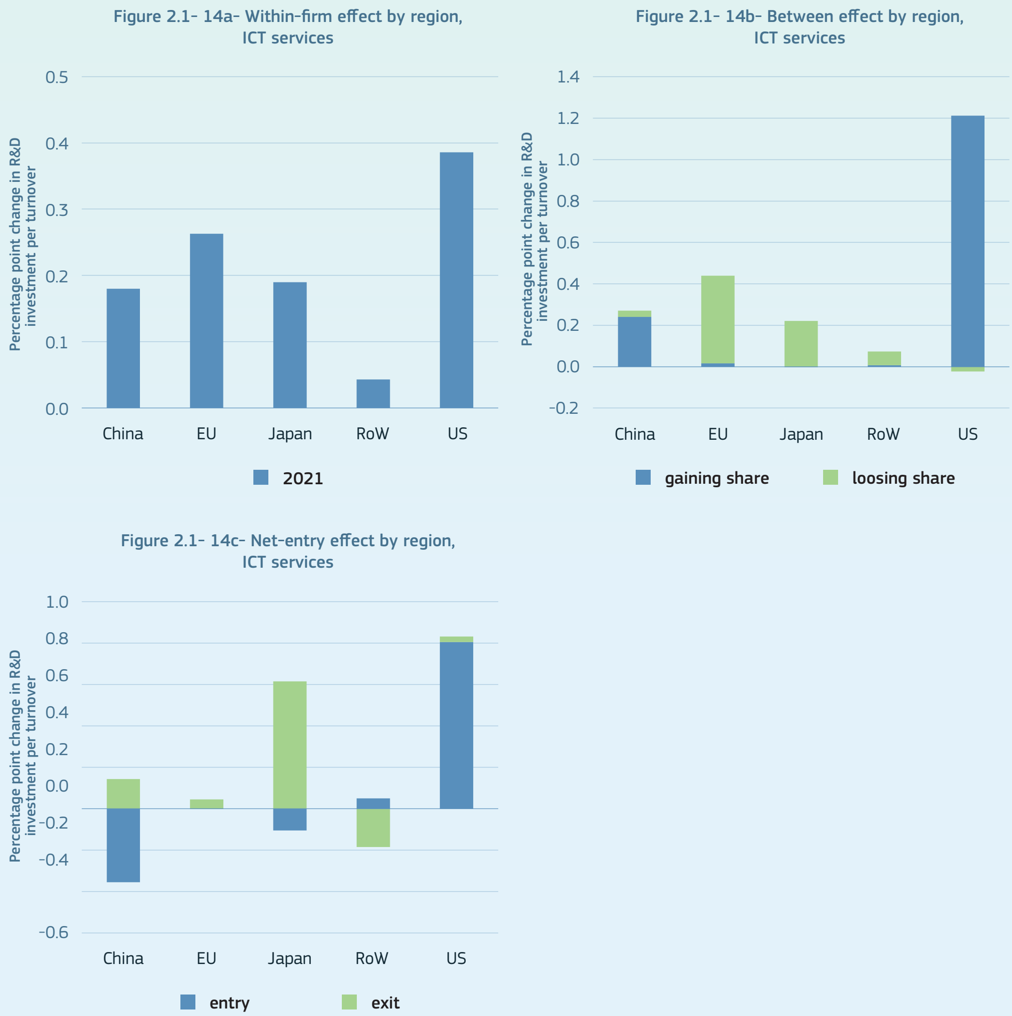


Science, research and innovation performance of the EU 2024

Source: Joint Research Centre, Industrial Strategy, Skills and Technology Transfer Unit, calculations based on the Industrial R&D Investment Scoreboard data.

As the ICT service sector showed the highest growth in terms of R&D intensity, it is warranted to analyse the drivers of this increase in detail. The biggest within-firm effect in ICT services comes from the US, followed by the EU and Japan. In the between effect, the large positive contribution is mainly from US firms, which are highly R&D intensive and gained market share in the world. The net-entry effect also shows the advantage of US firms, as the positive contribution comes from US firms entering the market. All these effects show the US dominance in ICT services.

Figure 2.1-15 Within-firm, between and net-entry effects by region in ICT services, Scoreboard companies, 2011-2021



Source: Joint Research Centre, Industrial Strategy, Skills and Technology Transfer Unit, calculations based on the Industrial R&D Investment Scoreboard data.

R&D activity in the EU is concentrated within a limited number of countries, though concentration has slightly decreased compared to the situation in 2010. In 2021, most R&D was performed in Germany (34%), France (16%) and Italy (7%) (Table 2.1-1). These three countries are responsible for close to 60% of R&D expenditure in the EU in 2022. While several Member States have increased their share in EU-wide R&D spending during the period 2011-2022 (Table 2.1-1), a clear divide persists between these leading countries and the rest of the EU. Total R&D intensity increased between 2011 and 2022 in 20 Member States, but significant heterogeneity remains across European countries.

Table 2.1-1 R&D investment trends across EU Member States, 2011-2022

Country	Share of EU R&D investments, 2021	Total R&D intensity, 2021	Trend GERD (2011-2021)	Business sector R&D intensity, 2021	Trend BERD (2011-2021)	Public sector R&D intensity, 2021	Trend public (2011-2021)
BE	5.23%	3.43	↑↑	2.53	↑↑	0.90	↑↑
BG	0.18%	0.77	↑↑	0.52	↑↑	0.24	↑
CZ	1.53%	1.96	↑↑	1.26	↑↑	0.69	↑
DK	3.10%	2.89	→	1.78	↓	1.11	↑
DE	34.24%	3.13	↑	2.11	↑	0.95	→
EE	0.18%	1.78	↓	1.00	↓	0.77	→
IR	1.37%	0.96	↓↓	0.77	↓↓	0.20	↓↓
EL	0.87%	1.48	↑↑	0.73	↑↑	0.75	↑↑
ES	5.45%	1.44	↑	0.81	↑	0.62	→
FR	16.19%	2.18	→	1.43	→	0.70	↓
HR	0.27%	1.43	↑↑	0.78	↑↑	0.65	↑↑
IT	7.31%	1.33	↑	0.78	↑	0.53	↑
CY	0.06%	0.77	↑↑	0.31	↗↗	0.36	↑
LV	0.08%	0.75	↑	0.27	↑↑	0.48	→
LT	0.19%	1.02	↑	0.50	↑↑	0.52	↓
LU	0.21%	0.98	↓↓	0.50	↓↓	0.48	→
HU	0.66%	1.39	↑	1.00	↑↑	0.38	↓
MT	0.03%	0.69	↑	0.46	↑	0.23	↑
NL	6.21%	2.30	↑	1.56	↑↑	0.74	↓
AT	4.04%	3.20	↑	2.20	↑	0.98	↑
PL	2.69%	1.46	↑↑	0.96	↑↑	0.50	↑
PT	1.16%	1.70	↑	1.06	↑↑	0.60	→
RO	0.37%	0.46	→	0.28	↑↑	0.17	↓↓
SI	0.34%	2.11	↓	1.48	↓	0.60	→
SK	0.30%	0.98	↑↑	0.56	↑↑	0.42	↑↑
FI	2.24%	2.95	↓	2.01	↓↓	0.93	↓
SE	5.40%	3.40	↑	2.51	↑	0.89	↓

→ Annual growth between -0.5% and 0.5% (inclusive)

↑ or ↓ Annual growth between 0.5% and 2% or between -0.5% and -2% (inclusive)

↑↑ or ↓↓ Annual growth above 2% or below -2%

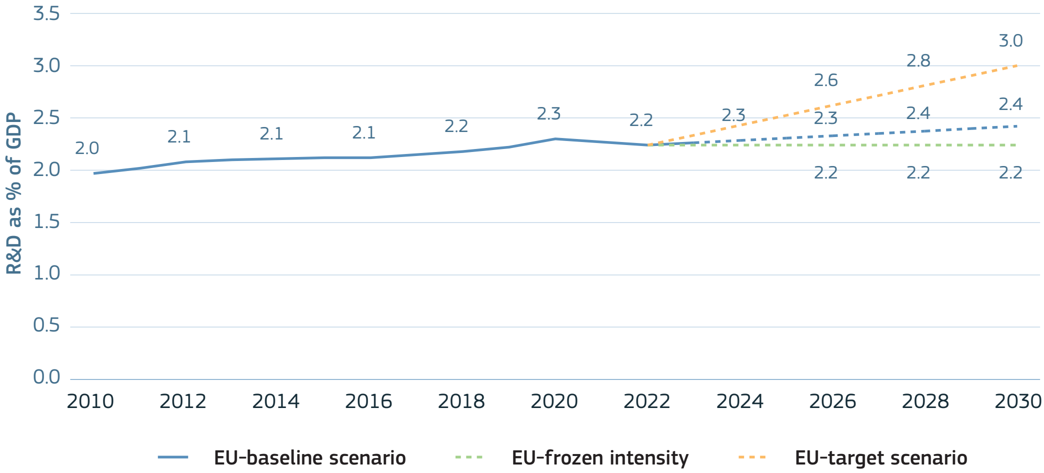
Science, research and innovation performance of the EU 2024

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

Note: Public sector is defined as government and higher education sectors.

If EU R&D intensity continues the trend observed in the past decade (1.1 % annual growth rate during the period 2011-2022), it will reach 2.4 % by 2030 (Figure 2.1-16). In order to attain the 3 % target by 2030, the average annual growth of the intensity must be 3.8 %, which is approximately 3 times higher than the average rate observed during the period 2010-2021.

Figure 2.1-16 Scenarios of EU R&D intensity until 2030



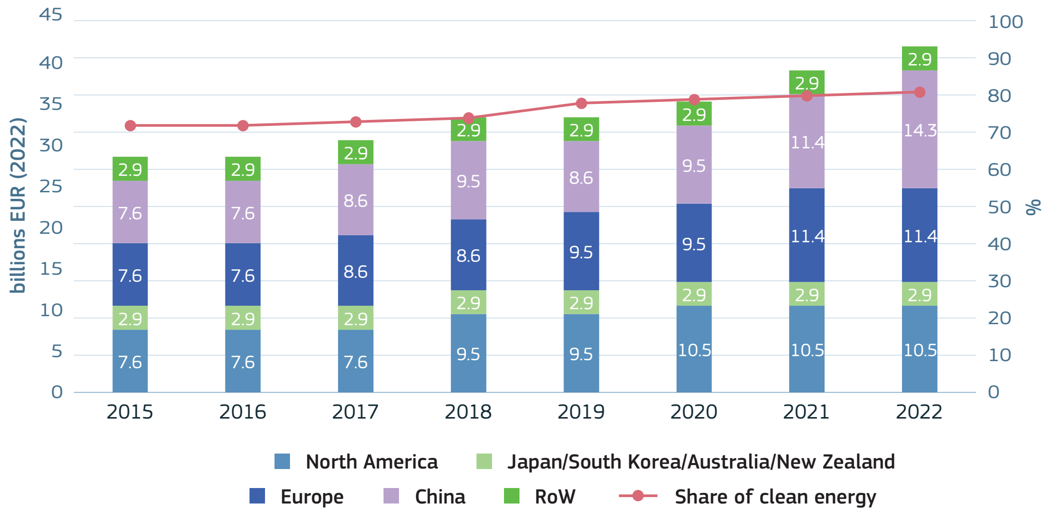
Science, research and innovation performance of the EU 2024

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

R&D investments and the twin transitions

Global R&D spending on clean energy increased between 2015 and 2022, with Europe investing more than the US but less than China in 2022 (Figure 2.1-17) (IEA, 2023; European Commission, 2023a). However, to achieve the European Green Deal's objectives and the Fit for 55 package's targets, it is crucial to keep accelerating the transfer of EU clean energy innovations into the market. According to the European Commission (2023a), in 2020, the private sector in the EU continued to invest comparable amounts – in absolute terms – with the US and Japan, accounting for around 80% of all R&I funding. In terms of private R&I investment per GDP, this still positions the EU ahead of the US but behind the major Asian economies.

Figure 2.1-17 Spending on energy R&D by governments, 2015-2022



Source: International Energy Agency, Spending on energy R&D by governments, 2015-2022, IEA, Paris.
Note: R&D is defined as spending reported by governments and state-owned enterprise spending. Estimations for 2022 are preliminary based on data available by mid-May 2023. US data is estimated from public sources. 'Rest of world' comprises Brazil, Chile, India, Indonesia, Russia, Saudi Arabia and South Africa.

Governments R&D intensities worldwide are much smaller than those of several top R&D spending companies. In the top R&D spending countries, government budgets for R&D (performed either by public or private sector) worldwide ranged from 0.48 % of GDP (China) to 1.07 % (South Korea) in 2020, while in the private sector, top spenders dedicated between 6 % and 28 % of their net sales to R&D in 2020. In the ICT sector, the tech giants dedicated budgets that amount to the same as some governments in absolute terms (Table 2.1-2).

Table 2.1-2 R&D investments and intensities for top spending countries and companies, 2020

	Industry sector (for companies)	R&D expenditure by government (in billion EUR)	R&D intensity (R&D investments as % of GDP for countries, % of net sales for companies), 2020
US Government		135.9	0.74
EU Governments		93.4	0.69
Chinese Government		61.3	0.48
Japanese Government		22.0	0.5
South Korean Government		15.5	1.07
Amazon	**Retail**	37.4052	11
Alphabet	**ICT services**	24.1776	15
Huawei	**ICT hardware**	19.272	16
Microsoft	**ICT software and services**	16.9068	13
Apple	**ICT hardware**	16.4688	7
Samsung	**ICT hardware**	16.4688	9
Meta	**ICT software and services**	16.206	21
Volkswagen	**Automotive**	13.86	7.6
Intel	**Semiconductors**	11.9136	5.6
Roche	**Pharmaceuticals, biotechnologies**	11.388	23.8
Johnson & Johnson	**Pharmaceuticals, biotechnologies**	10.6872	28.3

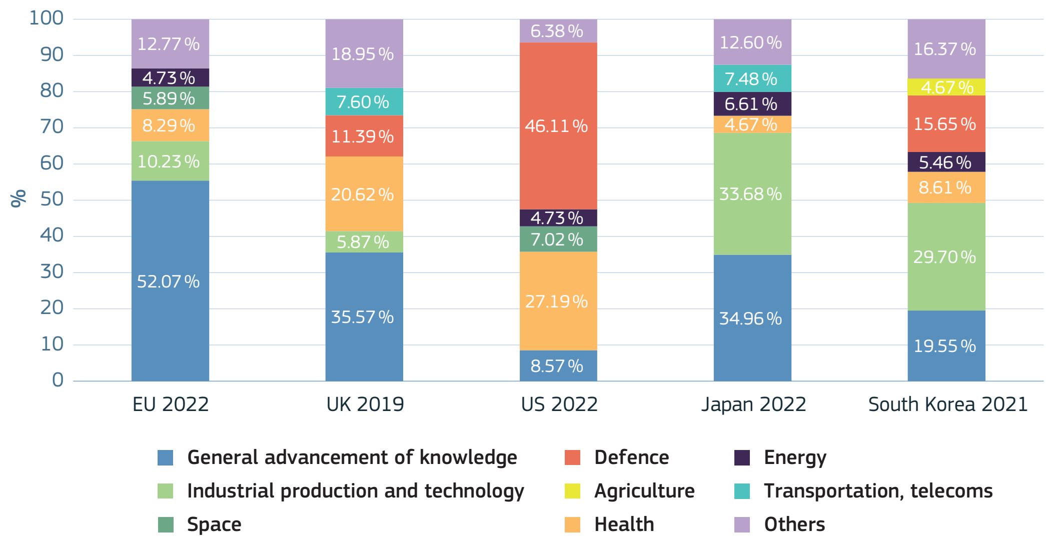
Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Eurostat and Nasdaq data.

Note: R&D expenditures from private companies also include support through government tax incentive schemes.

International competitors of the EU, such as the US, Japan and South Korea have adopted a strategic approach to R&I funding. Government budget allocations for R&D per socioeconomic objectives in these countries are concentrated in a few strategic sectors (Figure 2.1-18). For example, the US Government dedicates 46 % of its R&D allocation to defence, 27 % to health and only 9 % to general advancement of knowledge, whereas the Japanese and South Korean Governments dedicate 34 % and 30 % respectively to industrial production and technology, and 35 % and 20 % to the general advancement of knowledge. No data is available for China at this level, but recent studies tend to demonstrate that the Chinese Government has concentrated resources allocated to R&D in a few strategic sectors. The Made in China (MIC) 2025 strategy has set out 10 priority sectors and its successor, the 14th Five-Year plan, has created national laboratories in key S&T areas. Concerning the EU, data reporting categories are not allowed to have detailed information on the budget allocated to the higher education sector per precise socioeconomic objectives. Therefore, it appears that the EU allocates more than 50 % of its budget to the general advancement of knowledge. Hence, it is difficult to conclude that the EU is less strategic in its approach, but it seems that EU governments give more freedom to higher education institutions to direct R&D funding than their international counterparts. To conduct a meaningful comparative analysis, data collection on the actual public spending per socioeconomic objectives would be needed.

Figure 2.1-18 Government budget allocations for R&D (GBARD) by socioeconomic objective, 2022 or latest year available



Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Eurostat data.
Note: For each region/country, all sectors with a percentage below 4.5 % have been included in the category 'others'.
As far as the EU is concerned, socioeconomic objectives are not reported by the statistical offices for the budget allocated to the higher education sector.

2. Policies, instruments and approaches to boost and direct private R&I investments

To boost R&I investments towards achieving societal goals, governments worldwide employ different policy approaches. One of them is the mission-oriented policy. It is likely that this approach originates from the US, where the Manhattan project and the Apollo mission were launched in the 1940s. Since then, this approach for R&I policies has attracted attention by policymakers. Recently, the US and China have implemented mission-oriented policies such as the Cancer Moonshot 2.0 (US) and the MIC 2025 strategy and Major projects (China) with targeted objectives that require multi-agency and cross-sector cooperation. Missions are often designed to attract both public and private stakeholders and orient business R&I investments towards the purpose of the missions.

The EU Missions, launched under Horizon Europe (2021-2027), are a new way to focus investments and bring solutions. They address societal and global challenges, which the EU has addressed in past years, investing through various methods of intervention – from the scientific fellowships, general advancement of knowledge and lab research to the innovations of highly technological market potential. Therefore, the Missions naturally benefit from the indirect support of the EU framework programme, as well as other instruments such as LIFE, the instrument for environmental and climate action, the Innovation Fund, and Interreg, for European territorial cooperation, creating synergies across EU sectoral policies.

Over the past decade, around 5 000 R&I projects representing a total funding of EUR 13 billion are relevant to the Missions' objectives (Table 2.1-3). The EU continued its investments in 2023, notably through Mission-targeted investments (Mission work programmes), but also other actions, which to date account for EUR 3.2 billion, including around EUR 1.4 billion in Mission-specific calls[1].

Table 2.1-3 EU Missions in Horizon 2020, Horizon Europe (2014-2022)

	R&I projects (actions x 1 000)	Estimated EU funding (billion EUR)
Climate adaptation	0.5	2.2
Cities	1.2	3.2
Cancer	1.9	3.3
Ocean	0.5	3.4
Soil	0.4	1.3
R&I project values	4.7*	13

Science, research and innovation performance of the EU 2024
Source: European Commission, EU mission portfolio as of November 2022.
Note:*Total figure represents the value of unique investments. EU mission portfolios can consist of overlapping actions, such as, for example, Cities and Climate action.

1 31 mission-specific calls as of October 2023.

Examples of solutions funded under Horizon 2020 and Horizon Europe, contributing to the missions' objectives:

The Climate adaptation mission:

- Vineyards' Integrated Smart Climate Application (VISCA);
- Supporting viticulturists in climate change adaptation with VISCA DSS;

Mission ocean:

- Cleaning litter by developing and applying innovative methods in European seas (CLAIM);
- Floating rooms – marine litter collection and recovery system (Clean trash).

For more examples on Mission ocean, please see the *Ocean mission dashboard*, which presents the results of the analysis of a portfolio of 841 EU projects relevant to the Mission's objectives. These projects have been funded by 16 EU programmes over a period of 9 years between January 2014 and December 2022. It offers a structured overview of the projects' results and contribution to the objectives of the Mission, the Green Deal targets and geographical areas.

Mission soil:

- Cost-effective robots for smart precision spraying (SCORPION);
- Exploiting the multifunctional potential of belowground biodiversity in horticultural farming (EXCALIBUR)

Mission cities:

- Building green and climate-neutral city hubs (CLIMABOROUGH);
- Smart public transport initiatives for climate neutral cities in Europe (SPINE);

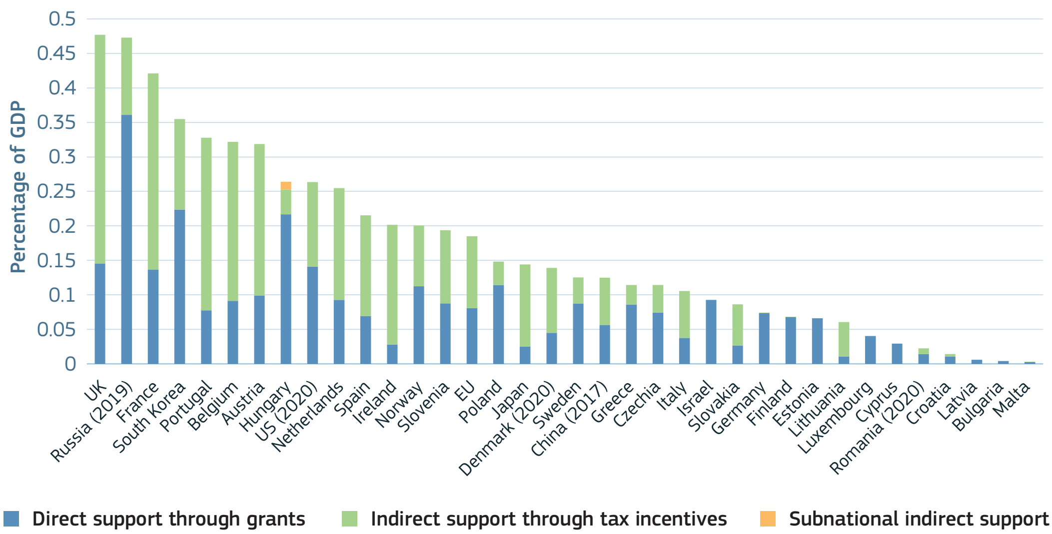
Mission cancer:

- Streamlined identification of tumour neoantigens for personalised anti-cancer immunotherapy (PeptiCHIP);
- PeptiCHIP platform for fast and accurate neoantigen identification.

Globally, public-private partnerships (PPPs), launched notably through innovative public procurement, represent one of the main instruments for national programmes and strategies to support R&I, partly since public finances are scarcer and programmes to support R&I activities are designed to leverage private investment.[2] The US has one of the longest and best track records of using public-private partnerships (PPPs) for R&I purposes (since the 1940s) with a wide diversity in the types of PPPs. China started later but has put increasing efforts into PPPs. As for the EU, some Member States launched their first initiatives into PPPs for R&I in the 1960s. The European Union introduced them in 2007 and has since increased their dedicated budgets incrementally (European Commission, 2023b).

Over the past decades, EU governments have increasingly favoured tax incentives to support private R&D investments over direct funding, even if this preference decreased slightly after the COVID-19 crisis (Figure 2.1-19). To support private R&D investments, governments worldwide also use different funding instruments, including direct support tools, such as R&D grants or government procurement of R&D services, and indirect support through R&D tax incentives, i.e., a preferential tax treatment of business R&D expenditures in the form of a tax credit, enhanced tax deduction or exemption. In 2020, R&D tax incentives accounted for close to 55 % of total support for business R&D in the EU compared to 58 % in 2019, while direct support to business R&D accounted for 45 % compared to 42 % in 2019. Besides, in a context of economic contraction due to the COVID-19 crisis, the total amount of government support to private R&D in the EU decreased in 2020 by 3.4 %, due to the decrease in tax support. While direct funding of business R&D increased in 2020, this increase was, in absolute terms, not large enough to offset the decline in R&D tax support (OECD, 2023a).

Figure 2.1-19 Direct government funding and tax support for business R&D, 2021 or latest year available



Science, research and innovation performance of the EU 2024

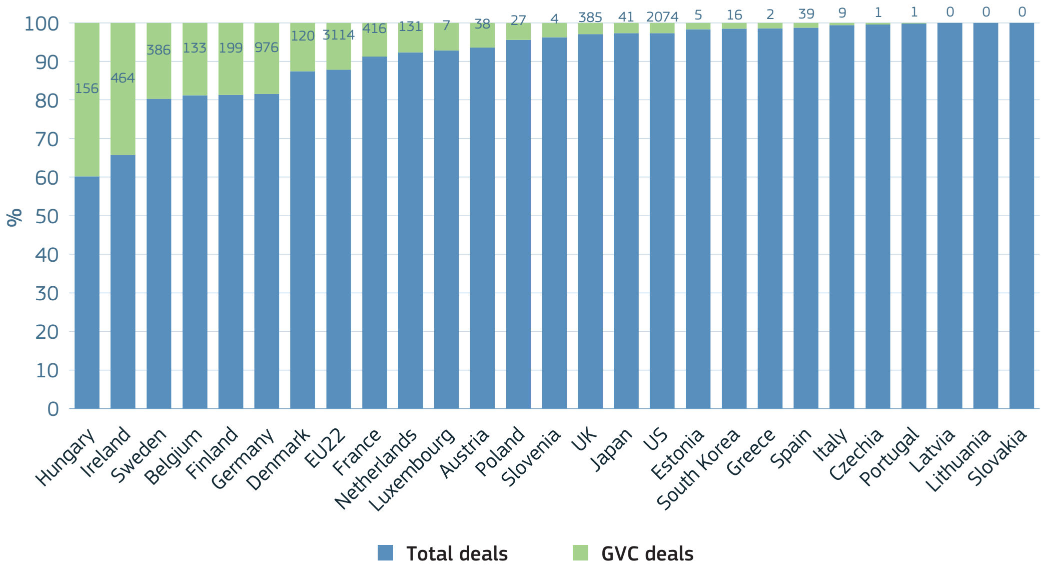
Source: OECD R&D tax incentives database (https://oe.cd/rdtax), April 2024.

Note: Data on subnational tax support for business R&D are only available for a group of countries. For additional information on the availability, design and implementation of R&D tax incentives in the EU region and OECD area, see OECD INNOTAX Portal, https://stip-oecd.org/innotax/

2 As argued by OECD (2005), public/private partnerships (P/PPs) offer a framework for the public and the private sectors to join forces in areas in which they have complementary interests but cannot act as efficiently alone.

