CHAPTER 5

A THRIVING INNOVATIVE EUROPE

CHAPTER 5.1

R&I FOR GREEN PRODUCTIVITY GROWTH

Key questions

- What are the R&I drivers of labour productivity growth in the EU?
- What role does R&I play in decoupling economic growth from CO_2 emissions?
- Can AI defeat the productivity slowdown of Western economies?

Highlights

- Productivity growth is a key driver of economic prosperity, which, in turn, plays a significant role in reducing poverty and elevating the overall quality of life.
- In the EU, total factor productivity drives 48% of labour productivity growth, followed by training and organisational capital (18%), training (8%), R&D (4%), software (4 %) non-ICT tangible (13%) and ICT tangible 5%.
- In the goods sector, tangible assets are key to productivity, while in the service sector, software, training, and organizational capital are more influential for labour productivity.
- Between 1990 and 2020, both the European Union (EU) and the United States (US) experienced GDP growth, alongside a decline in CO_2 emissions, even when accounting for offshore production.
- In 2020, even accounting for trade-adjusted CO_2 emissions, China's annual CO_2 output is approximately triple that of the EU, and twice that of the US.

Policy insights

- R&I is a key driver of European competitiveness and green growth.
- R&I plays a crucial role in accelerating economic growth decoupled from resource use by fostering the current decline in the cost of low-carbon technologies, as well as their deployment across the world.
- AI has the potential to address the productivity slowdown that has plagued Western economies in recent decades. However, for this success to be realised, it is crucial to implement policies that ensure AI augments rather than replaces human labour.

In the pursuit of economic growth and competitiveness, labour productivity stands as a pivotal metric, offering a lens through which we evaluate the efficacy of resource allocation within economies. Central to enhancing this productivity in the European Union (EU) are research and innovation (R&I) efforts, which have historically underpinned advancements in technology and society.

This chapter delves into the instrumental role of R&I in propelling labour productivity growth across the EU, with a particular focus on the concept of green growth (defined as economic growth decoupled from CO_2 emissions) and the productivity slowdown of which developed economies have been suffering in the past decades. The chapters also investigate the role of Artificial Intelligence in the mentioned dimensions.

1. R&I and labour productivity growth in the EU

Productivity is a vital economic indicator that reflects the efficiency with which inputs, like resources, are converted into outputs, such as products and services. Essentially, productivity measures our capability to generate more or equal output with the same or fewer resources. The higher our productivity levels are, the more we can do with less.

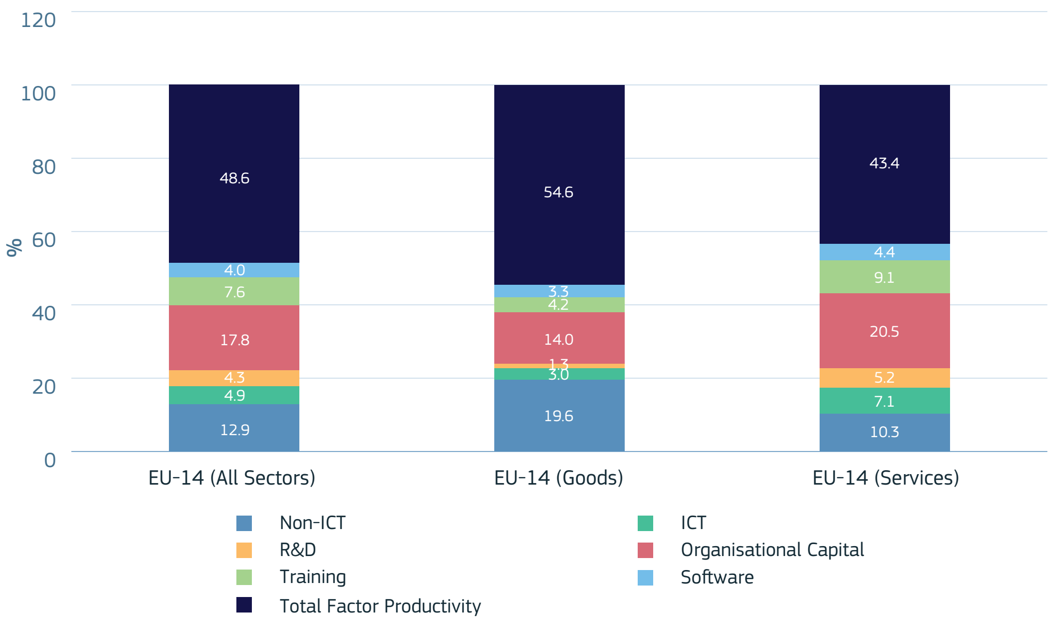
R&I are key engines to foster productivity growth. Indeed, since the Industrial Revolution, breakthroughs in technology, innovative organisational strategies, and the advancement of human capital have consistently fueled productivity improvements, which in turn have elevated living standards and economic growth (Dollar and Kraay, 2002).

Productivity growth is intrinsically linked to an economy's overall growth and competitiveness. On a broader societal level, productivity growth is instrumental in addressing critical issues like poverty. By enabling the production of more goods and services with fewer resources, productivity growth contributes to economic prosperity, which can lead to poverty reduction and improved quality of life (Kraay, 2004; Isaksson, 2004). Thus, the cycle of research, innovation and productivity growth is not only a catalyst for economic advancement, but also a crucial factor in fostering societal well-being and alleviating human suffering (Acemoglu and Guerrieri, 2008; Beugelsdijk et al., 2018).

In the EU, R&I significantly contribute to the growth of labour productivity. Specifically, between 1995 and 2019, intangible assets were responsible for nearly 80% of labour productivity increases. Breaking it down further, total factor productivity, often linked with innovation capacity, accounted for 48% of the labour productivity growth. Additionally, improvements in organisational capital contributed 18% to this growth, and training to 8%. R&D activities contributed 4%, while software investments alone added 4%. In contrast, non-ICT tangible assets, such as physical equipment and buildings, contributed 12% to labour productivity growth, and ICT (such as hardware) to 5% (see Figure 5.1-1).

The impact of various intangible and tangible assets on productivity growth varies significantly across different sectors of the economy. In the goods sector, non-ICT tangible assets, like machinery and buildings, play a crucial role in driving productivity. Conversely, in the service sector, intangible factors such as software, training, and organisational capital are more influential in enhancing labour productivity (see Figure 5.1-1). This diversity in the drivers of productivity growth across sectors can provide valuable insights for developing specific R&I strategies. Tailoring these strategies to the unique needs of each sector can effectively boost the overall competitiveness of the EU's economy.

Figure 5.1-1 Tangible and intangible drivers of EU-14 labour productivity growth by economic sector (1995-2019)



Science, research and innovation performance of the EU 2024

Source: Roth, Felix and Mitra, Alessio (2024).
Note: estimations performed using EU-KLEMS data and employing the cross-country sectoral growth accounting methodology as developed in the Horizon 2020 GLOBALINTO project by Roth Felix (2024). EU-14 refers here to Austria, Czechia, Denmark, Finland, France, Germany, Italy, Latvia, Lithuania, Netherlands, Slovakia, Slovenia, Spain, Sweden.

Box 5.1: The impact of EU R&I funding on firms' performance

The Horizon 2020 Framework Programme for Research and Innovation, a cornerstone initiative of the EU, was designed to foster and finance R&I endeavours in a wide array of scientific and technological fields. This flagship funding programme, operational from 2014 to 2020, not only supported entities within the EU member states, but also extended its reach globally.

In their 2024 study, Mitra and Niakaros delve into the causal impact of the Horizon 2020 programme on firm-level financial outcomes, including employment, assets, and revenue. Specifically, their paper explores the causal impact of receiving Horizon 2020 funding:

- as a whole;
- differentiating by sector.

Their analysis draws upon administrative records from CORDA and financial data from ORBIS, spanning from 2010 to 2022. The study's core sample comprises approximately 40 000 unique privately owned companies that applied for Horizon 2020 grants. To infer causality, the authors rely on the Difference-in-Differences (DiD) approach, accounting for staggered treatment timing and heterogeneous treatment effect.

The policy assessment reveals that EU R&I funding successfully achieves its 'additionality' goals by offering tangible EU value. Companies receiving Horizon 2020 grants experienced an average increase of about 20% in employment levels, and a notable 30% rise in both total assets and revenues in subsequent years (see Figure 5.1-2). However, this positive outcome is predominantly observed in firms operating within the *Information and Communication* and *Professional, Scientific, and Technical Activities* sectors. Firms in other sectors did not exhibit significant changes following the receipt of Horizon 2020 funding.

Figure 5.1-2 Causal impact of Horizon 2020 grants on beneficiary companies

Science, research and innovation performance of the EU 2024

Source: Mitra, Alessio and Niakaros, Konstantinos (2024). Note: The y-axes indicate the average treatment effect (ATT) of receiving a Horizon 2020 grant for a beneficiary firm compared to a non-beneficiary firm. The dots (or point estimates) represent the magnitude of the impact, while the bars (or confidence of intervals) indicate if the impact is statistically different from zero or not. The x-axes indicate the number of years before or after the receipt of the Horizon grant by the recipients.

2. R&I and green growth

Climate change and environmental degradation pose a critical threat to Europe and the globe. The European Green Deal is poised to address these challenges by revolutionising the EU into a modern, resource-efficient and competitive economy. Its goals are ambitious yet clear: achieve net-zero greenhouse gas emissions by 2050, foster economic growth independent of resource consumption, and ensure inclusive progress that leaves no person or community behind (COM/2019/640). This comprehensive plan is not just an environmental strategy, but also a path to equitable and sustainable economic development.

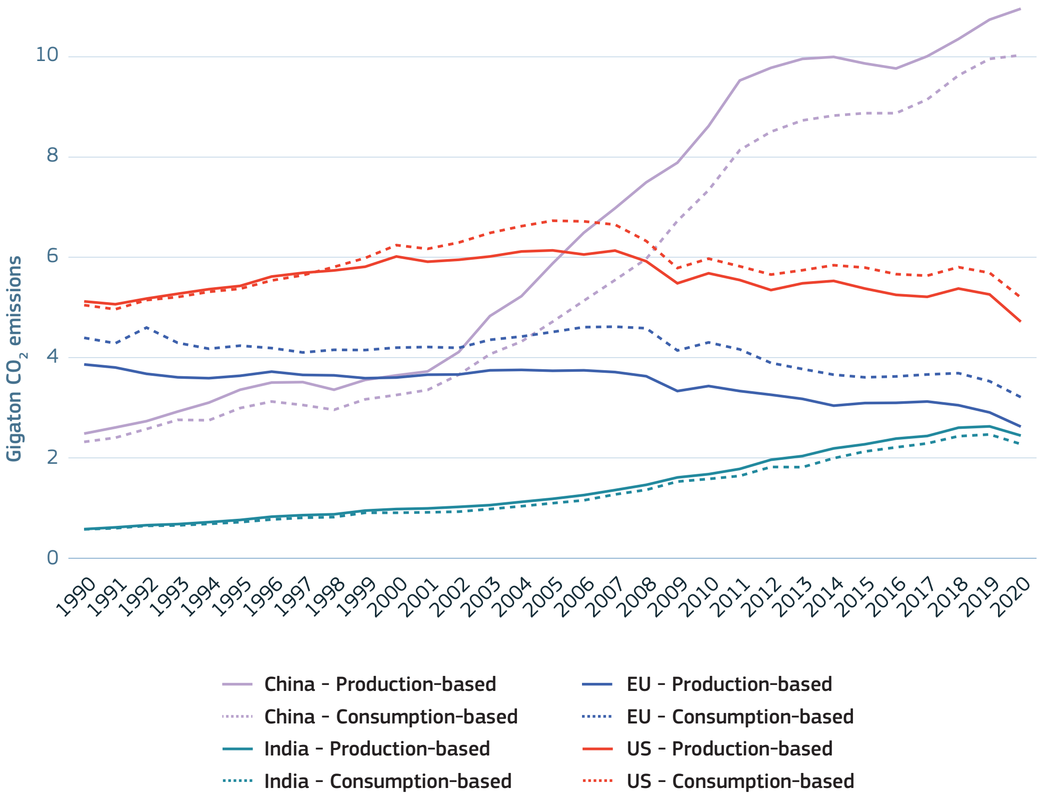
R&I are key drivers in Europe's ambitious journey to redefine its economic growth model. This new paradigm seeks to harmonise economic growth with the urgent need to respect planetary boundaries. In this context, productivity and economic growth maintain their policy importance as they are not just goals, but essential tools for boosting competitiveness, socio-economic development and addressing poverty (Dollar and Kraay, 2002; Isaksson et al., 2005; Beugelsdijk et al., 2018). Economic growth enables nations to invest in policies and ambitious programmes that lead to socially desirable outcomes such as health and education (Acemoglu, 2008). By generating the necessary resources, it enables substantial investments in green and digital technologies. These technologies are crucial for tackling the contemporary challenges we face, such as climate change and an ageing population.

While the EU has made strides in addressing climate change, it cannot tackle the issue in isolation. Multilateralism is important. Effective global collaboration with other major economies is imperative. Indeed, even after accounting for trade-adjusted CO_2 emissions (consumption-based emissions), China's annual CO_2 output is approximately triple that of the EU (Friedlingstein et al., 2022). Figure 5.1-3 charts the CO_2 emissions of key economic players from 1990 to 2021, tracking both production[1] and consumption-based[2] emissions. The data reveals a surge in China's emissions, contrasted by a decline in those of the EU and US. Notably, for manufacturing-driven countries like China, production emissions exceed consumption emissions due to the export of goods to Western countries. Conversely, the EU and US display higher consumption than production emissions, reflecting their importation of goods produced elsewhere, carrying the embedded carbon manufacturing costs.

1 Production-based emission: territorial emissions, which do not account for emissions embedded in traded goods.

2 Consumption-based emission: emissions generated in the production of goods and services according to where they were consumed, rather than where they were produced. Consumption-based emissions equals production-based emissions, minus emissions embedded in exports, plus emissions embedded in imports.

Figure 5.1-3 Global CO_2 emission trend



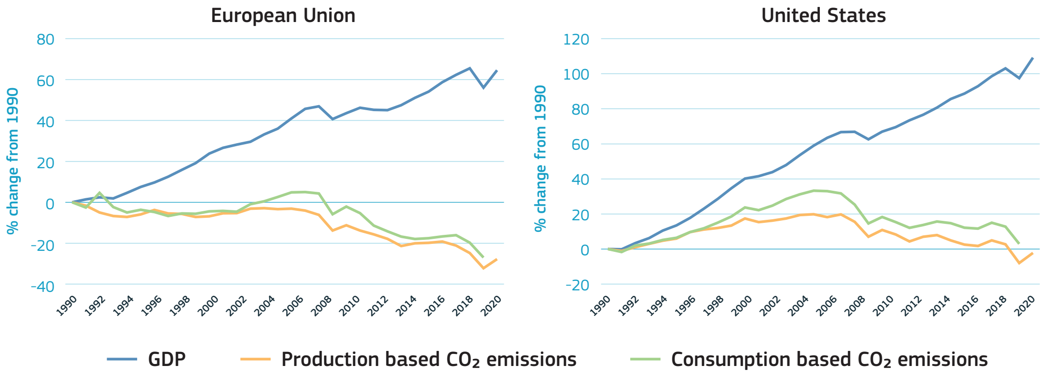
Science, research and innovation performance of the EU 2024

Source: Global Carbon Budget (2022). Note: CO_2 consumption represents CO_2 adjusted for trade. If a country's consumption-based emissions are higher than its production emissions, it is a net importer of carbon dioxide. If its consumption-based emissions are lower, then it is a net exporter.

In the past, there was a direct link between a nation's wealth and its CO_2 emissions. Higher incomes typically led to greater emissions due to increased energy consumption, much of which was derived from fossil fuels. This pattern has now shifted, particularly in high-income countries that are channelling investments into green technologies and striving for a decarbonised economy. These efforts have begun to break the traditional bond between economic prosperity and environmental impact (Kasperowicz, 2015; Agbugba et al., 2019).

Today, many high-income countries have decoupled economic growth from CO_2 emissions, even if we take offshored production into account. Figure 5.1-4 compares GDP, production-based CO_2 and consumption-based emissions, highlighting the relationship between economic growth and CO_2 emissions. In the EU and US, GDP has grown or remained stable, while both production-based and consumption-based CO_2 emissions have declined.

Figure 5.1-4 Economic growth decoupling from CO_2 emissions



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 World Bank and Global Carbon Budget (2022) data.
Note: Gross Domestic Product (GDP) figures are adjusted for inflation. CO_2 consumption represents CO_2 adjusted for trade.

Emissions have fallen in many high-income countries thanks to the replacement of fossil fuels with low-carbon energy and the transition toward a more intangible economy. This indicates that with the support of robust political will and the adoption of technological innovations and sustainable practices, economic progress can be achieved without a proportional increase in CO_2 emissions (Ritchie, 2021). A key question is whether we can decouple fast enough, and across more countries.

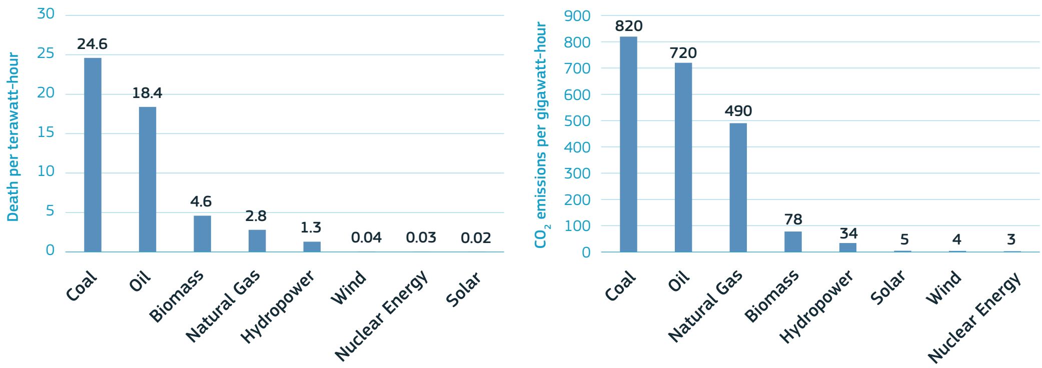
R&I plays a crucial role in accelerating economic growth decoupling from resource use by fostering the current decline in the cost of low-carbon technologies, as well as their deployment across the world. Indeed, while the costs of fossil fuels and nuclear power depend on the price of the fuel burnt and the power plant's operating costs, the cost of renewable power is defined mostly by the cost of the technology itself, as operating expenses are comparatively low, and there are no fuel costs.

A beneficial feedback loop drives the affordability of renewable technologies. As deployment expands, technological learning reduces costs, making these technologies economically viable for a broader range of applications. This expansion in applicability spurs further demand, propelling a cycle of increased deployment and continuous price declines. This self-reinforcing mechanism mirrors the learning curves observed in technological advancements like Moore's Law, a pattern not exhibited by fossil fuel technologies (Roser, 2020). Hence, renewable technologies not only benefit from, but also contribute to, an escalating cycle of affordability and accessibility.

Renewable energy sources and nuclear power stand as markedly safer and cleaner alternatives to fossil fuels (Kharecha and Hansen, 2013; Ritchie, 2020). Figure 5.1-5 underscores this by contrasting the estimated mortality rates attributable to various energy sources per electricity unit produced. When considering the consequences of air pollution and catastrophic events, it becomes clear that fossil fuels – particularly coal – are responsible for substantially more deaths per electricity unit than nuclear power and modern renewables. Figure 5.1-5 further highlights coal as the most polluting energy source per electricity unit produced, emitting vastly more greenhouse gases than its counterparts of nuclear, solar and wind energy. While oil and gas also surpass nuclear and renewables in terms of emissions, their impact is somewhat less severe than that of coal.

The vivid impact of nuclear accidents like Chernobyl and Fukushima starkly contrasts with the less visible, yet more deadly, effects of fossil fuel pollution. This discrepancy highlights a common behavioural bias called an 'availability heuristic', where the slow and steady impact of a hazard is often underestimated in comparison to more dramatic – but less statistically deadly – events. This bias can skew public perception, undervaluing the broader and more persistent threat posed by fossil fuel emissions relative to the rarer, albeit catastrophic, risks associated with nuclear energy.

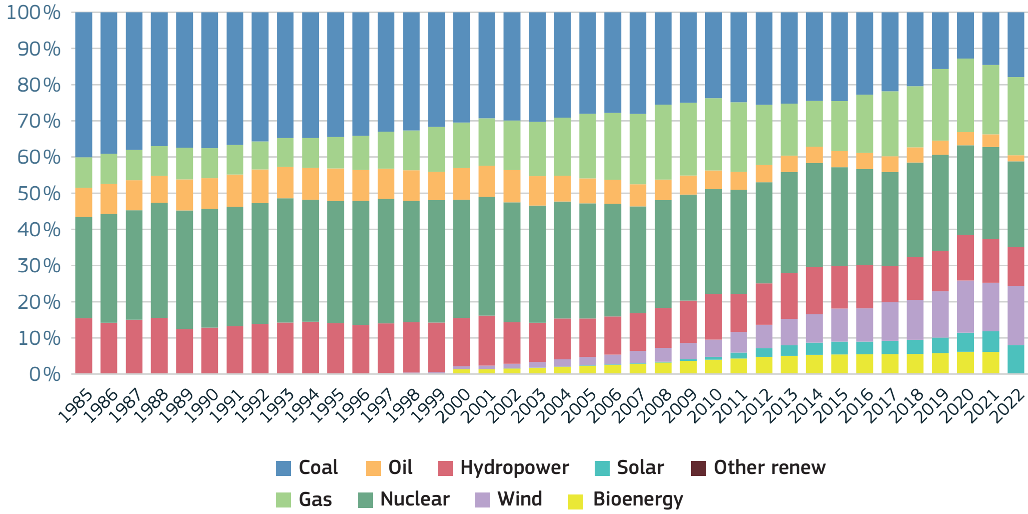
Figure 5.1-5 Cleanliness and safety of different energy sources



Science, research and innovation performance of the EU 2024
Source: Max Roser (2020), Hannah Ritchie (2020). Note: Deaths from accidents and air pollution per terawatt-hour of energy production. Greenhouse gases emitted per unit of electricity production include the burning of fuels, but also the mining, transportation and maintenance over a power plant's lifetime.

