CHAPTER 2

ZOOM OUT, ZOOM IN – THE GEOGRAPHY OF R&I

CHAPTER

2.1

ZOOM OUT – TECHNOLOGY AND GLOBAL LEADERSHIP

KEY FIGURES

1/5
of worldwide R&I output comes from the EU

9 %
of worldwide patents in semiconductors come from the EU

28 %
of worldwide patents in low-carbon technologies come from the EU

KEY QUESTIONS WE ARE ADDRESSING

- What is the overall position of the EU in the world in terms of R&I?
- What are the technological strengths and weaknesses of the EU on the global stage?
- Is the technological sovereignty of the EU at risk?

KEY MESSAGES

What did we learn?

- The changing geopolitical context increased uncertainties linked to the global and security outlook, calling for a reduction of industrial dependencies in strategic sectors through economic restructuring.
- The EU accounts for about one-fifth of worldwide R&I activities, with less than 7 % of the world's population.
- Major EU trading partners have improved their innovation performance at a faster pace in recent years.
- While the EU shows strengths in technological areas related to advanced manufacturing and advanced materials, its technological sovereignty is at risk in fields, including AI, big data, cloud computing, cybersecurity, robotics and micro-electronics.
- The EU is the international leader in clean energy innovation.

What does it mean for policy?

- Changes in the EU energy system induced by the Green Deal and accelerated by the Russian invasion of Ukraine are expected to have important geopolitical implications.
- Reducing strategic dependencies in key technological areas and value chains is necessary to strengthen the resilience of the EU.
- Increased efforts to commercialise research results will help the EU strengthen its technological leadership
- A reinvigorated multilateral approach would help the EU reinforce its open strategic autonomy, strengthening its role as a leading actor to foster international cooperation.

On the global stage, the EU is a key actor when it comes to R&I activities. It accounts for about one-fifth of worldwide R&I activities, with less than 7% of the world's population. The EU is an open research and innovation area that welcomes research organisations worldwide, and collaborates extensively with international partners on joint programmes. Europe is at the forefront of scientific advances. The EU leads in the fields of low-carbon technologies and renewable energies, and holds a strong position in industrial sectors such as pharmaceuticals, chemicals and mechanical engineering. At the same time, there is a need to reduce strategic dependencies on our main international partners. In its Communication of February 2020 Shaping Europe's digital future, the European Commission renewed its commitment to the creation of a stronger digital Europe, able to withstand the competitive pressure from its international partners, while protecting EU values and fundamental rights.

The need to strengthen European leadership in key technological domains has become more urgent with the outbreak of the COVID-19 pandemic. The acceleration of digitalisation and the significant supply chain disruptions caused by the COVID-19 pandemic have intensified the political discourse on EU technological and data sovereignty. To preserve and strengthen the EU's technological leadership, efforts are needed to increase R&D expenditure critical to the development of innovative solutions, improve access to materials along strategic value chains, and create a more efficient regulatory framework to develop and deploy advanced technologies (Csernatoni, 2021). Analysing the patterns of technological specialisation at global level is essential to identify critical emerging technological areas, assess the EU's global competitive position, and understand how to steer EU policy action accordingly (Confraria et al., 2021).

Furthermore, **the changing geopolitical context has increased uncertainties linked to the global and security outlook**. The Commission's recent Communication *Towards a green, digital and resilient economy: our European Growth Model* reinforces the commitment to strengthen the EU's long-term sustainable growth agenda, by leveraging international EU partnerships. The deterioration of Ukraine-Russia relationship, which culminated in the invasion of Ukraine, revealed important vulnerabilities, confirming the need to further accelerate EU economic transformation (European Commission, 2022d). The unprovoked Russian invasion of Ukraine is expected to affect global geopolitical relations, requiring **a reduction of industrial dependencies in strategic sectors through economic restructuring**, which will likely affect innovation. At the same time, the war will negatively impact the vibrant tech ecosystem in Ukraine, accelerate reshoring trends and worsen the global chips shortage (Ravet et al., 2022).

1. The position of the EU in the world: overview

The EU shows both strengths and weaknesses in terms of scientific performance (Table 2.1-1). In terms of overall scientific performance (total share of scientific publications and co-publications), the EU shows a strong position compared with the US, Japan and South Korea (see also Chapter 6.1 – Scientific performance). Nevertheless, the EU lags behind the US and China in terms of overall scientific excellence (i.e. share of 10% most cited publications), and other R&I indicators, including investments in intangibles (see Chapter 5.1 - Introduction: tangible and intangibles assets) and patent activities in several fields (e.g., the ICT sector, where it falls considerably behind all its main international competitors) (see also Chapter 6.3 - Innovation output, societal and market uptake and knowledge valorisation).

The EU performs well in fields related to health and environment. The EU leads in terms of the share of scientific publications in the health sector and, although behind the US in terms of patent applications related to health, it remains well above both Japan and China. Furthermore, the EU is strong in areas related to the green transition, outperforming both the US and China in terms of patent applications.

Major EU trading partners have improved their innovation performance at a faster pace in recent years. Despite its strengths, the EU risks falling behind in areas where it is exposed to global competition. The risk is particularly high considering the faster rate at which the EU's main competitors have been evolving. It is therefore important **to keep strengthening the EU's capacity to develop and implement advanced technologies, to stay competitive and avoid future strategic dependencies** (see section 2).

The EU lags behind the US and other competing international economies in terms of private sector R&D expenditure (EIB, 2021). The share of BERD in total R&D expenditure is around 67% in the EU, well below that of the US (73%), and China, Japan and South Korea, whose shares range between 78% and 80% (EIB, 2021; Confraria et al., 2021). The EU also underperforms in terms of number of firms investing in R&D. The EU share of top 2500 R&D investors has decreased over time, mostly due to the rise of Chinese tech companies (Grassano et al., 2021). Although the US keeps its position as leading innovator, the number of Chinese firms allocating resources to R&D has increased significantly. Between 2006 and 2018, Chinese R&D investors in the top 2500 increased from 0.5% to 20%, overtaking the EU (See Chapter 5.2 – Investment in R&D). Over the past decade, the EU's top R&D spenders have maintained a stable sectoral composition, with a heavy reliance on the automotive sector, while the US and China have specialised further in ICT sectors (EC R&D scoreboard 2021).