Governments around the world have also taken a strong interest in government venture capital (GVC). This interest stems in part from the fact that some of the world's most influential enterprises, such as Google, Intel and Apple, were financed by venture capitalists (Brander et al., 2015). The creation of GVC funds is primarily meant to correct supply-side failures in domestic venture capital (VC) markets (Colombo et al., 2016) and to promote innovation. The EU[3], while being far behind the US in terms of total public and private VC funding, but well ahead of Japan and South Korea, is the region with the highest relative share of GVC in total VC funding (Figure 2.1-20).[4] GVC investments are observed in around 8% of all VC investments, a number similar to the one found by Alperovych et al. (2015). In the US, GVC represents between 2% and 3% of investments, whereas in other regions it is about 1% of investments. However, despite the high number of GVC funds in Europe (e.g. Biotech Fonds Vlaanderen in Belgium, SITRA in Finland, Caisse des Dépôts et des Consignations Innovation in France, the Technologie-Beteiligungsgesellschaft in Germany, Piemontech in Italy, Axis Participaciones Empresariales in Spain), the existing literature and evidence on the impact of GVC on portfolio companies' performance in Europe is rather limited (Ariffin et al., 2023).

Figure 2.1-20 Number of total and government venture capital deals per country, 2000-2019



Science, research and innovation performance of the EU 2024

Source: OECD calculations according to Dechezleprêtre & Fadic (2020). Can Government Venture Capital help bring research to the market? OECD publishing office.

Note: The sample used in the analysis only includes firms that have investor information.

3 Only 22 EU Member States could be included in the analysis due to lack of data.

4 Related evidence from a pilot mapping exercise of business innovation support (OECD, 2023b) in five volunteer countries (Australia, Canada, France, Netherlands, Norway) highlights the important role of equity investments within the national business innovation policy mix. Equity investments, which inter alia include GVC, feature as the third most used instrument on average among the five countries considered.

Tax incentives and direct funding demonstrate a similar degree of effectiveness with a gross incrementality ratio (IR) of around 1.4 for both policy instruments, i.e., one extra unit of R&D tax or direct support translates into 1.4 extra units of R&D (OECD, 2023c). However, while R&D tax incentives can be easier to implement than direct subsidies, they can complicate the tax code and increase compliance costs on a recurrent basis (Table 2.1-4). This can also increase the burden for taxpayers and tax authorities. In addition, they are also harder to monitor and to direct, including towards societal challenges. Several studies also point to potential risks of tax competition (Alstadsæter et al., 2018; OECD, 2016; OECD, 2020). As for GVC, administrative costs are high, but budget control is stringent. Nevertheless, while access to financial and human capital through GVC tends to have bigger and longer effects on access to finance than subsidy (Söderblom et al., 2015), it seems to be associated with a higher risk of crowding out private investments, including R&D investments (Cumming et al., 2017; Kirihata, 2017).

Table 2.1-4 Main use, characteristics and impacts of R&I policy instruments used worldwide

	Direct funding of business R&D (R&D grants)	R&D tax incentives	Government venture capital funds
Definition and use	Main instrument to support public R&I performed by public institutions and basic research in all sectors, according to direction set by governments.	Firms in the information & communication and computer & electronics industries often account for a large share of R&D tax benefits.	GVC is an entity established, owned, funded and operated by the government to provide venture financing.
Main characteristics	▸ High budget control; ▸ Higher administrative burden and compliance costs; ▸ Risk of government failure in 'picking losers' (Dechezleprêtre et al., 2023); ▸ Often directional as governments select R&D projects with the highest social returns; ▸ Best suited to encourage high-risk projects and to meet policy goals; ▸ Adequate to target R&D activities with the highest discrepancy between social and private returns; ▸ Encourage cooperation and technology transfer.	▸ More limited ability to forecast and manage impact on public finances; ▸ Comparatively lower administration and compliance costs, but can complicate the tax code and increase compliance costs on a recurrent basis; ▸ Non-discretionary nature (ex-ante non-directional in terms of allocation of support to specific R&D projects, e.g. fields of research, technology or industrial sectors), and thus more easily compliant with competition and international trade rules (OECD, 2014); ▸ Greater risk of dead weight loss (subsidising R&D investments which would have been undertaken in the absence of support); ▸ Risk of entities relabelling other activities as R&D; ▸ Risk of tax competition and relocation of R&D activities (Alstadsæter et al., 2018; OECD, 2016; OECD, 2020).	▸ High budget control; ▸ Best suited to encourage high-risk projects and to meet policy goals, even if they are not immediately profitable; ▸ High administrative burden; ▸ Bureaucratic red tape and delays, making it more difficult for start-ups to access funding quickly; ▸ Less efficient allocation of resources and potentially 'picking winners' based on political considerations; ▸ Risk of crowding out private capital; ▸ Risk of not exiting investments in a timely and profitable manner in order to prioritise social or political goals over financial returns.
Impacts	OECD (2023) analysis shows a similar degree of input additionality for direct funding as a gross IR of around 1.4 for both instruments (one extra unit of R&D support translates into 1.4 extra units of R&D). It hints at the complementarity of direct and indirect support measures. It should be noted that most countries prevent directly funded R&D amounts to be claimed for tax purposes.		When GVC co-invests with international VC, it yields a positive effect on sales growth (Islam et al., 2018). Access to financial and human capital tends to have effects that are substantially bigger and longer than subsidy (Söderblom et al., 2015).

Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on multiple sources (see references section).

Innovation procurement or innovative public procurement is also an important tool to stimulate innovation, as it enables the public sector to steer the development of new solutions by private actors directly towards its needs. As defined by the European 2021 guidance[5], innovation procurement refers to any procurement that has one or both of the following aspects: buying the process of innovation – research and development services – with (partial) outcomes and/or buying the outcomes of innovation. The public buyer first describes its need, prompting businesses and researchers to develop innovative products, services or processes, which do not yet exist on the market, to meet the need. Aiming at triggering the demand to develop and/or purchase innovative solutions, the EU supports innovation procurement mainly through two different procurement approaches and funding schemes, notably pre-commercial procurement (PCP) and public procurement of innovative solutions (PPI).

In the EU, over the past two decades, policy approaches and instruments to support R&D have been designed increasingly in line with a new framework for R&I policies: the transformative innovation policy (TIP), or, extending to R&I, the transformative research and innovation policy (TRIP), which supports the transformative change of our economies (Steward, 2012; Schot and Steinmueller, 2018; Diercks et al., 2019; Haddad et al., 2022; European Commission, 2023b). Transformative change is focused on using science and technology to address grand societal challenges such as climate change, inequality and poverty. It is based on the idea that innovation can be used to create a more sustainable and equitable society (Schot and Steinmueller, 2018). TRIP differs from more traditional approaches to R&I policies on several aspects, including the policy rationale and the monitoring of these policies (Table 2.1-5). TRIP is still a relatively new concept, and there is no one-size-fits-all approach to implementing it. However, there are a number of principles that can be followed (Haddad et al., 2022; Schot and Steinmueller, 2018), such as:

- directionality and sustainability, which focuses on long-term, systemic impacts;
- involving a wide range of stakeholders;
- policy coordination, which involves using a mix of policy instruments and coordinating across levels of government;
- learning and experimentation, which includes evaluating the impact of policies over time.

5 DocsRoom – European Commission (europa.eu).

Table 2.1-5 Key differences between traditional R&I policy and TRIP

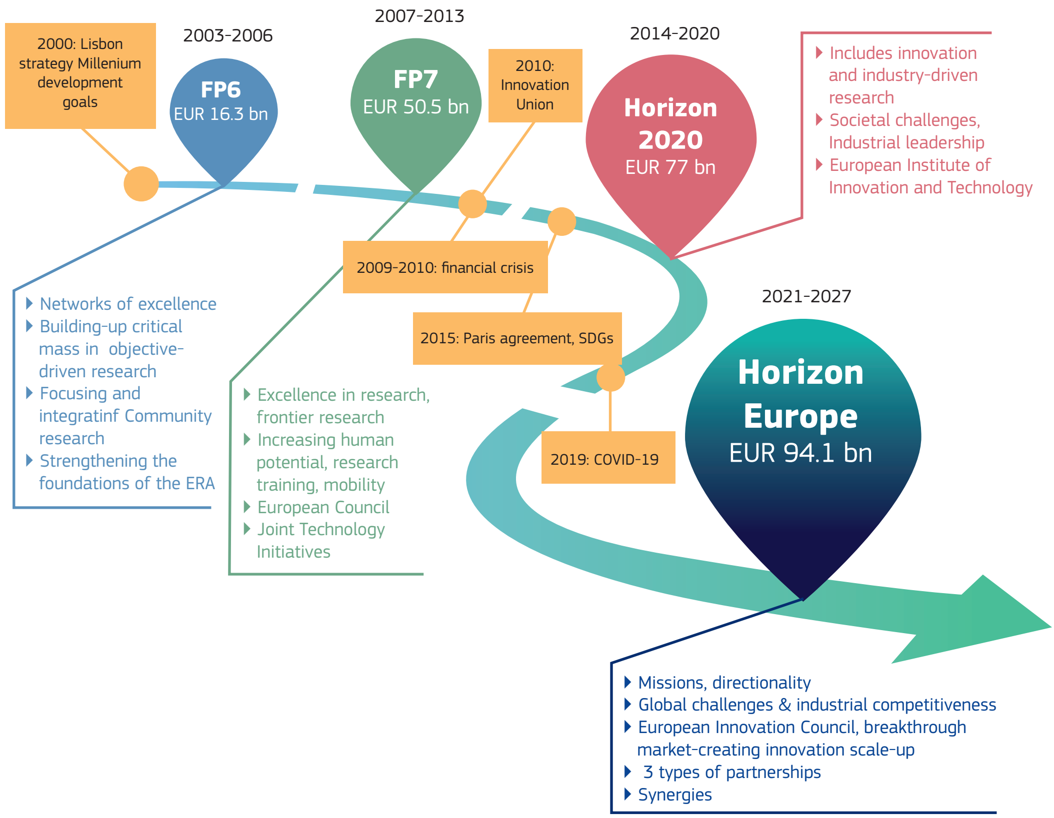
Characteristic	Traditional R&I policy	Transformative innovation policy
Focus	▸ Addressing market failures to boost economic growth and competitiveness.	▸ Achieving long-term, systemic impacts.
Policy rationale	▸ Stimulate and support innovation by directly funding R&D activities, providing incentives for firms to engage in R&D, and facilitating the transfer and diffusion of knowledge; ▸ The 'more the better' approach (Anderson et al., 2014), i.e. belief that increasing funding for R&D will inevitably lead to more and better innovations.	▸ Provide a direction of change, focusing on specific societal challenges and desired outcomes. Achieve systemic change through innovation.
Approach to innovation	▸ Linear innovation model, which assumes a sequential progression from basic research to applied research, development and ultimately commercialisation, and which can be stimulated by investing more money.	▸ System-level and mission-oriented approach that emphasises co-creation, experimentation and learning.
Instruments	▸ State financing of R&D; subsidies or tax incentives for business R&D, regulatory changes to improve access to finance and framework conditions for R&I.	▸ Policy mixes involving multiple sectors and stakeholders, such as regulatory change, market incentives, public-private partnerships through subsidies, tax incentives and innovation public procurement.
Evaluation	▸ Experts' ex-post assessment based on economic, research and innovation input and output indicators.	▸ More participatory/deliberative methods to agree on targets and indicators, long-term evaluation and monitoring, and formative and developmental analysis, as well as reflexivity; ▸ Identify strengths and weaknesses, in moving away from output indicators to focus more on impacts and the implementation process.

Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on multiple sources, including European Commission (2023); Santos and Coad (2023); European Commission (2023a).

Over the past 20 years, the European framework programme for R&I (EU FP for R&I) has not only grown in terms of budget but also in its scope, objectives, programme parts, pillars, instruments, and planning processes (European Commission, 2021; Figure 2.1-21). As part of its evolution, an increasing emphasis has been placed on activities to generate innovations with the potential to address societal challenges. While 'excellence' remains a key driving principle of FPs, new instruments based on 'directionality' of funding, i.e., defining the specific objectives which the supported R&I activities should achieve or targeting specific areas of R&I, have gradually been introduced. Moreover, the policy approach under the framework programme has taken on an increasingly more systemic approach and benefited from more inclusive and participatory design (European Commission, 2023a). This evolution throughout the years has therefore resulted in the FP embedding key elements of transformative research and innovation policies.

Figure 2.1-21 Evolution of the European framework programme for R&I in terms of budget, scope and objectives, 2002-2023



Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit.
Note: Budgets refer to planned budgets as the maximum overall amount included in the EU regulations.

The effectiveness of TRIPs requires using methods and approaches that are different from those of traditional R&I policy (Table 2.1-6). Designing, implementing and evaluating TRIPs effectively requires a comprehensive approach that encompasses systems thinking, experimentation, data collection, stakeholder involvement, continuous monitoring and evaluation (European Commission, 2023a; Santos and Coad, 2023). Evaluating TRIPs effectively requires innovative methods, which should:

- be holistic in scope, capable of addressing a diverse array of contexts without privileging any particular setting (e.g., high- or middle-income countries, 'free market' or more regulated economies);
- be able to address a diversity of options, without unduly favouring particular kinds of intervention (e.g., public or private, supply- or demand-side, or technology- or organisationally based innovations);
- rather than being hardwired to identify a notionally single 'best' prescription, be capable of addressing interactions, complementarities and tensions across portfolios of possible options (i.e., leaving open the possibility for finding mixes, not single interventions);
- engage with conditionalities in respect of particular features of options, contexts or the unfolding of time (e.g. interrogation at the granularity of particular instruments rather than general policies);
- give balanced attention to a plurality of relevant specialist understandings and perspectives (e.g., engaging diverse stakeholder interests);
- be capable of addressing uncertainties ex-ante (e.g., exploring the full range of possibilities for how innovations or their contexts may unfold over time, without artificial probabilistic aggregations) (Coburn et al., 2021).

Table 2.1-6 Key differences in evaluation methods for traditional and transformative R&I policy

Feature	Traditional R&I policy	Transformative innovation policy
Focus	▸ Measure the impact of R&I investments on economic growth and competitiveness; ▸ Focus on analysing the effectiveness and additionality of one single policy instrument, leaving context and conditions aside: what is the best policy option?	▸ Assess the ability of R&I to address societal challenges, sustainable development goals (SDGs) and achieve systemic change; ▸ Focus on a policy mix considering interactions with other policy instruments: which policy instruments are expected to perform more or less favourably, under which conditions and why?
Evaluation time frame	▸ Summative assessment approach: ▸ End-of-term or end-of-project focus: ▸ Summative assessments are usually administered at the conclusion of a programme; ▸ High-stakes nature: ▸ Results of summative assessments often carry significant impacts, such as certifications, or decisions regarding programme effectiveness; ▸ Objective measurement: ▸ Designed to provide quantifiable and objective data on specific outcomes or criteria.	▸ Formative assessment approach: ▸ Continuous programme progress evaluation to enable improvements;. ▸ Sense making process: ▸ Actors involved express expectations and a sense of urgency to take action, understanding the system and using system mapping (a powerful tool to attain the goal); ▸ Change trajectories of the assessment framework: ▸ Learning plans, theories of change for the system; ▸ Focus on the development, validation and rollout of the assessment / user journey, and not on output indicators.
Methods	▸ Quantitative methods, such as cost-benefit analysis and econometric modelling.	▸ Employs a mixed-method approach that combines quantitative and qualitative data to capture the complexity of transformative change, e.g., case studies, bibliometric analysis, simulation, deliberative decision analysis interactive metrics, uncertainty appraisal, multi-criteria mapping (Coburn et al; 2021; Santos and Coad, 2023; Haddad and Bergek, 2023; TIPC, 2019).
Stakeholders involved	▸ Primarily focuses on the perspectives of researchers, policymakers and industry leaders.	▸ Actively engages with a broader range of stakeholders, including civil society organisations, community groups and end users.
Challenges	▸ Attributing impacts to specific R&I investments, accounting for long-term effects, measuring intangible benefits;	▸ Hard to conceptualise systems – all policy cases have a different understanding of the systems; ▸ Hard to integrate different analytical levels, cover long time spans of missions (and impacts), and capture diversity and heterogeneity (Wittmann et al., 2022); ▸ Defining and measuring system-level changes, dealing with uncertainty and complexity, lack of data to measure impacts on societal challenges and SDGs; ▸ Significant time investment from both evaluators and participants.
Examples	▸ Evaluations of R&D tax credits, evaluations of research programmes, evaluations of technology transfer programmes.	▸ Evaluations of mission-oriented R&I programmes, evaluations of sustainability transitions, evaluations of transformative innovation policy.

Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on multiple sources.

References

Aghion, P., Askenazy, P., Berman, N., Cette, G., Eymard, L., (2012), 'Credit constraints and the cyclicality of R&D investment: Evidence from France', *Journal of the European Economic Association*, 10(5), pp.1001-1024.

Alperovych, Y., Hübner, G., Lobet, F., (2015), 'How does governmental versus private venture capital backing affect a firm's efficiency? Evidence from Belgium', *Journal of Business Venturing*, 30(4), pp. 508-525.

Alstadsæter, A., Barrios, S., Nicodeme, G., Skonieczna, A.M., Vezzani, A., (2018), 'Patent boxes design, patents location, and local R&D', *Economic Policy*, 33(93), pp. 131-177.

Anderson, N., Potočnik, K., Zhou, J., (2014), 'Innovation and creativity in organizations: A state-of-the-science review, prospective commentary, and guiding framework', *Journal of Management*, 40, pp. 1297-1333.

Ariffin, M., Muhammad, M. S., Hassan, H., M., Samad, A.R., (2023), 'Bibliometric Analysis of Government Venture Capital', *Journal of Information Technology Management*, 15(Special Issue), pp.166-188.

Barlevy, G., (2007), 'On the cyclicality of research and development', *American Economic Review*, 97(4), pp. 1131-1164.

Brander, J. A., Du, Q., Hellmann, T., (2015), 'The effects of government-sponsored venture capital: International evidence', *Review of Finance*, 19(2), pp. 571-618.

Coburn, J., Bone, F., Stirling, A., Hopkins, M., Mestre-Ferrandiz, J., Arapostathis, S., Llewelyn, M., (2021), 'Appraising research policy instrument mixes: a multicriteria mapping study in six European countries of diagnostic innovation to manage antimicrobial resistance', *Research Policy*, 50(4).

Colombo, M.G., Cumming, D.J., Vismara, S., (2016), 'Governmental venture capital for innovative young firms', *The Journal of Technology Transfer*, 41, pp. 10–24.

Comin, D., Gertler, M., (2006), 'Medium-term business cycles', *American Economic Review*, 96(3), pp. 523-551.

Cumming, D. J., Grilli, L., Murtinu, S., (2017), 'Governmental and independent venture capital investments in Europe: A firm-level performance analysis', *Journal of Corporate Finance*, 42, pp. 439-459.

Cumming, D., Johan, S., MacIntosh, J.G., (2017), 'A drop in an empty pond: Canadian public policy towards venture capital', *Journal of Industrial and Business Economics*, 44, pp. 103–117.

Dechezleprêtre, A., Einiö, E., Martin, R., Nguyen, KT., and Van Reenen, J., (2023), 'Do Tax Incentives Increase Firm Innovation? An RD Design for R&D, Patents, and Spillovers', *American Economic Journal: Economic Policy*, 15 (4), pp. 486-521.

Diercks, G., Larsen, H., Steward, F., (2019), 'Transformative innovation policy: Addressing variety in an emerging policy paradigm', *Research Policy*, 48, pp. 880-894.

European Commission (2023a), Progress on competitiveness of clean energy technologies, COM(2023) 652 final.

European Commission (2023b), The transformative nature of the European framework programme for research and innovation – Analysis of its evolution between 2002-2023, DG Research and Innovation, Publications Office of the European Union, Luxembourg.

European Commission (2023c), The 2023 EU industrial R&D investment scoreboard, DG Joint Research Centre, Publications Office of the European Union, Luxembourg.

Fabrizio, K.R., Tsolmon, U., (2014), 'An empirical examination of the procyclicality of R&D investment and innovation', *Review of Economics and Statistics*, 96(4), pp. 662-675.

Fatas, A., (2000), 'Do business cycles cast long shadows? Short-run persistence and economic growth', *Journal of economic growth*, 5, pp. 147-162.

Fuest, C., Gros, D., Mengel, P., Presidente, G., Tirole, J., (2024), EU Innovation Policy – How to Escape the Middle Technology Trap? EconPol Policy Report.

Haddad, C., Nakić, V., Bergek, A., Hellsmark, H., (2022), 'Transformative innovation policy: A systematic review', *Environmental Innovation and Societal Transitions*, 43, pp. 14-40.

Haddad, C., Bergek, A., (2023), 'Towards an integrated framework for evaluating transformative innovation policy', *Research Policy*, 52(2), pp. 1-17.

International Energy Agency (IEA) (2023), The World Energy Outlook 2023, IEA, Paris.

Islam, M., Fremeth, A., Marcus, A., (2018), 'Signalling by early stage startups: US government research grants and venture capital funding', *Journal of Business Venturing*, 33(1), pp. 35-51.

Kirihata, T., (2017), 'Crowding-in or crowding-out? The effects of public venture capital policies', *The Ritsumeikan Business Review*, 56(1), pp. 165-174.

Moncada-Paternò-Castello, P., (2016), EU corporate R&D intensity gap: *What has changed over the last decade?*, JRC Working Papers on Corporate R&D and Innovation.

OECD (2005), Public/Private Partnerships for Innovations, OECD Publishing, Paris.

OECD (2014), Tax incentives for R&D and innovation, OECD Publishing, Paris.

OECD (2016), R&D Tax Incentives: Evidence on design, incidence and impacts, OECD Publishing, Paris.

OECD (2020), The effects of R&D tax incentives and their role in the innovation policy mix: Findings from the OECD microBeRD project, 2016-19, OECD Publishing, Paris.

OECD (2023a), OECD R&D tax incentives database, 2022 edition. DSTI/STP/NESTI(2023)2/FINAL, OECD Publishing, Paris.

OECD (2023b), Government support for business innovation: Results from measurement pilots in five OECD countries, OECD Publishing, Paris.

OECD (2023c), The Impact of R&D tax incentives: Results from the OECD microBeRD+ project, OECD Publishing, Paris.

Rafferty, M. (2003), 'Do business cycles alter the composition of research and development expenditures?' *Contemporary Economic Policy*, 21(3), pp. 394-405.

Santos, A.M., Coad, A., (2023), 'Monitoring and evaluation of transformative innovation policy: Suggestions for Improvement', *Socio-Economic Planning Sciences*, 90.

Schot, J., Steinmueller, W.E., (2018), 'Three frames for innovation policy: R&D, systems of innovation and transformative change', *Research Policy*, 47(9), pp. 1554-1567.

Sedgley, N.H., Burger, J. D., Tan, K. M., (2019), 'The symmetry and cyclicality of R&D spending in advanced economies', *Empirical Economics*, 57, pp.1811-1828.

Söderblom, A., Samuelsson, M., Wiklund, J., Sandberg, R., (2015), 'Inside the black box of outcome additionality: Effects of early-stage government subsidies on resource accumulation and new venture performance', *Research Policy*, 44(8), pp. 1501-1512.

Steward, F., (2012), 'Transformative innovation policy to meet the challenge of climate change: sociotechnical networks aligned with consumption and end-use as new transition arenas for a low-carbon society or green economy', *Technology Analysis & Strategic Management*, 24(4), pp. 331-343.

Wittmann, F., Roth, F., Hufnagl, M., Lindner, R., Yorulmaz, M., (2022), 'Towards a framework for impact assessment for mission-oriented innovation policies', A formative toolbox approach, *Journal for Research and Technology Policy Evaluation*, 53, pp. 31–42.

CHAPTER 2.2

TECHNOLOGICAL LEADERSHIP AND GEOECONOMICS

Key questions

- What are the latest trends in the EU technological performance vis-à-vis other major global players?
- What are the EU's main industrial strategic dependencies?
- What can policy do and is it currently doing to strengthen the EU's technological sovereignty and strategic autonomy?

Highlights

- The EU retains its strength in green technologies, but needs to step up within the digital domain.
- Digital technologies are instrumental in enhancing competitiveness and fostering growth. Nevertheless, the EU's position to lead technological change in areas related to strategic productivity-enhancing technologies (e.g. Internet of Things, blockchain, artificial intelligence and cybersecurity technologies) remains weaker than that of the US and China.
- The EU remains vulnerable to supply chain disruptions in several key sectors, including critical raw materials and the manufacturing of green technologies, batteries and semiconductors.

Policy insights

- R&I policy remains key to building the EU's technological sovereignty and guaranteeing its strategic autonomy, calling for increasing efforts for the EU to remain a main actor in the development and governance of strategic technological fields.

- Increasing R&I investments remains key, calling for a structural approach towards strategic funding and technological development, targeted at bridging the specialisation gap between the EU and its main counterparts in those technologies more likely to deliver important productivity gains in the long term.

- At the same time, the EU can continue to leverage its comparative advantage in green technologies, whose demand is expected to increase given the type of industrial policies put forward by the EU's main counterparts.

- Furthermore, the risk for the EU to remain technologically dependent on other global players in strategic fields raises the stakes for science diplomacy and collaborations with international partners, from which the EU can gain in terms of technological complementarities.

- Addressing strategic dependencies along key supply chains also remains important, especially for clean energy technologies, to guarantee the ability of the EU to pursue its energy security and decarbonisation ambitions.

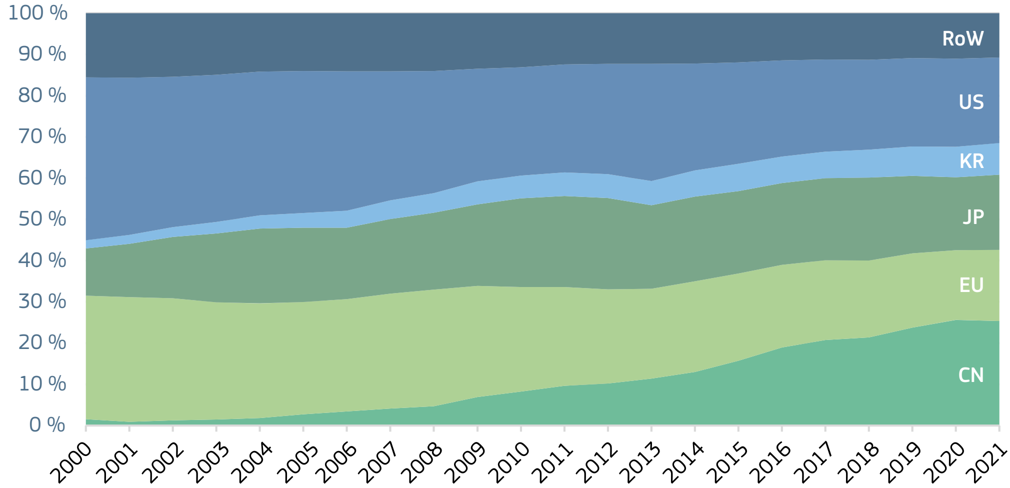
Since 2020, **a series of shocks have put into question the existing globalisation-driven growth model in the EU and worldwide**. The cumulative impacts of the COVID-19 pandemic, the Russian invasion of Ukraine, and the energy crisis have not only intensified geopolitical tensions, but also created a more inflation-prone and competitive global environment, marked by value chain fragmentation. On top of this, the trade war between the US and China, currently revamped by new Chinese export restrictions on important critical raw materials (such as gallium and germanium), threatens to drive up the cost of the clean-energy transition, and to intensify the technology race between global powers. Given current economic and political trends, the globalisation process may undergo significant changes, moving towards a restructuring of production networks in which regional blocks may start emerging more prominently.