The prevalence of fossil fuels as the primary energy source has historically been underpinned by their lower costs compared to alternatives. Figure 5.1-6 shows the historical trends of electricity production by source in the EU. To shift the global energy paradigm towards safer and cleaner options, R&I must be leveraged to drive down the costs of these alternatives. This strategy has already borne fruit in numerous high-income countries where renewable energy sources are now more economically viable than fossil fuels, demonstrating the potential for a broader, cost-effective energy transformation.

Figure 5.1-6 Electricity produced by source in the EU



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 Ember's Yearly Electricity Data; Energy Institute Statistical Review of World Energy (2023).

Simultaneously, advancements in production efficiency, driven by ongoing R&I, significantly boost the output yield per unit of energy. This enhancement not only optimises energy utilisation, but also paves the way for increased production capabilities. As a result, a wider array of goods and advanced technologies can be developed and manufactured, either by maintaining the current level of energy consumption or, more impressively, by reducing it. This shift not only reflects a leap in efficiency, but also marks a critical step towards sustainable production practices. By integrating cutting-edge R&I, industries can contribute more effectively to environmental conservation efforts, while also meeting the growing demands of a rapidly advancing technological era.

3. AI and the productivity slowdown of advanced economies

Despite expectations that digital technology would boost productivity, growth has stagnated over recent decades. This paradox has sparked extensive research seeking answers. Robert Solow famously remarked in 1987, 'You can see the computer age everywhere but in the productivity statistics.' Figure 5.1-7 illustrates the deceleration in productivity growth within the Euro area and the United States from 1950 to 2019. It depicts three distinct measures of productivity: growth in GDP per capita, labour productivity and Total Factor Productivity (TFP). Each of these metrics shows a trend of decline followed by a period of stabilisation, which is particularly intriguing given the rapid advancements in technology and heightened investment in R&D during this period.

Likely explanations are low technological diffusion, high human capital and organisational uptake costs for laggard firms and declining business dynamism. Indeed, while digital technologies boost individual productivity at the firm level (Hubbard, 2003; Bartel et al., 2007), this doesn't always translate to larger scale economic growth, often due to dynamic market and organisational factors. In fact, implementing ICT effectively is challenging, requiring complementary investments in human capital and managerial practices (Pilat, 2005). The digital transformation turns out to be particularly difficult for non-frontier firms, with non-trivial adjustment costs, organisational changes and new skills required, potentially leading to negative returns during the process of adjustment and experimentation (Brynjolfsson et al., 2019). Declining business dynamism, including the increase of 'zombie firms' and resource misallocation, also contributes to the productivity slowdown (McGowan and Millot, 2017). Moreover, a decrease in productivity growth through capital-embodied technical change, with variations seen in how US and EU firms convert R&D into productivity improvements, can be added to the list of culprits (Schubert and Neuhäusler, 2018). Further explanations include measurement difficulties in a service-based, intangible-heavy economy, and the long lag time for new technologies to diffuse and impact productivity (McGrattan, 2020).

This trend prompts the pertinent inquiry into whether the unfolding revolution of generative AI can overcome the enduring Solow Paradox. The resolution of this question remains to be seen. There are, however, many reasons to think that AI will bring a different digital revolution. Indeed, the AI revolution has broken the limitations of earlier digital technologies, significantly broadening their scope. It has transcended the boundaries of merely codifiable tasks – those routine operations that could be condensed into exact instructions – thereby demonstrating the potential to handle more complex and nuanced activities (Manyika and Spence, 2023).

Prior to the recent advancements in AI, digital machines were incapable of executing tasks that were not easily codifiable, such as recognising a cat in a picture. Before the advent of AI, the digital revolution had a profound impact in its sphere: automation quickly permeated various sectors, with machines replacing human tasks in areas such as bookkeeping, filing, accounting, banking and the management of supply chains. This shift marked a significant transformation in how these functions were traditionally executed. Concurrently, the shift to digital information storage and transfer made data more accessible and affordable. This, coupled with a surge in

Figure 5.1-7 Productivity growth slowdown, 1950-2022

Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's own elaboration, based on the Long-Term Productivity Database.

inexpensive online services, reshaped consumer behaviour and social interaction. However, the economic effects of these changes were not universal. Numerous tasks remained beyond the reach of automation, thus limiting the digital revolution's full impact. Notably, sectors centred on knowledge and creativity, including fields like medicine, law, advertising and consulting, were largely unaffected. In these industries, the inherent value lies in specific expertise and the execution of nonroutine tasks, which technology could not replicate (Manyika and Spence, 2023).

Large Language Models (LLMs) powered by deep learning, such as the famous OpenAI ChatGPT, are now capable of engaging in non-codifiable tasks. These include finding and assembling facts and insights, detecting logical and conceptual structures embedded in language, synthesising and reprocessing information, and drawing on experience, expertise and tacit knowledge to provide answers to complex and nuanced questions (Ghosh, 2023).

While the digital revolution automated routine tasks, the AI era demands a more nuanced and collaborative approach to workforce development and education. The digital revolution, marked by the automation of routine tasks, led to a significant shift in the labour market. In particular, it sparked a decline in jobs and income for some low and middle-class earners, a trend referred to as 'job and income polarisation' (Acemoglu and Autor, 2011). This shift necessitated a change in educational focus towards critical thinking and creativity (Deming, 2017; Deming and Kahn, 2017). With the advent of modern AI, the landscape is changing further. Adapting to an AI-assisted work environment requires new skill sets, prompting the need for partnerships between government, industry and educational institutions (Bouschery et al., 2023). Policies aimed at ensuring AI augments rather than replaces human labour are crucial. Additionally, AI research should prioritise enhancing human productivity rather than simply substituting it (OECD, 2023) (see Chapter 5.2 for more).

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CHAPTER
5.2

SKILLS AND HUMAN CAPITAL FOR R&I

Key questions

- Is digitalisation driving labour market polarisation around the world?
- What are the demanded and supplied skills in the EU?
- How is gender distributed across different occupations and economic activities?
- What are the most important skills that will drive future breakthrough technologies?

Highlights

- Technological advancements such as automation and computerisation, bundled with international trades, are spurring job polarisation by boosting demand for high-skilled labour and reducing routine, medium-skilled roles.
- Employment in the EU is predominantly concentrated within the manufacturing sector, in contrast to the US, where there is a greater focus on human health services. Additionally, the information technology (IT) and financial sectors in the US are significantly larger compared to those in the EU.
- In 2022, EU female graduates still predominantly pursue fields such as education, arts and humanities, social sciences, and health and welfare, whereas their male counterparts are more concentrated in Information and Communication Technologies (ICT), engineering, manufacturing and construction.
- From 2010 to 2022, there has been a significant increase in the proportion of employment in high-technology sectors across Europe. Female employees continue to represent a minority.
- Skills in physics, engineering and technology, computer electronics, mathematics and critical thinking are the most poised to propel the advancement of groundbreaking technologies in the future, catalysing economic growth.
- AI skills are highly valued in the job market, offering a substantial wage premium due to their versatility across multiple knowledge domains. These skills necessitate a blend of technical expertise in fields such as statistics, computer science and software engineering, as well as crucial soft skills including leadership and communication.

Policy insights

- The promotion of STEM skills development, coupled with communication and leadership skills, will likely give a competitive advantage over other nations and spur economic growth.
- Women are underrepresented in crucial areas like ICT, engineering and high-tech industries, limiting workforce diversity and size.
- Reskilling and upskilling – inclusive of underrepresented groups – is important to avoid the digital transformation further exacerbating inequalities and wage gaps.

In this chapter, we explore the evolving job market, shaped by technological advancements and global trade, highlighting a shift towards high-skilled labour and a decline in routine jobs. We examine differences in employment sectors between the EU and the US, and then deep dive in the EU graduates and employment statistics by field and economic activity, differentiating by gender. Gender disparities in education and employment persist, with women and men choosing traditionally gendered fields. Despite a rise in high-tech sector employment in Europe, women remain underrepresented.

We spotlight essential future-ready skills, including those in AI, which are increasingly valuable across multiple sectors. The chapter concludes with policy insights advocating for STEM and soft skill development to drive economic growth and addressing the gender gap in critical tech-driven fields. The emphasis is on reskilling and upskilling to prevent widening inequalities and wage gaps in the face of digital transformation.

1. Job polarisation in developed countries

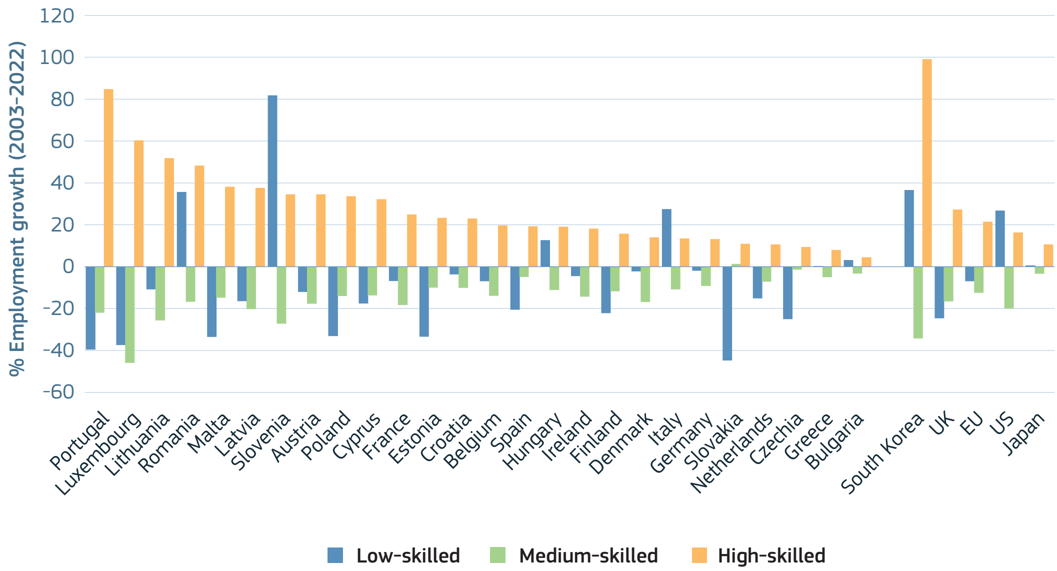
Digital transformation spurs job polarisation by boosting demand for high-skilled labour and reducing routine, medium-skilled roles, splitting the job market. Figure 5.2-1 showcases this trend across most developed countries. From 2003 to 2020, the share of high-skilled workers in the EU grew by 21%, while medium-skilled declined by 12%, and low-skilled by 7%. In the US the phenomenon appears more radical, with an increase of 16% in high-skilled workers, a decline of 20% in medium-skilled, and a rise of 27% in low-skilled.

The EU's share of high-skilled jobs has experienced steady growth in most years from 2003 to 2022. The annual growth rate for low-skilled jobs has worsened, while the medium-skilled growth rate is negative and steady. Interestingly, high-skilled jobs is the only category that continued to grow during the COVID-19 pandemic, showcasing superior resilience (Figure 5.2-2).

This shift is primarily fuelled by advancements in technologies such as automation and computerisation, which substitute for less-skilled workers and complement more highly-skilled ones. The deepening of digital technologies integration in the economy, which tends to require complex problem-solving and advanced cognitive abilities that high-skilled professionals possess, streamlines workflows and optimises processes, automating many repetitive tasks that have traditionally been the domain of medium-skilled workers. The result is a skill-biased alteration in labour demand, driving a wedge between the wage and employment prospects of high- and low-skilled workers (Acemoglu and Autor, 2011; Acemoglu and Restrepo, 2019).

International trade intensifies this polarisation, with developed economies tending to import products made with unskilled labour and export those requiring skilled labour. This global exchange pattern exacerbates the domestic shift towards high-skilled labour demand, potentially inflating the wage premium for skilled workers and contributing to a global redistribution of jobs (Mankiw, 2013).

Figure 5.2-1 World structural change trends in skills



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 ILO LFS data.

Note: Employment growth represents the growth from 2003 to 2022 in the employment share of total employment of low/medium/high-skilled workers. This approach allows for fluctuations in total employment levels.

Figure 5.2-2 EU trend in job polarisation

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 ILO LFS data.

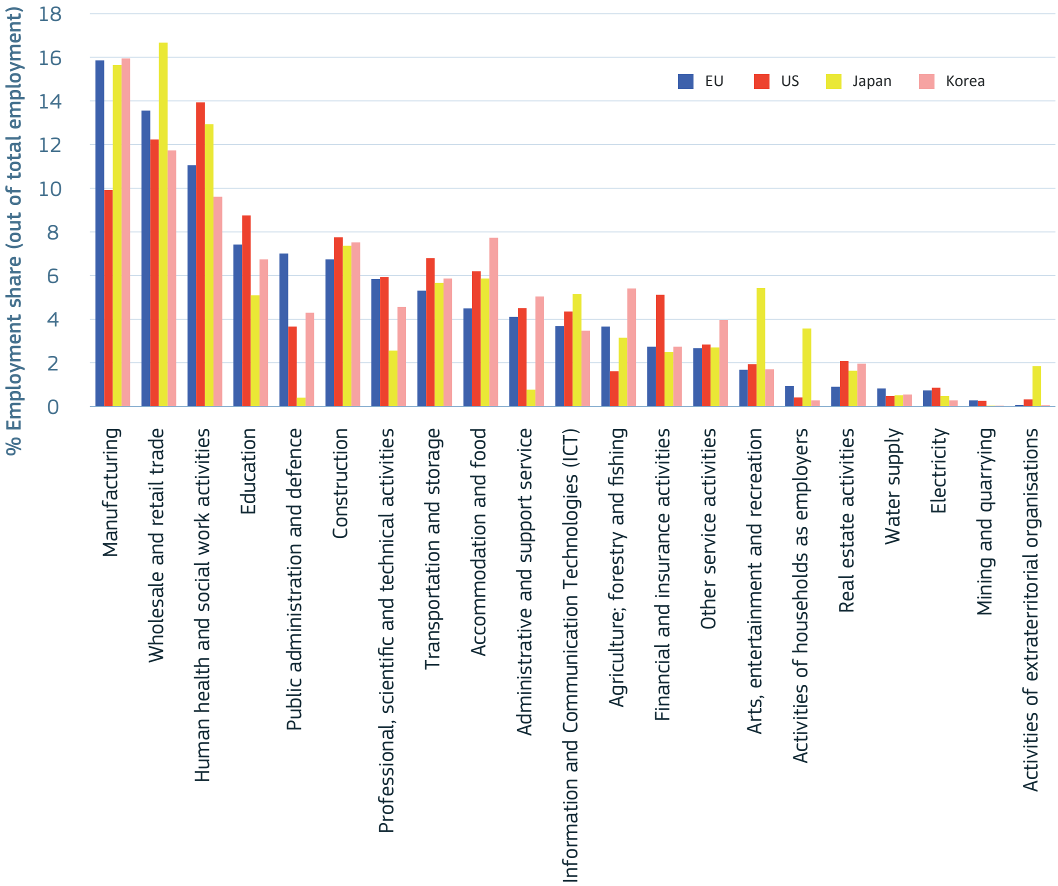
Note: Employment growth represents the growth from one year to the next

The concept of human capital further elucidates disparities in labour outcomes. Indeed, workers who accrue more human capital generally command higher wages, but when the supply of such workers lags behind demand, wage inequality can surge, reflecting an imbalance in the labour market.

This shift in the labour landscape elevates the value of and the need for workers with advanced technical training, analytical skills and the ability to innovate. The resultant structural change trends in skills requirements pose significant challenges to societal equity and economic stability, calling for strategic interventions that can facilitate workforce transitions through upskilling and education.

In 2022, the EU and the US displayed significant structural differences in the distribution of employment across the different economic activities. The EU's highest share of employment resided in the manufacturing sector, while in the US, it is in human health and social work activities. Furthermore, the EU's employment share in ICT is 15% smaller than that of the US, with financial and insurance activities being 47% smaller (Figure 5.2-3).

Figure 5.2-3 Labour market structural differences between EU and international competitors (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's own elaboration based on ILO LFS data.

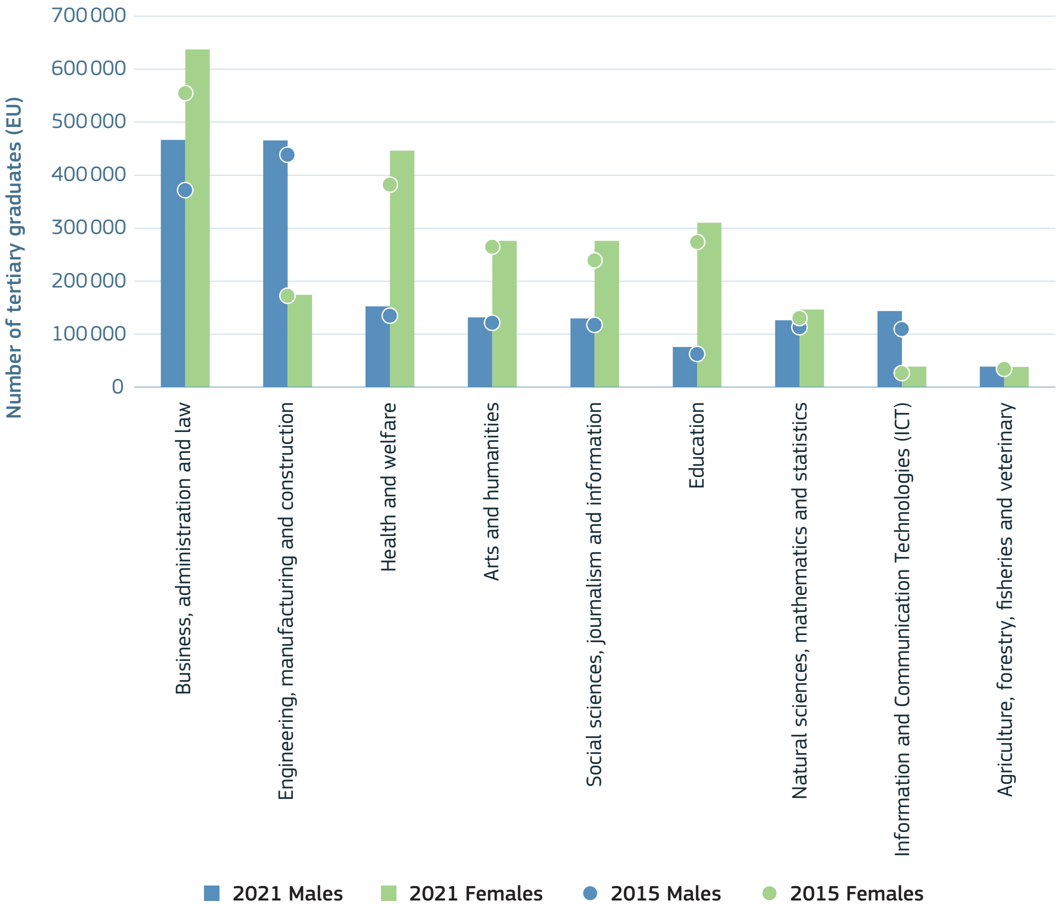
Note: Data on Japan refers to 2020. Economic sectors ranked by EU shares in decreasing order.

2. Skills allocation across the EU

Tertiary graduates represent an important skills supply measure. In the EU, business, administration and law hold the highest share of graduates, with engineering, manufacturing and construction ranking second, and health and welfare placing third. ICT experienced the highest growth in graduates from 2015 to 2021 (Figure 5.2-4).

Female graduates are concentrated in the fields of education, art and humanities, social sciences and health and welfare, while their male counterparts are predominant in ICT and engineering, manufacturing and construction. Notably, male graduates of ICT were around four times that of female graduates in 2022, and almost three times in the fields of engineering, manufacturing and construction. Such a gap is not closing, with the increase in male graduates from these fields higher than that of females. Conversely, female graduates are double that of male graduates in art and humanities and social sciences, four times in education, and three times in health and welfare (Figure 5.2-4).

Figure 5.2-4 **Graduates by sex and field of education (EU)**



Science, research and innovation performance of the EU 2024

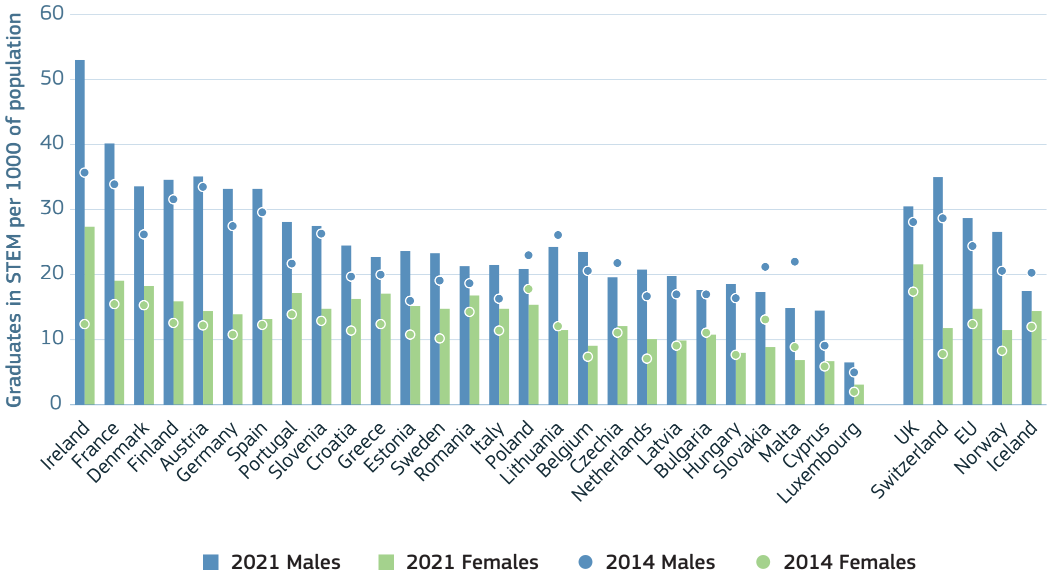
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's, based on Eurostat (Online data code: educ_uoe_grad04).

Note: Field of education ranked in 2021, decreasing total order (males + females).