Table 2.1-1: Overall global position of EU in R&I

	Indicators	Last available year	EU	Trend	United States	Trend	China	Trend	Japan	Trend	South Korea	Trend
General Indicators	GDP per capita, PPP (constant 2017 international $)	2020[1]	41504	↗	60236	↗	16411	↗↗	41380	↗	42251	↗↗
	Share of population aged 65+ (%)	2020	20.6	↗↗	16.6	↗↗	12.0	↗↗	28.4	↗↗	15.8	↗↗
	Gini coefficient of equivalised disposable income	2019[2]	0.31	→	0.39	→	0.51	n/a	0.33	n/a	0.35	↘
	CO_2 emissions (metric tons per capita)	2018	6.4	↘	15.2	↘	7.4	↗	8.7	→	12.2	↗
R&D Invesment	R&D investment as % of GDP	2019	2.20	↗	3.07	↗	2.23	↗↗	3.24	→	4.64	↗↗
	Business spending on R&D as % GDP	2019	1.46	↗	2.27	↗↗	1.71	↗↗	2.57	↗	3.73	↗↗
	Public spending on R&D as % of GDP	2019	0.73	→	0.66	↘	0.53	↗	0.63	↘	0.85	↗
Human Resources	Researchers employed per million population	2019	4157	↗↗	4414	↗	1340	↗↗	5360	↗	7913	↗↗
	Population aged 25-34 with tertiary education (%)	2019[3]	40.5	↗↗	50.4	↗	14.0	↗↗	61.5	↗	69.8	↗
Scientific Performance	Scientific publications (world share %)	2020	19.6	↘	15.6	↘↘	22.4	↗↗	3.3	↘↘	2.4	→
	Scientific excellence (% of publications within 10% most cited) (*)	2018	9.9	→	13.3	↘	11.1	↗↗	5.8	↘	7.8	→
	International scientific co-publications /million population	2020	783	↗↗	759	↗↗	126	↗↗	335	↗↗	549	↗↗
	Share of public-private co-publications (%)	2020	9.1	↗	8.4	↘	7.7	↗↗	10.7	→	7.9	↘
Innovation Performance	PCT patent applications (world share %)	2018	19.4	↘↘	22.0	↘↘	20.9	↗↗	18.3	→	6.5	↗
	PCT patent applications /million population	2018	106.4	↗	165.1	↗↗	36.7	↗↗	353.9	↗↗	308.7	↗↗
	European Innovation Scoreboard (index)	2021[4]	113	↗	120	↗↗	84	↗↗	114	↗↗	136	↗↗
	Number of unicorns	Jul 2021	60	n/a	392	n/a	157	n/a	6	n/a	11	n/a
	Number of companies in Top 100 of the R&D Industrial Scoreboard	2020	26	n/a	35	n/a	10	n/a	15	n/a	4	n/a
Export Capacity	Share of High-Tech and Medium High-Tech Exports (%)	2021[4]	57.1	↗	53.7	↗	58.1	↗	73.6	→	72.3	↗
	Share of Knowledge-Intensive Services Exports (%)	2021[4]	67.3	↗	70.8	→	65.9	→	69.3	↘	58.6	→
ICT Sector	Scientific publications (world share %)	2020	17.8	↘↘	10.3	↘↘	25.9	↘↘	2.7	↘↘	2.3	↘
	Scientific excellence (% of publications within 10% most cited) (*)	2018	9.7	↘	12.1	↘↘	11.6	↗↗	4.9	↗↗	8.1	↘
	PCT patent applications /million population	2017	17.9	↗	51.1	↗↗	17.4	↗↗	80.0	→	101.4	↗↗
	PCT patent applications (world share %)	2017	11.0	↘↘	22.9	↘↘	33.2	↗↗	14.0	↘↘	7.2	↘
	Business R&D intensity in ICT sector (%)	2019[5]	5.6	→	10.1	→	6.0	↗↗	7.6	↘	21.4	↗↗
Climate & Environment Sector	Scientific publications (world share %)	2020	19.8	↘↘	10.7	↘↘	25.1	↗↗	1.8	↘↘	2.1	↗
	Scientific excellence (% of publications within 10% most cited) (*)	2018	13.5	→	15.2	↘↘	15.7	↗↗	7.8	↘	11.0	↘
	PCT patent applications /million population	2018	0.98	→	1.22	→	0.24	↗↗	1.91	↗↗	2.77	↗↗
	PCT patent applications (world share %)	2018	22.5	↘↘	20.5	↘↘	16.9	↗↗	12.4	↘	7.3	↗
Health Sector	Scientific publications (world share %)	2020	21.0	↘	20.8	↘↘	16.6	↗↗	3.9	↘↘	2.5	↗
	Scientific excellence (% of publications within 10% most cited) (*)	2018	9.9	↗	13.6	↘	10.8	↗↗	5.9	→	8.0	↗
	PCT patent applications /million population	2018	4.7	↗↗	13.1	↗↗	0.9	↗↗	15.0	↗↗	13.8	↗↗
	PCT patent applications (world share %)	2018	17.4	↘↘	35.4	↘↘	10.3	↗↗	15.7	↗↗	5.9	↗↗

Best — Worst

→	Annual growth between -0.5% and 0.5% (inclusive)
↗ or ↘	Annual growth between 0.5% and 2% or between -0.5% and -2% (inclusive)
↗↗ or ↘↘	Annual growth above 2% or below -2%

Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Unit Common R&I Strategy & Foresight Service – Chief Economist Unit based on Eurostat, OECD, World Bank, DG R&I, DG JRC, Science-Metrix based on Scopus database and PATSTAT, EIS 2021.

Notes: [1] JP figure corresponds to 2019. [2]US figure corresponds to 2017 and CAGR 2013-2017. CN figure corresponds to 2011. JP figure corresponds to 2018. KR figure corresponds to 2018 and CAGR 2015-2018. [3]EU figure corresponds to 2020. CN figure corresponds to 2018 and CAGR: 2011-2018. [4])CAGR: 2014-2021. [5]JP figure corresponds to 2018 and CN to 2017 [6]Trend is defined by calculating the average annual growth (CAGR) between 2010 and the latest available year. (*)Definition: ratio between the number of scientific publications of the country among the top 10 % most cited worldwide by the total number of scientific publications of the country.

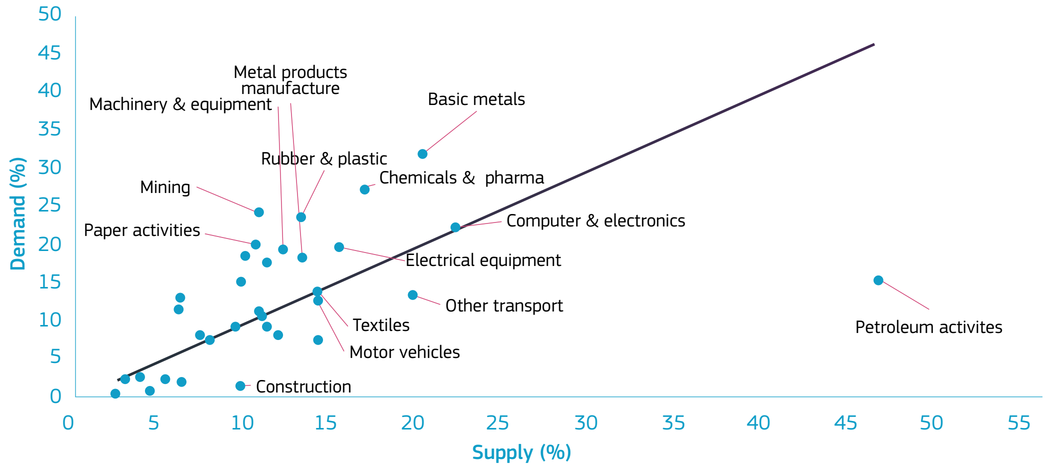
2. Industrial leadership and dependencies

The EU wants to strengthen its technological sovereignty. Technological sovereignty can refer to 'a state's or a supranational union's ambition to shape and direct (parts of) the global technological system' (Edler et al., 2021). Achieving technological sovereignty hinges on the ability to provide the necessary technologies without creating one-sided dependencies, thereby ensuring future economic wellbeing (Edler et al., 2021). The pace at which the technological performance of the EU's main competitors is evolving calls for increasing efforts to boost EU companies' ability to compete globally. The disruptions produced by the COVID-19 pandemic and recent geopolitical tensions have fuelled the debate on reducing strategic dependencies and achieving technological sovereignty.