From a policy standpoint, these factors have prompted a change in the European policymakers' agenda, now marked by three competing priorities: **achieving strategic autonomy, enhancing economic efficiency and advancing global decarbonisation**, (Aghion et al., 2023). The discussions on how to strike a balance between pursuing economic efficiency and ensuring economic and geopolitical resilience, while maintaining efforts to promote cohesion and social protection, have become central in policy and political debates. These discussions hold significant implications for future economic policies, including those related to research and innovation (R&I) and industrial policy.

1. Strengths and weaknesses of the EU's technological performance

The EU's share in total patent applications has been declining in recent decades. In 2000, the EU accounted for around 30% of the world's patent applications, while its share had declined to 17.3% in 2021 (Figure 2.2-1). On the contrary, China has experienced a significant increase over time, overtaking both Japan and the EU in 2017. In 2019, China was able to also outperform the US, with 23.8% of total patent applications against 21.5%, respectively. Since then, the position of the US has kept weakening, while Chinese performance has continued to improve, recording a global share of 25.4% in 2021, against the 20.7% observed in the US.

Figure 2.2-1 World share (%) of patent applications filed under PCT(1), 2000-2021



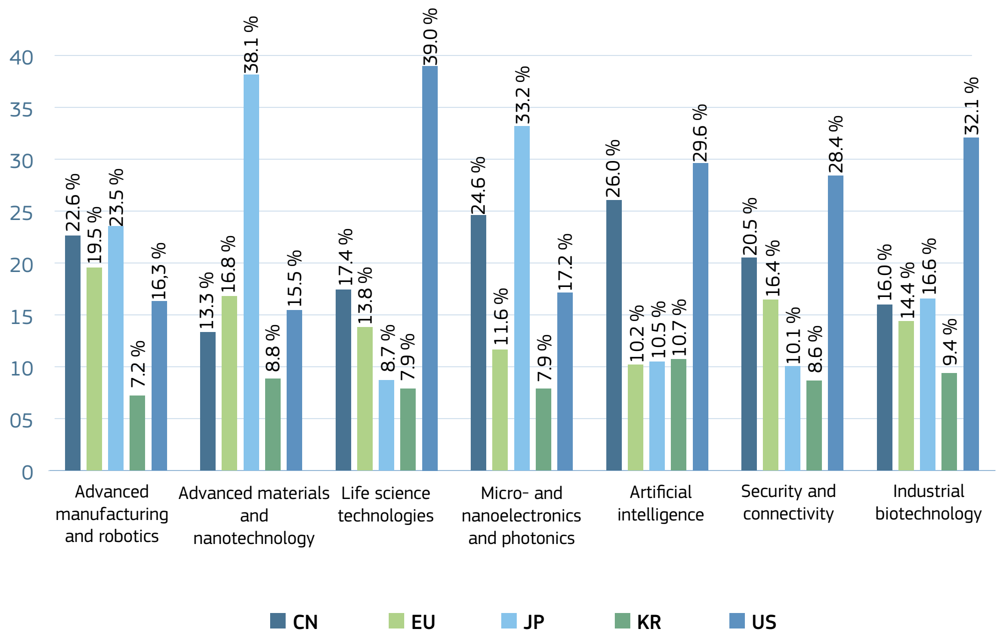
Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Fraunhofer ISI, using PATSTAT.

Notes: (1) Patent Cooperation Treaty (PCT) patents. Fractional counting method, inventor's country of residence and priority date used.

The EU underperforms in several key enabling technologies (KETs) compared to other big global innovators, in terms of world share of patent applications. In 2021, the EU's share in the world patent applications was lower than that of the US and China in several KET fields, including life science technologies, and security and connectivity. The fields in which the EU's performance is lowest are micro- and nano-electronics and photonics, as well as artificial intelligence (AI), in which the EU reported a share of 11.3 % and 10.2 % respectively in 2021, against the 24.6 % and 26 % recorded in China, and the 17.2 % and 29.6 % observed in the US (Figure 2.2-2). The EU's performance is also weak in the field of industrial biotechnology, where it ranks fourth after the US, Japan and China, with the gap with the US remaining substantial (14.4 % against 32.1 %). On the contrary, the EU maintains a stronger position in advanced materials and nanotechnologies, in which it outperforms both China and the US although it remains significantly behind Japan. Furthermore, the EU also retains strength in the areas of advanced manufacturing and robotics, positioning itself above the US (with 19.5 % versus 16.3 %, respectively), but remaining well below China and Japan (Figure 2.2-2).

Figure 2.2-2 World share (%) of patent applications filed under PCT(1), by key enabling technologies, 2021



Science, research and innovation performance of the EU 2024

Source: DG Research and innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Fraunhofer ISI, using PATSTAT.

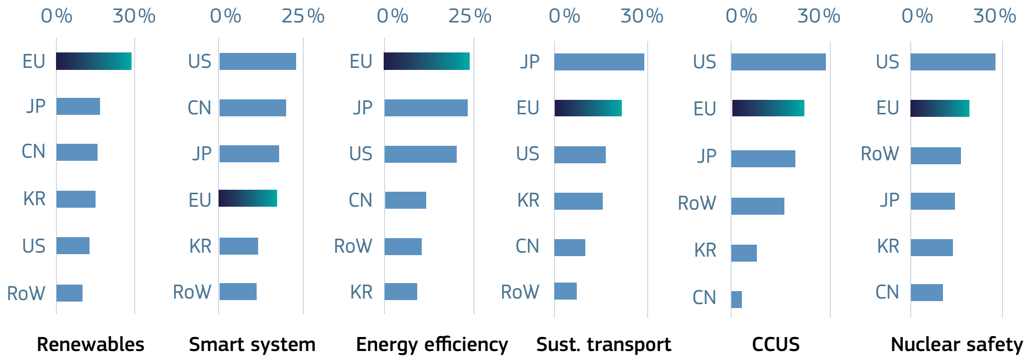
Notes: (1) Patent Cooperation Treaty (PCT) patents. Fractional counting method, inventor's country of residence and priority date used.

However, the EU remains strong in green sectors, although it faces increasing competition, especially from China. In 2019, China ranked first in terms of patent activities in green technologies. Nevertheless, when focusing on high-value green inventions, the EU remains in the lead, despite reporting a significant decrease as compared to the previous year.[1]

Furthermore, between 2014 and 2020, the EU kept leading in global high-value patent filings related to renewables (29 %) and energy efficiency (24 %), but lost ground in smart systems (17 %) ranking fourth after the USA, China and Japan (Figure 2.2-3).

1 Joint Research Centre, European Commission.

Figure 2.2-3 Share in global high-value patent filings relevant to the Energy Union R&I priorities, 2014-2020



Science, research and innovation performance of the EU 2024

Source: Georgakaki et al., (2023).
Note: CCUS stands for Carbon Capture, Utilisation, and Storage.

In terms of climate change mitigation technologies (CCMTs), the EU continues showing a positive degree of specialisation in most of the fields. In 2019, the EU showed the highest specialisation in the categories of buildings, production, transportation and waste, while reporting a negative specialisation index for adaptation technologies and ICT (Table 2.2-1). China was the most specialised in ICT (despite reporting a declining trend as compared to 2010), South Korea in energy, and the US in adaptation and carbon capture and storage (CCS).

Table 2.2-1 Specialisation index by CCMT group for major economies (2019) and change over 2010-2019: all applicants

CCMTs	EU		CN		JP		KR		US		RoW	
	Index	Change	Index	Change	Index	Change	Index	Change	Index	Change	Index	Change
Adaptation	-0.1	↓ -0.2	0.0	↑ 0.4	-0.5	↑ 0.1	0.0	↑ 0.4	0.2	↓ -0.4	0.7	↑ 0.2
Buildings	0.2	↑ 0.1	0.0	↑ 0.1	-0.1	↓ 0.0	-0.1	↓ -0.5	-0.2	↑ 0.1	0.2	↓ 0.0
CCS	0.2	↑ 0.0	-0.8	↓ 0.0	-0.1	↑ 0.4	-0.1	↑ 0.4	0.4	↓ -0.2	0.7	↑ 0.3
ICT	-0.5	↑ 0.1	0.6	↓ -0.7	-0.6	↓ -0.5	0.5	↓ -0.3	0.5	↑ 0.3	-0.4	↓ -0.4
Energy	0.1	↑ 0.0	-0.1	↑ 0.2	0.1	↓ 0.0	0.9	↑ 0.5	-0.4	↓ -0.3	-0.3	↓ -0.1
Production	0.3	↑ 0.3	-0.2	↑ 0.1	0.1	↑ 0.1	0.0	↓ -0.2	0.0	↓ -0.1	-0.1	↓ -0.1
Transport	0.6	↑ 0.3	-0.7	↑ 0.2	0.1	↓ -0.1	0.0	↑ 0.3	0.0	↓ 0.0	-0.2	↑ 0.4
Waste	0.5	↑ 0.2	-0.1	↑ 0.1	-0.4	↓ 0.0	-0.4	↓ -0.2	-0.2	↓ -0.3	0.6	↑ 0.3
Systems	0.2	↑ 0.3	-0.4	↑ 0.1	-0.2	↓ 0.0	0.1	↓ -0.4	0.2	↓ -0.1	0.4	↑ 0.3

Science, research and innovation performance of the EU 2024

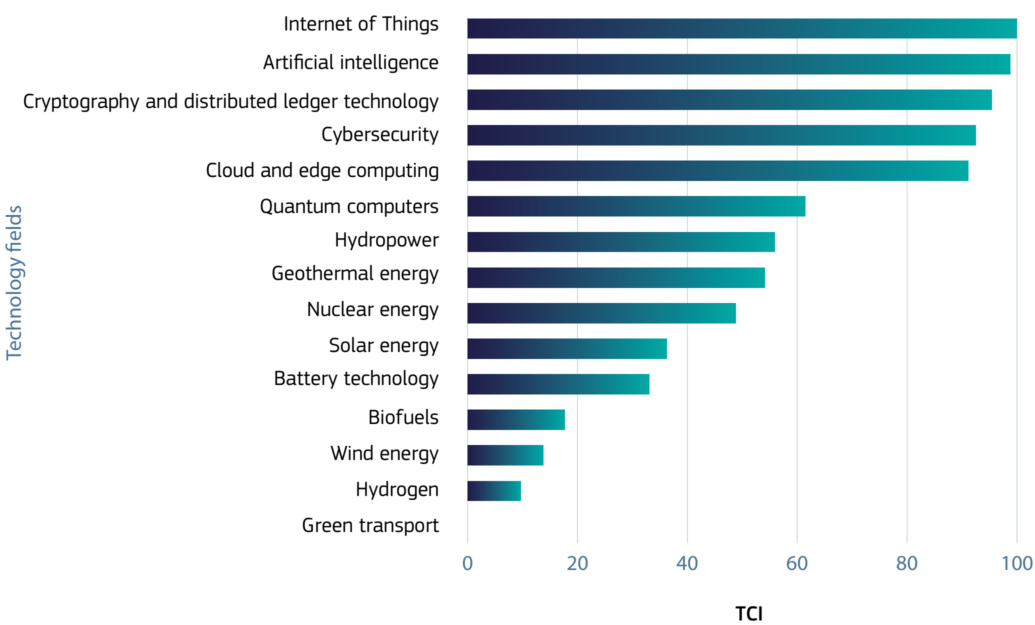
Source: Georgakaki et al., (2023).
Note: Based on high-value inventions.

Overall, the EU's knowledge base is characterised by a relatively higher degree of diversification than other global key innovators. Big global innovators such as China, the US, Japan and South Korea tend to report higher levels of technological specialisation in a lower number of technologies, which also appear to be less common than those characterising the technological portfolio of the EU and other countries (Di Girolamo et al., 2023).

The EU tends to specialise in technologies with lower growth and competitiveness potential (Box 2.2-1). Specialising in technologies that are less easy to replicate (such as digital technologies, semiconductors, medical technologies, etc.) confer a higher advantage in terms of growth potential and overall competitiveness (Balland and Rigby, 2017; Pintar and Scherngell, 2021). However, the EU is not currently well equipped to gain comparative advantage in these technology fields (e.g. computer technologies, digital communication, audio-visual technologies, optics, telecommunications and semiconductors), as compared to the US and China (Di Girolamo et al., 2023).

Digital technologies are instrumental in enhancing competitiveness and fostering growth. Among these, the Internet of Things (IoT), blockchain, AI and cybersecurity technologies, followed by cloud and edge computing and quantum computers stand out as technologies primed to significantly boost long-term productivity (Figure 2.2-4). Strategically important green technologies include hydropower, nuclear energy and advanced battery technologies, which remain key to the Union's ongoing commitment to the decarbonisation process.

Figure 2.2-4 The complexity of key strategic technologies



Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Google Patents data.

Note: On the y-axis, technologies are ranked by Technology Complexity Index (TCI), which measures complexity at the technology level, normalised between 0 and 100.

Box 2.2-1: Complexity and the concept of relatedness

The concept of **knowledge complexity** is receiving increasing attention in both academic and policy literature. It studies the geography and dynamics of innovation activities, adopting an outcome-based approach, i.e. data on the geography innovation activities (such as patent data) is used to infer the presence of bundles of capabilities.

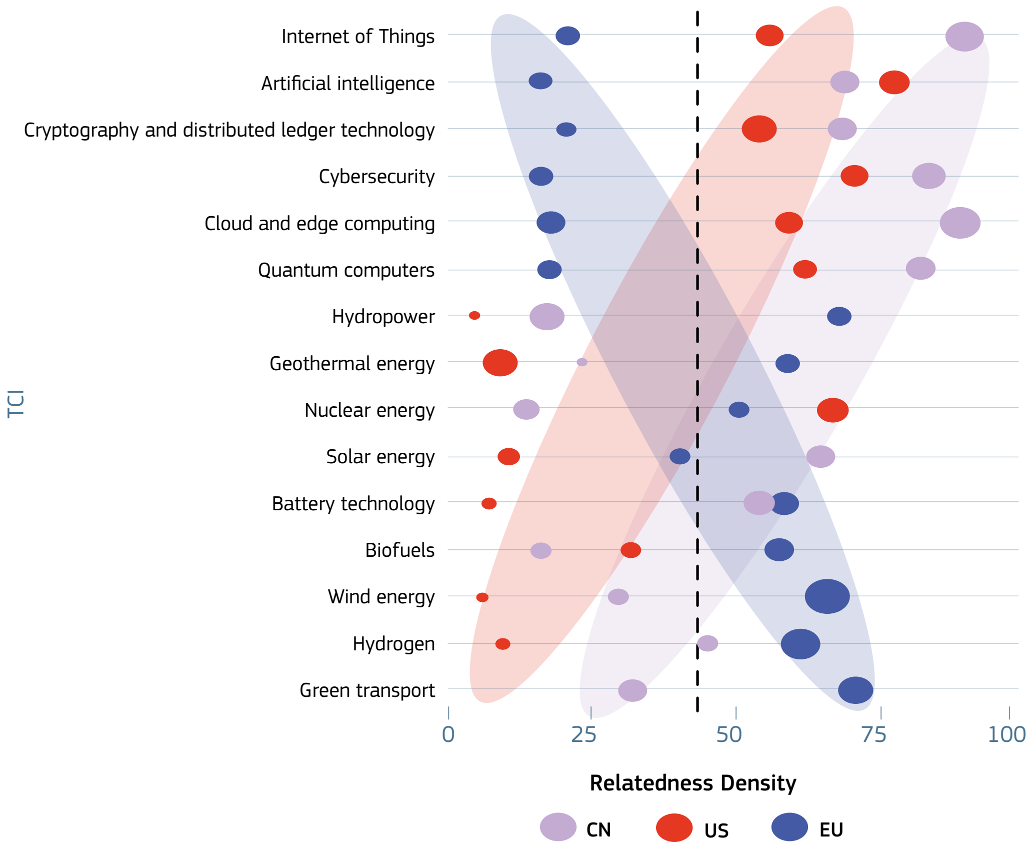
Specifically, the **Knowledge Complexity Index (KCI)** is an indicator measuring regions/countries' innovation capacity from data connecting such regions/countries to different types of technologies present in their portfolio. Similarly, the **Technology Complexity Index (TCI)** measures the complexity required to patent in a given technological field.

The intuition behind these indicators is that **technologies vastly differ in terms of value and growth potential**. Technologies relatively easy to copy and move over space typically require a lower number of capabilities to be undertaken, thereby conferring a lower competitive advantage to the countries/regions in which they are located. On the contrary, more complex technologies combine a higher number of capabilities, are more concentrated in space and are characterised by a higher potential in terms of growth and overall competitiveness (Balland and Rigby, 2017). Therefore, these indicators are calculated by studying the number of countries/regions able to patent in a given technological field, and infer the quality of a country/region's knowledge base by looking both at the technology fields in which it is able to specialise and at the other places where those technologies are also present (Balland and Rigby, 2017; Hidalgo, 2021).

Close to knowledge complexity is the concept of **technological relatedness**. Two technologies are considered related when they rely on the same knowledge and competencies to be produced (Hidalgo et al., 2018; Balland et al., 2019). Generally, relatedness provides information on the technological potential of a country/region in a given technology, as it refers to the costs that a country/region has to sustain when moving into a new technology (Boschma, 2017; Hidalgo et al., 2018). Intuitively, the more related current and new technologies are, the lower the cost to specialise in the new field. It follows that it is relatively easier to diversify in technologies requiring capabilities that largely overlap with those already present in a country/region. On the contrary, when the overlap between existing and new capabilities is small, jumping into a new technology field becomes more risky and costly (Bachtrogler-Unger et al., 2023).

The technological gap between the EU and other key players in strategic technologies persists. The EU's position to lead technological change in areas related to strategic productivity-enhancing technologies remains weaker than that of the US and China (Figure 2.2-5). In particular, the EU presents limited existing knowledge to develop specialisations in important digital fields (e.g. AI, IoT, blockchain technologies, quantum computers, etc.). Additionally, the position of the EU remains relatively weak also in other strategic areas, such as biotechnology, which have a major enabling and transformative nature in areas such as agriculture, environment, healthcare, life science, food chains or biomanufacturing (European Commission, 2023e). The EU has been making progress in this field, improving its scientific performance, but its specialisation potential remains significantly lower than the US (Di Girolamo et al., 2023). This implies that it will be challenging for the EU to build up capacity in such technologies in the future, calling for increasing efforts to reduce the gap with key competitors.

Figure 2.2-5 The EU positioning in complex technologies vs the US and China, 2019-2022



Source: DG Research and innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Google Patents data.

Note: The x-axis indicates the relatedness density in any of the technology fields considered. On the y-axis, technologies are ranked by complexity levels, normalised between 0 and 100. The size of the bubble captures the degree of specialisation that each country reports in a given technology field, as measured by the revealed comparative advantage (RCA).

Furthermore, the current pace of innovation appears to be insufficient to meet carbon neutrality goals. The global production of new climate-related inventions has been slowing down in the last decade, with a similar pattern being observed across all the main innovating countries. Between 2011 and 2020, global innovation efforts in climate-related technologies have been declining as a share of global patenting, decreasing from 12.6% to 9% (Cervantes et al., 2023).

On the contrary, **the share of trademarks covering climate-related goods and services has quadrupled in Europe in the last two decades**, suggesting that while firms appear to have reduced their R&D efforts in climate-related endeavours, the commercialisation and diffusion of existing technologies have kept increasing (Cervantes et al., 2023).

Climate targets set for 2050 cannot be met by only relying on existing technologies. Accelerating renewable energy use and enhancing energy efficiency, combined with increased electrification using current technologies, can achieve more than 80% of the required emission reductions by 2030 (IEA, 2023a). The rapid expansion of clean tech is expected to drive the reduction in fossil fuel demand by more than 25% in the decade. On the contrary, around 35% of the CO_2 reductions targeted by 2050 will have to hinge on technologies currently at the demonstration or prototype phase (IEA, 2023a). Carbon neutrality, thus, calls for a rapid and large-scale deployment of available technologies (such as wind and solar), as well as the development and broad uptake of technologies that are still not available on the market, such as green hydrogen (Cervantes et al., 2023).

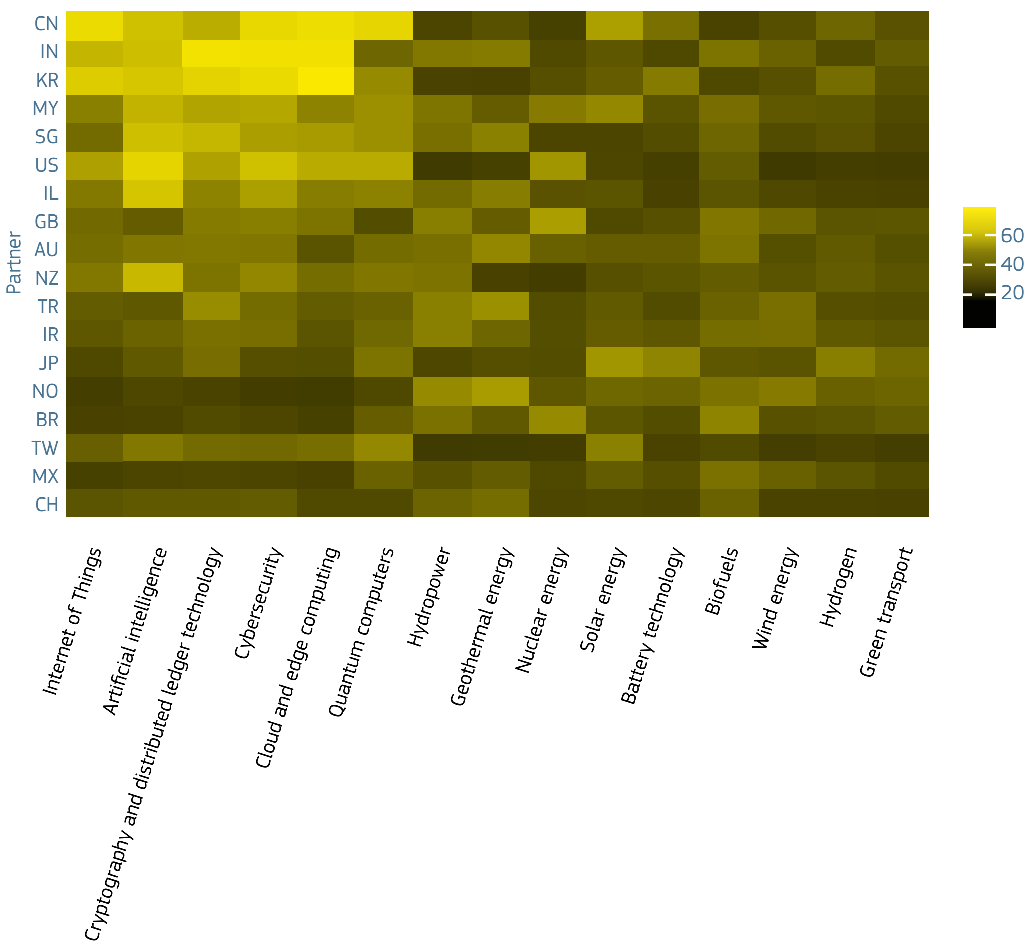
In this regard, the EU has important strengths on which to leverage. The EU remains leader in green infrastructures, outperforming both China and the US in areas related to climate adaptation and energy technologies, as well as in environmental technologies (Di Girolamo et al., 2023). Over the period 2019-2022, the EU reported a specialisation index higher than the US and China in technologies related to wind energy, hydrogen and green transportation, while little difference is observed for biofuels (Figure 2.2-5). Furthermore, although currently showing a lower level of specialisation in nuclear energy, solar energy, hydropower, geothermal energy and battery technologies, the EU has a high specialisation potential in these fields, indicating that the cost to further specialise in these types of technology would be relatively lower, as the EU could leverage on capabilities that largely overlap with those already present in the EU Member States (for more details, please refer to Box 2.2-1).

The risk for the EU to remain technologically dependent on other global players raises the stakes for science diplomacy and collaborations with international partners, from which the EU can gain in terms of technological complementarities. This is particularly relevant for more sophisticated technologies, which are strategic to the attainment of the EU's policy objectives. Figure 2.2-6 maps the EU's technological complementarities (i.e. to what extent non-EU countries can complement the EU's technological deficiencies in different technology fields) for 15 strategic technological areas. The highest degree of technological complementarity[2] is observed in fields related to IoT, AI, blockchain, cybersecurity, quantum computers, and cloud and edge computing. The countries showing the highest degree of complementarity (above 40%) in these areas are China,

2 Technological complementarities are measured exploiting the notion of relatedness density added, which allows to capture technological capabilities that are missing in a given country, but that can be accessed by strengthening external relations (Balland and Boschma, 2021).

India, South Korea, the US and Singapore for AI and blockchain technologies. A lower degree of complementarity (between 30% and 40%) is observed with Malaysia, Singapore, Russia and, to some extent, Israel. Biotechnology, medical technologies and pharmaceutics are other areas characterised by significant complementarities between the EU and other countries, notably the US, Taiwan, Canada and Israel (Di Girolamo et al., 2023).

Figure 2.2-6 The EU's technological complementarities, 2019-2022



Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Google Patents data.

Note: On the x-axis, technologies are ordered according to the degree of technology complexity (TCI index). On the y-axis, countries are ranked according to the average relatedness density added.

2. The need to reduce dependencies in strategic supply chains

The increasing pressure of achieving climate neutrality, combined with global economic instability and geopolitical shifts, poses new challenges for the EU's industry. Europe and the world are assisting to a new revival of industrial policies, which will have to face a different level of complexity and be equipped to address multiple objectives, including the decarbonisation process and the quest towards strategic autonomy (Aghion et al., 2023).

From an economic standpoint, **industrial policies are typically designed to address market failures**, such as coordination failures between economic actors and externalities. The latter refers to situations in which the costs or benefits of an economic activity are not uniquely borne or recouped by the economic agent that carries out such activity. Externalities may also take the form of national security externalities, which call for reducing dependence on a foreign source of supply (Juhasz et al., 2023).