Across Europe, the number of tertiary graduates in science, mathematics, computing, engineering, manufacturing and construction is increasing for both males and females. Yet, the gap is still substantial – in many countries, sometimes even increasing. The EU Member States with the highest overall graduates per capita in the aforementioned fields are Ireland, France, Denmark, Finland, Austria and Germany (Figure 5.2-5).

The rising demand for STEM skills in our tech-driven economy highlights the urgency for policies that encourage and support women to pursue STEM education. Initiatives such as scholarships, mentorship programs and campaigns that dismantle stereotypes are crucial not only to bridge the gender gap in these vital areas, but also to ensure a diverse and competent STEM workforce capable of driving innovation and addressing future challenges.

Figure 5.2-5 **Graduates in science, mathematics, computing, engineering, manufacturing and construction, by sex**



Science, research and innovation performance of the EU 2024

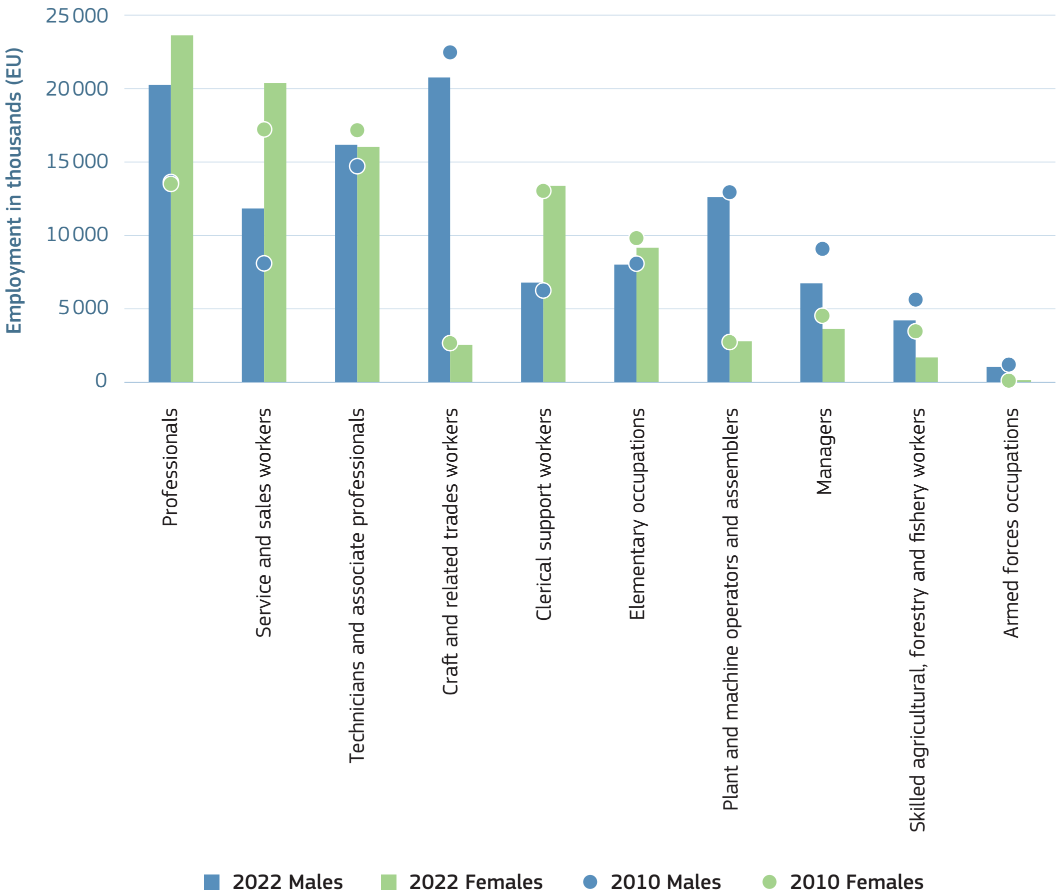
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's, based on Eurostat (Online data code: educ_uoe_grad04).

Note: For 2021, the UK data refers to 2019, the France data refers to 2015, and the Netherlands data refers to 2017. Countries ranked in 2021 decreasing total order (males + females).

Employment represents a relevant skills demand measure. In the EU, the occupational class of professionals holds the highest share of employment, followed by service and sales workers, and technicians and associate professionals. Regardless of the sex of workers, both professionals and service and sales workers enjoyed the largest growth from 2010 to 2022 (Figure 5.2-6).

Female employment is concentrated in the occupational classes of professionals, clerical support workers and service and sales workers, while its male counterparts are predominant in that of managers; skilled agricultural, forestry and fishery workers; plant and machine operators and assemblers; and armed forces occupations. Across 2022 in particular, male employment in the occupational class of managers was almost double that of females, eight times in that of craft and related trades workers, and four times in that of plant and machine operators and assemblers (Figure 5.2-6).

Figure 5.2-6 Employment by sex and occupation class (EU)



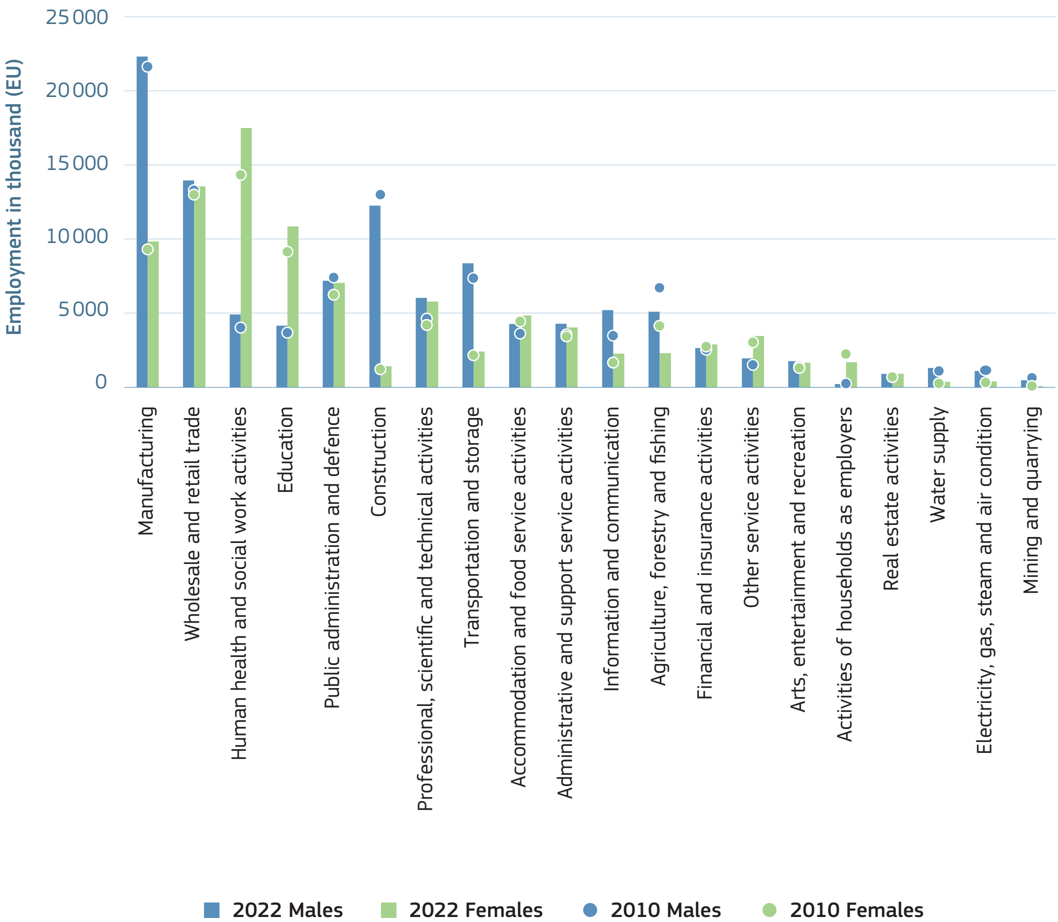
Science, research and innovation performance of the EU 2024

Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's based on Eurostat (Online data code: lfsa_eisn2).

Note: Occupation classes are defined using ISCO08 codes. Occupational classes ranked in 2022 decreasing total order (males + females).

Manufacturing represents the largest economic activity in the EU, employing the largest share of the EU workforce in 2022. The economic sectors of ICT; professional, scientific and technical activities; and human health and social work activities observed the largest employment increments from 2010 to 2022. Similarly to previously highlighted statistics, men are heavily predominant in economic activities such as agriculture, forestry and fishing; mining and quarrying; manufacturing; electricity, gas, steam and air conditioning; water supply; construction; transportation and storage; and ICT, while females represent a strong majority in education and human health and social work activities (Figure 5.2-7).

Figure 5.2-7 Employment by sex and economic activity (EU)



Science, research and innovation performance of the EU 2024

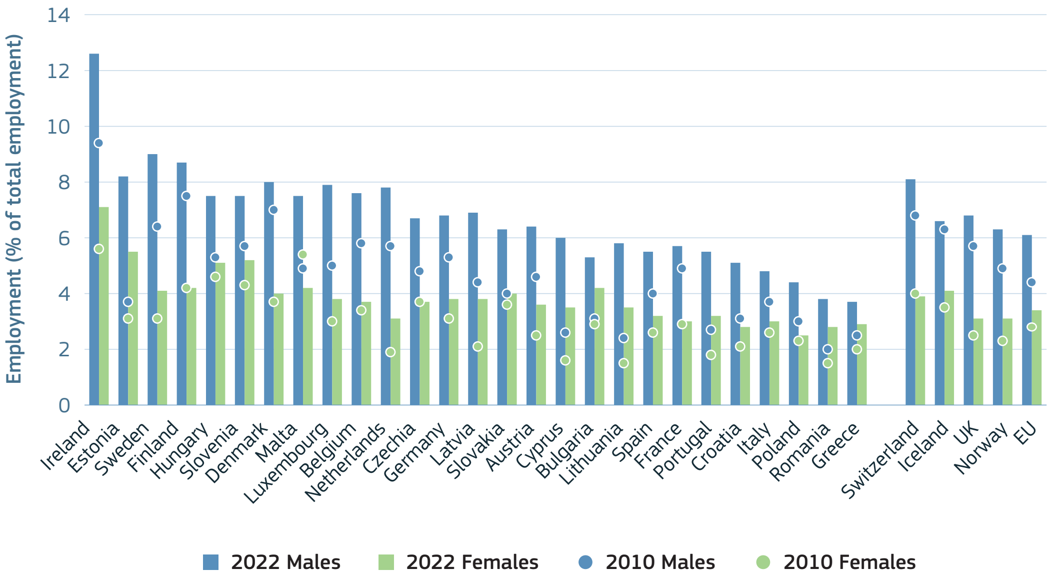
Source: DG Research and Innovation, Common R&I Strategy and Foresight Service, Chief Economist Unit's, based on Eurostat (Online data code: lfsa_eisn2).

Note: Economic activities are defined using NACE codes. Economic activities ranked in 2022 decreasing total order (males + females).

Across Europe, the share of employment in high-technology sectors out of total employment rapidly rose from 2010 to 2022. Ireland, followed by Finland and Sweden, showcase the highest rate of overall employment in high-technology sectors. Notably, female participation in high-technology sectors increased from 2010 to 2022, despite still representing a minority (Figure 5.2-8).

In our modern economy, the increasing demand for workers in the technology and knowledge-intensive sectors also underscores the critical need for policies to incentivise and facilitate women's participation in technology-intensive industries. Such policies are vital for harnessing the full potential of the workforce in these rapidly growing and evolving sectors.

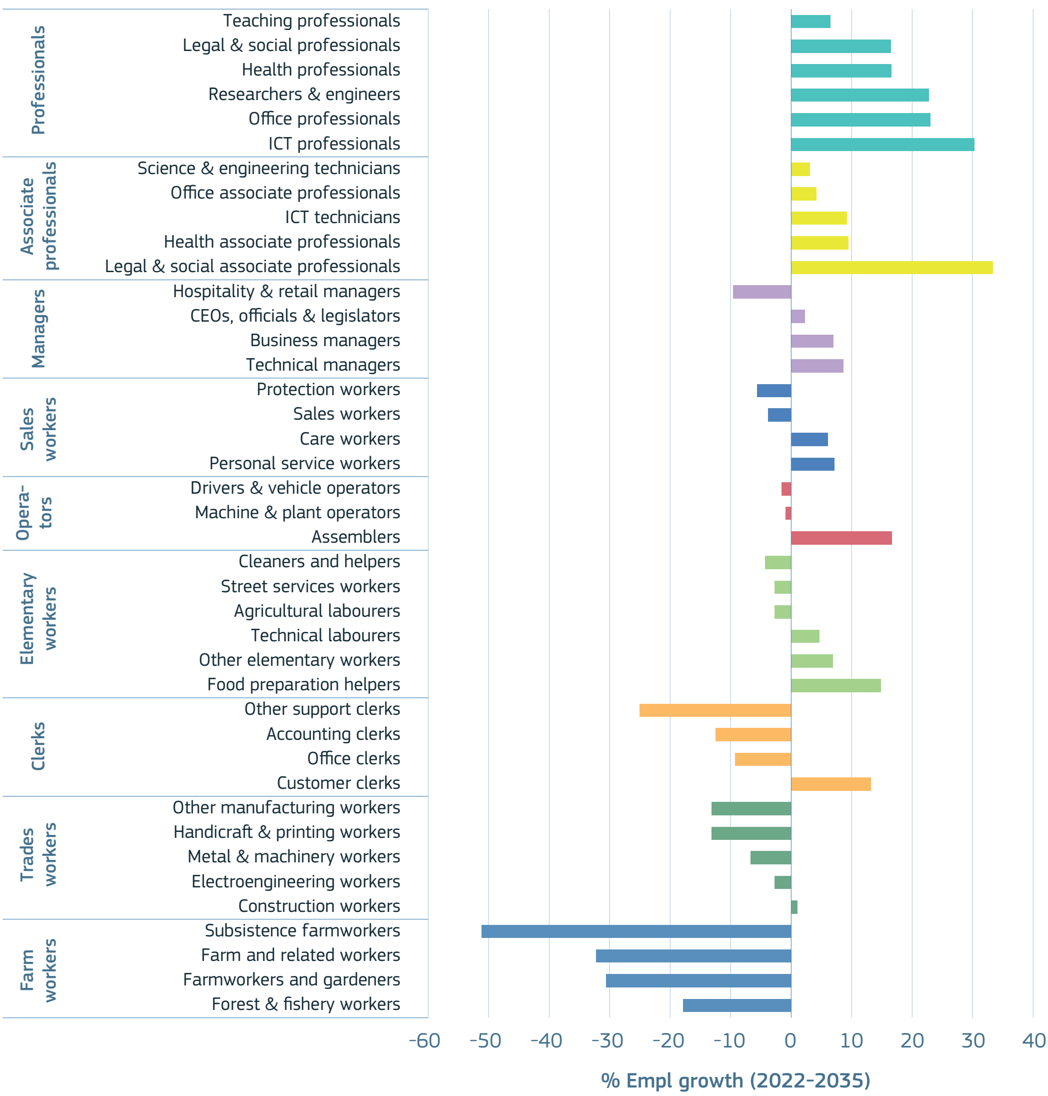
Figure 5.2-8 **Employment in technology and knowledge-intensive sectors by sex**



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, based on Eurostat (Online data code: htec_emp_nat2).
Note: Countries ranked in 2022 decreasing total order (males + females).

Looking toward the future, employment in technology and knowledge-intensive sectors is likely to continue its rise. The European Centre for the Development of Vocational Training (Cedefop) estimates a remarkable increase in the EU's future employment growth across 2022 to 2035 for professionals, ICT experts, researchers, engineers and so on. Conversely, employment in sectors such as agriculture, fishing and mining is expected to decline. (Figure 5.2-9).

Figure 5.2-9 **Future employment growth (%) by occupations in EU in 2022-2035**



Source: Cedefop future jobs database.
Note: Due to the unpredictable nature of the labour market and associated external factors, estimations are to be taken with caution.

3. STEM and social skills for technological breakthroughs

The analysis of modern breakthrough technologies and labour market challenges starts with understanding the complexity of production and its implications for economic growth. Indeed, highly sophisticated goods, which require diverse and exclusive production capabilities, are central to an economy's advanced development. This complexity is linked to the diversity[1] and ubiquity[2] of the labour skills and knowledge involved in producing these goods (Hidalgo and Hausmann, 2009).

Physics, engineering and technology, computer electronics, mathematics and critical thinking skills appear to be more complex[3] and are the core resources behind the production of sophisticated goods. Regions with higher occupational complexity also experience greater economic growth. This points to the strategic importance of fostering these skills for long-term economic competitiveness (Turco and Maggioni, 2022).

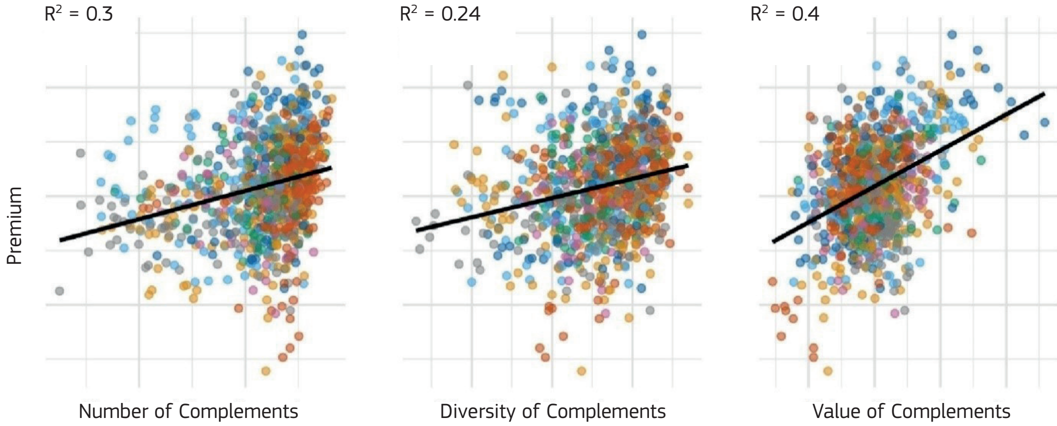
Complementarity is another fundamental aspect in assessing a skill's worth, defined as the ability of a skill to enhance and synergise with other skills. Firstly, a skill that can be combined with a wide range of other skills tends to be more valuable. Secondly, the diversity of the 'neighbourhood' of skills that can be paired with a particular skill adds to its value. And thirdly, if a skill complements other high-value skills, its individual worth is enhanced. Beyond complementarity, the demand relative to the supply of skills in the workforce also plays a significant role in determining their value. Skills that are in high demand but have a relatively low supply naturally command a higher value. Figure 5.2-10 showcases the positive relationship between skills premium and the complementarity associated with such skills (Stephany and Teutloff, 2024).

1 Defined here as relating to the variety of necessary skills and knowledge.

2 Defined here as concerning the rarity of such skills and knowledge.

3 See Box 1 of chapter 2.2 for a formal definition of 'complexity'.

Figure 5.2-10 Skills premium and complementarity



Science, research and innovation performance of the EU 2024

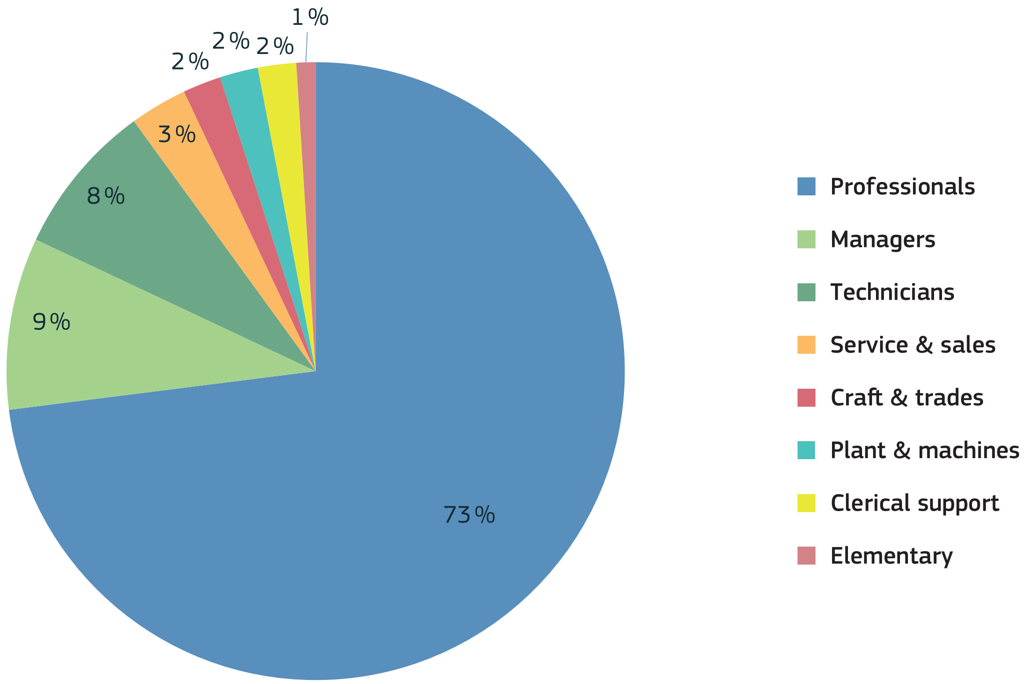
Source: Stephany and Teutloff (2024).
Note: Different colours represent different sectors in the economy. Time period of reference: 2014–2022. Estimates computed using US labour market data.

AI skills enjoy a significant wage premium. This higher value can be attributed in part to their complementarity; AI skills can be effectively combined with a diverse set of capabilities across various knowledge domains, making them highly adaptable and valuable in multiple contexts. Additionally, skills complementary to AI are often of high economic value in and of themselves. Finally, the sustained high demand for AI skills, coupled with a comparatively lower supply, further boosts their market value. (Stephany and Teutloff, 2024)

AI skills are in demand across all occupational classes, with the largest majority being requested from that of professionals. Indeed, from 2019 to 2022, around 73% of online vacancies in the EU requiring AI skills were aimed at professionals (Figure 5.2-11). This highlights how the impact of AI in the labour market is likely to be different compared to that of robotisation and early digitalisation technologies. Prior to the recent advancements in AI, digital machines were incapable of executing tasks that were not easily codifiable, limiting their profound impact to routine medium-skilled jobs such as book-keeping, filing, accounting, banking and the management of supply chains (Manyika and Spence, 2023). However, recent advancements in machine learning, deep learning and natural language processing are changing this, with AI technologies increasingly complementing and augmenting the capacities of highly skilled workers (Felten and Seamans, 2019; Bachmann et al., 2022).