EU industry plays an important role in realising the EU's global ambitions, safeguarding essential elements of EU strategic value chains (European Commission, 2020c). Production processes and supply chains have become increasingly interlinked in the last decades. The progressive integration of global value chains (GVCs) created huge economic benefits, and challenges. If, on the one hand, GVCs have improved companies' market position by increasing production diversification and reducing costs (OECD, 2020), they also made companies more vulnerable to external demand and supply shocks (European Commission, 2021a). The digital revolution has been accompanied by a gradual increase in market concentration and imbalances in revenue distribution. Already before the outbreak of the coronavirus, some vulnerabilities associated with GVCs became apparent. The increased integration of GVCs yielded important efficiency gains, but failed to prepare the global economy for unforeseen disturbances. It also prevented incorporation of sustainable practices crucial for long-term economic resilience (European Commission, 2021d). The COVID-19 crisis has exacerbated these aspects and reinforced the debate about the trade-off between the costs and benefits of international specialisation in GVCs, which are vulnerable to rapid and widespread global transmission of demand and supply shocks (OECD, 2021).

Reducing strategic dependencies in key technological areas and value chains is necessary to strengthening EU resilience in the post-COVID-19 scenario. Computers and electronics, chemicals and pharmaceuticals, basic metals and electrical equipment are the sectors in which the EU shows the highest foreign dependencies, both in terms of supply and demand (Figure 2.1-1). The EU is a net recipient of foreign direct investment (FDI), representing an important channel of growth for the European economy. FDI helps the EU enhance its competitiveness, create new jobs and open new markets for exporters (European Commission, 2020b). However, the disruptions to GVCs during the COVID-19 pandemic have increased the risks of strategic industries being acquired by foreign investors. This is particularly relevant (but not limited) to the health industry and acquire strategic industrial segments (such as those related to the production of medical equipment and/or research establishments) (European Commission, 2020a). This calls for action intended to screen FDI targeting EU countries. In March 2020, the European Commission published its Communication Coordinated economic response to the COVID-19 Outbreak, in which it calls for increased vigilance regarding FDI by all Member States.

Figure 2.1-1: **Downstream and upstream exposure of EU industry to extra EU markets**



Science, Research and Innovation Performance of the EU 2022

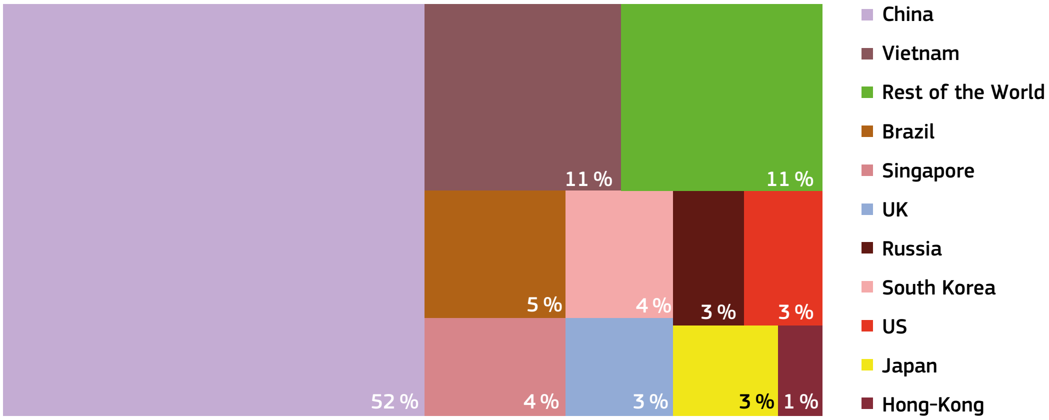
Source: European Commission SWD on Strategic Dependencies and Capacities, based on OECD 2016-AMNE data.
Note: The horizontal axis measures the share of value added for each EU sector that depends on intermediate inputs generated by extra-EU supply chains. The vertical axis measures the share of final demand absorbed by exports to extra-EU countries, for each EU sector.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-1.xlsx

The EU is heavily dependent on trading partners in non-EU countries for several strategic products[1]. These include **raw/processed materials (e.g. semiconductors) and chemicals, health and medical products** (such as active pharmaceutical ingredients (APIs), and **renewable energy production, green mobility and digital/electronics** (European Commission, 2021a). China accounts for more than half of the EU's strategic imports related to almost all types of products (Figure 2.1-2).

Vietnam follows with 11 %, exporting to the EU strategic chemicals such as red phosphorus (critical for the production of semiconductors), and tungstates (mostly used in high-temperature industrial applications) (European Commission, 2022c).

1 Dependencies are identified using data on external trade flows for more than 5,000 products. Overall, The EU results to be highly dependent on third countries for 137 products (accounting for about 6% of the extra-EU import value of goods) (European Commission, 2021a).

Figure 2.1-2: Share of EU imports value for identified dependent product[(1)] (critical materials) by country of origin



Science, Research and Innovation Performance of the EU 2022

Source: European Commission (2021a) based on BACI database.

Note: [(1)]Data on more than 5 000 products across all industrial ecosystems.

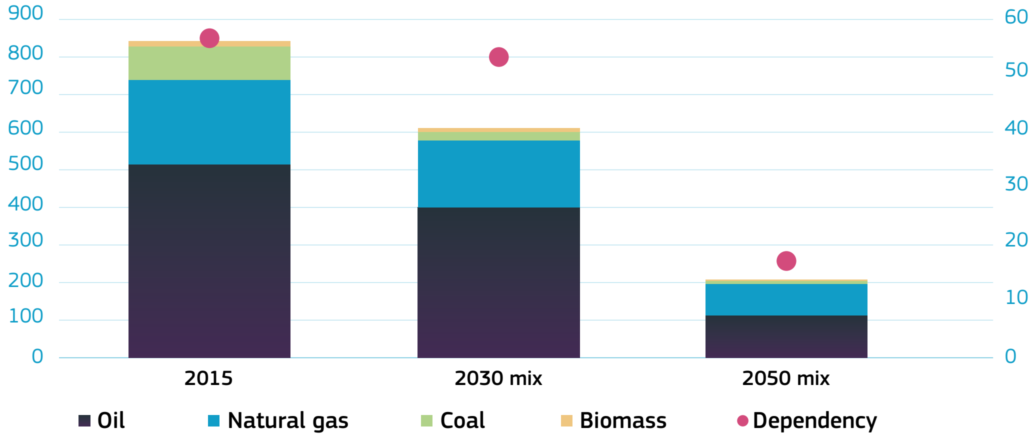
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-2.xlsx

Furthermore, implementation of the European Green Deal will produce significant changes in the EU's energy system and energy dependencies. Currently, about three-quarters of the EU energy system relies on fossil fuels (Leonard et al., 2021). In 2020, oil accounted for the largest share of gross available energy[2] in the EU, followed by natural gas with 23.7 % (Eurostat, 2022). Coal represented about 10 % of the energy mix, and has been on a decreasing trend since 2015. The importance of renewable energy (including biofuels) is increasing, although it still accounts for only about 17.4 % (Eurostat, 2020).

The successful implementation of the Green Deal will mark a radical change in the EU's energy mix by 2050. From 2030, a considerable reduction in the use of oil, gas and coal is expected, with consequent effects on EU energy imports. Projections for the period 2015-2030 estimate a reduction of between 71 % and 77 % in EU coal imports (Leonard et al., 2021). Similarly, EU imports of oil and natural gas are expected to drop by 23 %-25 % and 13 %-19 % respectively over the same time horizon. This reduction is expected to significantly accelerate in the post-2030 period, towards the 2050 net-zero objective (Figure 2.1-3).

2 Gross available energy represents the quantity of energy necessary to satisfy the energy needs of a country or a region (Eurostat, 2022).