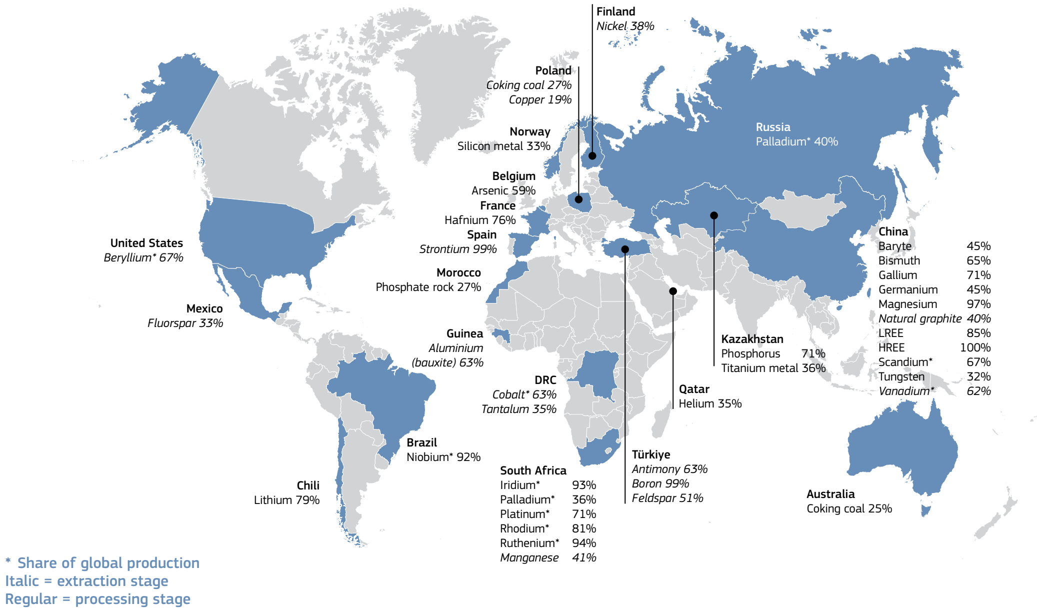
Supply chains have become increasingly and globally interconnected over recent decades, providing not only substantial economic benefits but also posing significant challenges. Global value chains (GVCs) have improved companies' market positions by reducing costs, but they have also made them more vulnerable to external demand and supply shocks (European Commission, 2021). Many companies have opted to specialise in specific tasks and source inputs internationally, rather than producing a complete product. This has led to a significant increase in the trade of intermediate goods, which accounted for approximately half of global trade in 2020 (EBRD, 2022). At the same time, the increased integration of GVCs also made economies more vulnerable to unforeseen disturbances (Dixson-Declève et al., 2021).

The EU vulnerabilities in strategic supply chains have reignited the debate on the trade-off between the costs and benefits of international specialisation in GVCs, which are susceptible to the rapid and widespread global transmission of demand and supply shocks. As a result, a reshaping of supply chain structures is taking place (Dadush, 2022), with the increasing tensions in international relationships pushing global enterprises to redefine their behaviour in an attempt to guarantee the resilience of their business activities (EBRD, 2022).

Increasing geopolitical risks and supply chain fragmentation are likely to push up the costs of the green transition, exacerbating the development of strategic dependencies and likely producing a negative impact on innovation. Among these strategic dependencies, raw materials require specific attention, as the green and digital transition will lead to significant increase in their demand (Bobba et al., 2020).

The supply of many critical raw materials to the EU is highly concentrated, which makes it particularly vulnerable to supply chain disruptions (Blengini et al., 2020). In particular, China is the largest supplier of several critical raw materials (e.g. baryte, bismuth, palladium), Russia and South Africa are the primary source for palladium and platinum group metals (such as iridium, rhodium and ruthenium), Brazil is the primary source of niobium, Australia supplies lithium, and the US is important for beryllium and helium (Figure 2.2-7).

Figure 2.2-7 Major EU suppliers of critical raw materials

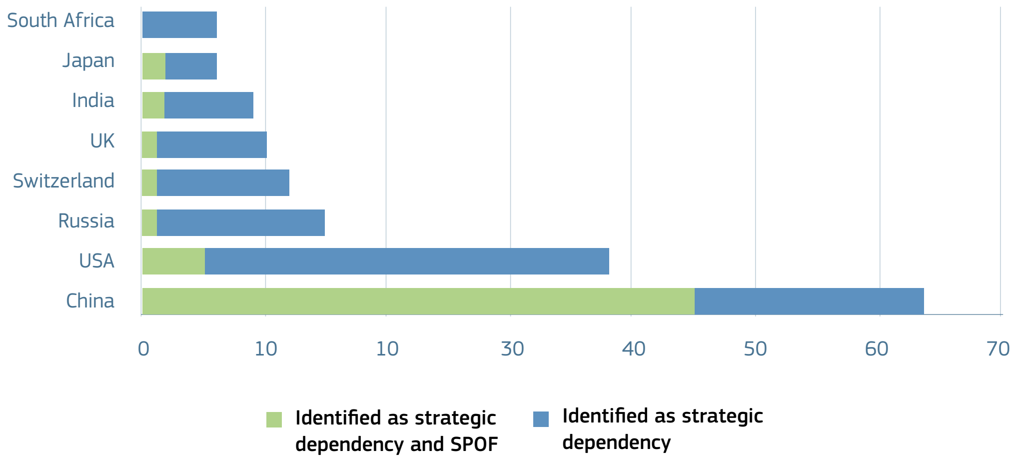


Science, research and innovation performance of the EU 2024

Source: European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Grohol and Veeh (2023).

In particular, most of the EU's strategic dependencies on China carry exceptionally high risks and can be defined as global single points of failure (SPOFs). These SPOFs are characterised by two main features: firstly, the dominance of a single exporter in the trade network affecting numerous countries; and, secondly, a high concentration of world exports in that area (Vandermeeren, 2024). Unlike the EU's dependencies on other third countries, a significant portion of its dependencies on China also qualifies as SPOFs (Figure 2.2-8), introducing an extra level of risk and vulnerability.

Figure 2.2-8 **Identified strategic dependencies and single points of failure (SPOFs)**



Source: Vandermeeren (2024) based on Arjona et al., (2023).

The green transition will require an enormous quantity of 'green metals'. Seventy-two countries, accounting for around 80% of global emissions, have committed themselves to net-zero targets (Energy Transition Commission, 2023). To achieve these goals, the world is expected to require 35 million tonnes of green metals annually by 2050. Specifically, there may be a 50-70% increase in copper and nickel demand by 2030, a 150% increase in cobalt and neodymium demand, and a six- to seven-fold increase in demand for graphite and lithium. Furthermore, the world will need a 15-fold increase in today's wind power, a 25-fold increase in solar power capacity, a three-fold expansion of the grid's size, and 60 times more electric vehicles (EVs) (Energy Transition Commission, 2023).

Despite its technological strengths, Europe remains a net importer of clean energy tech, due to cost-efficiency disadvantages in terms of manufacturing capacity. About one-quarter of electric cars and batteries, and nearly all solar photovoltaic (PV) modules and fuel cells in Europe are imported. In particular, the EU strongly depends on China's manufacturing capacities (which exceeds 90% in certain upstream segments of the value chain, such as ingots and wafers) for solar PV cells and modules; also, the cost of producing solar modules in Europe is currently estimated to be between 25-30% more expansive than in China (European Commission, 2023a). Similarly, China holds at least 60% of the world's manufacturing capacity for several other mass-manufactured technologies (e.g. wind systems and batteries). As an example, China holds more than 75 % of the manufacturing capacity for batteries for electric vehicles (EVs) (Vandermeeren, 2024).

On the contrary, **European manufacturers have a stronger international business in wind turbine components, although the industry is currently under duress**. In 2022, wind energy accounted for 16 % of electricity consumed in the EU on average. Furthermore, the technologies to harness wind energy that are developed and scaled up in Europe have become significantly cheaper over the last 10 years, making this form of energy the cheapest source of electricity in many European countries (European Commission, 2023c). Around 65 % of Europe's supply of wind turbine components is installed in other regions, where they have built local manufacturing facilities (IEA, 2023b). Moreover, European companies hold a significant share of the expanding global wind equipment market, although in decline with respect to the 2020 levels (European Commission, 2023c). Such a decline is largely due to the rapid deployment of wind energy in China. The increasing Chinese presence[3] combined with the difficulties experience by the European wind industry in 2022 are putting the EU's wind industry under distress, calling for pragmatic initiatives to address some of the key issues the EU wind manufacturing sector is facing (European Commission, 2023c).

Furthermore, **the EU has been developing its battery ecosystem, but still lacks the necessary technological production capabilities to keep pace with the swiftly rising demand for gigafactory-level production**. China, on the other hand, boasts an average cost of approximately EUR 68 million for constructing new battery gigafactories, resulting in 1 GWh of additional battery production capacity. In contrast, the EU's expenses for establishing new battery gigafactories average about EUR 100 million per GWh (European Commission, 2023a).

The EU also reports significant weaknesses in the semiconductor industry. Europe accounts for less than 10 % of the global semiconductor production, mainly focusing on the production of larger chips of 22 nanometres or more (European Parliament, 2022). The capacity to manufacture cutting-edge chips, ranging from 2 to 7 nanometres, is currently concentrated in two Asian companies, TSMC in Taiwan and Samsung in South Korea. However, the essential equipment required for producing these advanced chips is exclusively provided by ASML in the Netherlands. In addition, **European manufacturers also exhibit significant dependencies on the US**, mainly linked to the use of US-owned chip design tools (European Parliament, 2022).

3 China has also increased its capacity for the production of blades used in offshore wind turbines to almost 85 % (Vandermeeren, 2024).

3. The key role of technological progress for strategic autonomy

Recent geopolitical tensions and crises have contributed to the revival of industrial policy, which is providing the basis for a broader shift in the global economic paradigm. Open trade policies are being replaced by initiatives aiming at reducing the reliance on imports from other countries, while boosting national innovation, investment, production and employment (Aghion et al., 2023). This is particularly true for the US and China, while the EU opted for a balanced approach to achieve strategic autonomy, relying on both trade diversification (through the establishment of several new international partnerships) and strengthening in-house capacities in critical areas, as set out in the updated industrial strategy (European Commission, 2021) and the Green Deal Industrial Plan (European Commission, 2023d).

As a result of these systemic changes, European policymakers are faced with competing challenges. On the one hand, the objective of carbon-neutrality requires a complete restructuring of production and consumption processes, which calls for a global coordinated approach, and for green technologies to be produced rapidly and on a large scale. On the other hand, the risk of further exacerbation of geopolitical rivalries and other supply chain disruptions is likely to spur the friend-shoring and on-shoring of critical technologies and strategic manufacturing production to account for national security and defence concerns (Aghion et al., 2023).

In this context, R&I policy has an important role to play. R&I remains key to build the EU's technological sovereignty and guarantee its strategic autonomy. In its Communication on *European Economic Security Strategy*, the European Commission identified 10 technology areas (e.g. advanced semiconductor technologies, AI, quantum technologies, biotechnologies, energy technologies, etc.), set to play a pivotal role in enhancing the EU's economic security (European Commission, 2023b). The accelerated development of new strategic technologies, such as AI or high-performance computing, requires increasing efforts for the EU to remain a main actor in the development and governance of these fields.

This calls for higher R&I investments and a more structural approach towards strategic funding and technological development, as outlined by the new Strategic Technologies for Europe Platform (STEP), targeting R&I investments at bridging the specialisation gap between the EU and its main counterparts, while focusing on those technologies more likely to deliver important productivity gains in the long term.

At the same time, the EU can continue to leverage its strengths in green technologies where demand is expected to increase. Policies put forward by the EU's main counterparts are expected to significantly accelerate the global decarbonisation process (Kleimann et al., 2023). The global energy transition will increase the use of raw materials in the manufacture of wind turbines, PV panels, batteries, hydrogen production and storage, and other systems. The transition to e-Mobility will require batteries, fuel cells and lightweight traction motors, and not just for cars, but also for e-Bikes, scooters and heavy-duty transport. The EU could benefit from this market trend by capitalising on its strong leadership in green technologies and also by making the best of its strength in advanced materials.

Furthermore, investing in green innovations also remains crucial to reducing the short-term costs of the decarbonisation process. While there exists little doubt on the positive long-term effects of climate policies, the short-term effects of the green transition are quite different. On the one hand, the development of low-carbon technologies is likely to disrupt existing production processes, entailing significant costs for those sectors currently heavily relying on carbon-intensive inputs (Hasna et al., 2023). On the other hand, green innovation has the potential to create important knowledge spillovers on carbon-intensive industries, leading to a higher level of innovation in the economy as a whole (Porter and van der Linde, 1995). Notwithstanding the possible short-term negative economic effects of green transition, increasing green innovation remains key to producing alternative and less expensive low-carbon technologies, thereby helping to reduce the costs of the decarbonisation process (Hasna et al., 2023).

The European Commission has committed to **boosting breakthrough innovation in renewable and low-carbon technologies through the REPowerEU Plan.** Furthermore, the **industrial technology roadmaps for R&I**, under the *New ERA for Research and Innovation*, map the investments needs and conditions for some key products and processes to achieve the sustainable transition in the EU, while proposing technological options for low-carbon technologies in energy-intensive industries (including the use of green electricity and hydrogen), and pointing to available support instruments, synergies and action to accelerate the transition while ensuring the EU's competitiveness.

The strengthening of the EU's technological leadership needs to be accompanied by a reduction of supply chain dependencies. This is particularly relevant for clean energy technologies, for which the EU's significant dependency on imports of raw materials and components necessary for the low-carbon transition (coupled with potential global supply disruptions, political instability, concentrated sources of supply and international price volatility) may result in significant shortages that could pose a considerable risk for the Union's energy security and its decarbonisation ambitions.

The role of innovation in this sense remains key. Technological innovation can influence material demand through substitution, efficiency enhancement and design refinement, as well as the development of novel materials (IRENA, 2023). As an example, the chemical composition of materials used in EV battery production has evolved significantly over the past decade, with important implications for the demand for critical materials related to this type of technology (IRENA, 2023). Today, lithium-ion batteries with graphite-based anode chemistry, which accounts for about 70% of the market, are prevalent due to their superior performance. Nevertheless, the advent of new battery technologies, such as sodium-ion batteries, presents an opportunity to shift away from lithium and cobalt to more economical and abundant alternatives like sodium, potentially transforming the EV battery industry landscape.

The EU is launching several initiatives in this regard. The **European Chips Act** proposes a comprehensive strategy to advance semiconductor technology in Europe. It includes investments in next-gen tech, access to design tools, energy-efficient chip certification, investor-friendly policies, support for start-ups, talent development, supply security measures and international partnerships with likeminded nations. **The European Raw Materials Act** aims to ensure a secure and sustainable EU supply of critical raw materials (such as lithium, cobalt and nickel to produce batteries; gallium for solar panels; raw boron for wind technologies; titanium and tungsten for the space and defence sectors) by reinforcing domestic supply chains and reducing the EU's import dependencies. The **Net-Zero Industry Act** aims to scale up the manufacturing of clean technologies in the EU, simplifying the regulatory framework, as well as cutting red tape and unnecessary administrative burdens for the development of net-zero manufacturing projects.

Reducing strategic dependencies also calls for keeping the EU Single Market strong, the most important tool in the EU's arsenal, to accelerate the roll-out of strategic technologies by avoiding regulatory costs associated with fragmentation, uncertainty and bureaucracy. Similarly, developing appropriate sets of skills within the EU remains also key to avoid labour shortages (for more details, please refer to Chapter 5.2).

Reconciling the need for a global coordinated approach against climate change and that of securing strategic supply chains by strengthening in-house capacities or relying on close allies remains key. Geopolitical tensions fostered by ideological divide and mistrust between competing economic powers can increase the fragmentation of international supply chains, with a likely negative impact on innovation. R&I activities have become increasingly internationalised, and the EU needs to balance the benefits of research collaborations with the risks related to foreign interference.

In response to the current global trends, **the EU can use its international relationships to promote its values, defining areas of mutual interest as well as a division of knowledge with key partners**. Without reinforcing the role of the EU as a leading actor to foster international R&I cooperation, current technological dependencies will more likely put the EU's technology sovereignty and strategic autonomy in jeopardy.

This calls for higher international openness and reinforced cooperation (Dixson-Declève et al., 2023). Reacting to current geopolitical shifts and protectionist tendencies with similar types of policies may benefit the EU in the short run, but risk being counter-productive longer term. Achieving technological sovereignty does not have to come at the expense of multilateralism. Reducing cooperation would undermine the EU's credibility as a global actor committed to multilateral cooperation, and likely harm the EU's trade interests (Kleimann et al., 2023).

Building on the lessons learned from the COVID-19 pandemic and in response to the current global geopolitical trends, **the EU strategy on international R&I cooperation promotes rules-based multilateralism, pursues openness and modulates bilateral cooperation to make it compatible with EU interests**. With its 2021 Communication on the Global Approach to R&I, the Commission has reaffirmed the EU's commitment to preserve openness in bilateral and multilateral cooperation in science and technology in a spirit of reciprocity and safeguarding fundamental values and principles. The Communication aims to build partnerships that strengthen the EU's open strategic autonomy and leverage the EU's capacity to develop and take up strategic technologies, thereby increasing EU competitiveness and avoiding future dependencies. As an example, the EU's initiative on **Raw Materials Diplomacy** is designed to set up dialogues with strategic partners involved in raw materials, through various frameworks of cooperation (i.e. bilateral, regional or multilateral cooperation).[4]

4 https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/raw-materials-diplomacy_en

Partnerships and openness are also part of one of the three pillars of the new European economic security strategy. The strategy acknowledges the key role that openness plays in fostering innovation ecosystems, while calling for actions to mitigate security risks linked to foreign interferences. In this regard, the Commission adopted an Economic Security Package in January 2024, including two initiatives related to R&I: a White Paper on *Enhancing R&D support involving technologies with dual-use potential* (for more details, see Chapter 2.3); and a Proposal for a Council Recommendation on Research security (adopted in May 2024). The latter recognises the primary role of higher education institutions and research organisations in international cooperation, as well as the need to preserve academic freedom by supporting European research-performing organisations in addressing research security risks linked to increasing international conflicts and competition (European Commission, 2024).

References

Aghion, P., Ahuja, K., Bown, C. P., Cantner, U., Criscuolo, C., Dechezlepretre, A., Dewatripont, M., Hausmann, R., Lalanne, G., McWilliams, B. et al. (2023), *Sparking europe's new industrial revolution-a policy for net zero, growth and resilience*, Technical report, Bruegel.

Arjona, R., Connell, W., and Herghelegiu, C. (2023), *An enhanced methodology to monitor the EU's strategic dependencies and vulnerabilities*, Single Market Economy Papers

Bachtrogler-Unger, J., Balland, P. A., Boschma, R. & Schwab, T. (2023), *Technological capabilities and the twin transition in Europe: Opportunities for regional collaboration and economic cohesion.*

Balland, P. A., and Boschma, R. (2021), 'Complementary interregional linkages and Smart Specialisation: An empirical study on European regions', *Regional Studies*, 55(6), 1059-1070.

Balland, P. A., Boschma, R., Crespo, J., and Rigby, D. L. (2019), 'Smart specialization policy in the European Union: relatedness, knowledge complexity and regional diversification', *Regional studies*, 53(9), 1252-1268.

Balland, P.A., and Rigby, D. (2017), 'The geography of complex knowledge', *Economic geography*, 93(1), 1–23.

Blengini, G., El Latunussa, C., Eynard, U., et al. (2020), *Study on the EU's list of critical raw materials: final report*, EU Publications Office.

Bobba, S., Carrara, S., Huisman, J., Mathieux, F., and Pavel, C. (2020), *Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study*, EU Publications Office.

Boschma, R. (2017), 'Relatedness as driver of regional diversification: A research agenda', *Regional Studies*, 51(3), 351-364.

Buysse, K., and Essers, D. (2023), *Critical raw materials: from dependency to open strategic autonomy?*, NBB Economic Review 2023 No 13.

Cervantes, M., Criscuolo, C., Dechezleprêtre, A., and Pilat D. (2023), *Driving low-carbon innovations for climate neutrality*, OECD Science, Technology and Industry Policy Papers, No. 143, OECD Publishing, Paris, https://doi.org/10.1787/8e6ae16b-en.

Dadush, U. (2022), *Deglobalisation and protectionism*, Working Paper 18/2022, Bruegel.

Di Girolamo, V., Ravet, J., Mitra, A., Peiffer-Smadja O. and Balland, P. A. (2023), *The global position of the EU in complex technologies,* European Commission, Directorate-General for Research and Innovation, Publications Office.

Dixson-Declève, S., Bria, F., Charveriat, C. (2021), *Transformation post-COVID: global value chains: harnessing innovation to protect and transform the backbone of global trade*, Directorate-General for Research and Innovation, Publications Office.

Dixson-Declève, S., Renda, A., Schwaag Serger, S. (2023), *Research, innovation, and technology policy in times of geopolitical competition,* European Commission, Directorate-General for Research and Innovation, Publications Office of the European Union, https://data.europa.eu/doi/10.2777/745596.

EBRD (2022), Transition Report 2022-23, Business Unusual.

Energy Transition Commission (2023), Material and Resource Requirements for the Energy Transition, https://www.energy-transitions.org/publications/material-and-resource-energy-transition/.

European Commission (2021), Strategic dependencies and capacities, SWD (2021) 352 final.

European Commission (2022), Science, research and innovation performance of the EU 2022: building a sustainable future in uncertain times, Directorate-General for Research and Innovation, Publications Office of the European Union, https://data.europa.eu/doi/10.2777/497405.

European Commission (2023a), Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity, SWD (2023) 68 final.

European Commission (2023b), European Economic Security Strategy, JOIN (2023) 20 final.

European Commission (2023c), European Wind Power Action Plan, COM (2023) 669 final.

European Commission (2023d), A Green Deal Industrial Plan for the Net-Zero Age, COM (2023) 62 final.

European Commission (2023e), Recommendation on critical technology areas for the EU's economic security for further risk assessment with Member States, C(2023) 6689 final.

European Commission (2024), Enhancing Research Security, COM (2024) 26 final.

European Parliament (2022), Strengthening EU chip capabilities: How will the chips act reinforce Europe's semiconductor sector by 2030.

Georgakaki, A., Kuokkanen, A., and Letout, S. (2023), *Clean Energy Technology Observatory - Overall strategic analysis of clean energy technology in the European Union: status report - 2023*, European Commission, Joint Research Centre, Publications Office of the European Union, https://data.europa.eu/doi/10.2760/150096.

Grohol, M. and Veeh, C. (2023), *Study on the critical raw materials for the EU 2023: final report, European Commission*, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Publications Office of the European Union, https://data.europa.eu/doi/10.2873/725585.

Hasna, Z., Jaumotte, F., Kim, J., Pienknagura, S., and Schwerhoff, G. (2023), Green Innovation and Diffusion: Policies to Accelerate Them and Expected Impact on Macroeconomic and Firm-Level Performance, Staff Discussion Notes, 2023.

Hidalgo, C. A. (2021), 'Economic complexity theory and applications', *Nature Reviews Physics*, 3(2), 92–113.

Hidalgo, C. A., Balland, P.-A., Boschma, R., Delgado, M., Feldman, M., Frenken, K., Glaeser, E., He, C., Kogler, D. F., Morrison, A. et al. (2018), 'The principle of relatedness', in *Unifying Themes in Complex Systems IX: Proceedings of the Ninth International Conference on Complex Systems*, Springer, pp. 451–457.

IEA (2021), Net Zero by 2050: A Roadmap for the Global Energy Sector, OECD Publishing, Paris, https://dx.doi.org/10.1787/c8328405-en.

IEA (2023a), Net Zero Roadmap- A Global Pathway to Keep the 1.5 °C Goal in Reach, 2023 Update.

IEA (2023b), Energy Technology Perspectives 2023.

IRENA (2023), Geopolitics of the energy transition: Critical materials, International Renewable Energy Agency.

Juhász, R., Lane, N. J., and Rodrik, D. (2023), *The new economics of industrial policy*, No. w31538, National Bureau of Economic Research.

Kleimann, D., Poitiers, N., Sapir, A., Tagliapietra, S., Véron, N., Veugelers, R., and Zettelmeye, J. (2023), H*ow Europe should answer the US Inflation Reduction Act,* Bruguel Policy Contribution Issue n˚04/23, https://www.bruegel.org/sites/default/files/2023-02/PB%2004%202023_0_1.pdf.

Pintar, N., and Scherngell, T. (2022), 'The complex nature of regional knowledge production: Evidence on european regions', *Research Policy*, 51(8), 104170.

Porter, M. E., & Linde, C. V. D. (1995), 'Toward a new conception of the environment-competitiveness relationship', *Journal of economic perspectives*, 9(4), 97-118.

Vandermeeren, F. (2024), *Understanding EU-China* exposure, European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Publications Office of the European Union, https://data.europa.eu/doi/10.2873/425398.

CHAPTER 2.3

SECURITY & DEFENCE R&I

Key questions

- What are the global trends in defence R&I investment?
- What is the impact of dual-use technologies on security and innovation?
- What is the role of strategic defence R&I in response to global challenges?

Highlights

- Russia's unprovoked invasion of Ukraine emphasises the crucial need for EU defence research and development (R&D) and technological superiority in deterring aggression and protecting peace, freedom and democracy.
- Russia (4.3 %) and the US (3.3 %) have, relative to their gross domestic product (GDP), the highest defence expenditures, almost three and two times as much as China (1.6 %) and the EU (1.5 %).
- In nominal terms, the EU defence spending surpasses that of Russia and closely approaches China's levels. The US, by contrast, leads significantly in this regard, outspending the EU by roughly threefold in defence.
- EU defence investments are focused on the acquisition of defence equipment rather than funnelling resources into defence R&D. Within the R&D spectrum, there is a notable allocation towards non-research and technology (R&T) activities, underscoring a EU focus on the later stages of defence technology development, rather than on foundational research and technology demonstration.
- The EU (25 %) is globally the second exporter of defence equipment, behind the US (40 %) and in front of Russia (16 %) and China (5 %), exemplifying EU's technological defence capabilities. However, while the EU is relatively well positioned, the biggest arms-producing companies are non-EU, as the top 10 defence equipment producing companies are all non-EU based (US, China, UK and Russia).
- In Horizon 2020, projects with dual-use technology potential have been funded, with ICT and cybersecurity as the main areas.
- The further development and implementation of dual-use technologies can play a significant role in shaping the future landscape of both technological innovation and EU's and member states' security.

Policy insights

- The convergence of climate change, demographic shifts, political polarisation and geopolitical changes presents challenges to global security. EU's innovation efforts in security and defence can be regarded as essential in addressing these multifaceted difficulties.

- Under the current EU Framework Programme for R&I, activities carried out under the European Defence Fund should have an exclusive focus on defence research and development, while activities carried out under the 'civilian' specific programme and the EIT should have an exclusive focus on civil applications. Coordination between programmes may strengthen synergies in areas of dual-use technology.

- At a lower level of technology readiness levels (TRLs), defence R&D spillovers and overlaps between civilian and military interests are greater.

- For the EU to fully harness the potential of dual-use technologies, and maximise the utility of technological investments, it is imperative to foster synergies and bridge the divide between civilian and defence R&D, both within the Union and among its Member States, which can be enhanced by collaboration and co-investing.

The unprovoked invasion of Ukraine by Russia has placed the EU's (territorial) security and defence back at the centre of the EU's policy debate. In an era marked by rapid technological advancements and geopolitical shifts, the role of R&I in defence cannot be overstated. This chapter aims to explore the multifaceted impact of R&I in the realm of security and defence, underscoring the pivotal role it plays in maintaining and enhancing the EU's defence and security capabilities.

The significance of R&I in defence is further magnified when considering the concept of dual-use technologies. These technologies, developed initially for military purposes, find extensive applications in the civilian sector, leading to significant technological spillovers and advancements in various fields. Conversely, innovations in the civilian sector often contribute to the advancement of military technology, creating a symbiotic relationship between the two domains.