AI jobs require not only a high mastery of technical skills such as statistics, computer science, data analysis and software engineering, but also soft skills such as leadership and communication. Job listings calling for AI professionals indicate not only an expectation for high-level technical skills, but also the possession of competitive prowess in more social and qualitative skills (Borgonovi et al., 2023). This will likely put highly skilled individuals who only possess social and qualitative skills at a comparative disadvantage to those also possessing quantitative ones.

Figure 5.2-11 **Online job vacancies requiring AI skills in selected European countries, by occupation (2019-22)**



Science, research and innovation performance of the EU 2024

Source: Borgonovi et al. (2023).
Note: 'European countries' refers to Austria, Belgium, France, Germany, Italy, the Netherlands, Spain, Sweden and Switzerland.

Box 5.2: Labour shortages in high-skilled occupations in the EU

By Gralek Karolina and Caisl Jakub, DG EMPL F.4

The *Employment and Social Developments in Europe 2023 Review*[4] analyses labour shortages that have persisted over time. By combining different available approaches, it identifies 14 occupations (at ISCO 3-digit level) and 16 sectors (at NACE 2-digit level) facing persistent labour shortages in the EU. In particular, the report underlines that next to cyclical fluctuations, labour shortages strongly depend on structural drivers, such as skills shortages and mismatches, declining or inactive labour force, labour market segregation, labour mobility and migration, and working conditions. It also discusses relevant policies to address persistent labour shortages, as the impact of various drivers varies significantly across occupations and sectors.

Labour shortages could hinder the EU in reaping the full spectrum of benefits from technological advancements. For example, the economic activity and innovative capacity of companies may be limited, potentially weakening the competitiveness of the EU in the medium and long term. While persistent labour shortages are found across all skill levels, this box presents the main findings from the report focusing on high-skilled shortage occupations[5], given that the digital transformation is expected to especially boost the demand for high-skilled labour. Among the high-skilled occupations in particular, medical doctors, nursing and midwifery professionals, and software and applications developers and analysts are found to face persistent labour shortages over time.

Skills shortages and mismatches are driving persistent labour shortages in high-skilled occupations. For instance, even when controlling for different characteristics of occupations, high-skilled occupations with persistent labour shortages are more likely to have higher upskilling and digital skill needs, compared to high-skilled non-shortage occupations. They also face a higher demand for better-educated workers and greater job complexity. While the digital intensity of work is relatively low for most of the occupations with persistent labour shortages, this is not the case for software and applications developers and analysts, with around one-third of all required skills being digital.

4 https://op.europa.eu/webpub/empl/esde-2023/index.html

5 For the purpose of Box 1, high-skilled occupations include occupations that fall under categories 1) Managers, 2) Professionals and 3) Technicians and associate professionals (at ISCO 1-digit level).

High-skilled occupations with persistent labour shortages are characterised by high degree of gender segregation. This is especially the case for nursing and midwifery professionals (90 % of women in 2021) and software and applications developers and analysts (82 % of men). Medical doctors represent a rather gender balanced occupational group (54 % of women), but available evidence indicates that there may be strong gender segregation by certain medical specialisations. Differences in study fields of qualifications are found to explain sizeable shares of gender gaps in those occupations. In addition, even when holding an ICT-related qualification, women are less likely than men to work in an ICT occupation, pointing to other relevant factors such as gender stereotypes or the gender divide in advanced digital skills, thereby contributing to persistent gender segregation.

Poor working conditions in some occupations and a low share of migrant workers also contribute to persistent labour shortages in high-skilled occupations. The 'job strain' indicator calculated using Eurofound's *European Working Conditions Telephone Survey 2021* refers to difficult work environments, organisation and time. While software and applications developers and analysts enjoy the lowest job strain (7.8 %) across all shortage occupations, nursing and midwifery professionals report the highest job strain (60.5 %). The job strain for medical doctors (42.8 %) is also above the EU average (30.3 %). As concerns migrants born outside the EU, they tend to be concentrated in lower skilled occupations, with only 4 % working in high-skilled shortage occupations. This points to a limited contribution of migrants in alleviating persistent labour shortages in those occupations.

Looking forward, high-skilled occupations are projected to face high labour shortages by 2035. Future shortages are projected based on the Cedefop's 'future shortage indicator', which is constructed using information on labour market imbalances, expansion demand and replacement demand drawn from the Cedefop's Skills Forecast. According to this indicator, future shortages in high-skilled occupations will be strongly driven by expansion and replacement needs. Next to high-skilled occupations already experiencing persistent labour shortages, additional high-skilled occupations are projected to face high labour shortages in the future. Namely, these include chief executives, senior officials and legislators; production and specialised services managers; legal, social and cultural professionals; business and administration associate professionals; and legal, social, cultural and related associate professionals. While many of those occupations are expected to be highly exposed to AI, its impact on labour shortages remains unclear.

A comprehensive set of policies is needed to alleviate persistent and future labour shortages in high-skilled occupations in the EU. These include promoting skills anticipation and upskilling/reskilling; investing in adult learning; improving the matching between job requirements and candidate competences; increasing financial incentives to work (e.g. by reviewing tax-benefit systems); removing barriers to people entering the labour market (e.g. by expanding childcare access to help mothers to engage in paid work, or easing the recognition of migrant qualifications); improving work and pay conditions and social protection coverage; reducing stereotypes and discrimination; implementing policies to attract workers from abroad into jobs facing shortages; and strengthening social dialogue. In line with these findings and as a follow-up to the Val Duchesse Social Partners Summit of January 2024, in March 2024, the Commission has come forward with an action plan to tackle labour and skills shortages in the EU.[6] Addressing labour shortages could also contribute to reaching the EU headline 2030 targets set in the *European Pillar of Social Rights Action Plan*, and to prepare the EU economy for the advent of new technologies.

6 https://ec.europa.eu/commission/presscorner/detail/en/ip_24_1507

4. High-technology sector and AI: opportunities for competitiveness and challenges for inequality

The EU labour market is currently at a crossroads, marked by rapid technological advancements and changing social dynamics. Two of the most pressing issues in this landscape are the polarisation of the labour market and persistent gender disparities, especially in STEM fields. These challenges are further complicated by the rise of the high-technology sector and AI, which, while driving innovation and economic growth, also pose the risk of exacerbating wage inequality and gender gaps. Yet, if the first digital revolution was marked by the automation of routine tasks, sparking a decline in jobs and income for some routine middle-class earners, the advent of modern AI (also capable of automating non-routine, high-skill tasks) may change the landscape further (see Chapter 5.1 ‘R&I and productivity’ for more).

While the rise of the high-technology sector and AI offers numerous benefits, it also carries the risk of fostering wage inequality. High-skilled workers with expertise in these areas command premium wages, further widening the economic divide within the workforce. This burgeoning inequality poses a risk of social instability, as large segments of the population may find themselves economically marginalised. For this reason, it is vital to create policies ensuring AI complements rather than replaces human labour, with a focus on enhancing human productivity.

Compounding this issue is the gender disparity prevalent in STEM fields. Women are significantly underrepresented in areas like ICT, engineering and high-tech industries – sectors that are crucial to the future economy and are witnessing rapid growth. This underrepresentation not only limits the diversity and potential of the workforce, but also means that women are less likely to benefit from the opportunities and higher wages offered by these booming sectors. As the demand for skills in these areas grows, the gender gap in STEM could lead to a broader wage gap between men and women. Age differences in the familiarity and ease of learning new digital skills may also contribute to the socio-economic divide, as compared to older workers, young people are more likely to benefit from the newly emerging technologies.

To counter these trends, there is an urgent need for reskilling and upskilling initiatives. The focus should be on equipping the workforce – including underrepresented groups such as women – with the technical skills required in high-tech and AI-driven industries. However, preserving and enhancing soft skills such as leadership, communication and creative problem-solving is equally important. These skills are crucial for driving innovation and ensuring that technological advancements are effectively integrated into the workplace.

From an economic perspective, addressing these challenges is vital for the EU’s competitiveness on the global stage. A workforce that is diverse, technologically adept and equipped with a balance of technical and soft skills is better positioned to drive productivity growth and innovation. By fostering a labour market that is both fair and competitive, the EU can ensure sustainable economic growth and social stability.

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CHAPTER 5.3

BUSINESS DYNAMISM AND ACCESS TO FINANCE

Key questions

- What is the state of business dynamism in the EU, and how has it responded to recent crises?
- What are the latest trends in the EU's venture capital (VC) markets?
- What are the future challenges to financing innovation in the EU?

Highlights

- Business dynamism experienced a resurgence after the COVID-19 crisis, but investor appetite is falling with the latest economic outlook, posing new challenges for European tech companies.
- After the positive performance registered in 2021, VC activity in the EU is cooling down, with a more pronounced slowdown for late-stage investments.
- The financing gap with the US persists, especially in the scale-up phase. Nevertheless, the EU's VC market has shown resilience to short-term fluctuations, as well as considerable untapped potential.
- The European tech ecosystem has experienced an important increase in the scale of capital invested in clean and climate technologies, but has not fully unlocked its capacity to attract higher investments in strategic net-zero technologies.

Policy insights

- Establishing a conducive environment for companies to innovate remains at the core of the EU's strategy to enhance productivity, competitiveness and resilience. Efforts need to ensure that investments keep flowing to EU companies (particularly from EU-based investors) at the required scale to accelerate the roll-out of strategic technologies.

- Policies also need to account for the diverse nature of innovation activities, selecting the financial instruments that most suitably support different types of innovation.

- Making the EU more attractive to talent remains key, as new company formation in the European tech ecosystem is largely driven by more experienced individuals, with companies able to raise large rounds of funding typically run by experienced founders and/or managers with prior experience in successful tech firms.

- Addressing the still persistent gender gap in VC funding is important to guarantee social justice and boost economic impact.

An important interplay exists between finance, innovation and growth. Countries with better functioning financial intermediaries and markets tend to grow faster, thanks to the effective allocation of capital, higher quality of financial intermediation, capital flows and investment monitoring (Levine, 2005). Furthermore, finance is at the heart of any innovation-led economy, as firms need to collateralise their ideas to procure the funding necessary to finance their research and development (R&D) activities (Akcigit and Van Reenen, 2023).

Because of the forward-looking nature of innovation activities, recent crises and geopolitical turmoil are set to produce a significant impact on innovative firms and their financing opportunities. Recent geopolitical tensions and their economic effects have contributed to increasing inflation rates globally. In response, central banks have raised interest rates to temper demand and slow the inflationary pressure. The consequent increase in the cost of capital is likely to affect the path of future aggregate growth and innovation, creating new challenges for tech start-ups and VC markets.

1. Challenges for business dynamism in Europe

Recent shocks have produced heterogeneous effects on the European innovation ecosystem, hitting small firms the hardest. The COVID-19 crisis determined a significant drop in aggregate demand and increasing uncertainty, which put innovative companies under considerable pressure due to a severe lack of liquidity and disruptions along global supply chains (Criscuolo, 2021). Small businesses were those most negatively affected, relying on less diversified supply chains compared to larger companies. At a global level, about 30% of small and medium-sized enterprises (SMEs) appeared to have experienced negative profits during the first half of 2020 against the 17% of large firms, although heterogeneous effects have been observed across different countries (Brault, 2023).

Start-ups and young firms also appear to be more exposed to adverse business cycle conditions. The challenges these types of businesses typically face include a lack of easily accessible financing resources, and competition from incumbents, which can rely on pre-established customer bases. These aspects make start-ups and young companies more sensitive to economic disruptions, with significant repercussions on their survival ability and growth capacity.

Nevertheless, economic crises can also act as a driving force for innovation. Periods of significant distress can serve as a springboard for new businesses to refine their processes, pushing entrepreneurs to adapt to the changed economic environment by pursuing new opportunities and undertaking fresh innovation activities.

Overall, European businesses showed a good ability to adapt to the COVID-19 pandemic shock (aided considerably by substantial public economic support), although with significant heterogeneity across countries. The number of business establishments in the EU fell sharply in the first half of 2020 (European Commission, 2022a). However, the drop in business registrations was mostly short-lived, quickly followed by an increase in the number of entries in the years following the COVID-19 outbreak. The magnitude of the decline varied considerably across different countries. As an example, France, Hungary and the Netherlands reported a drop between 5% and 20%, but also experienced a rapid and sustained recovery characterised by high entry growth relative to pre-crisis levels.[1] On the contrary, countries like Sweden and Norway showed no decline, but nonetheless experienced a significant increase in the number of limited liability companies.[2] Yet, economies such as Italy, Portugal and Spain were hit harder, reporting a drop in business entries higher than 40% in the second quarter of 2020, and a slow and delayed recovery thereafter.[3]

The increase in business registrations also protracted into 2021 and the first quarters of 2022. As reported in Figure 5.3-1, the number of new business registrations in 2021 was significantly higher than the pre-crisis performance in several European countries. Norway and Sweden reported a 30% surge compared to 2019 levels, followed by France with 25%, Hungary with 20%, and the United Kingdom and the Netherlands with 12% each. Such a pattern has also been observed in the US, where the increase in new business applications with a higher likelihood of converting into employers was followed by an overall increase in job creation (Decker and Haltiwanger, 2023).

Although this boom represents an encouraging sign of a potential revival of business dynamism[4], uncertainty remains on whether this will hold in the long term.[5] After the surge experienced in 2021, business registrations have again begun to decline in several countries, sometimes reverting to the pre-crisis levels.[6] This suggests that the resurgence of business dynamism may be only transitory, and additional analyses are needed to clearly assess whether the observed positive pattern is merely the result of public support injections, as opposed to genuine company resilience.

1 Results from the Organisation for Economic Co-operation and Development (OECD) Project BRIDGE, based on the OECD Timely Indicators of Entrepreneurship by Enterprise Characteristics database, focusing on limited liability companies.

2 Focusing on limited availability companies has the potential to provide a better approximation of firms with growth potential. Entrepreneurs' motivation to start new ventures can be driven either by opportunity or necessity. While firms are created to capitalise on a business opportunity, necessity entrepreneurship is triggered by a lack of viable alternatives on the labour market, and is typically counter-cyclical. The activity of limited liability companies is more likely to be driven by opportunity considerations, thereby allowing them to better capture the creation of more growth-oriented businesses.

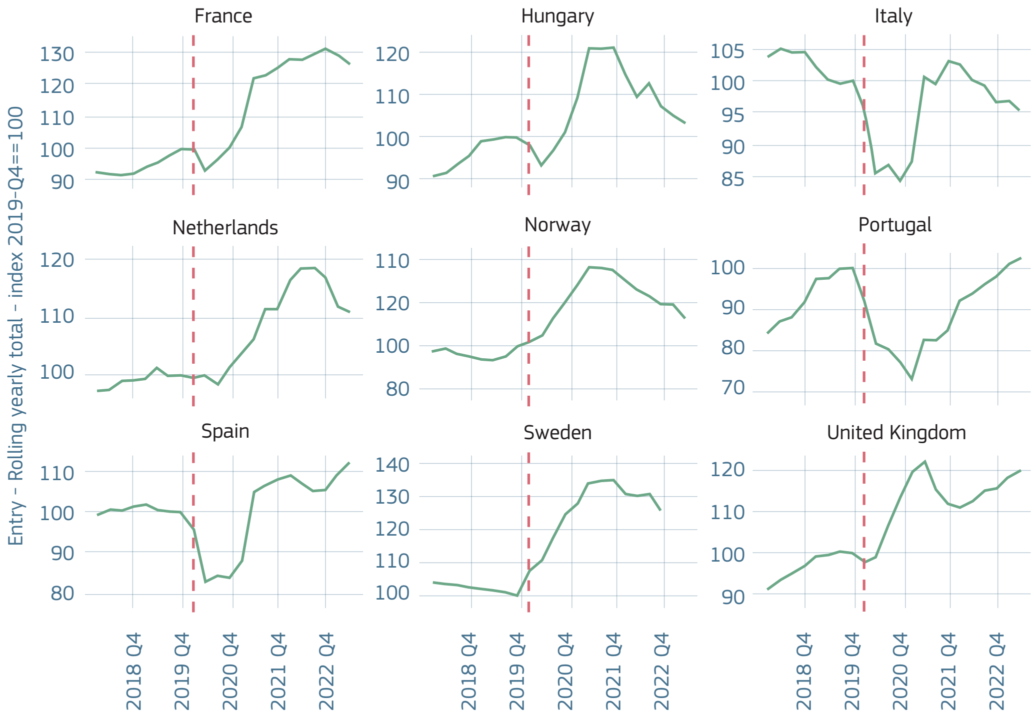
3 Results from the OECD Project BRIDGE, based on the OECD Timely Indicators of Entrepreneurship by Enterprise Characteristics database, focusing on limited liability companies.

4 In the context of this chapter, we focused exclusively on business registrations and bankruptcies as primary metric for assessing business dynamism. Nevertheless, other key indicators include, among others, job creation and destruction rates, and economic churn.

5 Financial Times. "How long can the entrepreneurship boom last?" October 6, 2023. Available at: https://www.ft.com/content/a9b68387-db34-4c69-85d8-1d28e9930adf.

6 Results from the OECD Project BRIDGE, based on the OECD Timely Indicators of Entrepreneurship by Enterprise Characteristics database, focusing on limited liability companies.

Figure 5.3-1 Change in rolling total number of registrations of limited liability companies, 2018 Q1-2023 Q2, selected countries



Science, research and innovation performance of the EU 2024

Source: OECD project BRIDGE based on the OECD Timely Indicators of Entrepreneurship by Enterprise Characteristics database.

Notes: The red line indicates the start of the COVID-19 pandemic. The figure plots for each country the evolution of a rolling yearly total number of registrations of limited liability companies, and is based on an index, normalised to 100 in 2019 Q4, of the total number of registrations in the last four quarters. Data generally refers to the total economy. Owing to methodological differences, figures may deviate from officially published national statistics.

Concerning the evolution of business bankruptcies, numbers remained low compared to 2019, mostly due to the massive support packages deployed in the aftermath of the crisis. The COVID-19 pandemic led to an unprecedented response from EU institutions, including the creation of the Next Generation EU Programme and the Recovery and Resilience Facility. The adoption of important support measures raised concerns over the risk of a "zombification" of the economy, contributing to the survival of unproductive companies and the slowdown of productivity-enhancing reallocation (European Commission, 2022a). Nevertheless, recent analyses suggest that while resource reallocation slowed down during the COVID-19 pandemic, its productivity-enhancing aspect continued (Calligaris et al., 2023). Furthermore, the latest evidence indicates that business bankruptcies are starting to revert to pre-pandemic levels as the support measures are lifted, although the increase observed in 2022 is likely to be due to the uncertainties linked to the difficult global conjuncture.

While innovative companies typically show good resilience to external disturbances, the ability of tech companies to thrive as others struggle seems to have reduced as a result of recent economic shocks. The change in the global economic outlook is putting tech companies under duress. Starting from the end of 2021, stock markets began to experience a decline (with digital firms being hit the hardest[7]), which was the first sign of various large-scale economic changes. These changes continued to negatively impact investor confidence and the distribution of capital, causing the decline to persist without clear signs of recovery (Atomico, 2022).

These changes are driven by several factors. On the one hand, digital markets are maturing and, converse to the past, are now also becoming vulnerable to economic cyclical shifts. Additionally, digital markets are also experiencing a shift in market dynamics, where tech firms are more frequently expanding into each other's business areas, thereby further increasing the degree of interconnection between differing segments.[8]

These structural changes are emerging amidst fast-changing geopolitical scenarios and increasing uncertainty, which are shifting investors' appetite. The unjustified Russian invasion of Ukraine, and the associated change in the macroeconomic environment and geopolitical situation, have represented a new turning point for the European entrepreneurial finance sector. Overall, the perceptions of the fundraising environment are worse than during the COVID-19 crisis (Kraemer-Eis et al., 2023). High interest rates and inflation rank highest among the main macro risks perceived by investors in the European tech ecosystem (Atomico, 2022), shifting the investor focus from rapid-growth companies to those that grow efficiently and generate strong cash flows.

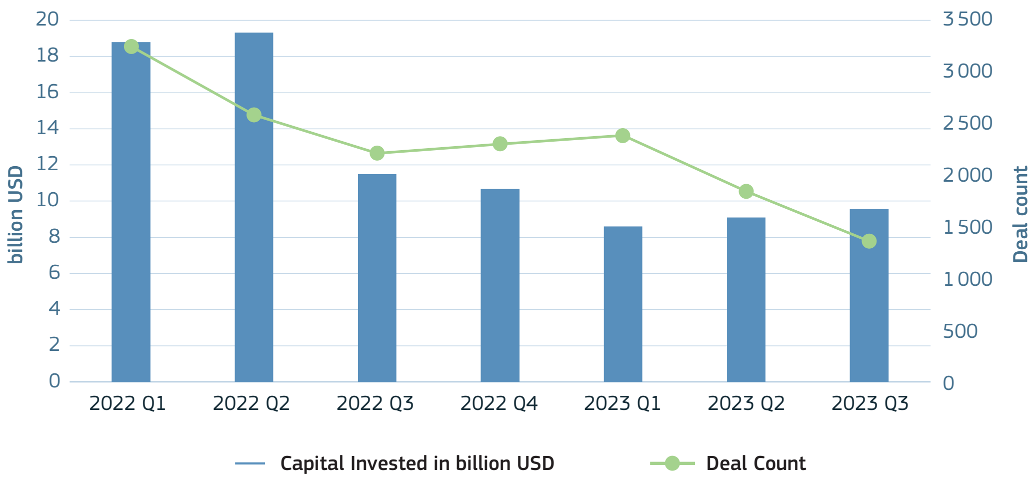
7 See https://www.economist.com/business/2022/12/24/how-techs-defiance-of-economic-gravity-came-to-an-abrupt-end.
8 Ibid.