Figure 2.1-3: Evolution of EU energy imports (55% lower emissions in 2030 compared with 1990 and climate neutrality in 2050)



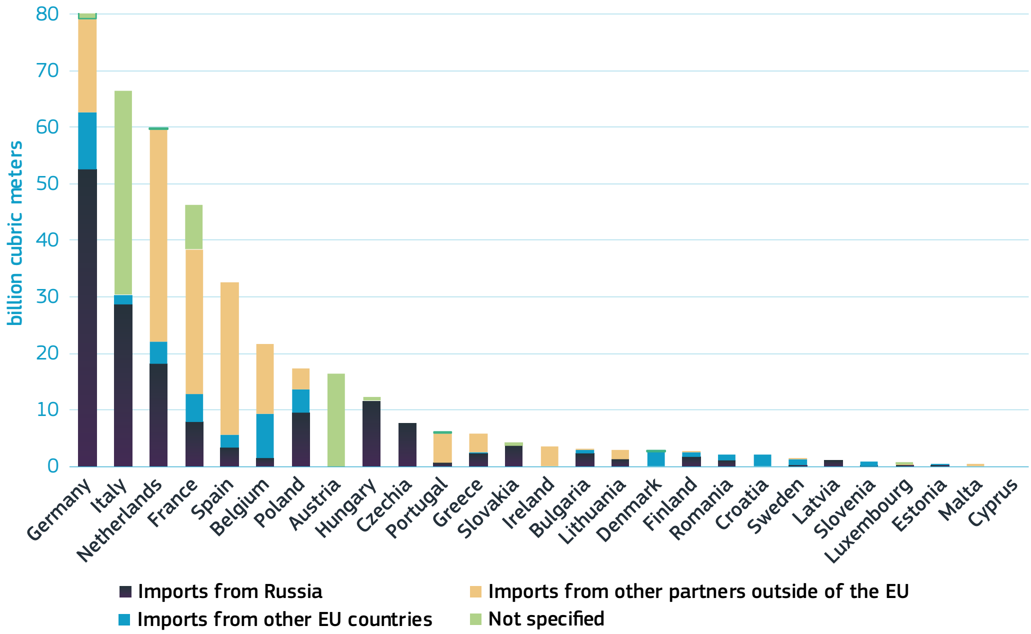
Science, Research and Innovation Performance of the EU 2022

Source: Leonard et al. (2021).
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-3.xlsx

Changes in the EU energy system induced by the Green Deal are expected to have important geopolitical implications. As the need for oil and gas decreases, EU imports from oil- and gas-producing countries in the EU neighbourhood will also decline (Leonard et al., 2021). This will change EU energy resource trade relationships. Notably, the implementation of the European Green Deal is likely to result in a considerable increase in trade of green electricity and green hydrogen, potentially increasing the importance of North Africa and Middle Eastern countries that benefit from extensive access to solar and wind energy (Leonard et al., 2021).

The achievement of the 2050 climate targets poses important challenges for EU energy security, especially in light of the increasing geopolitical tensions in Europe. The EU imports 92% of the natural gas it consumes. The total 155 bcm imported from Russia accounted for around 45% of the EU's gas imports in 2021 and almost 40% of its total gas consumption (IEA, 2022). In 2020, Germany and Italy imported most of their natural gas from Russia. France and the Netherlands rely less on Russia. Other countries rely almost fully on Russia for their natural gas imports, such as Hungary, Slovakia and Latvia. Portugal and Spain have low dependency while Ireland and Malta have almost no dependency on Russian gas (Figure 2.1-4).

Figure 2.1-4: Total natural gas imports and imports from Russia per country, 2020



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Unit Common R&I Strategy & Foresight Service – Chief Economist Unit based on Eurostat [online code: NRG_TI_GAS__custom_2309441].

Note: The labels on the graph are the share of natural gas imported from Russia over the total natural gas imported (= percentage of dependency to Russian gas).

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-4.xlsx

Cutting imports from Russia would have a negative impact on the European economy, although the effects would differ across Member States. The need to reduce EU dependency on Russian gas risks forcing European countries to resort to fossil fuels to meet their energy needs, even if other options are possible[3]. This would mean a significant setback for the EU's climate goals, putting into question the successful implementation of the EU decarbonisation process (Ravet et al., 2022).

In this regard, the EU's green transition will strongly rely on the deployment of new and advanced green technologies and on imports of the minerals and critical materials underpinning them.

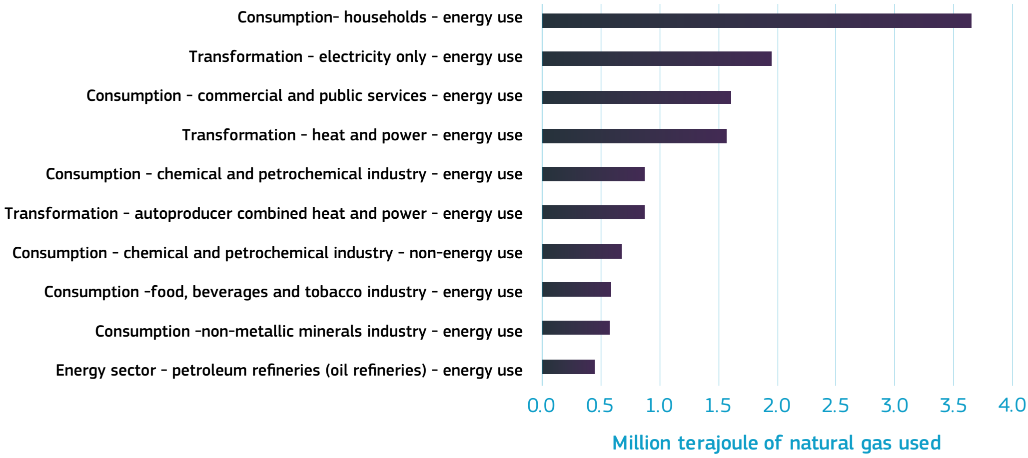
R&I investments and efforts should be strengthened to accelerate the development and deployment of energy efficient and clean energy technologies, thereby securing both EU independence and competitiveness.

3 For example, the IEA has proposed a 10-point plan for the EU to reduce reliance on Russian gas: https://www.iea.org/reports/a-10-point-plan-to-reduce-the-european-unions-reliance-on-russian-natural-gas

Some sectors rely specifically on natural gas, such as energy consumption in buildings and infrastructures (Figure 2.1-5). In these and other sectors, it is critical to foster R&I to ensure more independence. Furthermore, with RePowerEU, the Commission recently proposed an outline of a plan to make Europe independent of Russian fossil fuels well before 2030, starting with gas.

The Communication *Safeguarding food security and reinforcing the resilience of food systems* illustrates the need to address global food security in light of dependencies, with Russia and Ukraine being responsible for 30% of world wheat exports (European commission, 2022f).