1. Defence and security R&I around the world

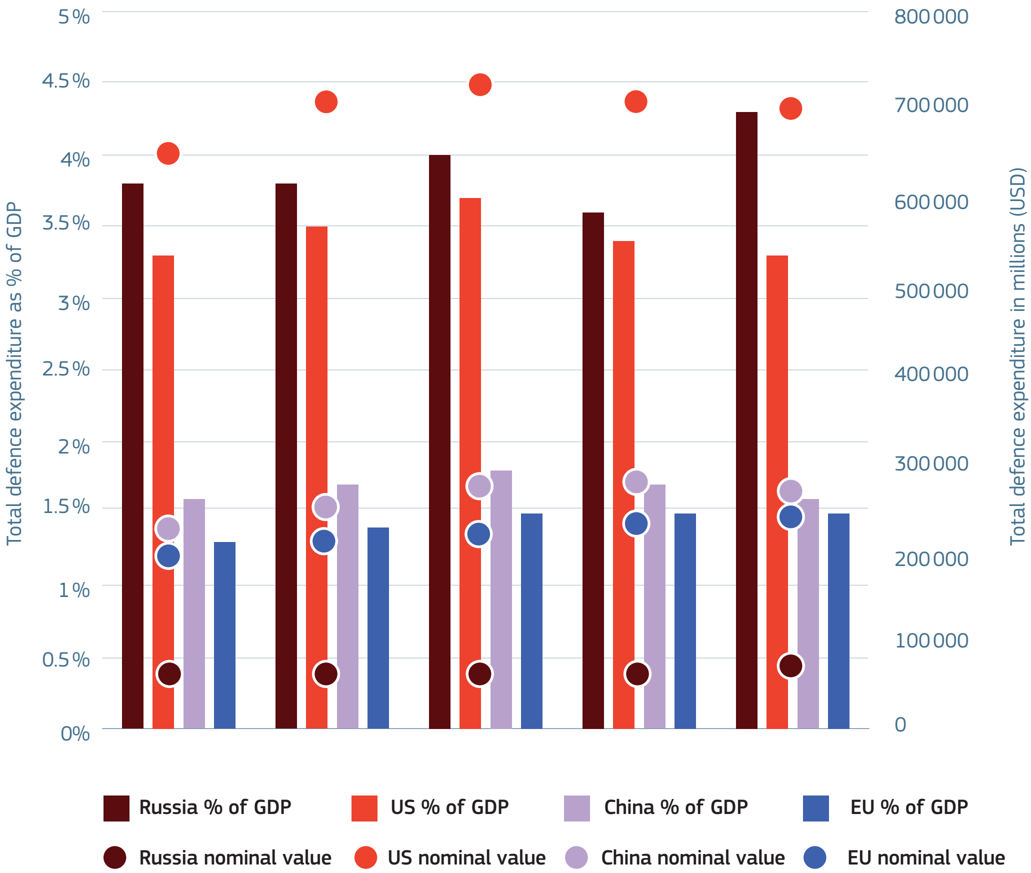
The defence sector is distinct and complex, characterised by its unique market structure and regulatory environment. Unlike the civilian sector, where there is a broad and diverse customer base, the defence industry primarily caters to a very specific set of clients, mainly national defence ministries and, occasionally, authorised private entities. This market limitation is further compounded by stringent export regulations and national security considerations that govern the sale and distribution of defence-related products and technologies. These regulations are often in place to prevent the proliferation of arms, and to ensure that sensitive technologies do not fall into the hands of potential adversaries or are used for purposes that could destabilise regions or global peace (Ball and Leitenberg, 2021).

Due to the highly sensitive nature of defence products and the limited market, companies in this sector face unique challenges regarding R&D investments. Private defence companies do invest significantly in R&D, although the source of funding is often the state. The nature and scope of this investment are substantially different from those in the civilian sector. Defence R&D is heavily supported and funded by government contracts, as the products being developed are often specific to the needs of the national military and security services. This close relationship with government entities means that defence R&D is often aligned with national security priorities and long-term defence strategies (Uttley, 2018).

Much of the information pertaining to defence R&D budgets, project details and technological advancements is classified. This secrecy is maintained to protect national security interests and to prevent sensitive technological information from being accessed by potential adversaries. This level of confidentiality often extends to the financial aspects of defence R&D, making it difficult for analysts and the public to gain a clear understanding of the actual investment levels and the distribution of funds across various projects. Hence, available data is often the result of rough, yet informative, approximations. Moreover, the defence sector is known for its long development cycles, especially for advanced weapon systems and platforms. The development of new technology in this sector is not only capital-intensive but also time-consuming, often spanning several years or even decades.

In 2022, the European Union allocated approximately 1.5 % of its GDP to defence spending. This figure is slightly lower than China's 1.6 %, significantly less than the US's 3.3 %, and substantially lower than Russia's 4.3 %. However, when examining defence expenditures in nominal terms, the European Union's (USD 232 billion) spending surpasses that of Russia (USD 63 billion) and closely approaches China's (USD 261 billion) levels. The US (USD 691 billion), by contrast, leads significantly in this regard, outspending the European Union by roughly threefold in defence (Figure 2.3-1).

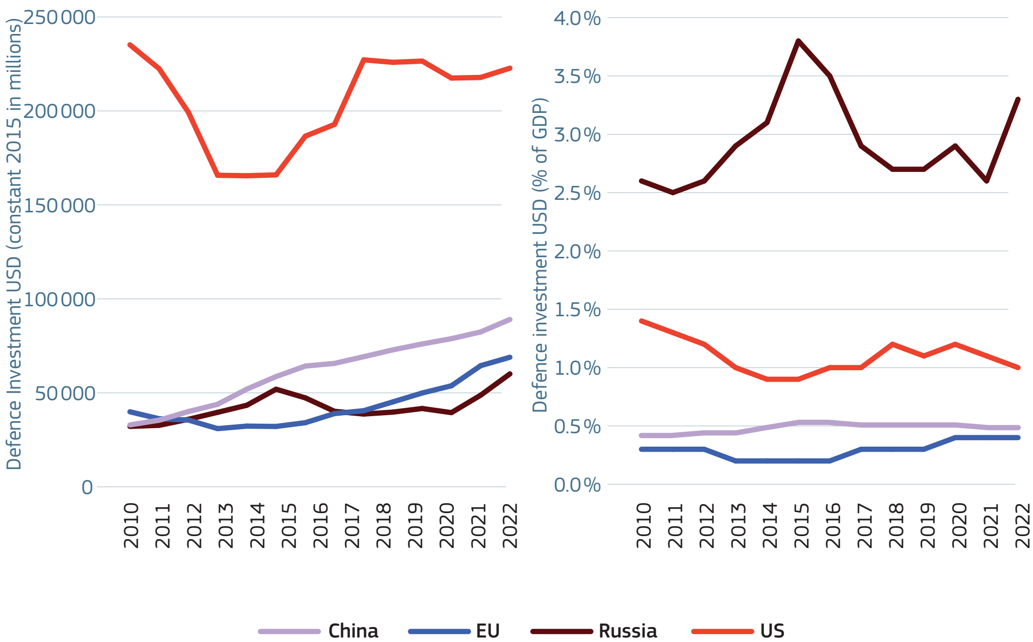
Figure 2.3-1 Defence spending across the world



Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's own elaboration based on EDA Defence Data 2022, the IISS Military Balance+, and World Bank data.
Note: Total defence expenditure as % of GDP is collected from EDA Defence Data 2022 (which uses the IISS Military Balance+ for the USA, Russia and China). Total defence expenditure in nominal values is derived from the EDA % of GDP figures by multiplying for the World Bank GDP (constant 2015 USD).

In 2022, the EU allocated approximately 0.4% of its GDP to defence investments (defence equipment procurement[1] + defence R&D[2]). This figure is slightly lower than China (0.5%), significantly less than the US (1%), and substantially lower than Russia (3.3%). However, when examining defence investments in real terms, The EU's (USD 64 billion) spending surpasses that of Russia (USD 49 billion) and closely approaches China's (USD 82 billion) levels. The US (USD 218 billion), in contrast, leads significantly in this regard, outspending the EU roughly threefold in defence investment. (Figure 2.3-2).

Figure 2.3-2 Defence investment spending across the world



Science, research and innovation performance of the EU 2024
Source: DG Research and innovation, Common R&I Stategy and Foresight Service, Chief Economist Unit's own elaboration based on DG DEFIS extractions from the IISS Military Balance+, and World Bank data.
Note: Defence investments in measured as Def Investment USD (constant 2015) and GDP is measured as GDP (constant 2015 US$). Defence Investment = defence equipment procurement + R&D (including R&T) expenditure.

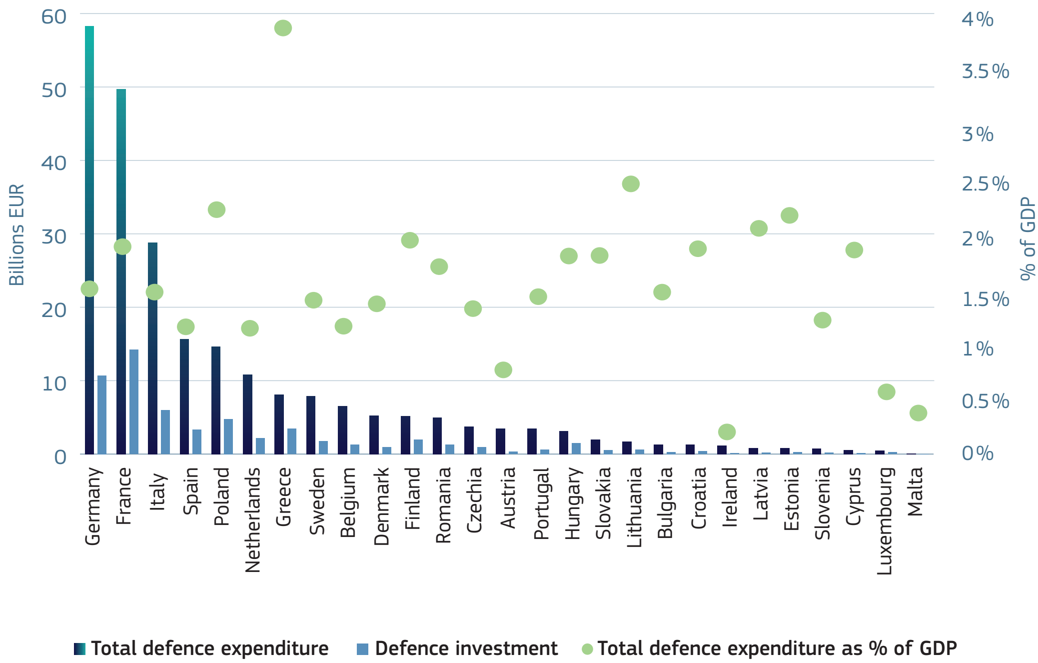
1 Expenditure for all major equipment categories, that are not included in operations and maintenance spending.

2 Defence R&D indicates any defence R&D programmes up to the point where expenditure for production of equipment starts to be incurred. R&D includes R&T. R&T indicates expenditure for basic research, applied research and technology demonstration for defence purposes. R&T is a subset of R&D expenditure.

In 2022, Germany, France and Italy were the primary contributors to the European Union's defence spending. Germany, allocating 1.5 % of its GDP to defence, equivalent to EUR 58 billion, accounted for 24 % of the EU's total defence expenditure. France, with a defence budget comprising 1.8 % of its GDP or EUR 49.7 billion, contributed 21 % to the EU's overall defence spending. Italy, also dedicating 1.5 % of its GDP to defence, amounting to EUR 28.7 billion, was responsible for 12 % of the total defence expenditure within the EU (Figure 2.3-3).

Looking at defence investments, France emerges as the leading contributor in the EU. In 2022, France topped the list with defence investments amounting to EUR 14.2 billion, followed by Germany with EUR 10.6 billion and Italy with EUR 5.9 billion. This distribution suggests that Germany allocates a larger portion of its defence budget to military personnel, while France prioritizes investments in military equipment and R&D to a greater extent (Figure 2.3-3).

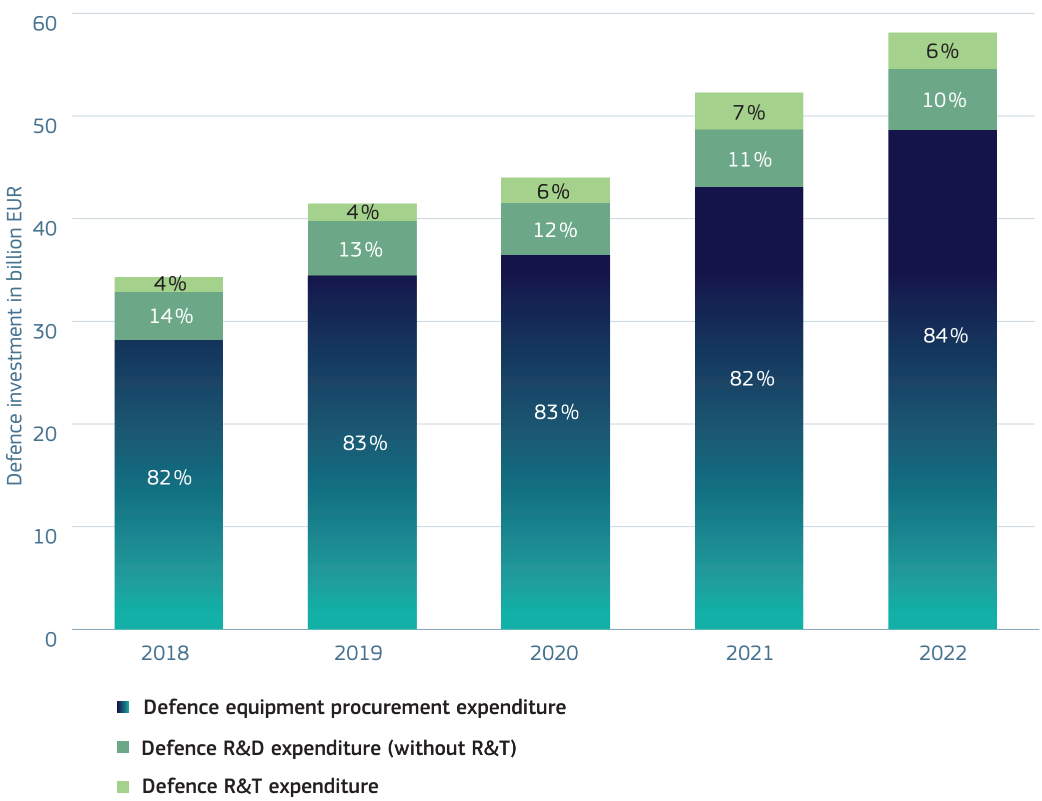
Figure 2.3-3 Distribution of defence expenditure within the EU (2022)



Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's own elaboration based on EDA Defence Data 2022.
Note: Defence Investment refers to defence equipment procurement and R&D (including R&T) expenditure. Nominal values are expressed in constant 2022 prices.

EU defence investments predominantly prioritise the acquisition of defence equipment over R&D. Moreover, within the R&D sector, a significant proportion of the funding is allocated to non-R&T activities. This emphasises the EU focus on the latter stages of defence technology development and production, as opposed to expenditures on basic research, applied research and technology demonstration for defence purposes. Furthermore, from 2018 until 2022, has seen a slight increase in the proportion of funds directed towards defence equipment procurement, while the share allocated to R&D has decreased. However, within the R&D domain, there has been a gradual shift from non-R&T components to R&T components. Overall, in constant 2022 prices, EU investment spending has experienced an upward trend over the past five years (Figure 2.3-4).

Figure 2.3-4 EU Defence investment decomposition by investment type (2022 prices)



Science, research and innovation performance of the EU 2024
Sources: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's own elaboration based on EDA Defence Data 2022.
Note: Defence investment refers to defence equipment procurement and R&D (including R&T) expenditure. Nominal values are expressed in constant 2022 prices.

Box 2.3-1: US approach to defence R&D and critical technologies

The United States Government has a long-standing tradition of investing heavily in R&I within the realms of defence and security, as well as in related sectors like aeronautics and space. This investment is reflected in the substantial funds allocated to various federal agencies, with the Department of Defence (DoD) receiving the largest share of the federal R&D budget. In 2020, the DoD was granted around USD 67 billion (approximately EUR 59 billion) for R&D, representing nearly 39 % of the total federal R&D budget. Another key player in this area is the National Aeronautics and Space Administration (NASA), which received about USD 11 billion (approximately EUR 9 billion) in R&D funding for the same year. Combined, the DoD and NASA account for roughly 45 % of the US' public R&D funding, highlighting the Federal Government's focused approach in supporting R&D initiatives.

The type of R&D of these funds, however, varies significantly between agencies. The DoD primarily invests in experimental development, with 86.6 % of its R&D budget dedicated to this area, while applied research and basic research receive 9.6 % and 3.7 %, respectively. In contrast, NASA's expenditure is more evenly distributed across different types of R&I: 36.4 % for basic research, 24.2 % for applied research and 39.3 % for experimental development.

A notable aspect of the US' R&I system is the presence of several agencies that focus on the development of critical technologies and disruptive innovations. The most prominent among these is the Defence Advanced Research Projects Agency (DARPA), a part of the DoD emphasizing the development of technologies used by the military. DARPA has set a precedent for other similar agencies, such as the Intelligence Advanced Research Projects Activity (I-ARPA), which emphasises artificial intelligence (AI), quantum computing, machine learning, high-performance computing and synthetic biology. There's also the Advanced Research Projects Agency-Energy (ARPA-E) under the Department of Energy, focusing on advancements in solar energy, batteries, transportation, radiation, grid and energy conversion technologies. Furthermore, the Home Security Advanced Research Projects Agency (HSARPA) works on technology development in areas like border and maritime security, cybersecurity, and chemical and biochemical defence. In 2022, a new addition was the Advanced Research Projects Agency for Health (ARPA-H), under the National Institutes of Health, concentrating on biomedical breakthroughs.

Science, research and innovation performance of the EU 2024
Source: Steeman, J.T., Peiffer-Smadja, O. and Ravet, J. (2024, forthcoming), European Commission, Directorate for Research and Innovation.

The available data on defence R&D spending is informative, but high expenditure in defence doesn't automatically equate to an efficient use of funds or a technological edge for the countries investing the most. Therefore, it is also important to consider arms sales and trade dynamics. These provide valuable insights, as buyers are unlikely to repeatedly purchase weapons that have proven to be flawed, inefficient or excessively priced relative to their technological capabilities. Arms sales can be seen as a complementary indicator of the true competitiveness of the technology developed through defence R&D.

On a global scale, private arms-producing companies of EU Member States are relatively well positioned but largely ranked after the main US and Chinese companies, with Leonardo (Italian) and Airbus (Trans-European) ranked globally in 13th and 14th place in 2022 in term of arms-selling revenues (Table 2.3-1). The main EU defence technological and industrial base is concentrated in 3 EU countries: France, Germany, Italy (ASD, 2022).

The US (40 %) is by far the main exporter of arms in the world, followed by Russia (16 %) and France (11 %), together accounting for 67 % of world volume, with the EU as a region as the second largest exporter globally (25 %) for the period 2018-2022. EU Member States are, in general, well positioned as global exporters of arms, with France (3rd, 11 %), Germany (5th, 4.2 %), Italy (6th, 3.8 %), Spain (8th, 2.6 %), The Netherlands (11th, 1.4 %) and Sweden (13th, 0.8 %) among the global suppliers (Table 2.3-2).

Countries from Asia and the Middle East are the main importers of arms globally, marked by India (1st), Saudi Arabia (2nd) and Qatar (3rd) as the top three importing countries, with 11 %, 10 % and 6 % of total global arm imports, respectively, for the period 2018-2022. EU Member States are not major importers. Overall, the global distribution of arms imports is more fragmented and evenly dispersed across various nations, unlike arms exports, which are concentrated in a handful of countries that possess the requisite technological infrastructure and production capabilities (Table 2.3-2).

Table 2.3-1 Arms sales, 2022, by company

Rank (2022)	Company	Country	Arms revenue in million USD (2022)	Arms revenue as a % of total revenue (2022)	Arm revenue growth (2022-2015)
1	Lockheed Martin Corp.	United States	59390	90	+32 %
2	Raytheon Technologies	United States	39570	59	+47%
3	Northrop Grumman Corp.	United States	32300	88	+30%
4	Boeing	United States	29300	44	-15%
5	General Dynamics Corp.	United States	28320	72	+19%
6	BAE Systems	United Kingdom	26900	97	-1%
7	NORINCO	China	22060	27	+23%
8	AVIC	China	20620	25	+28%
9	CASC	China	19560	44	+49%
10	Rostec	Russia	16810	55	-2%
11	CETC	China	15080	27	+18%
12	L3Harris Technologies	United States	12630	74	-25%
13	Leonardo	Italy	12470	83	+24%
14	Airbus	Trans-European	12090	20	-14%
15	CASIC	China	11770	32	+11%
16	CSSC	China	10440	20	+61%
17	Thales	France	9420	51	+9%
18	HII	United States	8750	82	NA
19	Leidos	United States	8240	58	+103%
20	Amentum	United States	6560	75	NA
21	CSGC	China	6460	15	-33%
22	Booz Allen Hamilton	United States	5900	64	+22%
23	Dassault Aviation Group	France	5070	70	+157%
24	Elbit Systems	Israel	4960	90	+43%
25	Rolls-Royce	United Kingdom	4930	32	+5%
26	CACI International	United States	4820	72	+60%
27	Honeywell International	United States	4630	13	+11%
28	Rheinmetall	Germany	4550	67	+41%
29	Naval Group	France	4530	99	+6%
30	Peraton	United States	4410	63	NA

Source: SIPRI Arms Industry Database.
Note: 2022-2015 growth is computed using 2015 arms revenue defined in 2022 constant dollars.

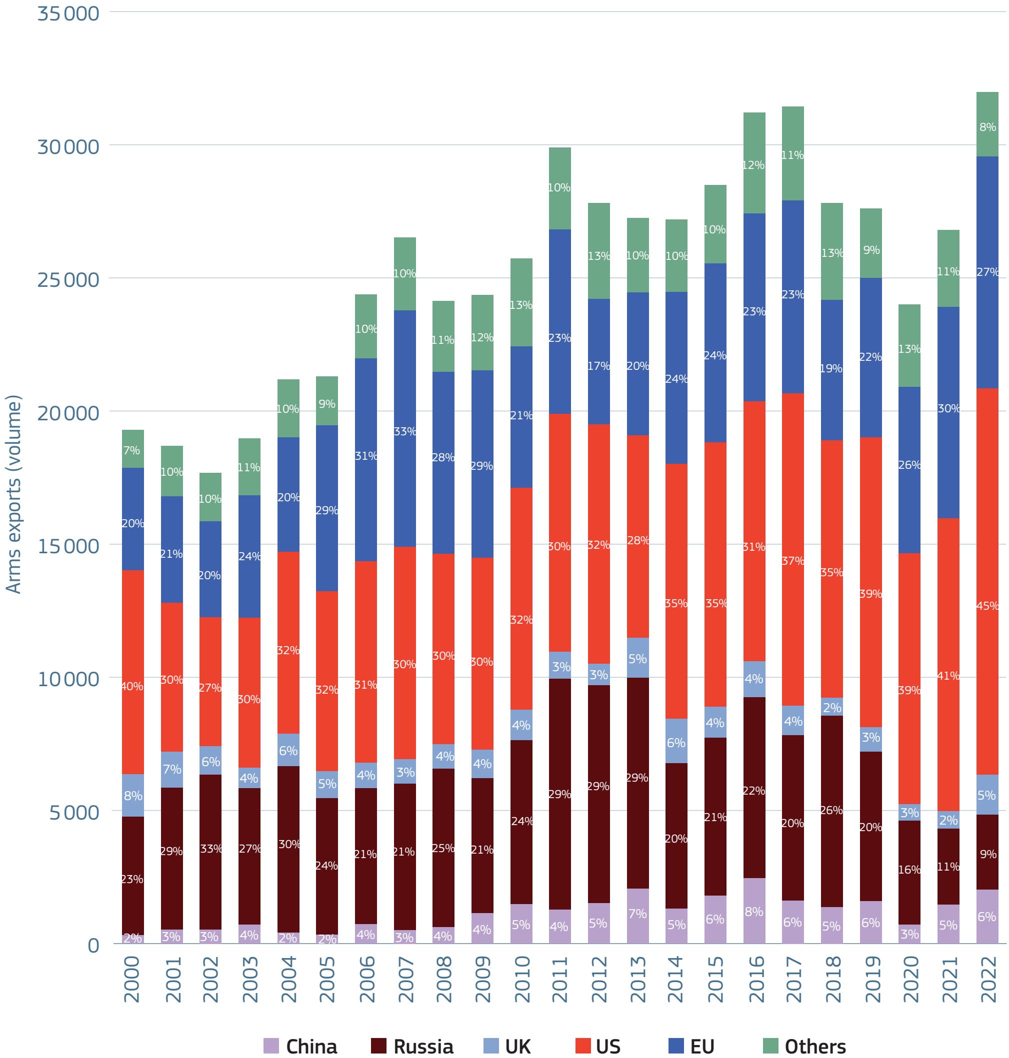
Table 2.3-2 Main exporters and importers of arms by country (2018-2022)

Rank	Exporter	Global share in %	Importer	Global share in %
1	United States	40.2	India	11.2
2	Russia	16.2	Saudi Arabia	9.6
3	France	10.8	Qatar	6.4
4	China	5.2	Australia	4.7
5	Germany	4.2	China	4.6
6	Italy	3.8	Egypt	4.5
7	United Kingdom	3.2	South Korea	3.7
8	Spain	2.6	Pakistan	3.7
9	South Korea	2.4	Japan	3.5
10	Israel	2.3	USA	2.7
11	Netherlands	1.4	UAE	2.7
12	Turkey	1.1	Kuwait	2.4
13	Sweden	0.8	United Kingdom	2.3
14	Switzerland	0.7	Ukraine	2
15	Australia	0.6	Norway	2
16	Canada	0.5	Israel	1.9
17	Ukraine	0.5	Netherlands	1.9
18	UAE	0.4	Algeria	1.8
19	Poland	0.4	Turkey	1.3
20	Belarus	0.3	Singapore	1.3

Science, research and innovation performance of the EU 2024
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's own elaboration based on the SIPRI Arms Transfers Database.
Note: EU Member States' global share is 24.7%.