2. The slowdown of VC investments and the strengths of the EU tech ecosystem

During the COVID-19 pandemic, VC investments in the EU underwent a cycle of rapid growth and subsequent decline. The global VC industry experienced unprecedented growth during the peak of the COVD-19 pandemic, with record deal counts and investment amounts across diverse sectors. The average size of VC investment in the EU grew across all funding stages.[9] However, 2022 marked a shift, as resources were reallocated to address post-pandemic challenges, leading to reduced market activity. The effects of government initiatives to foster technology commercialisation and workforce development are still emerging, and are expected to shape the industry's future trajectory (PitchBook, 2023a).

After the positive performance registered in 2021, VC activity in the EU is cooling down. The good performance reported in 2021 carried over into the first half of 2022. In 2022 Q2, investments amounted to USD 19.3 billion (Figure 5.3-2), in line with the performance registered at the end of 2021. Nevertheless, VC market activity in the EU started to cool off in the second part of the year, when VC investments dropped by about 40.5 % in Q3 compared to the previous period. At the end of 2022, VC investments were about 41.7% less than what was reported in 2021 Q4.[10]

Figure 5.3-2 VC(1) invested and deal counts in the EU, 2022 Q1–2023 Q3



Science, research and innovation performance of the EU 2024

Source: PitchBook data, as of 20th of November 2023.

Notes: (1) Investment values are calculated considering the headquarters country of the company involved in completed deals.

9 The OECD BRIDGE project, based on the OECD Start-Up Database, based in turn on Crunchbase and Dealroom.

10 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on PitchBook data, November 2023.

The same pattern protracted into 2023. In 2023 Q1, VC capital invested kept decreasing, presumably as a result of the difficult economic outlook. Historically, low interest rates made VC an attractive investment option, but with rates increasing, investors are diversifying their portfolios, potentially moving away from VC activity (PitchBook, 2023a).

The value of VC deals towards the end of 2023 was lower than in 2022. In 2023 Q3, VC deal value in the EU amounted to USD 9.5 billion (Figure 5.3-2), about 17 % lower than what was reported in the same period of 2022. However, deal value in the EU has increased during the first three quarters of 2023, although this recovery is not sufficient to match the performance of the previous two years.

Nevertheless, the deal value registered in 2023 is in line with those pre-2020. This suggests that the VC activity has undergone structural growth over a longer time horizon (PitchBook, 2023b). The VC invested in the EU in 2019 was USD 27.8 billion, slightly less than the USD 31.7 billion reported in 2023.[11] This indicates that the EU's VC market has shown resilience to short-term fluctuations, and a strong underlying growth trend.

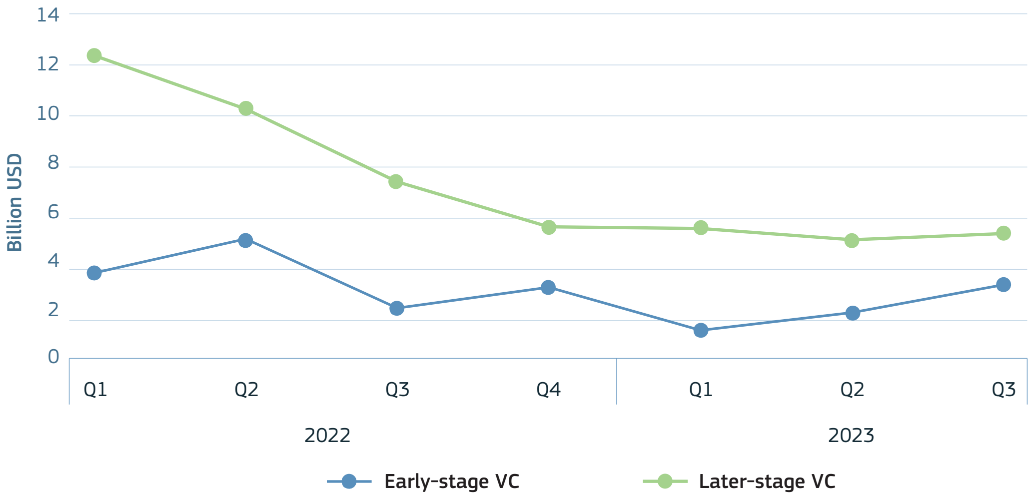
The slowdown in investment activity was more pronounced for later-stage[12] VC investments. In 2022, later-stage VC investments in the EU dropped more significantly than early-stage investment, decreasing from USD 12.4 billion in the first quarter of 2022 to USD 5.5 billion in the same period on 2023, and remaining broadly stable thereafter (Figure 5.3-3). The slowdown in late-stage investments is also reflected in the significant decline of VC rounds of more than USD 100 million (Atomico, 2023). Conversely, early-stage[13] investments started to recover as of the beginning of 2023, after the smaller contraction reported in the second half of 2022.

11 Data as of 20th of November 2023.

12 PitchBook database defines a later-stage VC deal as a Series C to Series D round, or a round that occurs more than five years after the company's founding date.

13 PitchBook database defines early-stage VC as a Series A to Series B financing round founded within five years of the company's founding date.

Figure 5.3-3 Early- and later-stage VC investments in the EU, 2022 Q1-2023 Q3



Science, research and innovation performance of the EU 2024

Source: PitchBook data, as of the 20th of November 2023.
Notes: (1) Investment values are calculated considering the headquarters country of the companies involved in completed deals.

Exit activity also remains weak. During the first three quarters of 2023, the deal value of exit activities (including both Initial Public Offerings [IPOs] and acquisitions) reached USD 7.6 billion, about 72 % less than what was observed over the same period of 2022.[14]

The VC market remains significantly larger in the US than in the EU. US VC funds are historically larger than their European counterparts. In 2021, the amount of VC capital invested in the US was almost six times higher than that observed in the EU, with USD 442.92 billion and USD 75.12 billion, respectively.[15] The US advantage partly decreased in 2022, when VC investment dropped by around 42%, against the 14% reduction observed in the EU.[16]

The financing gap between the EU and the US is observed at all development stages, but remains more prominent in the scale-up phase. In 2023, VC investments in the US exceeded those in the EU by a factor of 5 at the seed stage[17], and by a factor of 4 at early-stage financing. The largest gap is observed for scale-up operations, with the US VC investments at later-stage financing amounting to USD 103.3 billion, against the USD 18.2 billion reported in the EU (Figure 5.3-4).

The significant gap in late-stage financing between the EU and the US is also confirmed when looking at VC investments by deal size. As of November 2023, the US exhibits a larger number of VC investments across all deal sizes compared to the EU (Figure 5.3-4). The disparity is more

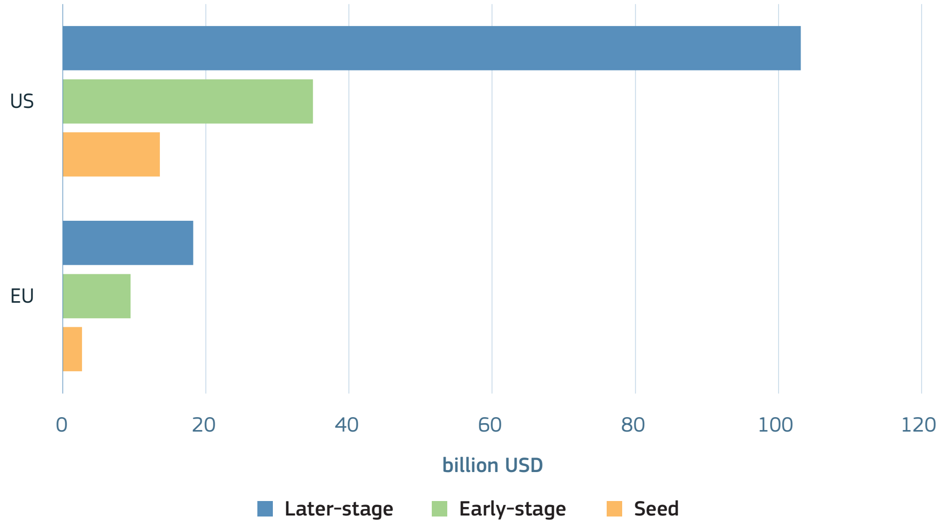
14 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on PitchBook data, as of 20th November 2023.

15 PitchBook data, as of 20th November 2023.

16 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on PitchBook data, as of 20th November 2023

17 A seed deal is when any investor type provides the initial financing for a new enterprise that is in the earliest stages of development.

Figure 5.3-4 VC investments(1) by development stage in the EU and US, 2023



Science, research and innovation performance of the EU 2024

Source: PitchBook data, as of 20th of November 2023.
Notes: (1) Investment values are calculated considering the headquarters country of the companies involved in completed deals.

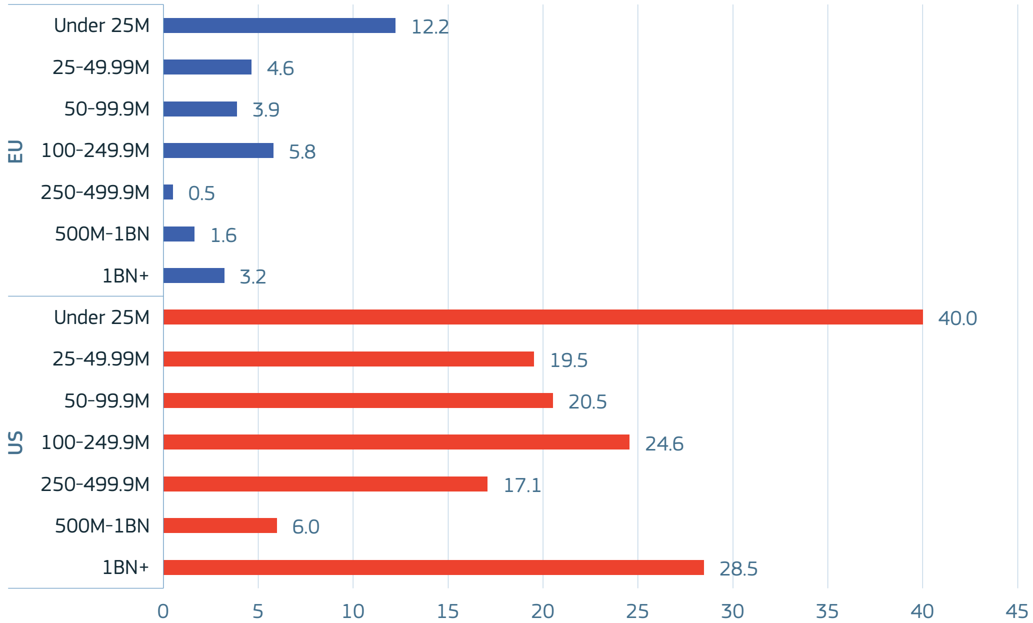
pronounced as the deal size increases, with the US showing a significantly higher volume of deals above USD 100 million. The gap becomes especially marked in the highest investment tiers, particularly for deals over USD 250 million. Specifically, for funds exceeding USD 1 billion, the US outnumbers the EU by a factor of more than 5.

Furthermore, the US tech ecosystem consistently offers a wider pool of start-up[18] companies for investors to back. Up to November 2023, the number of VC-backed start-ups in the US was more than twice that of the EU.[19]

18 Start-ups are defined using the PitchBook business status definition of start-up: a company in its formative stage/very early stage, with very few employees (such as lacking a full management team) and typically VC-backed. Please note that diverging data and definitions (as well as a number of different methodologies) are typically adopted to define start-up and scale-up companies (Vandresse et al., 2023). As such, it is extremely challenging to provide a comprehensive overview of the European landscape, using a unique definition.

19 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on PitchBook data, as of 20th November 2023.

Figure 5.3-5 Venture capital investments by round size in the EU and the US, 2023 (billion USD)



Science, research and innovation performance of the EU 2024

Source: PitchBook data, as of 20th of November 2023.
Notes: (1) Investment values are calculated considering the headquarters country of the companies involved in completed deals.

The largest share of VC-backed start-ups operates in the information and technology (IT) sector[20] and in the healthcare industry[21], and are mostly concentrated in France and Germany, accounting for more than 30% of the VC-backed start-up population in the EU.[22] Additionally, **60% of all global scale-ups are based in North America, while only 8% in EU countries**, with Germany and France again in the lead (Startup Genome, 2023).

Nevertheless, the number of new tech startups founded each year in Europe has exceeded that observed in US over the last five years. On average, around 15 200 new tech start-ups have been founded per year in Europe, compared to 13 700 in the US (Atomico, 2023), signalling that other factors are at play limiting the scaling-up of the EU start-up ecosystem.

20 The IT sector includes all companies whose primary focus is the development of software, hardware, or related computer peripherals, and all companies whose primary focus is on IT consulting, outsourcing or database management. This includes both business-facing companies and consumer-facing companies.

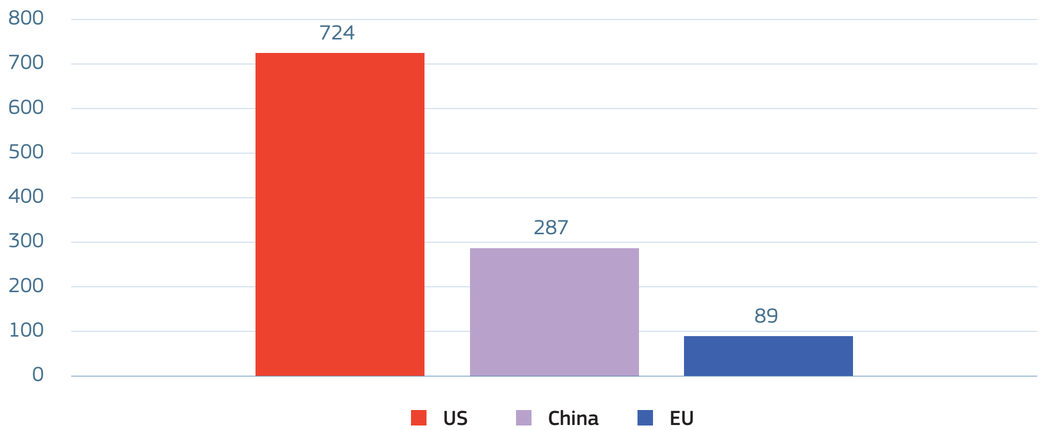
21 The healthcare sector refers to all companies providing medical products or services. This includes consumer facing organisations such as hospitals, health insurance companies and business-facing organisations that provide specific healthcare services, enterprise products or research and development.

22 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on PitchBook data, as of 20th November 2023.

Additionally, the role of institutional investors in the EU remains highly underdeveloped compared to the US. In 2021, government agencies accounted for a substantial share of total funds raised in the European VC market, although in decline compared to 2020 (European Commission, 2022b). On the contrary, institutional investors like pension funds and insurance companies play a minor role. Between 2020 and 2023, the amount of capital committed by pension funds and insurance companies accounted for about 31 % of the money flowing to VC funds, against the 67 % observed in the US.[23]

The EU also keeps lagging behind in terms of unicorn firms. As of November 2023, the number of companies holding the status of unicorns[24] in the US and China exceeded that in the EU by a factor of 8 and 3, respectively (Figure 5.3-6). Furthermore, the number of newly minted unicorns has significantly reduced, with only five new companies reaching a valuation of at least USD 1 billion.[25] This is in stark contrast with the performance observed in 2021, when more than 40 EU companies were able to attain unicorn status.[26] Nevertheless, when looking at the number of active unicorns, the performance of the EU has kept improving (even if only marginally), despite the difficult economic conjuncture.[27]

Figure 5.3-6 Number of active unicorns across world regions per headquarter, up to November 2023



Source: PitchBook data, as of 20th of November 2023.
Notes: A unicorn is defined as a venture-backed company that has raised a venture round with a post-money valuation of at least USD 1 billion. An 'active' unicorn is one that has not been exited, meaning that it is/was venture-backed as of the year shown.

23 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on PitchBook data, as of 23rd November 2023.

24 PitchBook defines a unicorn as a venture-backed company that has raised a venture round with a post-money valuation of at least USD 1 billion. An 'active' unicorn is one that has not been exited, meaning that it is/was venture-backed as of the year shown.

25 PitchBook data as of 20th November 2023.

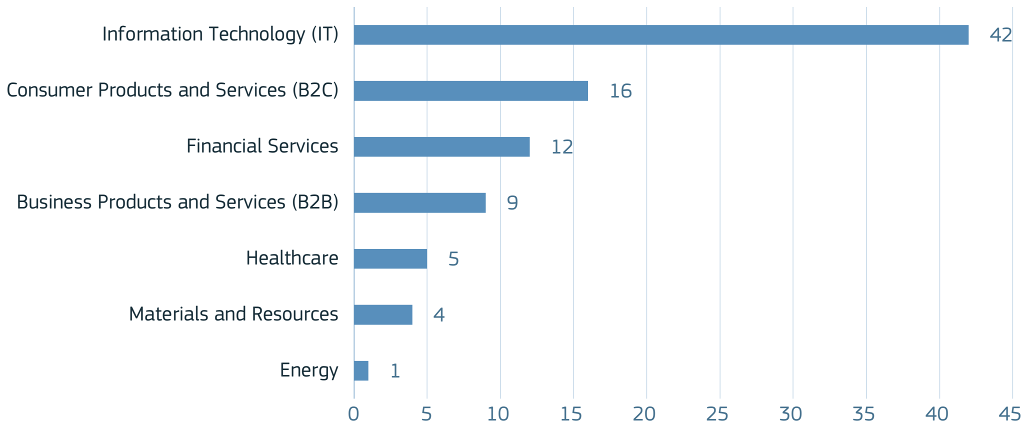
26 PitchBook data as of 20th November 2023.

27 PitchBook data as of 20th November 2023.

The EU's unicorns are mostly concentrated in the IT sector[28]. As of November 2023, there are 42 unicorn companies operating in the IT sector. The consumer products and services sector[29] ranks second with 16 unicorns, followed by the financial service sector[30] with 12 unicorn companies (Figure 5.3-7).

Despite lagging behind the US, the European tech landscape shows considerable untapped potential. Although the amount of capital raised by VC funds in the EU has been decreasing since the positive performance registered in 2021, the "dry powder"[31] available remains significant. This trend is evident in Figure 5.3-8, showing that the cumulative overhang in the EU has not decreased post-2021, but rather, has continued rising. This pattern may be the result of a more conservative approach by VC investors due to economic uncertainties, such as those prompted by geopolitical tensions or market fluctuations. As of November 2023, the amount of dry powder in the EU amounts to USD 66.9 billion, signalling the presence of readily available funds to invest in new opportunities or to support existing investments through additional funding rounds.

Figure 5.3-7 Number of active unicorns in the EU by industry sector in 2023



Science, research and innovation performance of the EU 2024

Source: PitchBook data, as of 20th of November 2023.
Notes: A unicorn is defined as a venture-backed company that has raised a venture round with a post-money valuation of at least USD 1 billion. An 'active' unicorn is one that has not been exited, meaning that it is/was venture-backed as of the year shown.

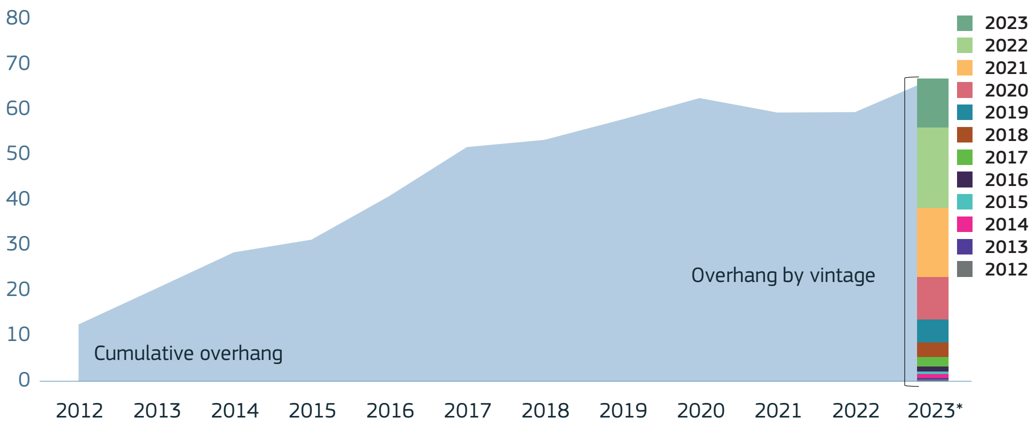
28 According to PitchBook, the IT sector includes all companies whose primary focus is the development of software, hardware or related computer peripherals, and all companies whose primary focus is on IT consulting, outsourcing or database management. This includes both business-facing companies and consumer-facing companies.

29 Business-to-consumer (B2C) refers to product or service transactions that are conducted between a business and a consumer, rather than between a company and a business or an individual consumer and another consumer. This includes companies engaged in the sale of clothing, accessories and related appeal products directly to consumers; companies engaged in sales of durable and non-durable products; companies providing media-based products and services directly to consumers; companies offering consumer media services not classified elsewhere; companies engaged in consumer retail, both via digital and brick and mortar locations; companies providing consumer-facing non-financial services, and companies providing customer-facing transportation services and products.

30 Professional services involving the investment, lending and management of money and assets for both businesses and individual customers.

31 Dry powder, or capital overhang, refers to the remaining amount of capital that can be called down to use for investment purposes.

Figure 5.3-8 **VC dry powder in the EU, 2012-2023 (billion USD)[(1)]**



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 PitchBook data.

Notes: (1) As of 2023 Q3.

Furthermore, funds raised remain highly concentrated within the Union. The European tech ecosystem is characterised by many different hubs and sub-regions, all at different stages of maturity. Germany and the Netherlands alone account for around 52% of total VC capital raised in 2023[32], but only 30.4%[33] of the EU GDP. This indicates that VC fundraising is disproportionally distributed across the Member States, and new investment opportunities may arise from territories currently underrepresented.

32 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on PitchBook data, as of November 2023.

33 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Eurostat data (online data code: nama_10_gdp__custom_9450868).