Figure 2.1-5: Top 10 sectors in the EU for transformation and consumption of natural gas, 2020



Science, Research and Innovation Performance of the EU 2022

Source: Eurostat [online code: NRG_CB_GAS__custom_2310132].
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-5.xlsx

3. Technological leadership and vulnerabilities in the context of the green and digital transition

The EU must strengthen its position in technological fields critical to the achievement of EU policy objectives. Six key enabling technologies (KETs) have been identified as essential to boost EU growth and preserve EU leadership: advanced manufacturing, advanced (nano) materials, life-science technologies, micro- and nano-electronics, photonics, AI, and security and connectivity technologies (European Parliament, 2021). The EU ranks

Table 2.1-2: EU global position by Key Enabling Technologies (KETs)

KET	Indicator	Last Available Year	EU	Trend	United States	Trend	China	Trend	Japan	Trend
Advanced Manufacturing	Total Publications (world share %)	2020	24.0	↗↗	11.6	↗↗	25.5	↗↗	2.4	↙
	Top 10% Cited Publications (world share)	2018	22.2	↗↗	18.2	↗↗	25.0	↗↗	1.7	↗↗
	PCT Patent Applications (world share %)	2018	17.8	↗	25.0	↗↗	14.9	↗↗	23.7	↗↗
Advanced Materials	Total Publications (world share %)	2020	15.0	↗↗	8.8	↗↗	34.6	↗↗	3.1	↙
	Top 10% Cited Publications (world share)	2018	12.5	↗↗	12.7	↗	41.8	↗↗	1.9	↙
	PCT Patent Applications (world share %)	2018	18.1	↗	17.2	↗↗	12.3	↗↗	36.1	↗↗
Industrial Biotechnology	Total Publications (world share %)	2020	22.1	↗↗	11.2	↗	20.8	↗↗	2.2	↗
	Top 10% Cited Publications (world share)	2018	14.3	↗	13.4	↙	39.4	↗↗	2.0	↙↙
	PCT Patent Applications (world share %)	2018	18.4	↙	36.9	↗↗	12.5	↗↗	12.2	↗↗
Micro- and Nano-electornic	Total Publications (world share %)	2020	12.9	↙↙	8.7	↙↙	33.9	↙↙	3.0	↙↙
	Top 10% Cited Publications (world share)	2018	24.2	↗↗	15.9	↙↙	22.5	↗↗	1.9	↗↗
	PCT Patent Applications (world share %)	2018	9.8	→	16.3	↙	29.2	↗↗	28.6	↗
Nanotechnolgy	Total Publications (world share %)	2020	14.0	↗↗	9.3	→	34.8	↗↗	3.2	↙
	Top 10% Cited Publications (world share)	2018	13.5	↗	16.5	↙	37.9	↗↗	2.4	↙↙
	PCT Patent Applications (world share %)	2018	17.2	↙↙	32.2	↙↙	16.5	↗↗	13.3	↙↙
Photonics	Total Publications (world share %)	2020	15.5	↗	10.7	↙	33.1	↗↗	3.9	↙
	Top 10% Cited Publications (world share)	2018	11.8	↗	12.2	↙	43.1	↗↗	1.7	↙↙
	PCT Patent Applications (world share %)	2018	15.3	→	19.8	↗	22.2	↗↗	25.5	↗↗

Best — Worst

→	Annual growth between -0.5% and 0.5% (inclusive)
↗ or ↘	Annual growth between 0.5% and 2% or between -0.5% and -2% (inclusive)
↗↗ or ↘↘	Annual growth above 2% or below -2%

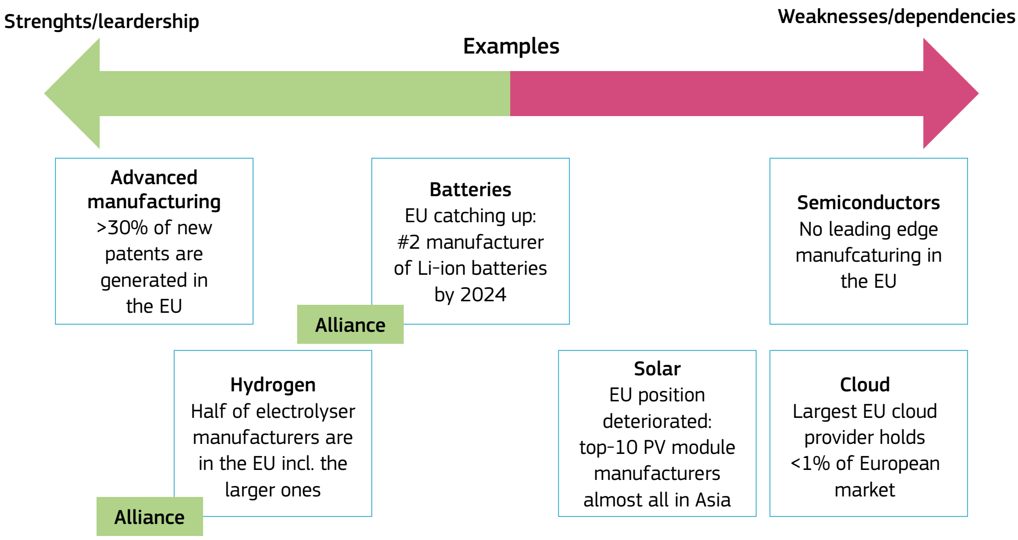
Source: DG Research and Innovation - Unit Common R&I Strategy & Foresight Service – Chief Economist Unit based on Science-Metrix using data from Scopus and PATSTAT database.
Notes: Trend is defined by calculating the average annual growth rate (CAGR) between 2010 and the latest available year.

second after the US in patent applications in the fields of advanced materials, industrial biotechnologies and nanotechnologies. However, the EU is significantly behind Japan, the US and China in micro- and nano-electronics and photonics, where its share of patent applications is 9.8% and 15.3% respectively (Table 2.1-2).

While the EU shows strong performance in advanced manufacturing and advanced materials (either in terms of publications or patent applications), **its technological sovereignty is at risk in other fields, including AI, big data, cloud computing, cybersecurity, robotics and micro-electronics** (European Commission, 2021a). Contributing to this low performance is the **scarce availability of high-quality data** at EU level, and **a lack of digital skills**, both representing important resources for the development and deployment of advanced technologies, in particular AI technologies (European Parliament, 2021). The EU also remains significantly **dependent on foreign suppliers** in micro- and nano-electronics, photonics, and life-science technologies, which exposes it to geopolitical challenges (European Parliament, 2021).

Nevertheless, the EU has tools at its disposal to build capacity. **Industrial alliances, Important Projects of Common European Interest (IPCEIs) and EU funding programmes, notably Horizon Europe, play an instrumental role in supporting EU capacity-building**. Initiatives such as the European Battery Alliance and the European Clean Hydrogen Alliance strengthen the EU's global position in

Figure 2.1-6: EU strategic capacity: strong in some technologies, highly dependent in others



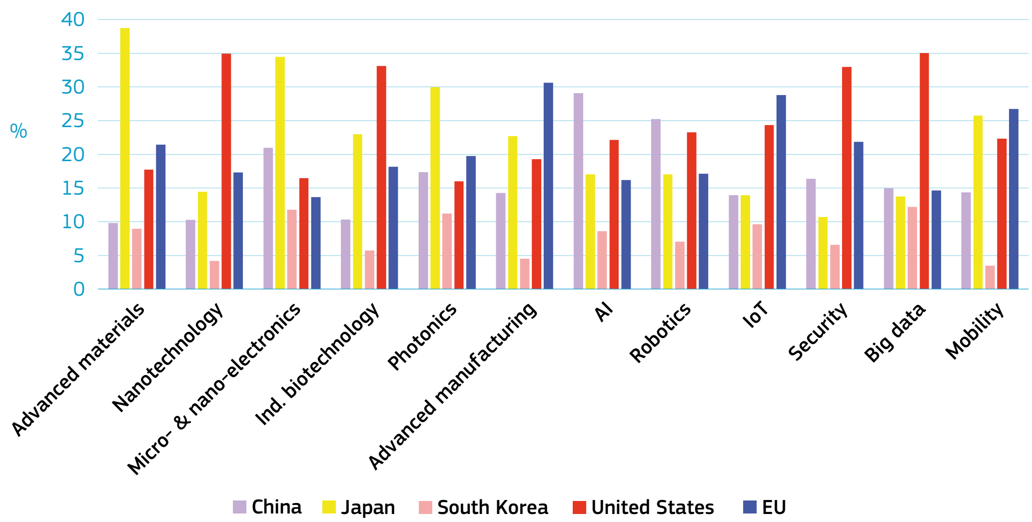
Source: European Commission, DG Internal Market, Industry, Entrepreneurship and SMEs.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-6.xlsx

these fields, and mitigate foreign dependencies (Figure 2.1-6). Similarly, Horizon Europe will play a key role in boosting project pipelines in strategic areas, through the implementation of several European partnerships, for instance the Batteries Partnership. IPCEIs also represent an important tool to promote research and innovation activities. Ongoing IPCEIs on batteries and semiconductors are delivering results, and new IPCEIs on cloud computing, hydrogen and a second one on semiconductors are under discussion.