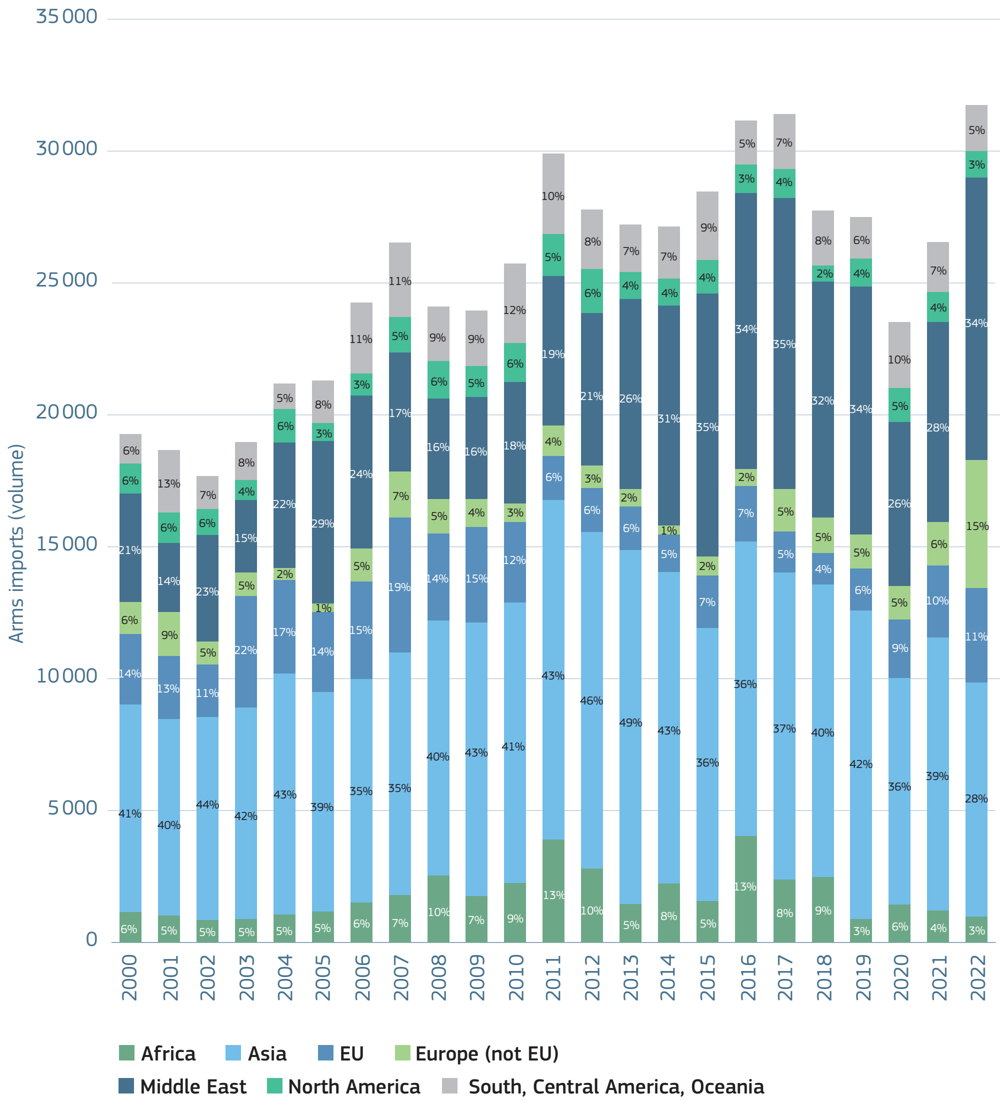
Examining historical patterns from 2000 to 2022 reveals a notable increase in the global share of arms exports by both the EU and the US. Conversely, Russia and the United Kingdom have experienced a decline in their share of the global arms export market. China's arms exports, however, have shown a significant rise, increasing from 2% of the global share in 2000 to 6% in 2022. Focusing on the destinations of these arms, the Middle East and Asia have consistently been the primary importers, accounting for the vast majority of arms imports throughout the period 2000-2022. Notably, arms imports from European non-EU countries witnessed a threefold increase in 2022, largely as a result of Russia's unprovoked invasion of Ukraine (Figures 2.3-5 and 2.3-6).

Figure 2.3-5 Arms exporters trend



Science, research and innovation performance of the EU 2024
Source: DG Research and innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's own elaboration based on the SIPRI Arms Transfers Database.

Figure 2.3-6 Arms importers trend



Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's own elaboration based on the SIPRI Arms Transfers Database.

Note: Imports classified as being from NATO and the United Nations are excluded.

2. Investments in dual-use technologies and socioeconomic returns

The concept of dual-use technology encompasses a wide range of products, services and technologies that are inherently versatile, serving both civilian and military purposes. This versatility is evident in fields like advanced materials, nano-electronics, biotechnology, advance robotics and autonomous systems, and information and communication technologies (ICT). These areas demonstrate the fluidity with which research, technology development and manufacturing can pivot between civil and defence applications (European Commission, 2014).

Dual-use technology represents a crucial frontier with profound implications for the future of innovation and national security. Transfer in the context of dual-use refers to the adaptation of technologies developed in one sector for use in the other. This adaptability not only fosters innovation but also promotes economic efficiency by maximising the utility of technological investments. As the divide between civil and military applications continues to diminish, dual-use technologies are poised to become a cornerstone of socioeconomic growth, driving both industrial innovation and national defence capabilities (European Commission, 2021a,b).

The North Atlantic Treaty Organization (NATO) aligns with this perspective, as evidenced by its comprehensive strategy[3] aimed at promoting the development and adoption of dual-use technologies. This strategy involves collaborative efforts with public and private sector entities, academic institutions, venture capital and civil society. Together, they work towards the development and adoption of new technologies, while also establishing international principles for their responsible use. This collaborative approach is key to maintaining NATO's technological superiority, which is crucial for the defence and security of its member countries (Reding, D.F. and Eaton, J., 2020; NATO, 2021). To effectively support these objectives and foster the advancement of (dual-use) emerging and disruptive technologies, NATO leaders agreed at the 2021 Brussels Summit to establish a NATO Innovation Fund. The EUR 1 billion venture capital fund will provide strategic investments in start-ups developing dual-use emerging and disruptive technologies in areas that are critical to allied security. The fund will be the world's first multi-sovereign venture capital fund.[4] In 2023, NATO doubled down on dual-use technologies with the launch of DIANA (Defence Innovation Accelerator for the North Atlantic). DIANA is an acceleration programme and test centre network to bring start-ups together with operational end users, scientists and system integrators to advance compelling deep tech with dual-use solutions for the Alliance.

3 Exemplified by the recent NATO 2022 Strategic Concept and NATO 2030 Agenda.

4 NATO – Topic: Emerging and disruptive technologies.

The history of dual-use technologies is a fascinating journey from government-led innovation to a more private-sector-driven landscape of today. During the height of the Cold War, the US Federal Government was the primary conductor of technological R&D. This era witnessed the birth of numerous technologies initially intended for military use but later found critical applications in civilian life (Ruttan, 2006; Mazzucato, 2013). Some of the most groundbreaking innovations include:

- ***The internet***: initially developed as ARPANET by the US Department of Defence, the internet revolutionised global communication and information sharing.
- ***Global Positioning System (GPS)***: initially developed by the US Department of Defence for military navigation, GPS is now integral to civilian navigation systems, location-based services, and various applications across transportation, agriculture and emergency response services.
- ***Radar technology***: originally developed for military use during World War II, radar technology is now used in civilian air traffic control, meteorology and even automotive safety systems.
- ***Scanning machines***: technologies like MRI and CT scanners have roots in technologies developed for military purposes, significantly advancing medical diagnostics.
- ***Semiconductors and integrated circuits***: much of the early development in semiconductor technology was driven by defence needs. These components are now fundamental to almost all modern electronics, including computers, smartphones and household appliances.
- ***Material sciences***: many advanced materials, such as Kevlar and carbon fibre, were initially developed for military applications but are now widely used in civilian industries, including automotive, aerospace and sports equipment.
- ***Space exploration technologies***: rocket technology, initially developed for military purposes, played a crucial role in launching humans to the moon and continues to be vital in space exploration.

Government defence R&D can foster the speed of innovation and ultimately promote productivity growth (Moretti, E et al., 2023). However, as highlighted by different case studies of US post-war military R&D, the effectiveness of defence R&D hinges on the scale of investment and the programme structure. Large-scale programmes are influential in guiding firms' strategic decisions and allow for exploring a variety of technological avenues. The programme structure is also key, particularly in the IT sector, where US military R&D has historically encouraged new firms and facilitated inter-firm knowledge sharing, thus nurturing a competitive industry. These factors – investment scale, technological diversity and a structure promoting innovation – are essential for delivering the economic and civilian advantages of defence R&D (Hall et al., 2010).

In today's tech-driven landscape, dominated by major corporations, military transformation increasingly focuses on the challenge of quickly adopting and adapting civilian-developed technologies for military use. This shift signifies a major change in the dynamics of defence innovation. Rather than originating primarily from military-driven R&D, many cutting-edge technologies are now emerging from the commercial sector and are being repurposed for defence uses. Such increased synergies between civilian innovation and military application are fostering a new era of defence capabilities, where the rapid pace of technological change in the private sector directly informs and enhances military effectiveness and strategic superiority (Reding and Eaton, 2020).

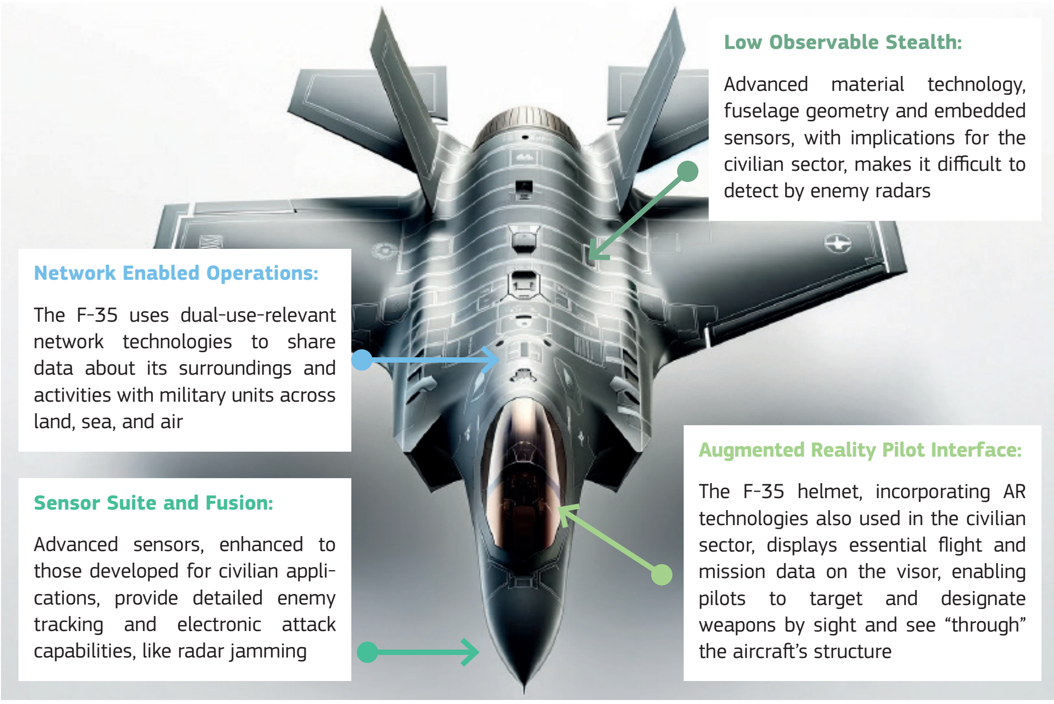
The F-35 Lightning II fighter jet stands as a premier example of collaborative, public-private-led innovation, encapsulating an array of dual-use technologies. Developed by Lockheed Martin, following their victory over Boeing in a competitive bid for a US Government contract, it has been described by the US Air Force's Chief of Staff as a 'computer that happens to fly'. The jet exemplifies cutting-edge technology in aerial warfare, encompassing electronic warfare technologies, advance sensor and network systems, stealth capabilities and augmented reality interface. Its development is a global endeavour, involving suppliers and companies from the US, Australia, Belgium, Denmark, Germany, Italy, Japan, the Netherlands, Norway, Switzerland and the UK. These international collaborators engage in the production, technological development and sustainment of what is considered the most technologically advanced fighter jet in the world. Significantly, over 25 % of the F-35's components are manufactured in Europe by European firms, reflecting its global production footprint and the extensive international cooperation driving its innovation.[5]

Advanced features that endow the NATO fighter jet with airspace superiority stem from the integration of many dual-use technologies, such as advanced materials, network systems, sensors, communication and digital technologies. Figure 2.3-7 shows how such technologies have impacted the jet performance capabilities, as well as how its production fosters their diffusion and expertise across NATO member industries.

The European Defence Agency (EDA) has identified a set of technologies, most of them dual-use, that will define the future of military capabilities. Such technologies are the Internet of Things (IoT), biotechnology and human enhancement, advance materials and manufacturing, hypersonic weapon systems, new space technologies, quantum technologies, blockchain, robotic and autonomous systems, and AI (see Figure 2.3-8).

5 Lockheed Martin website.

Figure 2.3-7 **F-35 Lightning II features derived from dual-use technologies**

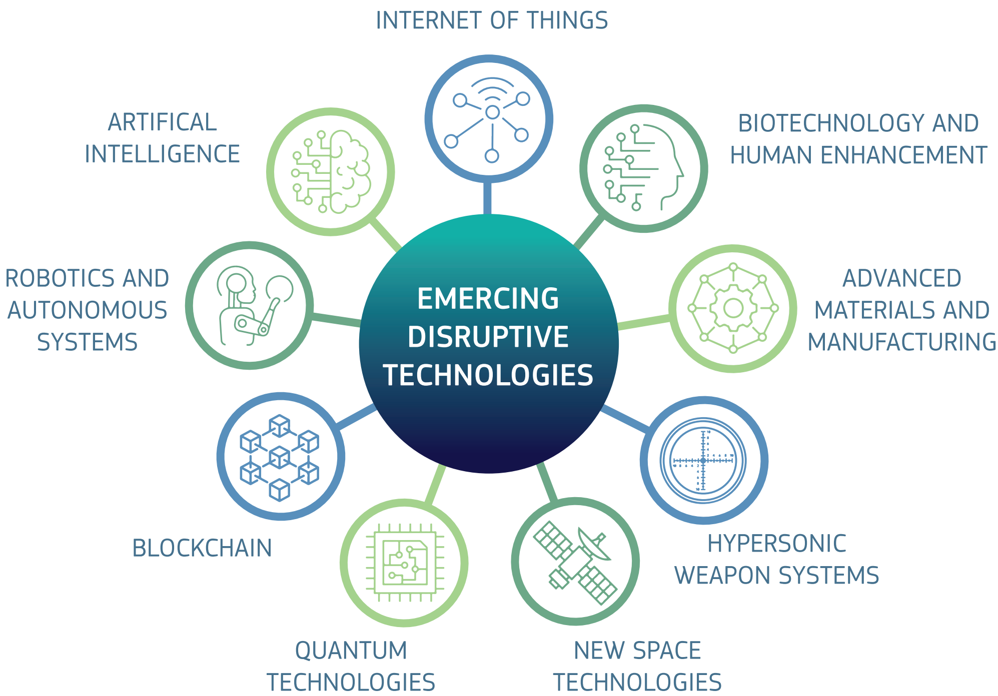


Science, research and innovation performance of the EU 2024

Source: Human-AI generated. Author's own elaboration based on Lockheed Martin specifics.

Figure 2.3-9 depicts the military applications of the EDA's emerging disruptive technologies with high dual-use potential. Interestingly, all these technologies are part of the technological classes with higher complexity and long-run economic return (see Chapter 2.2). IoT enhances situational awareness and streamlines operations but raises cybersecurity and interoperability concerns. AI automates decisions and improves autonomy in systems, requiring strict validation and ethical considerations. Biotechnology advances health monitoring and training for soldiers, with long-term prospects for brain-computer interfaces but mindful of ethical implications. Robotics increase operational efficiency and safety, necessitating careful integration regarding autonomy and ethics. Advanced materials offer new protective and stealth capabilities, with additive manufacturing poised to transform logistics. Quantum technologies promise superior computing and secure communications, though integration with existing systems remains a challenge.

Figure 2.3-8 Technologies for future military capabilities



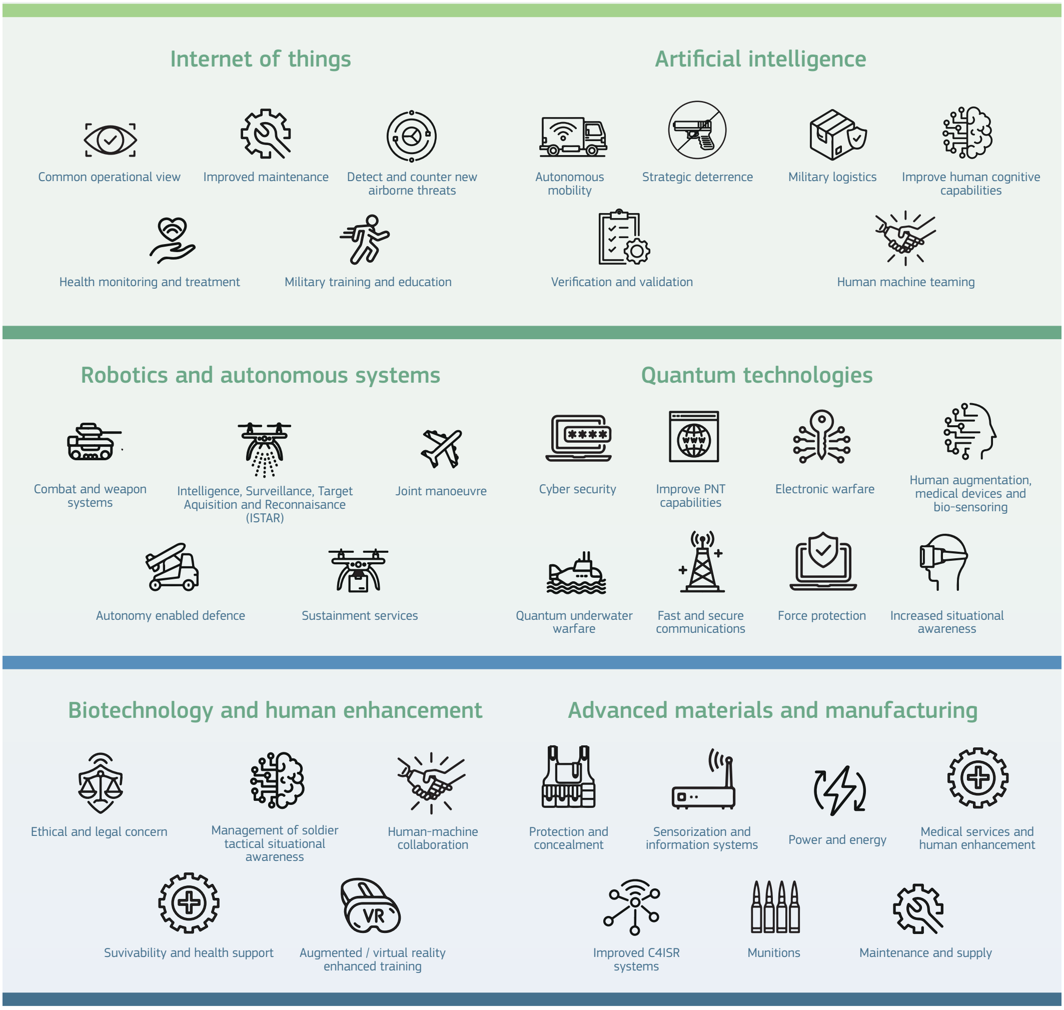
Source: European Defence Agency, (2023).

The main part of European Commission's EU framework programme for R&I does not allow for the financing of defence R&D projects.[6] Under the current EU Framework Programme for R&I (Horizon Europe), activities carried out under the European Defence Fund should have an exclusive focus on defence research and development, while activities carried out under the 'civilian' specific programme and the EIT should have an exclusive focus on civil applications. However, if research is intended to develop or improve dual-use technologies or goods, it can qualify for funding, as long as the goods or technologies are intended for civil applications (EC, 2021c). This opens up support for dual-use technologies, particularly at a lower level of technology readiness levels (TRL), where the spillovers and overlaps between civilian and military interests are larger.

Indeed, Horizon 2020 has already funded many projects with dual-use technology potential. Hristova et al. (2019) studied potential dual-use projects within Horizon 2020. A total of 349 projects related to security and defence research were identified, with ICT and cybersecurity as the main areas, of which almost 90% (311 projects) have dual-use potential, meaning that the civil application outputs could be used for defence purposes. Figure 10 shows the number of Horizon 2020-funded projects related to security and defence classified by a thematic focus.

6 Under the current EU Framework Programme for R&I (Horizon Europe), activities carried out under the European Defence Fund should have an exclusive focus on defence research and development, while activities carried out under the 'civilian' specific programme and the EIT should have an exclusive focus on civil applications.

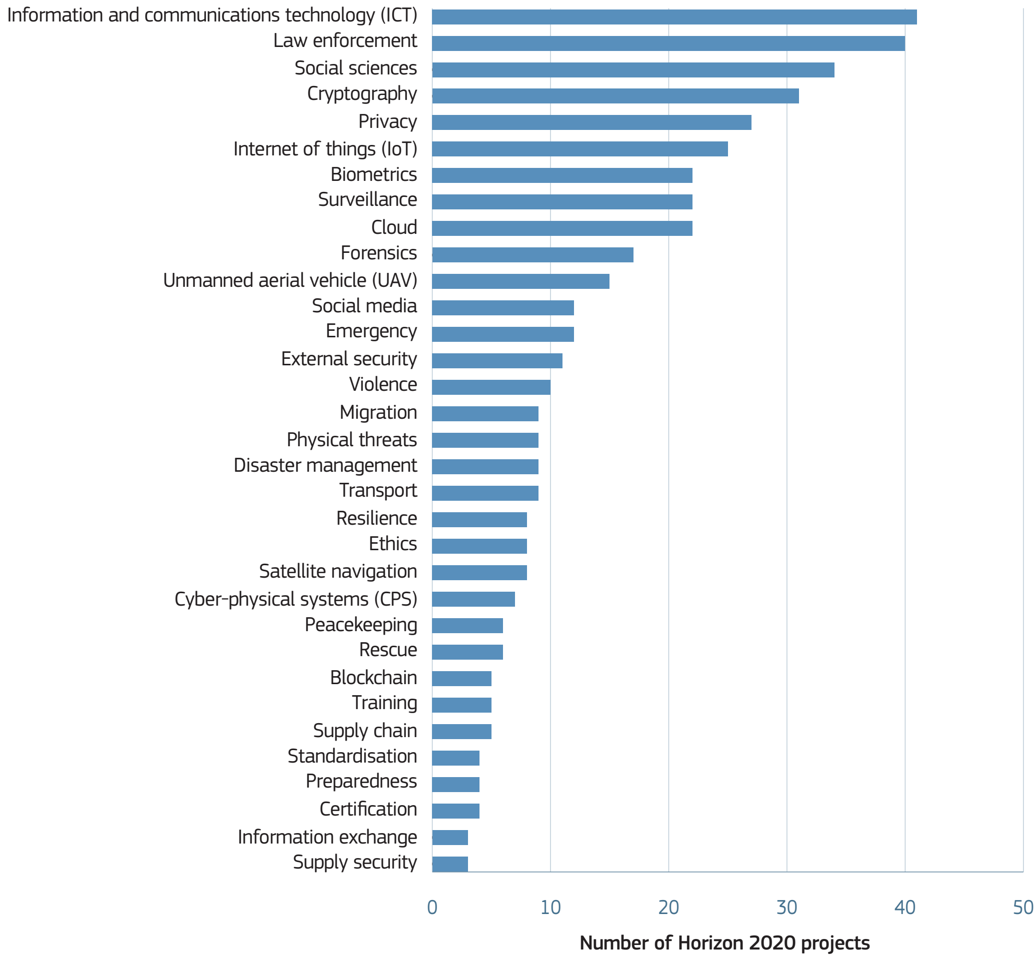
Figure 2.3-9 Defence applications of emerging disruptive dual-use technologies



Science, research and innovation performance of the EU 2024

Source: European Defence Agency, (2023).

Figure 2.3-10 Horizon 2020 projects related to security and defence, by topic

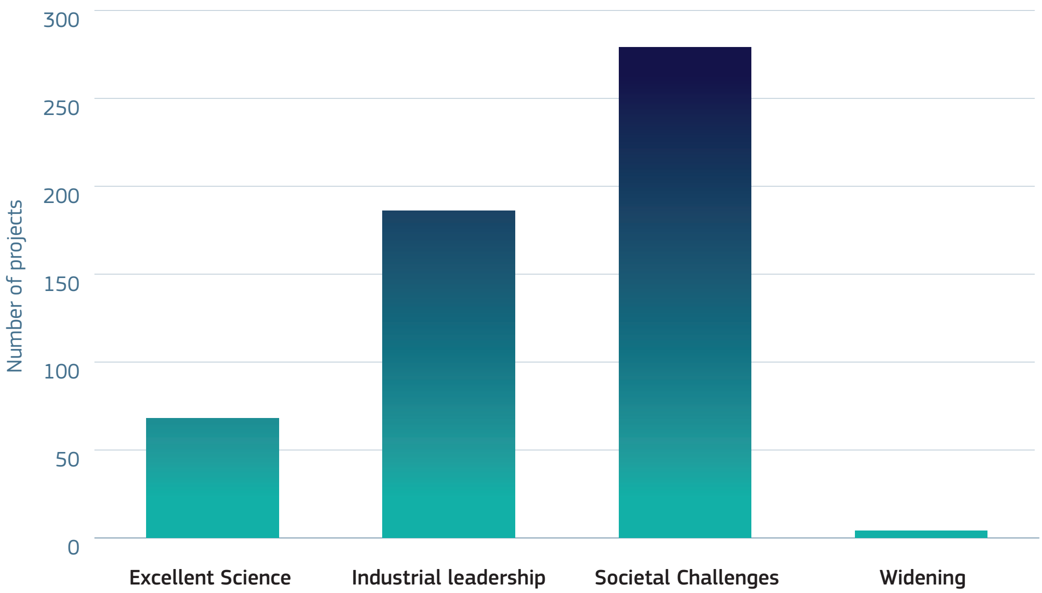


Science, research and innovation performance of the EU 2024

Source: Hristova et al. (2019).

Only 60% of the Horizon 2020 projects related to security were financed through the security-dedicated programme section; the remainder received funding through other channels. Figure 2.3-11 depicts the distribution of such security-related projects across all of Horizon 2020's programme parts, showing the broad spectrum of objectives of modern dual-use technologies.

Figure 2.3-11 Horizon 2020 projects related to security and defence by programme pillars



Source: Hristova et al. (2019).

3. Defence R&I and current global challenges

Russia's unprovoked invasion of Ukraine has sharply underscored the critical importance of defence R&D and technological superiority, not only for deterring aggressions but also in safeguarding peace and prosperity, and upholding the fundamental principles of freedom and democracy.

The convergence of climate change, demographic shifts, political polarisation and geopolitical changes presents unprecedented challenges to global security. Innovation in defence and security technologies is not only essential but imperative to address these multifaceted threats and ensure stability and peace in an increasingly complex world (European Defence Agency, 2023).

Such dimensions can be clustered as follows:

- **Climate change is accelerating, presenting long-term security risks**, such as rising sea levels, extreme weather events and natural disasters. These environmental shifts necessitate enhancements in military capabilities for operating in increasingly hazardous conditions. Furthermore, climate-induced scarcities of resources like water, agricultural land and essential raw materials will likely heighten global competition and could be exploited by adversaries to destabilise economies and incite unrest.

- **Significant demographic transitions**, including aging populations, declining middle-class influence and uncontrolled migration, pose security challenges. These changes are poised to increase the need for responsive and adaptable security strategies. First, ageing necessitates a re-evaluation of national defence and public safety strategies to cater to an older population's unique needs. Second, a weakened middle class could heighten the risk of radicalisation and civil unrest, requiring nuanced and socially sensitive security approaches. Third, uncontrolled migration, fuelled by conflict, economic disparities and climate change, places significant strain on host countries' infrastructure, social services and communal harmony. This leads to humanitarian issues and increased tensions, necessitating effective border control and migrant integration strategies.