Box 5.3-1: The Importance of Governmental Venture Capital

Ramon Campano and Giuseppina Testa

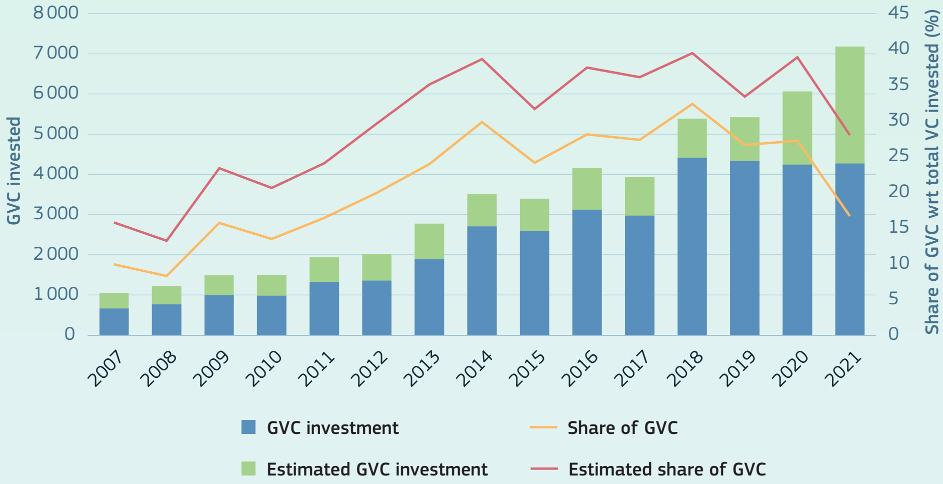
Promising start-ups have the potential, when properly funded, to contribute disproportionally to employment, innovation and economic growth. They are innovative and often operate in high-tech sectors. However, their market and technological characteristics make them likely to suffer from financial constraints, hindering their growth (Berger and Udell, 1988). For this reason, regional, national and supra-national governments all over the world intervened via "**Government Venture Capital programmes**", i.e. VC funds financed with public money and often managed by public agencies to support innovative companies.

Government intervention is justified by the presence of a market failure in the venture capital market (when the level of VC investments is suboptimal, i.e. too low, from a societal perspective) and **serves both to bridge the equity capital gap of promising start-ups and to foster the development of the venture capital market** (Colombo et al., 2016).

To understand the role and positioning of governments in the VC market in Europe, we gathered data on 128 national and regional government venture capital (GVC) institutions located in eleven high-income EU economies, including information on their founding year, ownership, geographical mandates, and policy mix. Additionally, we collected data on 392 GVC funds, such as their type of intervention, committed capital, annual disbursement, duration, management, and investment criteria. This data was obtained from annual reports published on the websites of GVC institutions and press releases. We also validated the data with the respective managers of the GVC funds. This comprehensive approach allowed us to gain a deep understanding of the implementation of GVC funds since their inception. Based on such official accounts we estimate that **over the period from 2007 to 2021, the collected GVC initiatives invested a total of EUR 36.6 billion, with an average annual disbursement of EUR 2.4 billion** (Figure 5.3-9).

Governments have steadily increased their VC investments over time. Between 2007-2021, the estimated amount of GVC investments accounted for 30.9 % of the total VC investments. Furthermore, the share of GVC on total VC investments significantly increased over the same period, from 10 % in 2007 to nearby 40 % in 2020, with a decline in 2021 (Figure 5.3-9). In absolute terms, we calculated GVC investments to be EUR 36.6 billion in the period 2007-2021, compared to EUR 165.4 billion in total, according to the European VC association, Invest Europe (Testa et al., forthcoming).

Figure 5.3-9 Trends in GVC investments in absolute terms and as a percentage of total VC investment (million EUR)



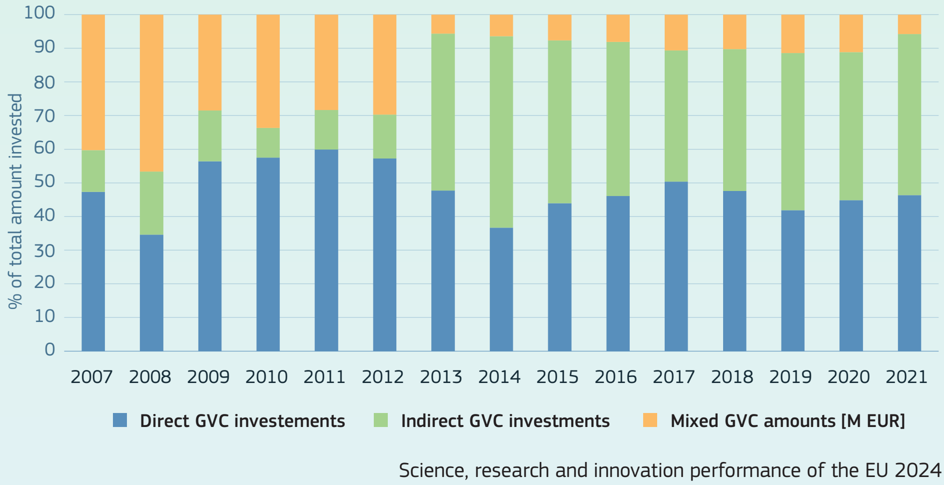
Science, research and innovation performance of the EU 2024

Source: Testa et al., (forthcoming).
Notes: The filled bars indicate collected data, while the dashed bars referred to the estimated data.

GVC funds differ significantly in terms of their investment strategy private investor involvement, budget management, size, and investment process. Examples of different investment strategies are that governments can invest directly (alone or/and alongside private investors) in companies (direct GVC funds), or they can set up funds (that are entirely or partially financed by the public sector and either managed by public officials or private sector managers) that invest in companies (indirect GVC funds). In the selected EU countries, the significance of direct, indirect, and mixed GVC funds has evolved over time in terms of the total investment amount (Figure 5.3-10). Direct GVC investments were predominant in the early years of the analysis. However, since 2013, there has been **a notable increase in indirect GVC investments**, which account for approximately half of the total GVC investments in recent years. Mixed initiatives are gradually declining.

In relation to their industry focus, the majority of GVC funds in the sample are "generalist", i.e. have no general industry regulations or restrictions regarding their investments. **About 81% of our GVC funds are closed-end funds**, indicating that they focus their investment activities on a limited period of time, after which they are 'closed' to new investments performing 'follow-on' investments, only. Closed-end funds on average have a lifetime of about 8 years (values range min = 1; max = 21), suggesting that they are not particularly patient (for comparison average private VC funds have typically a lifetime of 10 years, with the possibility to extend by two additional years). **The consequence of this is that there might be the risk of missed opportunities to invest in deep-tech and groundbreaking technologies that require longer periods to develop marketable products.**

Figure 5.3-10 Total GVC investments by type of initiative and year (million EUR)



Source: Testa et al., (forthcoming).

There exists a **great deal of variation in terms of characteristics of GVC institutions**, such as ownership, experience, geographical focus, stated objectives and policy mix. These institutions have different multiple objectives, ranging from stimulating economic growth, innovation, increasing employment to fostering VC market.

GVC institutions have shifted from providing one-time financial support to a wide range of financial instruments to support SMEs and start-ups throughout their entrepreneurial journey. All this suggests the importance of public sources in the financing of promising start-ups dynamically. While in the economic literature (e.g. Alperovych et al., 2020; Munari and Toschi, 2015) GVC institutions have been highly criticized for their underperformance, particularly when compared to private sector VC investors, we believe, as argued by other scholars (Owen, 2019; Bertoni et al, 2019), that there is often a lack of appreciation for their different role, and their policy goals, such as tackling socio-economic challenges, environmental concerns, and/or mitigating regional disparities, which goes beyond the maximization of financial returns.

International investors have become progressively more involved in the European tech ecosystem (especially in later-stage financing), although a slowdown has been observed in recent years. Domestic funding remains the predominant source of finance in the European VC market, especially in early-stage rounds where domestic investors still account for around 80% of VC invested in rounds less than USD 20 million (Atomico, 2022). Nevertheless, the role of international investors appears more important in later-stage rounds. Indeed, the European tech ecosystem experienced significant capital injection into later-stage rounds in recent years, leading to a rapid increase in the number of investors in rounds above USD 100 million (Atomico, 2022). Among these new investors from outside Europe, those originating from the US hold the highest share, although their number has declined since 2021 (Atomico, 2022), presumably as a result of the difficult economic conjuncture.

Furthermore, the European tech ecosystem has experienced a significant increase in the scale of capital invested in clean[34] and climate tech[35]. The amount of capital invested in these two segments has significantly increased over the last five years. As of November 2023, clean and climate technologies accounted for 39% of total VC invested in the EU.[36] The surge in green companies has been accompanied by a significant slowdown in fintech investment, which accounted for only 10% of the resources invested in 2023.[37]

VC investments in the clean energy domain proved to be more resilient in the EU than in the rest of the world. In 2022, the EU's VC investments in the clean energy domain reported a 42% increase compared to 2021, reaching EUR 7.4 billion (European Commission, 2023). Early-stage investments in EU clean energy start-ups more than doubled in 2022, increasing at a much faster rate than in the US, but less than in China. This growth was mostly driven by deals in industries related to green steel production, renewable carbon products and clean energy generation (small modular nuclear reactors and installation services for solar PV). Later-stage investments in EU clean energy scale-ups also increased between 2021 and 2022 (by a factor of 1.3), as opposed to the significant drop observed in both the US and China (-10% and - 29%, respectively) (European Commission, 2023).

However, the EU has still not fully unlocked its capacity to attract higher growth deals when looking at strategic net-zero technologies as defined in the Net-Zero Industry Act (NZIA) (except for batteries). Global VC investment in strategic net-zero technologies increased from EUR 19.5 billion in 2021 to EUR 20.8 billion in 2022 (European Commission, 2023). Nevertheless, the EU's increase was lower than observed at a global level, particularly in the US, which recorded a 41% increase against the EU's 2.3%. US growth was primarily driven by investments in renewable hydrogen and fuel cells, sustainable biogas/biomethane, heat pumps and geothermal (European Commission, 2023).

34 In PitchBook, clean tech companies include developers of technology which seeks to reduce the environmental impact of human activities, or to significantly reduce the amount of natural resources consumed through such activities.

35 In PitchBook, the segment of climate technology includes companies developing technologies intended to help mitigate or adapt to the effects of climate change. The majority of companies in this vertical are focused on mitigating rising emissions through decarbonisation technologies and processes. Applications within this vertical include renewable energy generation, long-duration energy storage, the electrification of transportation, agricultural innovations, industrial process improvements, and mining technologies, among others.

36 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on PitchBook data, as of 20th November 2023.

37 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on PitchBook data, as of 20th November 2023.

To meet the NZIA target of manufacturing at least 40% of the EU's annual deployment needs of strategic clean technologies (solar PV, wind, batteries, heat pumps, electrolysers, and CCS), at least EUR 92 billion investments over the period 2023-2030 will be needed. Out of these, between EUR 16 billion and EUR 18 billion are expected to come from public investments, while EUR 25 billion are expected to be raised from private investors given the current rate of private investments in these technologies (Cleantech for Europe, 2024). This implies a financing gap of EUR 50 billion over the period 2023-2030, and calls for a coordinated approach to secure sufficient and swift funding to compete on the global stage.

The share of total investment captured by Artificial Intelligence (AI) is also increasing. Despite the global economic downturn, the amount of capital invested in companies operating within the AI realm[38] has shown more resilience than other segments. According to PitchBook data, 2022 investments in companies linked to AI and machine learning technologies remained close to the 2021 levels, with AI's share in total investment at around 16% in 2023.[39]

38 According to PitchBook, this category refers to companies developing technologies that enable computers to autonomously learn, deduce and act through the utilisation of large data sets. The technology enables the development of systems that collect and store massive amounts of data, and analyses that content to make decisions based on probability and statistical analysis. Applications for Artificial Intelligence & Machine Learning include speech recognition, computer vision, robotic control and accelerating processes in the empirical sciences where large data sets are essential.

39 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on PitchBook data, as of 20th November 2023.

Box 5.3-2: Deep tech innovation in Europe

Deep tech innovation is rooted in cutting edge science, technology and engineering, often combining advances in the physical, biological and digital spheres and with the potential to deliver transformative solutions in the face of global challenges. Deep tech innovation differs from other forms of technological innovation by finding its source in a deep interaction with the most recent scientific and technological advances (including in the fields of materials and biology), and by seeking to produce a profound impact in the targeted application areas that also help address the most pressing challenges, such as the green transition.

Deep tech start-ups have a different risk profile compared to traditional companies. Deep tech innovations typically have strong disruptive potential, but face specific issues such as higher development costs, longer time spans to move from discoveries to market, and technological risks. The technological risk is linked to the very nature of deep tech innovation, which entails the development of game-changing technologies completely new to the market, whose development is, thus, characterised by a significant degree of uncertainty (European Commission, 2022a).

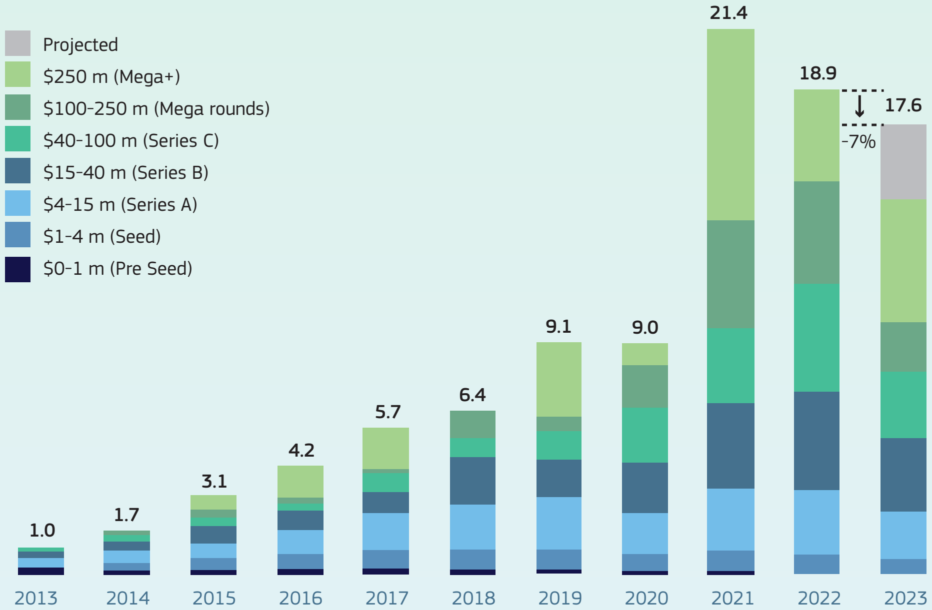
Nevertheless, deep tech start-ups also face lower market risk. Deep tech companies are typically built around advanced technologies that are not easy to replicate or replace, thereby providing significant barriers to entry for potential competitors. Additionally, deep tech start-ups can rely on highly skilled personnel, whose expertise allows to maintain a competitive edge in developing and improving cutting-edge technologies (Dealroom, 2023).

Deep tech innovation is critical for navigating the green and digital transitions, to accelerate the EU's open strategic autonomy, to find alternatives technologies in disrupted markets, from renewable energy to agri-tech, and address health emergencies. Deep tech spans many industries and technology segments, including novel AI (e.g., autonomous driving, privacy enhancing technologies, explainable AI); space tech (e.g., launch, earth observation, in-space manufacturing); novel energy (e.g., hydrogen, fusion, new battery chemistry); computational biology and chemistry (e.g., AI-enabled drug discovery, protein design, biofuels); and quantum innovations (Dealroom, 2023).

In 2023, the level of VC investment in European deep tech companies was close to that of 2022, as opposed to regular tech companies. Deep tech showed significant resilience to the recent economic downturns, maintaining relatively high investment levels across the different funding stages (Figure 5.3-11).

Nevertheless, the share of capital coming from European investors dropped to half at later-stage of funding, posing a potential threat to Europe's technological independence. At the initial (pre-seed) phase, deep tech VC in Europe

Figure 5.3-11 **VC investments in European Deep tech start-ups by stage, 2016-2023 (billion USD)**



Science, research and innovation performance of the EU 2024

Source: Dealroom, (2023).

is predominantly sourced from within the region. However, at more mature funding stages, almost half of the investment comes from the US and Asia (Dealroom, 2023). Efforts are thus needed to increase the attractiveness of deep tech investments for domestic investors. In this regard, the **European Innovation Council (EIC)**, with its EUR 10 billion, is increasingly recognised as the largest deep tech investor in Europe (see Box 3). Separately, **the European Tech Champions Initiative**, structured as a fund-of-funds, aims to allocate EUR 3.75 billion to tackle the European scale-up gap, providing growth financing to European tech champions in their late-stage growth phase (European Commission, 2022b). Additionally, the Strategic **Technologies for Europe Platform (STEP)** initiative aims to boost investments in critical technologies, including deep tech.

Attracting talents represents another important challenge for deep tech companies in Europe. Deep tech technologies require a unique skillset. High quality education and attractive working conditions are key to attracting and ensuring a flow of highly skilled and talented individuals, which can contribute to achieving wider policy priorities such as the twin transitions, and a competitive edge in strategic value chains. Furthermore, skilled growth investors, able to assess transformational technologies and support companies in building their businesses, are needed to increase growth investments in the years to come (Dealroom, 2023).

3. Policy initiatives to scale up the EU's tech ecosystem

Financial frictions represent a significant constraint for innovation. Innovative ideas are the engine of economic development, and the creative disruption they trigger is a key driver of companies' and industries' dynamics. From the moment a new idea manifests to its potential use within the production process and future arrival on the market, inventors face several inefficiencies. In particular, financial constraints not only affect the size and the quality of the innovator pool, but can also impact the speed and efficiency at which new ideas are integrated into production (Ackigit and Van Reenen, 2023).

Furthermore, the financing of innovation differs significantly from that of tangible assets. The challenges linked to financing innovation are related to the non-rival and non-excludable nature of innovation outcomes, which prevent firms from ensuring full returns on their R&D investments. Additionally, the intangible nature of technological knowledge and the inherent risks and uncertainties of innovation projects create financial frictions in securing external investment (European Commission, 2022a).

Therefore, establishing a conducive environment for companies to innovate lies at the core of the EU's strategy to enhance productivity, competitiveness and resilience. In this regard, the EU's capital markets remain considerably fragmented, with resources heavily concentrated in few regions and significant untapped potential across the entire EU. This calls for increasing efforts to progress and complete the Capital Markets Union (CMU), whose role remains key to providing additional and alternative funding opportunities. This is particularly relevant to ensure that investments keep flowing to the EU's companies at the required scale to accelerate the roll-out of strategic net-zero technologies. STEP, established in June 2023, aims to earmark public funding for allocating and distributing financial support to investments in critical technologies, such as deep and digital technologies, clean technologies and biotechnologies. This initiative is designed to mitigate the risks associated with innovation investments, bridge the divide between project developers, corporate and institutional investors, and ultimately facilitate increased private-sector investment (European Commission, 2023).

Policy actions also need to account for the different nature of innovation activities, as the suitability of different financial instruments varies depending on the types of innovation firms undertake (Mitra et al., 2023). Due to the constraints faced in accessing external financing, innovative firms in the EU still largely rely on internal resources to finance their innovation activities (European Commission, 2022a). Nevertheless, grants are among the financing instruments showing the largest positive association with firms' likelihood to innovate, confirming the key role of grant schemes for the EU's innovation performance, as well as the importance of the EU's Framework Programme for R&I, which employs grants as primary financing instruments to promote and foster innovation within the EU (Mitra et al., 2023).

Furthermore, improving access to non-banking financing remains high in the EU's innovation agenda. Equity and venture capital financing are key to creating growth opportunities in the EU. This is particularly relevant for deep-tech companies, which have strong disruptive potential and are set to play a pivotal role in navigating the green and digital transitions (European Commission, 2022b).

The "New European Innovation Agenda" (NEIA) aims to foster a new wave of deep-tech innovation, which requires breakthrough R&D and large capital investment in the EU. The NEIA is currently in its implementation phase, with 24 of the 25 core actions announced either completed or ongoing. These actions aim to improve access to finance, enable innovation through experimentation spaces (e.g., regulatory sandboxes), help strengthen and better connect innovation players across Europe, attract and retain talent, and improve the European innovation policy framework (European Commission, 2022b).

In this regard, the EIC has a central role to play. The EIC focuses on deep-tech innovations where significant funding is needed over a long timeframe before returns can be generated. It is designed to identify ground-breaking ideas and bridge **two critical financing gaps** that innovative companies face in their growth journey to create scalable deep tech propositions: the transition phase from the laboratory to the market, and the scale-up phase for high-risk innovations.

Box 5.3-3: Access to Finance – the EIC

Sivasegaram Manimaaran

The EIC, a flagship initiative of the Commission's Horizon Europe programme, was established to provide a one-stop-shop for breakthrough innovators at all stages of development, ensuring a pipeline of ideas and companies that are either ripe for investment now, or will be in the future. Support for companies through the EIC comes in the form of both non-dilutive grant funding and investments in individual startups and SMEs. With long time horizons and a high-risk tolerance, investment through the EIC is designed to crowd in essential private investment.

Through such syndication, the EIC leverages the domain knowledge and expertise of more specialised funds, and in turn, ensures that EIC beneficiaries will be viewed as credible propositions by the market when seeking additional future financing. To date, over 500 startups and SMEs have gained support through the EIC Accelerator and its investment arm, the EIC Fund, which has been fully operational since October 2022. To date[40], over EUR 1.3 billion in investments in over 200 deep-tech companies have been approved, and over a hundred of these approved investments have resulted in investment agreements that have crowded-in approximately 3.5 euro of additional equity investment for every euro of investment via the EIC, thus contributing to the emergence of a single market for innovative risk capital in Europe.

Importantly, the EIC has also consistently sought to support female led companies, now representing over 19% of the portfolio[41], **and has increased its reach to companies from less developed regions**, now standing at over 20% of applicants. The resulting portfolio of projects under the Accelerator now features scaling companies, including well over 100 that have achieved centaur status[42] or higher valuations, in critical technology areas such as Biotech, Energy Storage, Hydrogen, Semiconductors and Quantum Technologies, amongst many others.

Support from the EIC also goes beyond the pure provision of funding. Its Business Acceleration Services, which include connections to large corporate and public procurers, also help startups and SMEs make connections that are essential to gain market traction.

40 End of January 2024.
41 Companies with female CEOs.
42 A centaur is defined as a private, technology-based company valued at more than EUR 100 million.