Security and connectivity technologies are critical to EU technological leadership. With the acceleration in digitalisation and the COVID-19 crisis, increasing the resilience and security of connectivity infrastructures has become a pressing issue. The EU is increasing its efforts to build a cybersecure digital economy, building a solid legislative framework to safely process and store digital data and to reduce the risks of human rights violations associated with the development of sensitive cyber surveillance technologies (Csernatoni, 2021) (See Chapter 7.2 – Other framework conditions). Furthermore, the geopolitical tensions resulting from Ukraine's invasion make it even more urgent to further develop strategic capacities in areas such as defence and cyber (European Commission, 2022d). In March 2022, the Commission published a Communication on the European growth model, acknowledging the necessity for European countries to increase their investments in the defence and space industries (including cyber defence) to strengthen EU industrial resilience, critical to fulfilling EU policy objectives.

For Europe to remain an economic power at global level, ensuring leadership in 'green' and 'digital' solutions is essential. While in some areas, such as advanced manufacturing and green technologies, the EU performs well, more efforts are needed to maintain and further build a strong global position in digital technologies. The EU falls significantly behind the US and

Figure 2.1-7: Share of global patent applications in digital/manufacturing technologies, 2018



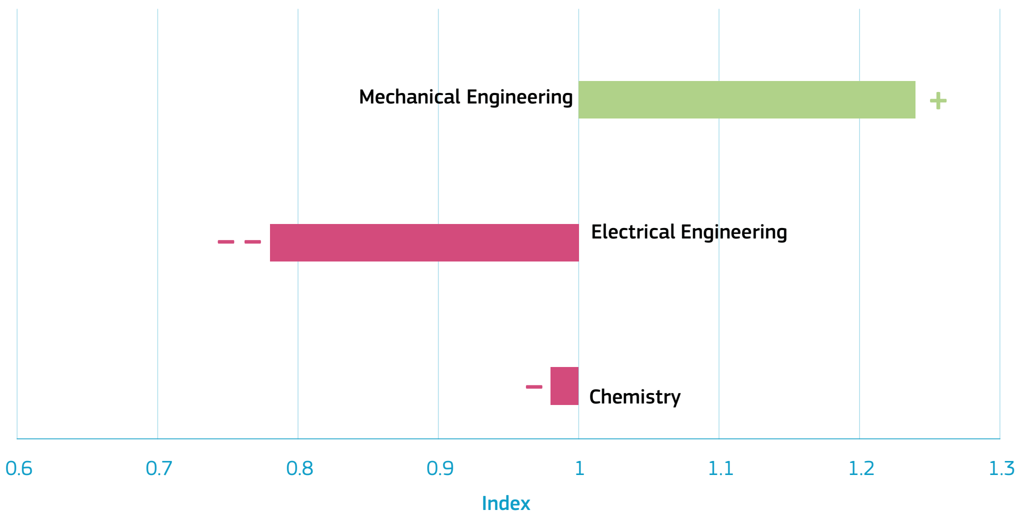
Source: ATI Project.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-7.xlsx

struggles to keep up with China in many digital technologies, such as nanotechnologies, AI and big data (Figure 2.1-7). Current levels of funding will likely be inadequate for the EU to match or overtake the US and China in such key sectors, calling for increasing resources to strengthen the European research and innovation capacities.

The EU is highly specialised in the field of mechanical engineering. In 2018, the EU reported a specialisation index[4] well above 1 in the field of mechanical engineering (Figure 2.1-8). As reported in Table 2.1-3 the EU ranks first in patent applications in almost all related sub-fields, with a share of patent applications ranging between 29% and 34.5%. The only sub-fields in which the EU does not rank first are those related to textile and paper machines, and thermal processes where Japan is first with a share of patent applications of 25.5% and 29.3%, respectively.

In contrast, the EU reports a lower degree of specialisation in the fields of chemistry and electrical engineering. In the chemistry sector, the EU reports a specialisation index close to 1, and a strong relative performance in terms of patent applications. Ranking second in most of the chemistry sub-fields, the EU leads in chemistry engineering, environmental technology, and food chemistry with a share of patent applications of 26%, 23.6% and 24.2%, respectively (Table 2.1-3). Electrical engineering

Figure 2.1-8: EU Specialisation Index in patent applications, by technological field, 2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Unit Common R&I Strategy & Foresight Service – Chief Economist Unit based on Science-Metrix using data from PATSTAT database.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-8.xlsx

4 The specialisation index here is defined as a country's share of EPO patents in a particular technology field over the country's share in all patent fields, relative to the world share. An index of 0 indicates that the country does not hold any patent in a given sector. An index equal to 1 indicates no specialisation, i.e. the country's share in the sector equals its share in all fields. A value greater than 1 signals a positive specialisation.

is the technological field in which the EU has the lowest specialisation index (less than 0.8). When compared with other economies, the EU underperforms in all the relevant sub-fields, positioning itself well below China and the US, especially in the areas related to digitalisation, such as audio-visual technology, telecommunications, computer technology, and digital communication (Table 2.1-3). For digital communication technologies, the gap with China is particularly striking (40.3% of patent applications against 14.3%).

The EU has some strengths in the field of semi-conductors, but remains weak in

Table 2.1-3: PCT patent applications (world share %) in 2018, by technological field