- **The COVID-19 pandemic** has highlighted the vulnerability of densely populated, interconnected societies to contagious diseases. The potential use of health threats as weapons by state and non-state actors adds a new dimension to national and global security, necessitating innovative defence solutions.

- **The increasing use of tactics like social engineering, misinformation** and unconventional warfare broadens the spectrum of security threats. Innovations in defence technology are essential to address these challenges, including cyber threats, hybrid warfare tactics and new biological weapons. Future conflicts are likely to see an increase in the misuse of social media and information control to destabilise societies. Defence strategies must therefore evolve to counter misinformation and social polarisation effectively.

- **In the context of the evolving international landscape**, characterised by a multipolar order, EU defence capabilities are important for global stability. Regions such as Africa, the Middle East and the Asia-Pacific can be pivotal with a higher degree of volatility. Consequently, this necessitates the consideration and development of adaptive and proactive defence strategies that are responsive to the changing geopolitical environment.

4. EU policies related to defence and security R&D

The unprovoked invasion of Ukraine by Russia, along with the ongoing conflict, has sharply focused attention on the EU's security and defence needs, placing them at the forefront of the EU's policy discussions. Even before the full-scale invasion, the EU had begun to broaden its role in these areas. This expansion was initially triggered by Russia's annexation of Crimea, as well as increasing threats in terrorism, cybersecurity and security. In response, the EU launched several policy initiatives aimed at strengthening its defence capabilities. These initiatives included the Permanent Structured Cooperation (PESCO), the establishment of the Directorate-General for Defence Industry and Space (DG DEFIS) and the creation of the European Defence Fund (EDF). These efforts build upon the foundational pillars of EU defence and security policy, specifically the common foreign and security policy (CFSP) and the common security and defence policy (CSDP), detailed in Box 2.3-2.

The Strategic Compass for Security and Defence, approved by the European Council in 2022, prioritises boosting investments in technology, research and disruptive innovations to strengthen the EU's security and defence by 2030. Its main goal is to ensure the EU's decisive action in crises and the protection of its citizens. Key focuses include enhancing technological and industrial sovereignty, investing in innovative and dual-use technologies, and building capacities to defend EU interests. Additionally, it emphasises the importance of international cooperation, particularly with NATO, which is essential for collective defence among EU Member States.

During the last couple of years, the NATO-EU cooperation has been strengthened and deepened, with NATO and the EU currently having 23 Member States in common. The renewed cooperation materialised with the Third Joint Declaration on EU-NATO Cooperation at the beginning of 2023, which states that the organisations want to further strengthen the cooperation in existing areas, and expand and deepen the cooperation in other areas to address the growing geostrategic competition and emerging and disruptive technologies, among other things. On this aspect, a relevant difference to highlight is that the EU does not have a permanent military command structure along the lines of NATO.

The EU's key instrument to support competitive and collaborative defence projects throughout the entire cycle of R&D is the European Defence Fund (EDF). Its focus is on strengthening the European defence capability and industrial landscape, encouraging SME participation and emphasising breakthrough innovations. With the EDF, for the first time, the EU budget is used to fund multinational defence projects, with the fund as a key initiative under the CSDP. The EDF has an initial budget of almost EUR 8 billion for 2021-2027, with EUR 2.7 billion to fund collaborative defence research and EUR 5.3 billion to fund collaborative capability development projects, with national contributions.[7] Recently, a Defence Innovation Hub within the European Defence Agency was announced to develop cutting-edge innovations for defence (European Council, 2022).

7 European Defence Fund, https://defence-industry-space.ec.europa.eu/system/files/2022-05/Factsheet%20-%20European%20Defence%20Fund.pdf

Box 2.3-2 EU's main pillars of security and defence policy

Common foreign and security policy[8]

The common foreign and security policy (CFSP) is the EU's joint foreign and security policy. The CFSP was first established in 1993 under the Maastricht Treaty. It has been progressively reinforced by subsequent treaties, particularly the Treaty of Lisbon. The main objectives of the CFSP are to preserve peace; reinforce international security; and promote international cooperation, democracy, the rule of law and respect for human rights and fundamental freedoms. The European External Action Service (EEAS) is the diplomatic service of the EU and in charge of the CFSP (and the CSDP). For the 2021-2027 period the actions are financed via the CSDP programme with a total budget of EUR 2.68 billion. Actions include civilian stabilisation missions, the Kosovo Specialist Chamber and the European Security and Defence College.

Common security and defence policy[9]

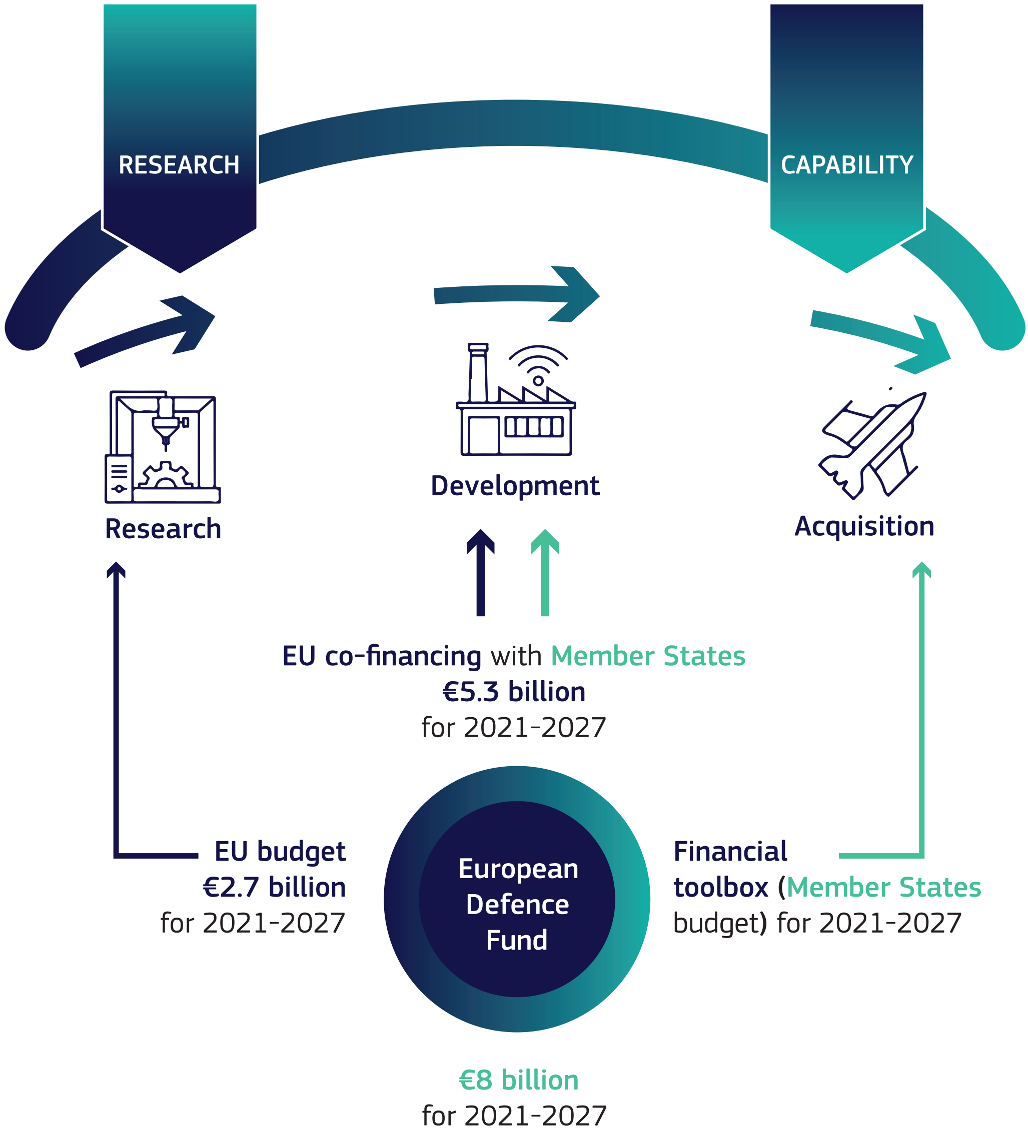
The common security and defence policy (CSDP) is the part of the CFSP that relates to defence and crisis management. An important part of the CSDP is the possibility of setting up military or civilian missions to preserve peace, prevent conflict and strengthen international security.

PESCO

To strengthen cooperation on defence matters by EU Member States, the Treaty of Lisbon provides a provision to set up permanent structured cooperation between Member States (PESCO). Currently, 26 of the 27 EU Member States' armed forces are cooperating on a few projects via PESCO (with the exception of Malta) to pursue structural integration. The European Defence Agency was established in 2004 to facilitate the integration of EU Member States within the CSDP.

8 Common foreign and security policy (europa.eu).
9 The Diplomatic Service of the European Union | EEAS (europa.eu).

Figure 2.3-12 Overview and budget distribution of the European Defence Fund



Source: European Defence Fund.

Horizon Europe, particularly the European Innovation Council and the clusters *Civil Security for Society* and *Digital, Industry and Space* in Pillar 2 on 'Global challenges and European industrial competitiveness', can play a role in the EU's R&D initiatives focused on defence and security (Hristova et al., 2019). Additionally, other programmes like the European Regional Development Fund, the Connecting Europe Facility, the Digital Europe Programme, InvestEU and the Space Programme are also crucial. They contribute not only through direct funding but also through related policies that facilitate the integration, adoption and dissemination of new technologies and innovations, as reported by the European Commission in 2022.

In 2022, the European Investment Bank (EIB) launched the Strategic European Security Initiative (SESI), allocating up to EUR 6 billion for projects on dual-use research and civilian security infrastructures. SESI aims to tackle security challenges across cybersecurity, the New Space industry, AI and quantum technologies, building on its predecessor's foundation. By June 2023, in response to changing geopolitical dynamics and increased funding needs, the EIB's Board of Directors raised its security and defence financing cap to EUR 8 billion. This expansion not only increases funding but also broadens support within the sector, maintaining a strict policy against financing weapons, ammunition and core military or police infrastructure.

To prepare a coherent EU future defence and security landscape, jointly investing in cutting-edge defence technologies is essential. At the same time, to maximize the potential of dual-use technologies, it's crucial to enhance collaboration and bridge the gap between civilian and defence research, technology, and innovation (RTD&I) across the EU and its member states.

The recently published European Commission's White Paper reignited a comprehensive discussion on enhancing support for research and development in technologies with dual-use potential (European Commission, 2024). It proposes three strategic directions for future advancement: (1) extending and building upon the existing framework, (2) diversifying the focus beyond solely civilian applications in specific segments of the programme succeeding Horizon Europe, and (3) establishing a specialised entity devoted exclusively to R&D in dual-use technology areas.

Launched in March 2024, the European Defence Industrial Strategy (EDIS) by the European Commission and EU High Representative aims to enhance the EU defence industry's efficiency and competitiveness. The strategy focuses on decreasing the industry's fragmentation and lowering weapon imports. Key goals include boosting intra-EU defence trade to 35 % of the EU defence market by 2030, ensuring that 50 % of defence procurement is sourced from within the EU, and promoting that at least 40 % of defence equipment purchases are made collaboratively by EU countries (European Commission, 2024).

References

ADS (2022). 2022 Facts & Figures. Aerospace, Security and Defence Industries Association of Europe.

Ball, N., & Leitenberg, M. (Eds.). (2021). *The structure of the defense industry: An international survey* (Vol. 19). Routledge.

European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, (2014), EU funding for Dual Use, https://ec.europa.eu/docsroom/documents/12601.

European Commission, Joint Research Centre, Hristova, M., Luque-Perez, E., Bordin, G., (2019), Security and defence research in the European Union : a landscape review : with a specific focus on man-made risks and threats intended to cause harm, Hristova, M.(editor), Luque-Perez, E.(editor), Bordin, G.(editor), Publications Office.

European Commission (2021a), Action Plan on synergies between civil, defence and space industries Brussels, 22.02.2021 COM (2021) 70 final.

European Commission (2021b), Guidance note — Research with an exclusive focus on civil applications.

European Commission (2022), Roadmap on critical technologies for security and defence. Strasbourg, 15.2.2022 COM(2022) 61 final.

European Commission, (2024), White paper on options for enhancing support for research and development involving technologies with dual-use potential COM(2024) 27 final.

European Council (2022), A Strategic Compass for Security and Defence, 7371/22.

European Defence Agency (2023), Enhancing EU military capabilities beyond 2040 : main findings from the 2023 long-term assessment of the Capability Development Plan, Publications Office of the European Union.

Hall, B. H., & Rosenberg, N. (Eds.), (2010), Handbook of the Economics of Innovation, Elsevier.

Mazzucato, M., (2013), The Entrepreneurial State: Debunking Public vs. Private Sector Myths, Anthem Press.

Moretti, E., Steinwender, C., Van Reenen, J., (2023). 'The intellectual spoils of war? Defense R&D, productivity, and international spillovers', *Review of Economics and Statistics*, pp. 1-46.

NATO Advisory Group on Emerging and Disruptive Technologies (2021), Annual report 2021.

Reding, D. F., Eaton, J., (2020), Science & technology trends 2020-2040, Exploring the S&T edge, NATO science & technology organization, pp. 71-73.

Ruttan, V. W., (2006), Is war necessary for economic growth?: military procurement and technology development, Oxford University Press.

Uttley, M., (2018), Defence procurement. Routledge handbook of defence studies, pp. 72-86.

CHAPTER 2.4

RESILIENCE AND PREPAREDNESS

Key questions

- What types of risks are currently affecting Europe and its partners?
- How has Europe drawn lessons from past crises to effectively tackle current challenges?
- How does R&I contribute to enhancing resilience and preparedness, and what potential future scenarios does it enable us to anticipate?

Highlights

- Geopolitical risk has significantly intensified over recent years. Europe also faces the compounding effects of the aftermath of recent crises, where risks are complex and interconnected.
- The EU and other economies in Europe have demonstrated considerable resilience, adapting swiftly to acute challenges and new realities. Indeed, 70% of EU citizens believe it is a place of stability in uncertain times.
- Private R&D investments have proven more stable compared to capital expenditure, remaining resilient in the face of economic crises. This trend suggests that businesses perceive R&I as a strategic tool for mitigating the impacts of crises. R&I is therefore a vital component for ensuring economic resilience and fostering long-term competitiveness.
- R&D can play a key role in addressing global risks. Global Risks Perception Survey (GRPS) respondents find that R&D has a strong potential for ensuring risk reduction and preparedness, especially for infectious diseases (81%), adverse outcomes of frontier technologies (58%) and extreme weather events (56%).

Policy insights

- In navigating present challenges, it is essential to maintain a forward-looking, strategic perspective. Embracing the power of R&I can help spearhead a new European drive towards a more adaptive, resilient and innovative future.
- Strengthening global research networks that link researchers, institutions, and industries across the world can help achieve preparedness through R&I.

The recent crises have ushered in a new era of 'polycrisis' or 'permacrisis', whose key feature is a high level of uncertainty. The COVID-19 pandemic, the Russian invasion of Ukraine, the energy crisis and its broader inflationary consequences, and the increased frequency of climate-related extreme events cannot be seen as one-off crises but rather a manifestation of a new reality to which policies need to adapt. Dealing with 'black swan' or 'grey rhino' events requires building resilience, strengthening adaptability, and promoting anticipation.[1]

Faced with higher degrees of uncertainty, policymaking may require a comprehensive rethink in order to ensure continued progress towards long term objectives across a range of scenarios, while also addressing the short-term impact of crises. Recently, the Expert group on the economic and societal impact of research and innovation (ESIR) stressed the need for policies to avoid falling into the trap of 'short-termism', and instead adopt a "protect, prepare and transform" approach[2]: 'protect' through a timely and coordinated response in cases of emergency; 'prepare' for a broad set of future risks, through coordination, foresight, community involvement and re-skilling; 'transform' the economy and society towards a competitive, green and fair Europe.

1. How Europe shows resilience in uncertain times

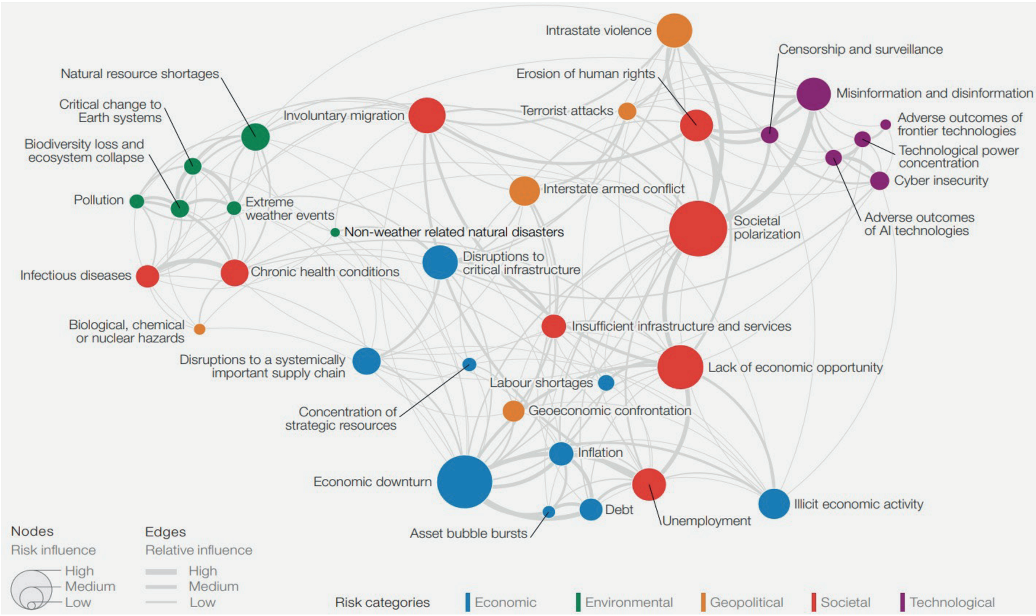
Europe continues to be exposed to the cumulative effects of recent crises. Despite a heightened awareness of the interconnectedness of global risks, disorderly dynamics have contributed to a very high level of perceived uncertainty in Europe (World Economic Forum, 2023). The world in 2024 is facing major crises related to climate and conflict, and, within the global risk landscape (Figure 2.4-1; World Economic Forum, 2024), the most interconnected risks are societal polarisation and economic downturn. While the scientific understanding of the distinct threats giving rise to these crises is extensive, a more general awareness of the causal links among these factors remains limited (Homer-Dixon et al., 2022). Hence, while individual crises may have been contained thus far, the simultaneous shocks to Europe's economic, environmental, geopolitical, societal, and technological systems have created unprecedented challenges, whose aggregate effects on the risk landscape are multifaceted and complex (World Economic Forum, 2023).

Conflicts outside of Europe perpetuate an ongoing state of uncertainty in the region. The Gaza conflict and its spillover potential, coupled with the Russian invasion of Ukraine, poses an acute challenge for the EU.

1 Black swan and grey rhino events were also key concepts in the previous edition of this report, the Science, research and innovation performance of the EU 2022 report (European Commission, 2022). Black swan events are very rare, unpredictable and have very high impact, while grey rhino events can be observed from afar, but are difficult to stop once in motion.

2 European Commission (2023), Research and innovation to thrive in the poly-crisis age, Directorate-General for Research and Innovation, Publications Office of the European Union, Luxembourg https://data.europa.eu/doi/10.2777/92915.

Figure 2.4-1 Global risks landscape

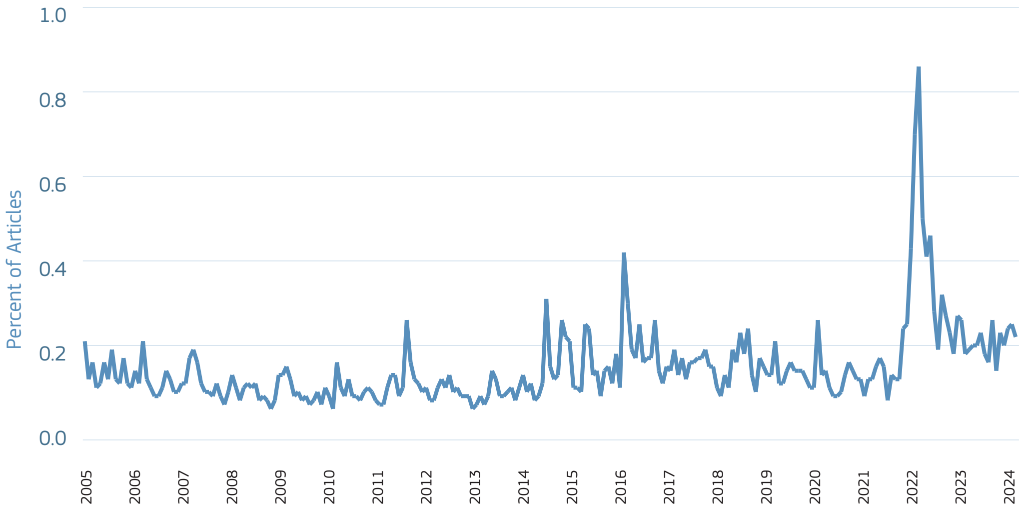


Source: World Economic Forum, Global Risks Report 2024

These events may result in a renewed spike in energy prices causing another economic slump and tighter financial conditions, as well as increased geopolitical risks — most dramatically illustrated by the two ongoing wars in Europe's neighbourhood. Further risks relate to the persistence of inflation, vulnerabilities in trade relations and energy markets, as well as risks associated with climate change and the degradation of natural capital (European Commission, 2024a). Broader global factors, such as geopolitical tensions in the US and China, technological shifts, and environmental threats, add complexity to the 2024 outlook (Economist Intelligence Unit, 2024). Measuring the extent of geopolitical risk associated with these events is a challenge as there is a shortage of robust indicators to quantify these phenomena (Caldara et al. 2022). The geopolitical risk (GPR) index is an attempt to provide such a quantitative measure (Figure 2.4-2).[3] Although the index is measured based on English-speaking newspapers (US, UK, Canada), it provides a proxy for the level of uncertainty in other regions, such as the EU and specific countries.

3 The Geopolitical Risk (GPR) index utilised in this study is constructed from a sample comprising approximately 25 million news articles sourced from the print editions of prominent English-language newspapers spanning the period from 1900 to the present day. This dataset comprises approximately 30,000 and 10,000 articles per month in the recent and historical samples, respectively. The index is derived by quantifying, on a monthly basis, the proportion of articles discussing adverse geopolitical events and associated threats. For the recent GPR index, starting from 1985, automated text searches were conducted on the electronic archives of ten newspapers: the Chicago Tribune, the Daily Telegraph, the Financial Times, the Globe and Mail, the Guardian, the Los Angeles Times, the New York Times, USA Today, the Wall Street Journal, and the Washington Post. The selection of six newspapers from the US, three from the United Kingdom, and one from Canada was deliberate, aiming to encompass events of global significance. The index computation involves tallying the monthly count of articles addressing escalating geopolitical risks, divided by the total number of articles published.

Figure 2.4-2 Average of Geopolitical Risk Indexes for available EU countries over the last 20 years



Science, research and innovation performance of the EU 2024

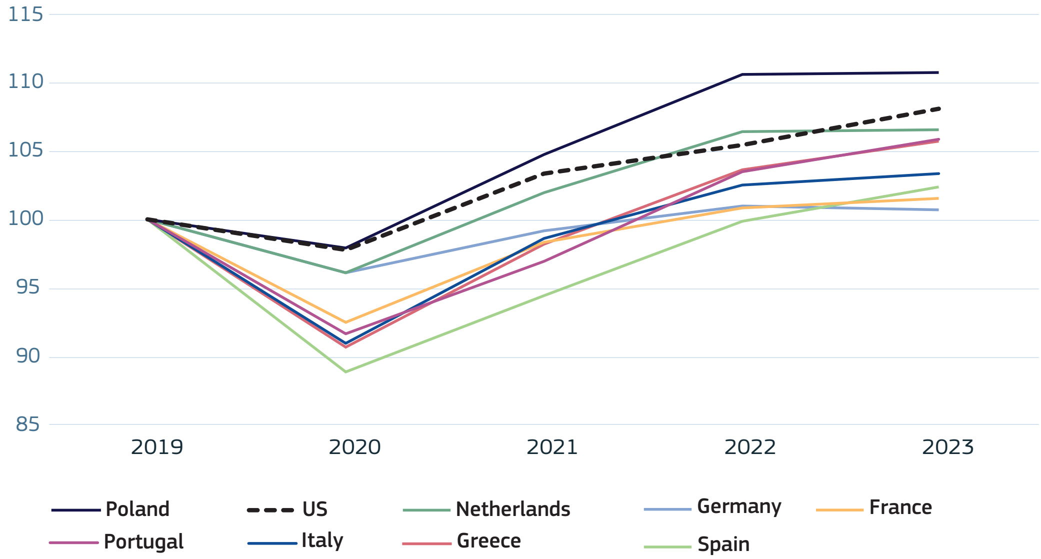
Source: World Bank Group (2024), Global Economic Prospects, January 2024.
Note: Unweighted average of Country-Specific GPR Indexes for available EU countries (Belgium, Germany, Denmark, Spain, Finland, France, Hungary, Italy, Netherlands, Poland, Portugal, Sweden). Labels for years are positioned on the 1st of January.

A key foundation to containing the risk of a 'polycrisis' is a thorough understanding of the interconnectedness of individual crises. For example, viewing the war in Ukraine as an isolated interstate conflict, ignores the strong effect it has on the instability of the global food supply chain, which has been a major driver of the increase in the cost of living. As the short-term ramifications of the invasion on e.g. agricultural production compounded longer-term trends of more volatile crop yields, policymaking needs to be aware of the interrelations between cyclical developments and structural trends. The perceived uncertainty resulting from these crises is further amplified by the spread of misinformation and societal polarisation.

As a recent illustration of countries' capacity to deal with a crisis, the economic impact of COVID-19 shows strong heterogeneity among member states (Figure 2.4-3). While some member states, such as Spain, Greece, and Italy, were among the hardest-hit economies, others, such as Ireland, Denmark, and Poland have been able to maintain positive growth rates. This regional disparity might be related to varying effectiveness and stringency in governmental reactions, market dynamics, and the inherent resilience of different economies. The sectoral composition of economies was also an important determinant, as tourism- and services-intensive countries were particularly hard-hit. However, many affected EU economies — including those most affected by the pandemic — have leveraged the crisis to drive digitalisation and foster new opportunities for start-ups, particularly in the online trade sector (European Commission, 2022). Tourist-dependent economies were also able to rebound (Figure 2.4-3), driven by a recovery in tourism activity in 2023 as well as a shift towards spending by residents on services like restaurants (International Monetary

Fund, 2023). Moreover, the positive perception of the EU among its citizens underscores this resilience. The 100th Standard Eurobarometer survey shows that seven EU citizens out of 10 (70%) believe that the EU is a place of stability in a troubled world. This is the case for the majority of respondents in all Member States (European Commission, 2023d).