Making the EU more attractive to talent is also crucial to competitiveness. High quality education and working conditions are key to attracting and ensuring a flow of highly skilled and talented individuals, which can contribute to achieving wider policy priorities such as the twin transitions, and a competitive edge in strategic value chains. The EU appears to be losing the global race for talent, with skilled researchers and potential academics more often moving from the EU to the US (see Chapter 3.2).

A deep talent pool is a key ingredient to a successful innovative ecosystem. Companies able to raise large rounds of funding and thus quickly scale up are more likely to be run by experienced founders and/or managers (Atomico, 2022). Furthermore, new company formation in the European tech ecosystem is largely driven by individuals who have previously worked in unicorn companies (Atomico, 2023). These founders can leverage the extensive knowledge and networks gained from their experiences in successful tech companies, giving them a substantial advantage in establishing their ventures. In Europe, around 9000 new companies have been initiated by alumni of exited unicorns founded in the 2000s (marking a 50% increase compared to those from the 1990s) (Atomico, 2023). This trend emphasises the key role of strong network effects in fostering innovation and growth within the industry, with important implications for the future trajectories of Europe's tech sector.

Furthermore, as the EU's VC market and tech industry continue to grow and mature, it is important to ensure a more inclusive development trajectory. Despite the fluctuations observed in recent years, 75% of all VC funding in Europe in 2023 was raised by companies with male founding teams. On the contrary, only 7 % of the rounds raised were captured by all-women founding teams (Atomico, 2023).

There exists a significant disparity between the number of deals secured by teams led solely by women and the actual funding they receive, with a gap ranging from 2 to 6 times depending on the year (Atomico, 2022). This indicates that even when all-women teams are successful in raising funds, they tend to receive smaller amounts compared to their male counterparts, and this trend appears to be worsening over time. Concerning mixed-gender teams, the share of funding rounds obtained in 2022 was only 10%, in decline compared to the 12% registered in the previous year. Nevertheless, the overall percentage of funding allocated to these teams has slightly increased, suggesting that the average funding amount per deal for mixed teams is trending upwards (Atomico, 2022).

Addressing the gender gap in VC investment remains essential, not only for social justice, but also to boost economic efficiency. Diverse teams, including those led by women, bring unique perspectives that can catalyse further innovation, which is vital for a dynamic and competitive market. Moreover, by unlocking the full potential of female entrepreneurs, the EU can tap into a largely underutilised resource, boosting overall economic productivity and innovation.

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CHAPTER 5.4

R&I VALORISATION AND THE UPTAKE AND DIFFUSION OF INNOVATIVE OUTPUT

Key questions

- How is the EU performing in terms of knowledge diffusion and innovation uptake?
- What is the role of policy in supporting knowledge valorisation and the uptake of R&I results?

Highlights

- The EU's innovation performance has been improving over time, and the adoption of digital technologies by EU companies is increasing, reducing the gap with the US. Nevertheless, more efforts are needed to maximise the returns to R&I through knowledge diffusion and valorisation, boosting the take-up of innovative solutions, for example by strengthening collaborations between academia, public and private sectors.
- Increasing the speed at which scientific findings are converted into commercial and societal applications is crucial for maintaining the EU's competitive edge and sustain its path towards the Sustainable Development Goals (SDGs).
- Thanks to its pan-European approach and broad set of instruments, the EU's Framework Programme for R&I plays a central role in supporting market and societal take-up of innovative results at different stakeholder levels.

Policy insights

- A systemic approach to knowledge diffusion and valorisation in R&I policy is critical for designing policies effectively promoting the societal and market uptake of innovation. Such an approach needs to take into account the dynamics of diffusion across actors, and create framework conditions to steer the uptake of innovation towards desired socioeconomic goals.

- A strategic approach to intellectual assets management which combines economic interests and societal benefits is also essential to improve access to knowledge and to support competitiveness through increased value creation while advancing societal progress.

- Strengthening collaboration across academia, industry and government helps to enhance and accelerate the transformation of research into practical applications.

- An adaptable regulatory framework and a proactive standardisation strategy remain key to foster innovative activities. In this regard, the EU's focus on regulatory sandboxes and its Standardisation Strategy aims to streamline the integration of research into the market, while ensuring the legislative agility needed to keep pace with rapid technological advances.

In the EU, **the diffusion of knowledge and the uptake of innovation are pivotal to maintaining economic competitiveness and driving sustainable growth**. Effective knowledge valorisation and dissemination ensure that research findings are transformed into practical applications, fuelling innovation across various sectors and enhancing productivity. Moreover, embracing innovation is key to addressing societal issues driving societal progress, thereby fostering an inclusive and forward-looking economy. This process is essential for the EU to respond to global challenges, harness new market opportunities and sustain its position in the global economy.

In this context, **knowledge valorisation is central to transforming R&I findings into practical applications, catalysing economic growth, societal evolution and innovation**. Knowledge valorisation involves transforming data, expertise and research results into viable products, services and solutions, as well as formulating knowledge-based policies that yield social and economic benefits (European Commission, 2022a). By creating linkages across different domains and sectors, knowledge valorisation maximises the impact of R&I results, ensuring that investments from both government and the private sector in research are not only recouped, but also leveraged to generate tangible societal advantages. This approach is key to transforming theoretical knowledge into practical, sustainable innovations that drive progress and address societal needs.

1. The need to boost the take-up of innovation and the diffusion of knowledge

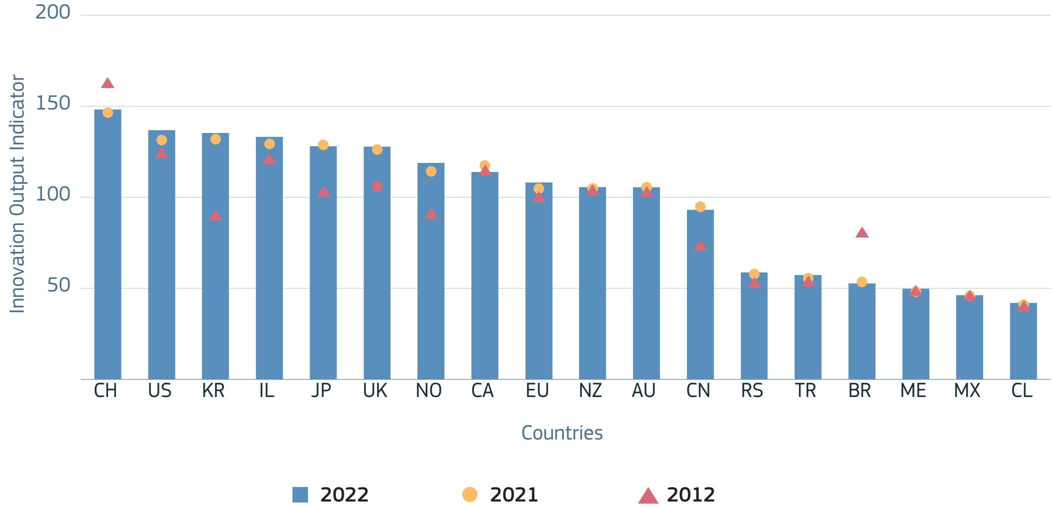
The innovation performance of the EU has consistently increased over the last decade. Since 2016, the European performance as measured by the European Innovation Scoreboard (EIS) has improved by 8.5 percentage points (p.p.), keeping the EU among the top innovation performers worldwide (European Commission, 2023a).[1] A similar positive trend is also confirmed by the Innovation Output Indicator (IOI)[2], which reports the EU's score as increasing from 100 to 115 between 2012 and 2022. This increase places the EU ahead of China[3] (Figure 5.4-1), although still trailing behind the US, South Korea and Japan (Bello et al., 2024). Sweden tops the Member States' IOI ranking, followed by Germany, Finland and Ireland. On the contrary, Romania, Latvia, Poland and Bulgaria show a lower performance (Bello et al., 2024).

1 A decline was observed only in 2020 due to the economic disruptions triggered by the COVID-19 pandemic (for more details, please refer to Chapter 4.1).

2 The Innovation Output Indicator (IOI) is a composite indicator which has been developed by the European Commission since 2013. Its objective is to support policymakers by offering an output-oriented metric of innovation performance at the country and EU levels. The IOI measures countries' capacity to derive economic benefits from innovation by tracking the extent to which innovative ideas reach the market, create knowledge-intensive jobs and increase technological capability.

3 The score of non-EU countries, and in particular China, needs to be interpreted with caution, considering the presence of missing indicators that could lead to an underestimation of the performance.

Figure 5.4-1 The IOI indicator



Source: Bello et al., (2024).
Note: The score is normalised to the EU 27 International score in 2012.

In 2020, more than 50% of active companies in the EU undertook innovation activities.[4] The propensity of EU firms to innovate is higher among large companies. The share of large companies (more than 250 employees) that reported innovation activities was about 79%, against the 60.2% observed for companies of medium size (between 50 to 240 employees) and the 42.5% of companies with less than 50 employees.[5]

However, the technological take-up and socio-economic impact of innovation remains weak. Although an increase has been observed in the degree of technological adoption worldwide (with more people having access to internet, improved access to safe sanitation and a surge in electric vehicle sales), the speed of technological take-up still appears low to promptly address pressing global challenges (WIPO, 2023).

The adoption of digital technologies by EU companies has been increasing in recent years, and the digital divide between the EU and the US is shrinking. In response to the COVID-19 pandemic, over half of EU companies have prioritised investments in digitalisation, reducing the gap with their US counterparts in adopting cutting-edge digital technologies. From the 11 p.p. gap recorded in 2019, the share of EU companies adopting advanced digital technologies rose to 70% in 2023, closely approaching the 73% observed in the US (EIB, 2024).

Nevertheless, successfully managing the digital transition continues to pose several challenges. As an example, in 2021, 61.6% of European enterprises decided against the adoption of AI technologies due to lack of relevant expertise, while 43.7% did not proceed with the

4 Eurostat/CIS Survey 2020 [inn_cis12_inact__custom_8898623].
5 Eurostat/CIS Survey 2020 [inn_cis12_inact__custom_8898623].

purchase of cloud computing services because of insufficient knowledge of this technology.[6]

Knowledge diffusion is essential in facilitating the take-up of innovative results. It contributes to the widespread circulation of new ideas, encouraging the creation of new collaborations and fostering interdisciplinary advancements. Furthermore, it facilitates technology adoption, increasing awareness and understanding of new available technologies. Facilitating the access and sharing of intellectual assets such as patents, know-how and data is pivotal in this respect. According to the Global Innovation Indicator (GII) 2023, any national intellectual property policy should be aligned or even integrated into the national innovation policy (WIPO, 2023).

The share of the EU's high-tech product exports to non-EU countries is stalling. The share of high-tech exports over total trade not only helps measure the technological competitiveness of an economy, but also reflects the ability to commercialise and disseminate the results of R&I products (European Commission, 2022b). Although the value of high-tech product exports in the EU increased by 16 % between 2021 and 2022, (reaching EUR 446 billion), their share over total trade slightly decreased from 17.6 % to 17.3 %.[7]

Knowledge transfer also plays a crucial role in strengthening the presence of innovative companies in an economy. It involves sharing knowledge and expertise across different actors, thereby facilitating the flow of cutting-edge ideas and technologies from research entities to businesses, and fuelling the development of new products, processes and services essential for a competitive and dynamic economic landscape.

In 2019, the link between patent activities and science in the EU was lower than the world average. Non-patent literature (NPL) citations can be used as a proxy for understanding the link between patent activity and scientific research, as they refer to existing scientific and technical knowledge relating to patented inventions. In 2019[8], the average number of EU NPL citations was around 10 % lower than the global average.[9] The same performance was observed in China, while in the US, the link between patent activities and science appears stronger[10] (around 40 % higher than the world average).

6 Technology Adoption Dashboard, Technology adoption dashboard (bruegel.org).

7 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Eurostat data [online data code: ds-018995__custom_9278739].

8 Data refers to the most available information available at the time of writing, considering the limitations linked to the patent granting process and the typical 5-years window available for citations to be edited.

9 DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Fraunhofer data on patent applications filed under EPO.

10 It should be noted that US patent applicants are bound by particular legal mandates, requiring the inclusion of a comprehensive list of citations associated with the patent in their filing request. As such, the better performance of the US must be read considering the potential bias that the US patent filing process may create.

While knowledge transfer aims to ensure the diffusion of information, skills and expertise, knowledge valorisation refers to the process of extracting economic or social value from knowledge. Moving beyond the simple transfer of knowledge, valorisation involves a high degree of co-creation between R&I actors and translating research findings or academic knowledge into industrial applications that produce economic and societal benefits (European Commission, 2022b). In particular, efficient collaboration between industry and academia is a key driver of innovation and of competitiveness for the European industry and economy.

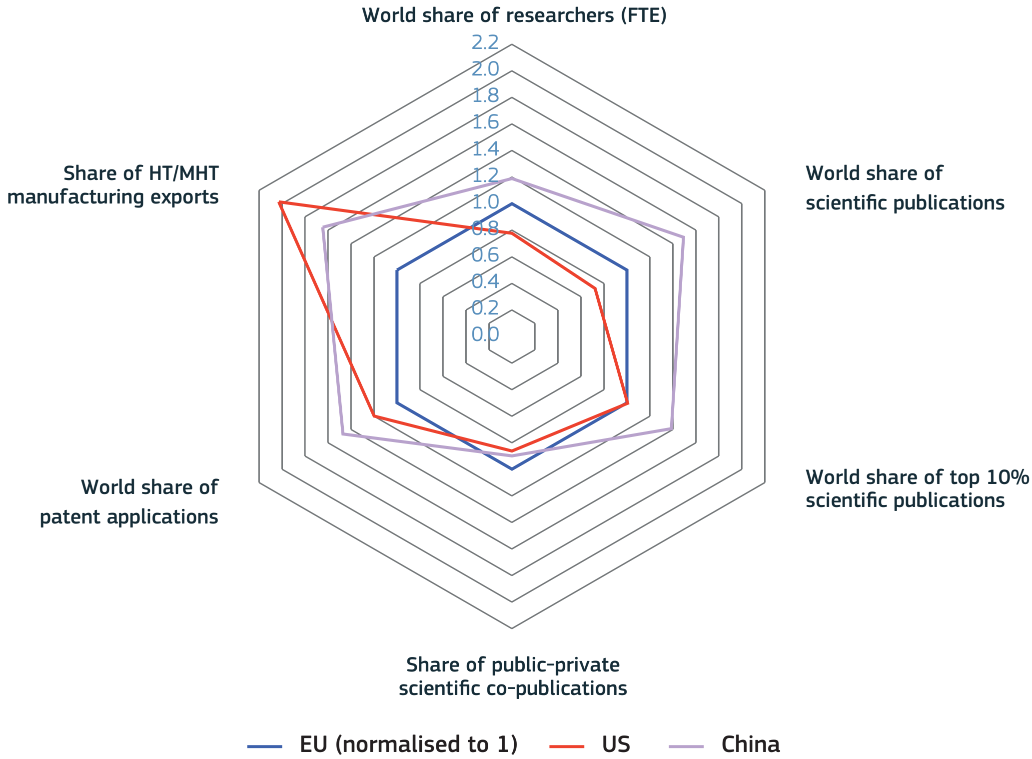
Many elements come into play to measure knowledge valorisation. Capturing the multifaceted and complex nature of knowledge valorisation requires the use of different indicators to ensure a comprehensive assessment of its economic, social and technological impacts. Current indicators, which primarily focus on the transfer and dissemination of knowledge, fall short in capturing the intricate relationship between knowledge creation, diffusion and valorisation. To address this gap, research methods such as social network analyses of university-industry collaborations (Wickramasinghe, 2022) could be leveraged to enable a more precise mapping of these interactions. Nevertheless, despite these data constraints, available evidence still offers important insights into the state of play of knowledge valorisation in Europe.

Despite a demonstrably strong research workforce and ties between academia and the business sectors, the EU continues to lag behind the US and China across several dimensions. As reported in Figure 5.4-2, the two global innovators outperform the EU both in terms of patent applications and share of high-tech exports, for which the gap with China is particularly pronounced. Furthermore, the EU fails to excel in scientific production, especially compared to China, which boasts a substantial advantage in terms of scientific quality (Figure 5.4-2).

Collaborations between public research performing institutions and the business sector are one of the most important channels for both knowledge diffusion and valorisation. It boosts private investments in research, leads to more inventions and to the creation of intellectual assets such as patents, know-how, data and prototypes, and facilitates the flow of knowledge and talent into companies. This synergy not only enhances researcher skills and their understanding of market needs, but also nurtures their entrepreneurial culture. The outcome is a significant improvement in the competitiveness of the European industry and the R&I ecosystem, supporting the development of green, innovative and digital solutions for society (Wickramasinghe, 2022).

The extent to which universities and businesses collaborate on R&D activities varies considerably across Member States. According to the GII 2023, only nine of the EU's Member States ranked among the top 20 countries in terms of university-industry R&D collaborations. Among these, only the Netherlands showed a better performance than China (sixth in the ranking), although remaining below the US (second), while Belgium reported the second highest performance among the EU's Member States, holding the ninth position (WIPO, 2023).

Figure 5.4-2 Knowledge valorisation approach, latest available year



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 Science-Metrix, Eurostat, JRC (INNOVA VI), OECD and UNESCO.

Public Research Organisations (PROs) and Higher Education Institutes (HEIs) also play a crucial role in the diffusion and valorisation of knowledge. PROs act as bridges between academic research and practical applications, facilitating knowledge diffusion between research agents and industry (Vega-Jurado et al., 2021). HEIs hold the potential to enhance the economy's human capital through their educational activities, leading to higher levels of employment and income (Pastor et al., 2018). Furthermore, the research and knowledge transfer initiatives undertaken by HEIs are key to creating scientific and technological advancements, contributing to an increase in technological capital.

Innovative companies in the EU tend to collaborate more with universities than with research entities, showing important differences across Member States. The share of companies collaborating with HEIs and PROs has been stalling or declining in most European countries (Andriescu and Collier, 2023). According to the Community Innovation Survey (CIS), in 2020, only 5.5% and 10.5% of the EU's innovative companies cooperated on R&D and other innovation activities with research organisations and HEIs respectively.[11] Ireland ranks first at the Member State level, with 13.3% of innovative firms collaborating with research entities, followed by Slovenia, Austria, Finland and Belgium.

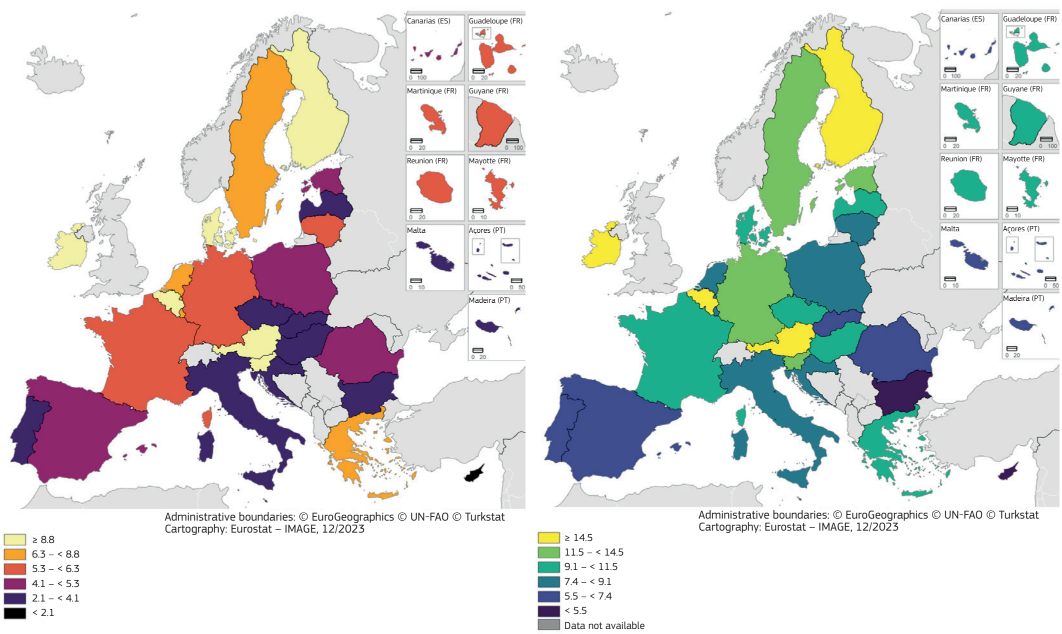
11 Eurostat/CIS Survey 2020 [online data code: inn_cis12_coop].

Conversely, Cyprus, Bulgaria, Slovakia and Malta report the lowest performance, significantly below the EU's average (Figure 5.4-3A). In terms of collaborations with HEIs, Finland, Austria and Ireland show the best performance, with a share of collaborations above 14% (Figure 5.4-3B). By contrast, Bulgaria, Romania and Cyprus significantly underperform as compared to the EU average, with shares between 4 and 5.5%.[12]

Figure 5.4-3 Share (%) of the EU's innovative enterprises collaborating with research institutes and universities and higher education institutes, 2020

A. Research Organisations

B. High Education Institutes



Source: Eurostat/CIS Survey 2020 [online data code: inn_cis12_coop].

12 Eurostat/CIS Survey 2020 [online data code: inn_cis12_coop]

2. From scientific results to concrete solutions for higher EU competitiveness

Enhancing competitiveness calls for the adoption of a robust 'from-lab-to-fab' strategy, which is key to ensuring efficient innovation chains and knowledge spillovers from research to commercialisation. Knowledge diffusion and valorisation are critical for the process of creative destruction, which drives economic development. Innovations, stemming from new knowledge and its applications, disrupt established industries and stimulate the development of new ones. This cycle leads to the continuous renewal of the economic landscape, where old technologies are replaced by new, more efficient ones, thereby fueling economic growth, competitiveness and progress.

Europe has long struggled with the problem of translating scientific results into market-viable solutions. Such a phenomenon is typically referred to as the "European Paradox": the idea that despite the quality and volume of European scientific production being on par with its major global competitors, the EU's capacity to innovate and, thus, its competitive edge remain hampered by difficulties associated with converting this scientific capacity into innovative output (Argyropoulou et al., 2019; Nagar et al., 2023).