	Technological Field	Indicator	Last Available Year	EU	Trend	United States	Trend	China	Trend	Japan	Trend	South Korea	Trend
Chemistry	Basic materials chemistry	PCT Patent Applications (world share %)	2018	20.6	↙	24.0	↙	9.7	↗↗	23.3	↗↗	5.8	↗↗
Chemistry	Biotechnology	PCT Patent Applications (world share %)	2018	19.0	↙	35.2	↗	13.9	↗↗	13.0	↗↗	6.1	↗↗
Chemistry	Chemical engineering	PCT Patent Applications (world share %)	2018	26.0	↗	23.2	↗	13.4	↗↗	14.3	↗↗	6.5	↙↙
Chemistry	Environmental technology	PCT Patent Applications (world share %)	2018	23.6	↙	19.0	↙	19.0	↗↗	14.5	↙	7.6	↗↗
Chemistry	Food chemistry	PCT Patent Applications (world share %)	2018	24.2	↙	17.3	↙↙	9.7	↗↗	18.5	↗	11.6	↗↗
Chemistry	Macromolecular chemistry, polymers	PCT Patent Applications (world share %)	2018	21.9	↗	18.2	↗	10.9	↗↗	33.1	↗↗	8.1	↗↗
Chemistry	Materials, metallurgy	PCT Patent Applications (world share %)	2018	22.0	↗	14.9	↗	13.0	↗↗	29.7	↗↗	9.4	↗↗
Chemistry	Micro-structural and nano-technology	PCT Patent Applications (world share %)	2018	21.2	↗	30.8	↙	13.5	↗↗	15.6	↗↗	4.0	↙↙
Chemistry	Organic fine chemistry	PCT Patent Applications (world share %)	2018	21.8	↙↙	28.7	↙	15.1	↗↗	12.7	↙	5.3	↗↗
Chemistry	Pharmaceuticals	PCT Patent Applications (world share %)	2018	17.5	↙	39.8	↗↗	8.8	↗↗	8.6	↗	8.2	↗↗
Chemistry	Surface technology, coating	PCT Patent Applications (world share %)	2018	20.1	↗↗	16.9	→	11.9	↗↗	33.2	↗↗	7.8	↗↗
Electrical Engineering	Analysis of biological materials	PCT Patent Applications (world share %)	2018	26.9	↗↗	20.2	↙	25.0	↗↗	3.9	↗↗	8.4	↗↗
Electrical Engineering	Audio-visual technology	PCT Patent Applications (world share %)	2018	10.1	↙	11.8	↗	40.1	↗↗	22.2	↗↗	5.8	↗↗
Electrical Engineering	Basic communication processes	PCT Patent Applications (world share %)	2018	17.8	↗	24.2	↗	18.7	↗↗	24.2	↗↗	4.0	↗↗
Electrical Engineering	Computer technology	PCT Patent Applications (world share %)	2018	9.6	→	30.3	↗↗	31.7	↗↗	12.1	↗	5.6	↗↗
Electrical Engineering	Control	PCT Patent Applications (world share %)	2018	17.2	↗↗	19.3	↗↗	24.9	↗↗	23.9	↗↗	3.4	↗↗
Electrical Engineering	Digital communication	PCT Patent Applications (world share %)	2018	14.3	↗	24.4	↗↗	40.3	↗↗	5.3	↗↗	6.6	↗↗
Electrical Engineering	Electrical machinery, apparatus, energy	PCT Patent Applications (world share %)	2018	20.6	↗↗	12.9	↗	18.5	↗↗	28.2	↗↗	8.9	↗↗
Electrical Engineering	IT methods for management	PCT Patent Applications (world share %)	2018	7.3	↗↗	27.0	↗↗	29.0	↗↗	13.3	↗↗	8.5	↗↗
Electrical Engineering	Measurement	PCT Patent Applications (world share %)	2018	23.2	↗	22.6	↗↗	14.9	↗↗	20.2	↗↗	4.9	↙↙
Electrical Engineering	Medical technology	PCT Patent Applications (world share %)	2018	17.8	↗	35.6	↗↗	10.2	↗↗	14.8	↗↗	5.7	↗↗
Electrical Engineering	Optics	PCT Patent Applications (world share %)	2018	12.8	↗↗	17.4	↗↗	26.6	↗↗	27.7	↗↗	6.5	↗↗
Electrical Engineering	Semiconductors	PCT Patent Applications (world share %)	2018	9.4	↙↙	18.8	↙	27.8	↗↗	27.7	→	8.6	↗↗
Electrical Engineering	Telecommunications	PCT Patent Applications (world share %)	2018	13.7	↙	21.9	↗	31.3	↗↗	14.0	↗	9.2	↙↙
Mechanical Engineering	Engines, pumps, turbines	PCT Patent Applications (world share %)	2018	32.4	↙	15.5	→	11.0	↗↗	23.4	↗↗	3.6	↗↗
Mechanical Engineering	Handling	PCT Patent Applications (world share %)	2018	29.1	↗	17.4	↗	13.6	↗↗	20.0	↗↗	4.8	↙↙
Mechanical Engineering	Machine tools	PCT Patent Applications (world share %)	2018	30.7	↗	14.1	↗	15.6	↗↗	23.4	↗↗	4.6	↗↗
Mechanical Engineering	Mechanical elements	PCT Patent Applications (world share %)	2018	34.5	↗	14.8	↗	11.7	↗↗	23.8	↗↗	3.4	↗↗
Mechanical Engineering	Other special machines	PCT Patent Applications (world share %)	2018	30.5	↗↗	21.6	↗↗	9.6	↗↗	17.7	↗↗	4.9	↗↗
Mechanical Engineering	Textile and paper machines	PCT Patent Applications (world share %)	2018	24.5	→	21.2	↗↗	13.2	↗↗	25.5	↗↗	4.3	↗↗
Mechanical Engineering	Thermal processes and apparatus	PCT Patent Applications (world share %)	2018	23.9	↙	13.5	↙	14.9	↗↗	29.3	↗↗	5.5	↗↗
Mechanical Engineering	Transport	PCT Patent Applications (world share %)	2018	34.4	↗↗	12.8	↗↗	13.9	↗↗	24.0	↗↗	3.6	↙↙

Best | | | | Worst

→	Annual growth between -0.5% and 0.5% (inclusive)
↗ or ↘	Annual growth between 0.5% and 2% or between -0.5% and -2% (inclusive)
↗↗ or ↘↘	Annual growth above 2% or below -2%

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

Notes: Trend is defined by calculating the average annual growth rate (CAGR) between 2010 and the latest available year.

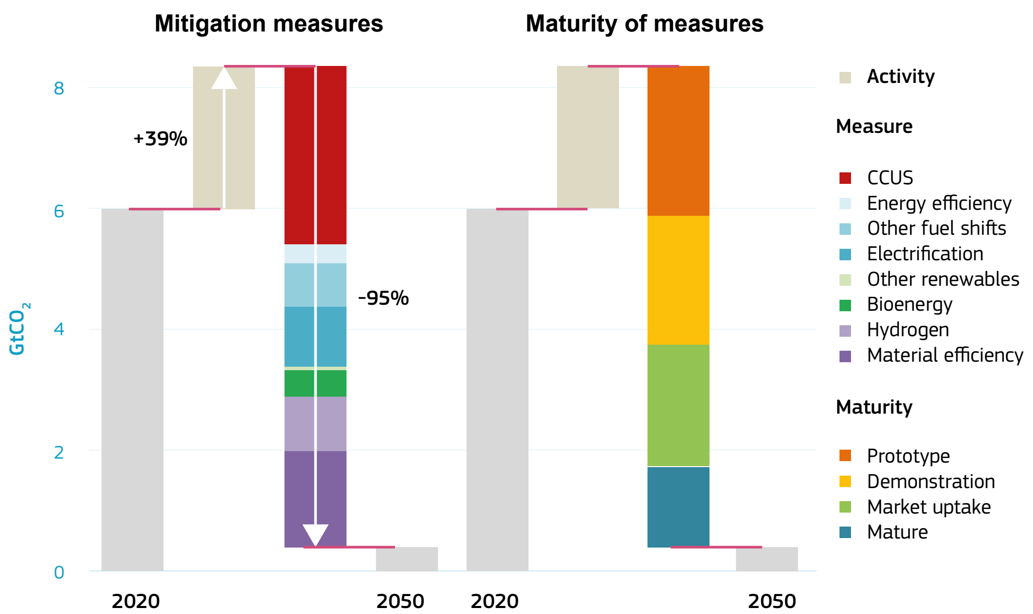
terms of total patent applications, with a share of 9.4% against 27.8% and 18.8% for China and the US, respectively (Table 2.1-3). The EU is strong in R&D in the field of semi-conductors, hosting world-leading research and technology organisations (RTOs) pioneering the production techniques of advanced chips (European Commission, 2022b). The EU is also specialised in the design of specific chips for power electronics and in industrial segments related to equipment manufacturing and raw materials, crucial for the production of advanced chips. Nevertheless, the EU accounts for only 10% of the global revenue share of semi-conductor chips (European Commission, 2022b).