Figure 2.4-3 Economic impact of COVID-19 (real GDP levels, 2019 = 100)



Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on Eurostat data.

Utilising the Economic Resilience Index (ERI)[4] to examine the individual dimensions of resilience also reveals conceptual differences among the EU countries. In Table 2.4-1, which shows the composite score[5] of the 25 measured EU countries in the six resilience dimensions of the ERI, it becomes evident that the ability of EU economies to absorb, recover from, and adapt to shocks reveal great disparities. Notably, of the 25 EU countries, some of Europe's largest economies such as France, Spain and Italy are positioned in the middle or lower ranks. While Scandinavian countries such as Sweden, Denmark, and Finland score highly across all categories, France and Italy struggle to produce comparable composite scores, due to low scores across categories such as Education & Skills, Financial Resilience, and Social Progress & Cohesion.

4 ZOE, the Institute for Future-Fit Economies has developed the Economic Resilience Index (ERI), which assesses the future-preparedness of economies to thrive when faced with continuous crises. The index considers in total 27 different indicators, divided into six dimensions: Economic Independence, Education & Skills, Financial Resilience, Governance, Production Capacity and Social Progress & Cohesion (See Hafele et al., 2023).

5 The composite score can be understood as both the average of all 27 indicators as well as the average of the six dimensions. Each country score can take on a value between zero and one ranging from worst to best performance.

Table 2.4-1 Economic Resilience Index ranking

Rank	Country	Composite score	Economic independence	Education & Skills	Financial Resilience	Governance	Production Capacity	Social Progress & Cohesion
1	Sweden	0.78	0.74	0.9	0.73	0.79	0.78	0.75
2	Denmark	0.74	0.59	0.88	0.63	0.9	0.62	0.81
3	Finland	0.74	0.6	0.92	0.59	0.9	0.69	0.75
4	Netherlands	0.67	0.49	0.86	0.77	0.79	0.6	0.61
5	Germany	0.65	0.75	0.6	0.7	0.75	0.62	0.53
6	Austria	0.64	0.41	0.67	0.69	0.82	0.61	0.7
7	Ireland	0.63	0.42	0.76	0.66	0.62	0.74	0.66
8	Belgium	0.63	0.46	0.62	0.67	0.75	0.63	0.69
9	Estonia	0.62	0.56	0.72	0.6	0.61	0.78	0.53
10	Slovenia	0.62	0.66	0.58	0.73	0.44	0.45	0.76
11	France	0.56	0.72	0.49	0.55	0.69	0.56	0.38
12	Czechia	0.51	0.44	0.48	0.71	0.37	0.7	0.43
13	Cyprus	0.49	0.35	0.47	0.35	0.43	0.61	0.66
14	Hungary	0.45	0.44	0.25	0.61	0.29	0.56	0.53
15	Lithuania	0.41	0.42	0.3	0.47	0.4	0.42	0.45
16	Latvia	0.41	0.45	0.32	0.46	0.3	0.45	0.46
17	Croatia	0.4	0.46	0.22	0.47	0.23	0.46	0.52
18	Spain	0.39	0.53	0.45	0.34	0.44	0.16	0.4
19	Italy	0.39	0.67	0.34	0.3	0.38	0.28	0.34
20	Slovakia	0.38	0.44	0.19	0.67	0.29	0.24	0.42
21	Portugal	0.35	0.17	0.55	0.24	0.37	0.37	0.39
22	Poland	0.32	0.34	0.39	0.34	0.22	0.32	0.31
23	Bulgaria	0.29	0.53	0.1	0.32	0.12	0.41	0.22
24	Greece	0.28	0.47	0.2	0.09	0.35	0.25	0.28
25	Romania	0.25	0.56	0.06	0.22	0.07	0.4	0.17

Science, research and innovation performance of the EU 2024
Source: ZOE Institute for Future-fit Economies, The Economic Resilience Index 2023 (Hafele et al., 2023).

Furthermore, there doesn't seem to be a strong link between economic resilience and CO_2 emissions per capita, suggesting that, in the search for the formula of economic resilience, factors beyond GDP and elevated levels of material consumption play a role (Hafele et al., 2023).

The Recovery and Resilience Facility (RRF) continues to be a powerful instrument in the face of uncertainty. Since its start of operation in 2021 it has become a central element in the EU's efforts to enhance the economic resilience of its Member States (European Commission, 2023c) while supporting the economic recovery and twin transitions. An amount of EUR 233 billion have already been disbursed under the RRF and around 75% of the milestones and targets planned to be achieved by end 2023 either have already been assessed by the Commission as satisfactorily fulfilled or are reported as completed by Member States. Furthermore, through their RRPs, Member States have made significant progress in addressing the CSRs issued in the context of the European Semester (European Commission, 2024b).

2. R&I for resilience and preparedness

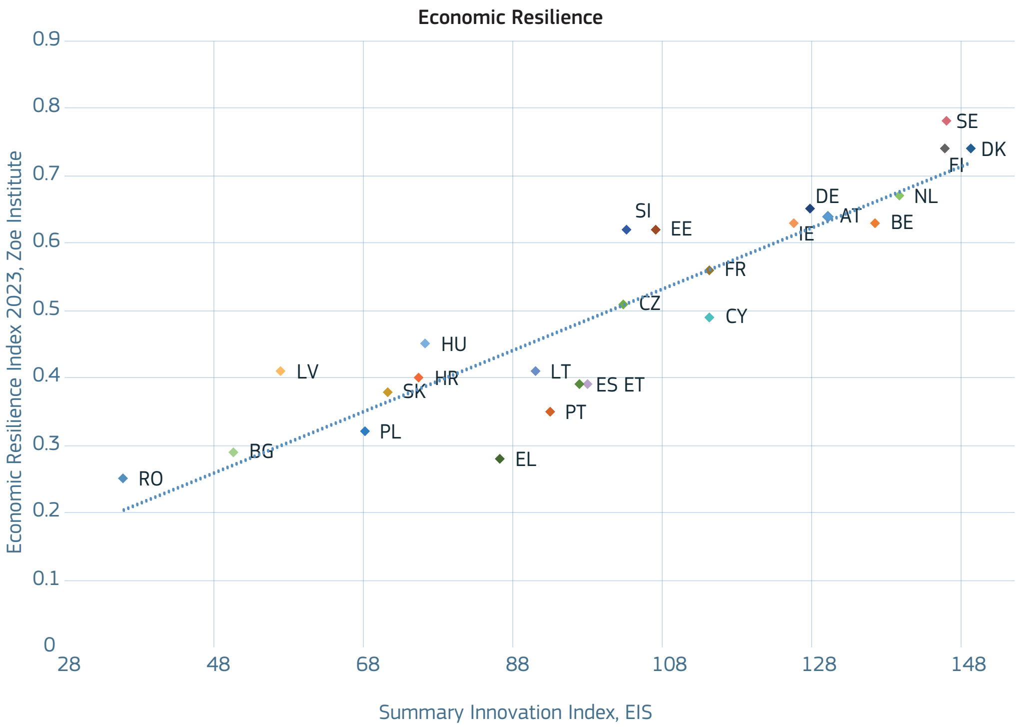
The recent geopolitical shifts stress the critical role of R&I in strengthening the resilience of the EU economy. Promoting technological sovereignty in strategic sectors can contribute to economic security and shield the EU from geopolitical fallout. New technologies can also provide ways of substituting necessary critical materials, e.g. for the green transition, where important dependencies on single countries exist. Furthermore, innovation fosters the economic resilience of firms and innovative firms contribute significantly to the dynamism of the EU economy. Novel products and services not only stimulate competitive markets, but also foster resilience by diversifying economic activities and reducing dependency on traditional industries. Innovation also helps firms cushion the negative impact of economic disturbances. Figure 2.4-4 illustrates the high degree of correlation between innovation and resilience. [6]

R&I enhances preparedness for unavoidable environmental hazards like extreme weather events and non-weather-related natural disasters. The escalating impacts of climate change, combined with strained planetary boundaries, are introducing unprecedented disruptions to key societal systems – be they water supply, energy, health, transport, or product markets. R&I can help accelerate the de-risking of key systems and infrastructures, scale up civil protection capabilities and facilitate the medium- to long-term financial and economic transition for climate change adaptation and/or mitigation. Additionally, it can help improve resource efficiency and promote the development of circular economies. For instance, technological breakthroughs in nuclear fusion power generation would represent a game-changer; it would offer clean energy, accelerating the shift towards achieving net zero, while concurrently mitigating the risk of pollution and contamination.

6 For resilience, the aforementioned Economic Resilience Index (ERI) was used, and for innovation, the Summary Innovation Index. The Summary Innovation Index measures the performance of the EU national innovation systems and is referenced from the the annual European Innovation Scoreboard (EIS), which provides a comparative assessment of the research and innovation performance of EU Member States and selected third countries, and the relative strengths and weaknesses of their research and innovation systems (European Commission, 2023a).

The power of R&I to strengthen preparedness is further acknowledged by GRPS respondents, who emphasise the pivotal role of research and development in addressing health, environmental, and technological risks (Figure 2.4-5) (World Economic Forum, 2024).

Figure 2.4-4 Innovation capacity and economic resilience

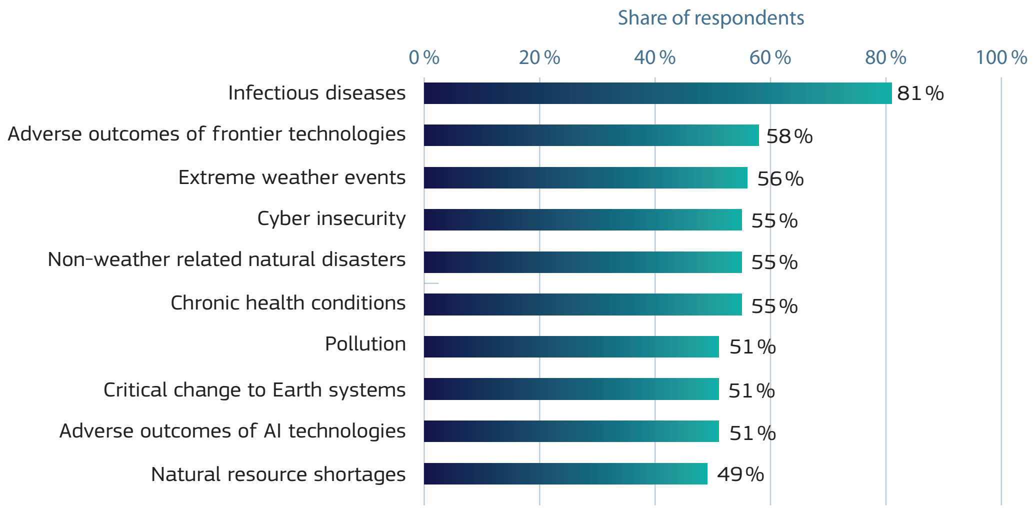


Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit, based on the European Innovation Scoreboard (European Commission, 2023a) and the Economic Resilience Index (Hafele et al., 2023).

Private R&D investments have proven more stable compared to capital expenditure, remaining resilient in the face of economic crises. This trend was observed both during the Global Financial Crisis of 2009 and the COVID pandemic (Figure 2.4-6), suggesting that businesses perceive R&D as a strategic tool for mitigating the impact of crises; it may also reflect a preference of companies — typically larger ones — to not jeopardise their future growth potential by shelving R&D projects. Unlike

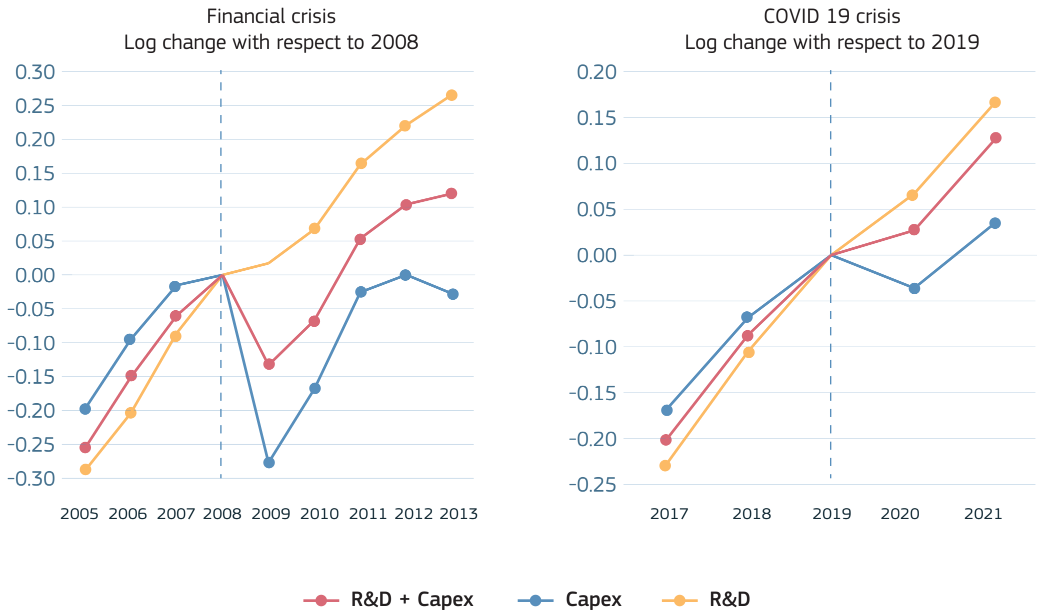
Figure 2.4-5 **Top global risks addressed by research and development**



Science, research and innovation performance of the EU 2024
Source: World Economic Forum Global Risks Perception Survey 2023-2024.
Note: To the question “Which approach(es) do you expect to have the most potential for driving action on risk reduction and preparedness over the next 10 years?” related to each item, respondents could select up to three responses from nine options, including research and development.

more traditional forms of capital investment, R&D tends to be seen as a vital component for ensuring economic resilience and fostering long-term competitiveness. This resilience of R&D investment could be attributed to the recognition that innovation and technological advancement are key drivers of sustainable growth, especially in turbulent times (European Commission, 2023b).

Figure 2.4-6 R&D and Capex before and after major crises, by investment type



Science, research and innovation performance of the EU 2024

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission (2023b).

Notes: The graph plots coefficients of year indicator variables from regressions controlling for net sales and firm fixed effects. All values are in 2015 PPP USD, except for net sales, which are in 2015 USD. Values x100 are % changes compared to the base year (2008 or 2019).

In the wake of the 2009 financial crisis and the COVID-19 pandemic, R&D investment by leading firms has significantly contributed to their economic recovery. A positive correlation between R&D spending and key performance indicators can be seen, for instance concerning turnover growth and productivity gains (European Commission, 2023b).

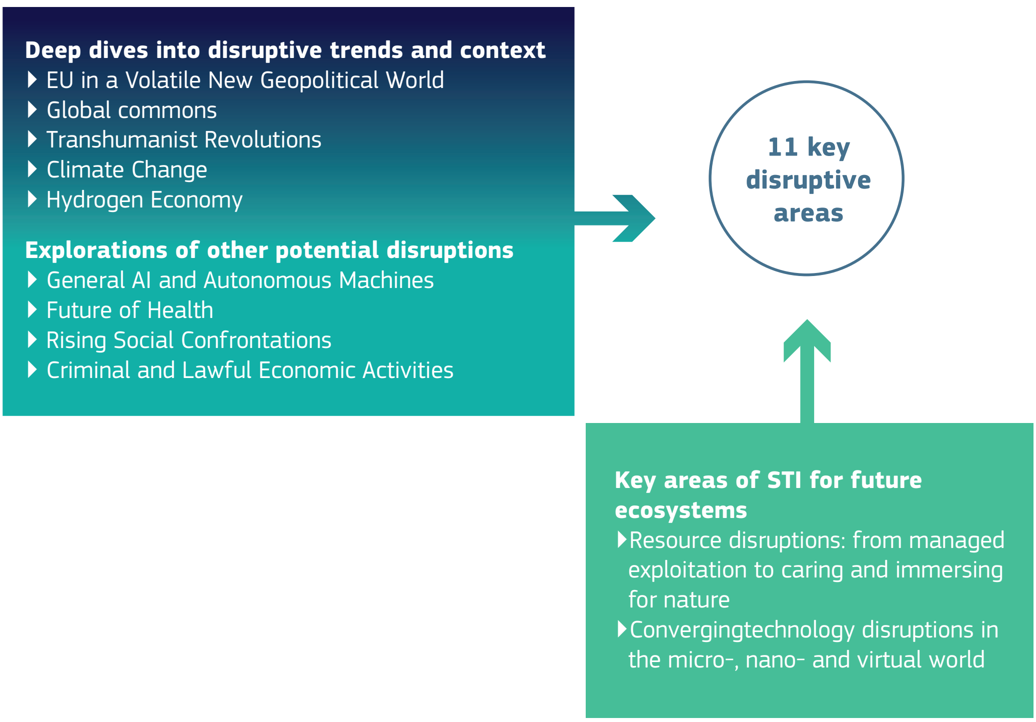
However, this trend is not uniform across regions. For instance, American and Chinese firms saw a more rapid recovery in their R&D and capital expenditures than their European counterparts. This regional disparity might be influenced by varying governmental policies, market dynamics, and the inherent resilience of different economies.

3. What the future may bring for Europe and the role of R&I

Europe's green transition efforts aim to achieve carbon neutrality and significantly increase sustainability in the coming decades. A successful transformation can be defined as limiting the existential risks of climate change and the environmental crisis. It will also be crucial in strengthening the EU's strategic autonomy and economic security, and in reinforcing Europe's long-term competitiveness, social model and resilience. However, to succeed, Europe will have to address and overcome some key social and economic challenges. This will require making difficult political choices and confronting acute trade-offs that are expected to have an immense impact on our societies and economies.

Foresight studies on European R&I have identified 11 key disruptive areas over a time perspective of 20–30 years (Box 2.4-1 and Figure 2.4-7). These potential key areas of change are divided into three subsections: 1. World of global tensions; 2. Technology and society; and 3. R&I for future ecosystems.

Figure 2.4-7 Exploring potential futures in key areas of change



Source: European Commission, Directorate-General for Research and Innovation (2023): Horizon Europe Strategic Plan 2025-2027 Analysis

Box 2.4-1: R&I foresight in the EU

In today's rapidly changing world, the use of strategic foresight exercises is more relevant than ever. Foresight enables groups, leaders and organisations to prepare, shape, anticipate future trends and increase the robustness of policy to future risks. It is becoming an increasingly important tool contributing to better-informed political processes, governance and decisions based on the best possible understanding of drivers of future trends and resulting scenarios. The interest in foresight has grown at both national and European level as part of a response to current - and potentially forthcoming - challenges. Harnessing the power of collective intelligence through strategic knowledge exchange and dialogue is key to reach a new shared understanding of the bigger picture of tomorrow. By distilling new insights across different horizons, and encouraging development of collaborative and anticipatory strategies, collective foresight can inform decisions affecting the future in a structured way. One particular strength of collective foresight comes from engaging with a wide spectrum of relevant actors, such as experts and stakeholders. Appreciating diversity and embracing differences can lead to a more critical understanding of the whole system and to more dependable solutions.

The metaphor of the Fox and Hedgehog[7] bridges the gap between risk and foresight. The Fox and the Hedgehog represent two distinct views of the world (Berlin, 1953). The Hedgehog has a single and broad understanding of the world and uses it as a framework for interpretation. In contrast, the Fox, knows many small details and uses a broad range of experiences and knowledge to navigate complexity. Both strategies have advantages when it comes to making decisions under uncertainty (Logan et al., 2024). However, in foresight, the Hedgehog's possibly rigid and singular approach might be surpassed by the Fox's flexible and varied way of thinking (Tetlock, 2005). In R&I policy, integrating the flexibility and openness of the Fox with the strategic focus and coherence of the Hedgehog can help to promote R&I and address challenges with wisdom and agility.

The EU has played an important role in driving foresight for decades, working hand-in-hand with Member States and associated countries. The European Commission's growing efforts to embed strategic foresight into EU policymaking was reflected in the appointment of Executive Vice-President Maroš Šefčovič in 2019 as the first ever member of the College of Commissioners in charge of strategic foresight. Since then, the EU has developed a set of initiatives and processes across its institutions, including the publication of annual strategic foresight reports as well as a Future

7 The metaphor stems from poet Isaiah Berlin, who elaborates on a fragment by the Greek poet Archilochus, who wrote 'The fox knows many things, but the hedgehog knows one big thing.' It should be noted that this metaphor can be interpreted in different ways.

of Europe (Ministers of Future) conference, signalling its attention to resilience, the EU's ability to act in the world — the decline of which has been a core concern for the EU since the Gonzales report of 2010 — and the EU's pursuit of the twin green and digital transition in line with the EU's sustainability objectives.

The EU has also increased the use of foresight exercises and activities in various policy areas. R&I foresight under the Horizon Europe programme has aimed at exploring future trends, opportunities and challenges in key disruptive sectors. Its objective has been to inform political processes by using both possible and plausible predictions of future developments. In the context of more traditional R&I policy, where there is considerable uncertainty about both the directions and the expectations of R&I, key questions concern the significance of the objectives, the extent to which there are trade-offs between them, and the extent to which such trade-offs are determined by current structures and technologies.

The Russian invasion of Ukraine dramatically underscored that the world system is at a crossroads and may evolve towards a new bipolar or multipolar configuration, with important implications for global governance and its institutions. The EU's relationship with the US and the extent to which the US engages with global issues and in global governance institutions are critical for the EU's future. The EU's foresight activities have explored scenarios with high and low levels of global engagement from the United States, and high and low levels of global agency for the EU.[8] These scenarios put the EU's pursuit of digital leadership into context, as the US is the de facto leader in many such technologies, followed by China. The EU faces a critical investment gap – in which, for example, the annual R&D budget of Amazon is more than four times that of the annual budget for the EU framework programme for research and innovation.

The indispensable digital transition of the EU economy and society could be framed as a battle for leadership, or as participation in a global digital and sustainable transition. The choice of strategic framing affects the chosen approach to key policy directions for R&I, especially as regards international cooperation and global regulatory frameworks. Framing the EU as – at least partly – a follower, rather than a global leader, could make the strategic orientations more conducive to global collaborations for global challenges.

8 European Commission (2023e), Reference foresight scenarios: Scenarios on the global standing of the EU in 2040, Publications Office of the European Union, Luxembourg. https://publications.jrc.ec.europa.eu/repository/handle/JRC132943

The internal coherence of the EU is significant for its ability to act in the global scene, and promoting this internal coherence is a very important function of R&I policy. In addition, recognising the significance of the relationship with the US has important implications for the extent and forms of R&I cooperation with the US. Recognising the importance of R&D for defence and security raises important concerns about the security of the R&I process, as well as the possibility of the leakage of strategically important capabilities through R&I projects.

Building resilience cannot happen when operating in silos. Instead, a collaborative approach that fosters global scientific communication is crucial (Homer-Dixon et al., 2022). As the past has shown, enhancing global research networks that link researchers, institutions, and industries across the world, is fundamental for achieving preparedness through R&I, as it leads to effective communication and facilitates resource-sharing. For instance, during COVID-19, co-funding from the public sector was essential for healthcare companies to rapidly deploy an effective vaccine (World Economic Forum, 2024). Implementing science, technology and innovation (STI) policies can play a pivotal role by providing incentives to strengthen and expand networks in 'normal times', along with continued support for investments in critical infrastructures and technologies (OECD, 2022).

Leveraging the potential of R&I requires a multifaced perspective. When tackling current challenges, maintaining a forward-looking perspective is crucial and can lead to more durable and beneficial outcomes. Committing to groundbreaking initiatives typically represents a prolonged and somewhat risky investment (World Economic Forum, 2024). Furthermore, investing in R&I can also result in possibilities for future growth and adaptability (Atanassov et al., 2019), thereby strengthening resilience and preparedness. The effectiveness of this dual approach also becomes evident when looking at COVID-19. While nations rebuild health systems post-COVID-19, emphasis lies also on addressing workforce challenges and strengthening resilience against future pandemics. In the same vein, investing in R&I emerges as one practical and strategic approach for a more adaptive future (OECD, 2024).

References

Atanassov, J., Julio, B., Leng, T. (2019), 'The Bright Side of Political Uncertainty: The Case of R&D', *The Review of Financial Studies*. Caldara, D., Matteo I., (2022), 'Measuring Geopolitical Risk'; *American Economic Review*, 112(4), pp. 1194-1225.

Economist Intelligence Unit (2024), Risk outlook 2024, Ten critical risk scenarios facing the global economy.

European Commission (2022), Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times, DG Research and Innovation, Publications Office of the European Union, Luxembourg.

European Commission (2023a), European Innovation Scoreboard 2023, DG Research and Innovation, Publications Office of the European Union, Luxembourg. European Commission (2023b), The 2023 EU industrial R&D investment scoreboard, DG Joint Research Centre, Publications Office of the European Union, Luxembourg.

European Commission (2023c), Recovery and Resilience Facility Annual Report 2023, Secretariat-General, Publications Office of the European Union, Luxembourg.

European Commission (2023d), Standard Eurobarometer 100 - Autumn 2023, Publications Office of the European Union, Luxembourg.

European Commission (2023e), Reference foresight scenarios: Scenarios on the global standing of the EU in 2040, Publications Office of the European Union, Luxembourg.

European Commission (2024a), 'European Economic Forecast, Spring 2024', DG Economic and Financial Affairs, *European Economy Institutional papers* 286.

European Commission (2024b), Strengthening the EU through ambitious reforms and investments, SWD(2024) 70 final.

Hafele, J., Bertram, L., Demitry, N., Le Lannou, L-A., Korinek, L., Barth, J., (2023), The Economic Resilience Index: assessing the ability of EU economies to thrive in times of change, ZOE Institute for Future-fit Economies: Cologne.

Homer-Dixon, T., O. Renn, J. Rockström, J. Donges, Janzwood, S. (2022), *a call for an international research program on the risk of a global polycrisis*, Technical Paper 2022-3, version 2.0. Cascade Institute.

International Monetary Fund (2023), World Economic Outlook Update, July 2023: Near-Term Resilience, Persistent Challenges.

I. Berlin. (1953), The Hedgehog and the Fox, Wiedenfeld and Nicolson, London.

Logan, R.J., Cavana, R.Y., Howell, B.E., Yeoman, I., (2024), 'Why Do Key Decision-Makers Fail to Foresee Extreme 'Black Swan' Events? a Case Study of the Pike River Mine Disaster, New Zealand', *Systems*, 12(1), 34.

OECD (2022), How did COVID-19 shape co-creation? Insights and policy lessons from international initiatives. OECD Science, Technology and Industry Policy Papers, No. 134, OECD Publishing, Paris.

OECD (2024), Collective Action for Responsible AI in Health, OECD Artificial Intelligence Papers, No. 10, OECD Publishing, Paris.

Tetlock, P. (2005), Expert Political Judgment: How Good Is It? How Can We Know? , Princeton University Press: Princeton, NJ, USA.

World Economic Forum (2023), Global Risks Report 2023, Geneva, Switzerland.

World Economic Forum (2024), Global Risks Report 2024, Geneva, Switzerland.

World Bank Group (2024), Global Economic Prospects, Washington, DG.