Nevertheless, the question of the validity of the European Paradox remains. Significant concerns have been raised regarding Europe's actual scientific power – particularly when compared to that of the US (Rodríguez-Navarro and Narin, 2018) – and the availability of conflicting evidence makes it difficult to confirm the actual strength of the European research output (for more details, please see Chapter 3.1). Less disputed, however, is Europe's lack of entrepreneurial capacity to transform research excellence into innovation, growth, wealth and jobs (Argyropoulou et al., 2019).

The EU's scientific research value is partly realised when it successfully transitions to the market, a crucial step for enhancing welfare and economic gains (European Commission, 2023a). On average, it takes about 20-25 years for scientific findings to reach the market, whereas products available in the market today often incorporate technology that was developed over a decade ago (European Commission, 2022b). These extended timeframes exceed the usual duration of policy cycles, posing significant challenges for policy evaluation and strategic planning (European Commission, 2023b).

However, new technologies and market-based solutions alone may not be sufficient to address societal challenges. Science is expected to drive the creation of solutions to current and future societal challenges, such as climate change, ageing population, biodiversity loss and increasing inequalities. The essence of knowledge valorisation lies in the ability to focus on more traditional technology-based solutions to these issues, along with how technologies and non-technology solutions can be embedded in broader societal systems, thereby triggering a transformative change in current practices. Furthermore, the rapidly evolving geopolitical environment calls for a more strategic approach to R&I activities and, in turn, to knowledge diffusion and valorisation. In this context, it is crucial to foster a strategic approach to the management of intellectual assets such as patents, know-how and data in international collaborations.

Therefore, closing the divide between research, innovation and their market and societal applications poses challenges at both the micro and macro levels. Micro-level challenges centre around individual researchers, start-ups and small businesses, and relate to the journey of transforming ideas into marketable products. Conversely, the macro level involves broader systemic and structural factors, with governments and large institutions shaping policies and creating environments conducive to innovation and commercialisation, as well as societal uptake. The interplay of these micro and macro dynamics is essential to ensure the effective conversion of scientific research into societal and economic advantages (Pinto et al., 2023).

Limited funding resources and potential skill gaps are some of the difficulties experienced by researchers and innovative companies. Access to skilled personnel remains critical to the uptake of innovative output, as exemplified by the higher adoption of advanced digital technologies by companies operating in regions where the population has above-average digital skills (EIB, 2024). At the same time, financial constraints and limited R&D investments represent a critical challenge, as they stifle the creation of new knowledge and the improvement of existing technologies, can reduce opportunities for collaborative networking, and slow down technology transfer, thereby delaying the commercialisation of new technologies and their subsequent diffusion.

Furthermore, the successful development and diffusion of new products and services (especially those addressing grand societal challenges) often require significant changes in societal norms, values and expectations. As such, the effective design of policy interventions needs to take into account practices, norms and embedded values characterising the societal systems adopting novel products, processes and technologies (Warneryd and Karltorp, 2020; Lopolito et al., 2022). An example of this is social innovation. The collaborative, experimental and problem-solving nature of social innovation initiatives has a positive impact on innovation uptake and diffusion. By bringing together diverse perspectives, fostering experimentation and addressing real-world challenges, social innovation initiatives create an environment where knowledge is more readily shared and translated into action, thus potentially contributing to a faster uptake and diffusion of innovative solutions (Purtik and Arenas, 2019).

While grassroots approaches such as social innovation can effectively drive innovation, they may not always be enough to ensure the widespread adoption of technologies that rely heavily on contextual factors, such as clean energy and transportation technologies. These technologies often need to be integrated into existing energy systems (including standards and regulations) and infrastructures, which can be challenging without a more coordinated approach. To better support the diffusion of these technologies, it is important to consider a wide range of factors that co-develop over time, creating positive feedback loops that can accelerate adoption and diffusion (Palm, 2022). These factors include aligning policies, building infrastructure, attracting early adopters and creating value chain modules.[13]

13 Policy alignment involves ensuring that regulations, standards and practices are supportive of new technologies. Infrastructure development involves creating the necessary facilities and networks to support their adoption. Early adopters are individuals or businesses that take on new technologies early on, helping to create a critical mass of demand and demonstrate their feasibility. Value chain module formation involves creating the early building blocks of the industry that support new technologies, such as specialised manufacturing facilities or service providers (Palm, 2022).

Box 5.4-1: Values, Learning and Knowledge in Solar PV Adoption – A Case Study

Bianca Cavicchi

Warneryd and Karltorp (2020) explore the **interplay of values, learning and knowledge acquisition in driving the expansion of the solar photovoltaic (PV) niche, particularly in the context of large building adoption.** The authors delve into the motivations and experiences that have propelled solar PV uptake and diffusion in Sweden.

The study underscores the **central role of values in shaping the niche expansion of solar PV**. Owners of solar PV systems on large buildings are drawn to the technology's alignment with their values, such as sustainability, fair costs and induced innovativeness. These values translate into positive experiences, fostering a desire to assume new roles and contribute further to the niche's growth. Values also contribute to the establishment of a strong social identity within the niche, shaping a positive narrative that attracts new actors and influences policy decisions.

The installation of solar PV plants has increased the engagement of organisations in their local electricity system. This engagement has spread to members and employees, who have learned more about the energy system and the prospects for reduced energy costs and energy self-sufficiency provided by solar PV technology. The process has also led to the development of new business models for the adoption of solar PV, which can contribute to further upscaling.

The positive experiences within the solar PV niche enable knowledge transfer to mainstream energy system stakeholders, attracting them to exploit the benefits of a more decentralised energy system. For instance, energy utilities are shifting their focus to customer value and housing regime stakeholders integrating electricity infrastructure development as a core activity. The study showed that solar PV adoption can lead to knowledge acquisition and transfer, thus fostering a change in routines, values, increased engagement in the energy system, and a greater understanding of the role of solar PV in sustainability transitions.

Therefore, creating an ecosystem conducive to innovation and able to support the translation of research and innovation into societal and market solutions represents a multifaceted challenge, calling for policies able to act on different fronts. Good framework conditions positively affect business investment decisions, ease market access for new and innovative companies, contribute to reallocating resources towards more productive and innovative activities and increase societal trust (European Commission, 2023b). This calls for increased engagement with policy makers to co-create policies that provide the necessary infrastructure to boost innovation development, diffusion and uptake; promote collaborations across different actors; and develop an innovation-friendly regulatory framework.

An innovation ecosystem able to foster a culture of collaboration between academia, industry and government entities is critical to boost knowledge valorisation. Multi-actor approaches in innovation projects allow for the bringing together of diverse perspectives and expertise from businesses, researchers, policymakers and end-users. Such approaches enhance problem-solving capabilities and facilitate the translation of theoretical knowledge into practical solutions through more interactive tools and models of collaboration. Such a multi-actor approach applied to R&I projects was developed in Horizon 2020 and has been implemented in a multitude of calls in Horizon Europe Pillar II (especially in Cluster 6), aiming at ensuring the involvement of all relevant actors and making the R&I process more demand-driven (European Commission, 2023b). Additionally, the Commission Recommendation on the Code of Practice on industry-academia co-creation for knowledge valorisation provides further guidance for R&I actors to improve stakeholder collaboration and co-creation.[14] The creation of enabling environments and the management and valorisation of the outputs of such partnerships are covered by the Code of Practice, which interestingly outlines the importance of intermediaries (e.g., scientific associations) in fostering and developing co-creation between industry and academia.[15] In parallel, this has inspired stakeholders to create dedicated practices for specific actors, such as small and medium-sized enterprises (SMEs).[16] The Code of Practice on intellectual assets management[17] and on standardisation[18] for knowledge valorisation also provide relevant guidance to support the valorisation of results arising from industry-academia joint-activities.

Furthermore, developing this collaborative culture calls for a deeper reflection on how different stakeholders – especially the public – interact. On the one hand, the multi-actor approach could be further deepened, focusing more on the performance of different actors and their ability to function in a network (Wickramasinghe, 2022). On the other hand, the concept of co-creation suggests engaging diverse actors throughout innovation processes. However, questions remain regarding the effects on public engagement. Although co-creation offers new participation opportunities, it also tends to favour economic benefits over social justice (Ruess et al., 2023). This approach often conflates the roles of

14 Commission Recommendation (EU) 2024/774 of 1 March 2024 on a Code of Practice on industry-academia co-creation for knowledge valorisation C/2024/601 OJ L, 2024/774, 5.3.2024, ELI: http://data.europa.eu/eli/reco/2024/774/oj

15 *Ibid*.

16 For example, the SIXLabs Playbook supporting knowledge valorisation process of SMEs by Puurtinen, Hanna-Greta; Pohjola, Petri (2023) https://urn.fi/URN:NBN:fi-fe20231004138761

17 Commission Recommendation (EU) 2023/499 of 1 March 2023 on a Code of Practice on the management of intellectual assets for knowledge valorisation in the European Research Area, OJ L 69, 07.03.2023

18 Commission Recommendation (EU) 2023/498 of 1 March 2023 on a Code of Practice on standardisation in the European Research Area, OJ 69, 07/03/2023

citizens, consumers and users, blurring the line between self-motivated opportunity and fair democratic participation (Ruess et al., 2023). Therefore, deepening the understanding of how the government and public interact is crucial to ensure that policy development remains both inclusive and reflective of diverse societal needs, ultimately leading to more effective and equitable outcomes. The Code of Practice on citizen engagement for knowledge valorisation[19] outlines the key role of citizens in this regard, where "knowledge valorisation" is expected to "benefit society". It addresses the issue through a comprehensive approach integrating organisational frameworks, skill enhancement and cross-sectoral collaboration, while prioritising social inclusion, diversity and gender equality as central pillars of the enrichment of knowledge. The Code of Practice also contains recommendations for the management of these actions, both to support the scalability of citizen projects, and to sustain their efforts in the long term.[20]

An efficient regulatory framework[21] also plays a pivotal role in knowledge valorisation by creating an environment conducive to innovation and attracting investments. Effective regulations are key to ensuring the protection of intellectual property rights and fundamental for innovators and researchers to feel confident in investing time and resources into developing new ideas. At the same time, a strong regulatory framework helps build trust among key stakeholders (e.g., investors, entrepreneurs and consumers) by ensuring that new products and services meet quality and safety standards. This trust is essential for the successful commercialisation and widespread adoption of innovations. Moreover, effective regulation is instrumental in facilitating collaborations across different sectors and countries, which are crucial for the exchange and application of knowledge.

Nevertheless, providing an adequate environment that maximises the appropriation of science is particularly challenging. Various obstacles hinder the effectiveness of the EU's regulatory framework as catalysts for innovation. These include the absence of flexible regulatory tools that can proactively adapt to the speed of innovation, the prolonged duration of legislative procedures, the potential for market fragmentation due to inconsistent treatment of the same innovation across different Member States, and challenges in the national-level implementation of EU regulations (European Commission, 2023b).

In this regard, experimental approaches represent an important tool in the design and implementation of efficient R&I policies. In a fast-changing world, policymakers need to be able to adapt quickly to new challenges and opportunities. Experimental approaches are used to evaluate novel solutions or different business models within a controlled real-life setting prior to their market introduction. As such, policy experimentation allows policymakers to test new policies on a smaller scale and within a controlled environment before widespread implementation, thereby helping to identify and mitigate potential risks and unintended consequences.

19 Commission Recommendation (EU) 2024/736 of 1 March 2024 on a Code of Practice on citizen engagement for knowledge valorisation C/2024/600 OJ L, 2024/736, 5.3.2024, ELI: http://data.europa.eu/eli/reco/2024/736/oj

20 *Ibid.*

21 E.g., well-designed laws, regulations, and guidelines that effectively support and promote innovation while ensuring safety, quality, and fairness in the market. Specific principles include comprehensiveness, proportionality, coherence, stakeholder participation, basis in evidence, transparency and learning from experience, as outlined by the Better Regulation Guidelines https://commission.europa.eu/document/download/d0bbd77f-bee5-4ee5-b5c4-6110c7605476_en?filename=swd2021_305_en.pdf

Central to experimentation approaches are regulatory sandboxes and experimentation clauses. Current regulatory sandboxes[22] in the EU are designed for innovations expected to benefit both consumers and society. They grant regulators a certain level of flexibility, enabling them to uphold regulatory norms while adapting to new developments. Additionally, regulatory sandboxes are instrumental in fostering an environment of learning, keeping pace with sector-specific advancements, and reinforcing connections among regulators across diverse policy fields. They find legal support in experimentation clauses, which enable authorities responsible for applying and enforcing legislation to exhibit a degree of pliancy when dealing with innovative technologies, products or methodologies, even when they do not fully align with existing legal requirements (European Commission, 2023b).

The efficient management of intellectual assets is essential to derive more value from knowledge. The Code of practice on the management of intellectual assets for knowledge valorisation[23] helps stakeholders to successfully approach the various steps of intellectual assets management and address the challenges linked to the adequate control and sufficient leverage of intellectual assets. It promotes a strategic approach to intellectual assets management where both economic interests and societal benefits are taken into account.

Standardisation is also important to the creation of a well-functioning and resilient innovation ecosystem. Developing new standards, coupled with the EU's increased participation in international standardisation bodies, is essential to the success of Europe's digital and green transition, and to boosting the competitiveness and resilience of European industry (European Commission, 2023b).

European standardisation needs to adapt to rapid innovation, delivering timely yet high-quality standards. These standards not only facilitate knowledge sharing among various stakeholders, but also bridge the research-market gap, increasing the market uptake of technological innovations. Additionally, standardised methods for evaluating technology impacts throughout their lifecycle are crucial for promoting innovation across industries, benefiting both policymakers and businesses (European Commission, 2023b).

22 Regulatory sandboxes are defined as concrete frameworks which, by providing a structured context for experimentation, enable where appropriate in a real-world environment the testing of innovative technologies, products, services or approaches, for a limited time and in a limited part of a sector or area under regulatory supervision ensuring that appropriate safeguards are in place, Regulatory sandboxes and experimentation clauses as tools for better regulation: Council adopts conclusions - Consilium (europa.eu)

23 Commission Recommendation (EU) 2023/499 of 1 March 2023 on a Code of Practice on the management of intellectual assets for knowledge valorisation in the European Research Area, OJ L 69, 07.03.2023

Standardisation also plays a crucial role in research and R&I investment agendas, facilitating the widespread deployment of new and strategic technologies. The EU Standardisation Strategy[24] highlights the untapped potential of EU-funded, pre-normative research in shaping future standardisation trends, allowing new technologies to create opportunities for industries.

In this regard, the role of Horizon Europe remains key, as it entails the anticipation of standardisation needs and strong linkages between strategic priorities and pre-normative research[25] (see Box 2 for more details on the initiatives around standardisation policy in the EU).

Box 5.4-2: Standardisation

Gergely Tardos

Since 2022, the Commission has proposed **a handful of initiatives to support the valorisation of research results through standardisation and to find answers on what is the effective strategy to bring R&I results closer-to-market**. Standardisation is a key policy instrument to help valorise research results across the European Single Market and internationally. Driving stronger and more systematic integration of R&I and standardisation to deliver greater social, economic and environmental impact from R&I activities is one of the main pillars of the European Standardisation Strategy[26].

The strategic role of standards is underlined by the **Council Recommendation on the guiding principles for knowledge valorisation[27], where measures and policy initiatives were adopted for improving knowledge valorisation in the Union by broadening the scope of actors and focusing on the entire R&I ecosystem**. The guiding principles respond to the needs of knowledge valorisation actors and provide a common reference to improve knowledge valorisation in the EU.

26 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0031
27 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022H2415&qid=1670573108748

24 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on An EU Strategy on Standardisation: Setting global standards in support of a resilient, green and digital EU single market https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0031

25 Pre-normative research (PNR) is research necessary to establish norms and standards in the deployment of a new technology. It is necessary to cover the knowledge gaps, to define adequate uses and safety levels, ensure level playing fields for both incumbents and newcomers, especially in the development and market uptake of new technologies. Research undertaken during the standardisation process is named co-normative research, which often follows up on further research needs determined after the pre-normative phase. https://www.biobasedeconomy.eu/research-knowledge/

Their implementation is supported by the **Code of Practice on Standardisation**[28] **which promotes standardisation as a powerful and currently under-utilised knowledge valorisation tool**. The Code of Practice contributes to the successful synchronisation and systematic integration of R&I and standardisation, raises awareness among researchers and innovators, and facilitates a consistent approach to standardisation activities. Its recommendations guide beneficiaries of public R&I funds on how best to valorise project results through standardisation. Further, the Code of Practice lays a particular emphasis on the involvement of Standard Development Organisations in R&I projects, needs assessment, synchronisation of different timelines of R&I projects and standardisation processes, stakeholder management, and liaising intellectual assets management and standardisation needs of R&I projects.

The Code of Practice was developed on the basis of a scoping study that singled out 40 Horizon 2020 projects as best practice cases renowned for valorising their results by means of standardisation. Almost all areas of Horizon 2020 are represented by the best practice cases, including ICT, transport, security, health, construction and circular economy (Radauer et al., 2022).

With the aim to support researchers and innovators participating in Horizon projects, **HS Booster**[29] **connects projects with standardisation bodies and provides hands-on guidance to help projects valorise their results through standardisation**. It has two main objectives: firstly, to develop an engaged community of European standardisation experts and increase the participation of research performers. Secondly, service design and delivery for projects, including a Standards Training Academy.

A European Standardisation Panel Survey was launched in October 2023 with the objective to identify industry's demand for standards as results of R&I projects. Survey results support the assessment of **how Horizon programmes tackle the standardisation needs of industry and raise awareness of the importance of the standardisation potential of R&I projects, which is indispensable for market uptake**. The analysis of the 3700 responses to the survey highlights how industry urges a stronger link of standardisation and R&I through the efforts of all innovation ecosystem players. One of the survey findings is that while there is untapped potential to bring innovation into the standards-development process, company standardisation and innovation/strategy departments are very often not coordinated.

28 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023H0498&qid=1678171117168
29 https://www.hsbooster.eu/

3. Horizon Europe as a central player for a better take-up of innovative results

Thanks to its pan-European approach, the scale of its support and its strong networks with all R&I players, the EU Framework Programme for R&I plays a unique role in supporting the development of the EU's R&I system. The Framework Programme covers a wide spectrum of measures and programmes intended to boost the uptake of R&I results by encouraging academia-industry collaboration, enhancing knowledge valorisation and supporting the commercialisation of innovative technologies. It also inherits and builds upon the success of its predecessor, the Horizon 2020 programme, which had a marked impact on the EU economy (European Commission, 2024).

Several policy instruments and initiatives under Horizon Europe aim to bring together organisations from business, higher education and research sectors. As an example, the European Institute of Innovation and Technology (EIT) has created Europe's largest innovation ecosystem, with over 3 000 partners. It focuses on supporting entrepreneurial education, developing innovative projects, business creation and acceleration, as well as on creating new innovative solutions to address global challenges in areas of climate change, digitisation, sustainable energy, raw materials, manufacturing, food production, healthy living, urban mobility, and culture and creativity (European Commission, 2023b). Other initiatives intended to promote industry-academia collaborations include supporting individual researchers in their research endeavours; promoting innovative training, exchanges and mobility; and encouraging the development of joint research programmes.[30] **The European missions of Horizon Europe are also set to play a key role in fostering innovation throughout the EU**, aiming to connect all relevant actors through new forms of partnerships for co-design and co-creation (European Commission, 2023b).

Horizon Europe also offers specific tools to maximise the impact of research projects and foster collaborations between research actors and users. The Horizon Results Booster provides tailor-made support to both closed and ongoing projects, thus enhancing their societal and economic impact. The Horizon Results Platform serves as a dissemination tool for project beneficiaries, helping to improve the connection with potential partners for commercialisation. Additionally, the Competence Centre on Technology Transfer at the European Commission offers expertise in technology transfer, including capacity building and innovation ecosystems.

The European Research Council (ERC) is the premier European funding organisation for excellent frontier research. Established in 2007, the ERC aims to encourage the highest quality research in Europe and to support investigator-driven frontier research across all fields based on scientific excellence.[31]

30 Respectively: the Marie Skłodowska-Curie Actions, the Innovative Training Networks (ITN), the Research and Innovation Staff Exchange (RISE), and Individual Fellowships

31 https://erc.europa.eu/about-erc/erc-glance

It plays a pivotal role in fostering innovations as it is particularly suitable for generating knowledge spillover and thus driving subsequent inventive activities. Recent evidence further suggests that ERC science holds the same innovative potential as non-ERC funded European research of comparable quality, and that publications originating from ERC projects are more likely to inspire inventions with significant technological and commercial potential (Nagar et al., 2023).

Nevertheless, despite the robust spillover effect generated by ERC science on inventive activities, Europe keeps grappling with the challenge of fully capitalising on the benefits derived from this spillover. The inventive capacity inspired by ERC science appears to be primarily concentrated in entities located in the US, confirming its capacity for assimilating and exploiting high-level scientific research for innovation (Nagar et al., 2023). In terms of the European Paradox, this evidence seems to confirm the European ability to produce research of excellent quality, but calls for increasing efforts to strengthen the European innovation ecosystem and invest in the absorptive capacity necessary to leverage local scientific excellence (Nagar et al., 2023).

In this regard, the European Innovation Council (EIC) is instrumental in identifying and fast-tracking the commercialisation of breakthrough technologies. It was designed to bridge two critical funding gaps that innovative companies face in their growth journey: the transition phase from laboratory to market, and the scale-up phase for high-risk innovations (European Commission, 2023b).

In doing so, the EIC supports the most talented and visionary European researchers and entrepreneurs, adopting a bottom-up approach that enables the proposal of revolutionary ideas across diverse scientific and technological domains, potentially impacting multiple sectors and applications (EIC, 2022).[32]

Lastly, the Framework programme also provides tools for boosting the diffusion and uptake of its results by interacting with complementary policy areas. In this regard, it contributes to the production of evidence-based policy by feeding the lessons learned from its projects and methodological insights into the EU's policy. As an example, specialised tools, such as the Feedback to Policy mechanism, support the European Commission in its commitment to create more effective policymaking (as part of the Better Regulation agenda[33]). This also includes the evaluation of existing policy frameworks and the consideration of diverse viewpoints and foresights, as seen in initiatives like the Horizon Europe Foresight Network. Furthermore, it promotes innovative policy development through experimental approaches and pioneering formats, including mission-based policies.

32 For more details on the EIC, please refer to Chapter 5.3.
33 Better regulation - European Commission (europa.eu).

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