Global demand for semi-conductor chips is expected to double by 2030 as a result of the acceleration in the digital transition. Given the key role played by semi-conductor chips in the production of digitalised products, they represent a strategic area in the race towards technological sovereignty (European Commission, 2022b). In its Communication of February 2022, the European Commission proposed the **European Chips Act**, to create a resilient and competitive EU semi-conductor ecosystem, reducing excessive dependencies and strengthening the EU's capacity to react to future supply chain disruptions (European Commission, 2022b). In this regard, **the Russia-Ukraine conflict is expected to accelerate the reduction of industrial dependencies in strategic sectors through economic restructuring**. Potential closer alignment between China and Russia will profoundly modify the exchange of energy, raw materials, industrial parts and goods between the West, China, and Russia (Simchi-Levi and Haren, 2022). EU industries, including semi-conductors, automotives, and medical equipment, will need to **reorganise and re-diversify their supply chains**, while fostering local supply chain strategies. In this direction, both the US Chips Act and the European Chips Act are examples of government efforts to reduce dependence on Asia in strategic technological sectors.

Such a shift in the focus of global trade policy, from mutual economic benefits of open trade policies to geopolitical considerations limiting interdependence, will likely have implications for innovation and economic growth. As an example, Góes & Bekkers (2022) estimate that a hypothetical decoupling of the global trading system into a US- and a China-centric bloc, would reduce total welfare in 2040 (compared to a baseline without decoupling) by about 5% worldwide, around 4% in the West and 10% in the East. Low-income regions would be the most affected, as they benefit most from the positive technology spillovers of trade. By cutting ties with richer and innovative markets, less productive countries are likely to shift their supply chains towards lower-quality inputs, which, in turn, induce less innovation. In contrast, richer western countries, even if they were to suffer welfare losses, would see their innovation path less affected (Ravet et al., 2022).

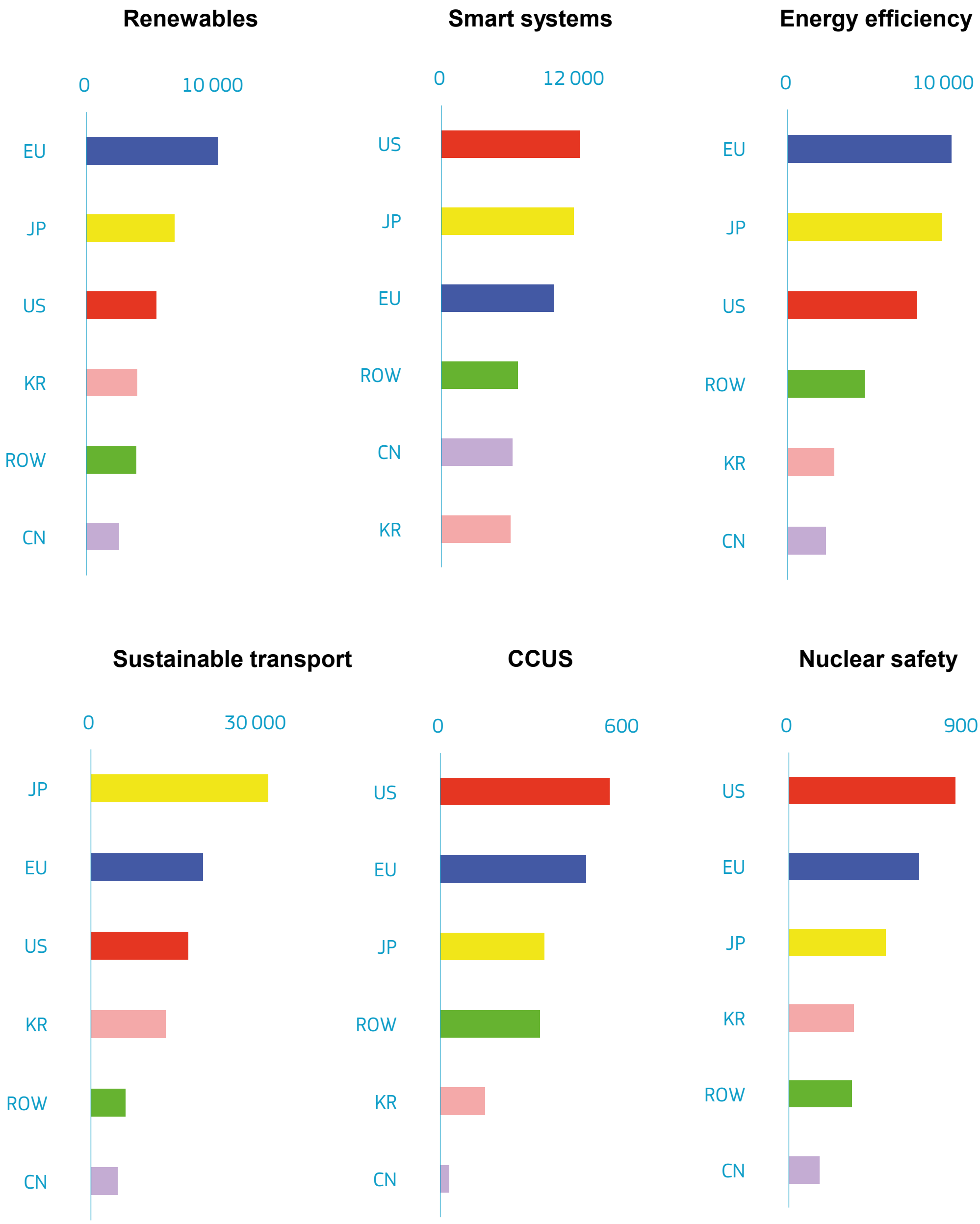
An acceleration in clean energy innovation is necessary to meet the EU net-zero emission target. The net-zero emissions by 2050 scenario (NZE), presented by the IEA (2021), investigates the actions needed for the global energy sector to achieve net-zero CO_2 emissions by 2050. The successful decarbonisation of the global energy system over the next decades hinges on the use of different technologies (mostly related to energy efficiency, electrification, renewables, hydrogen and hydrogen-based fuels, bioenergy, and carbon capture, utilisation and storage (CCUS)), and the ability to make market behaviours more sustainable (IEA, 2021). The industrial sector represents the second-largest source of CO_2 emissions globally. In 2020, industrial CO_2 production amounted to around 8.4 Gt (Figure 2.1-9). Meeting the net-zero target by 2050 would require a 95 % reduction of global CO_2 emissions from heavy industry, relying on the implementation of technologies currently under development (Figure 2.1-9) (IEA, 2021). As such, **ensuring that innovative clean energy technology will reach maturity in the next decade is among the main challenges in the EU's race towards climate neutralit**y (European Commission, 2022a).

Figure 2.1-9: **Global CO_2 emissions in heavy industry and reductions by technological options (mitigation measures) and technology maturity level, in the net-zero emissions scenario of the IEA**



Source: IEA, Net zero by 2050 (2021).
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-9.xlsx

Figure 2.1-10: EU positioning in high-value patents in the energy union R&I priorities (total over 2005-2018)

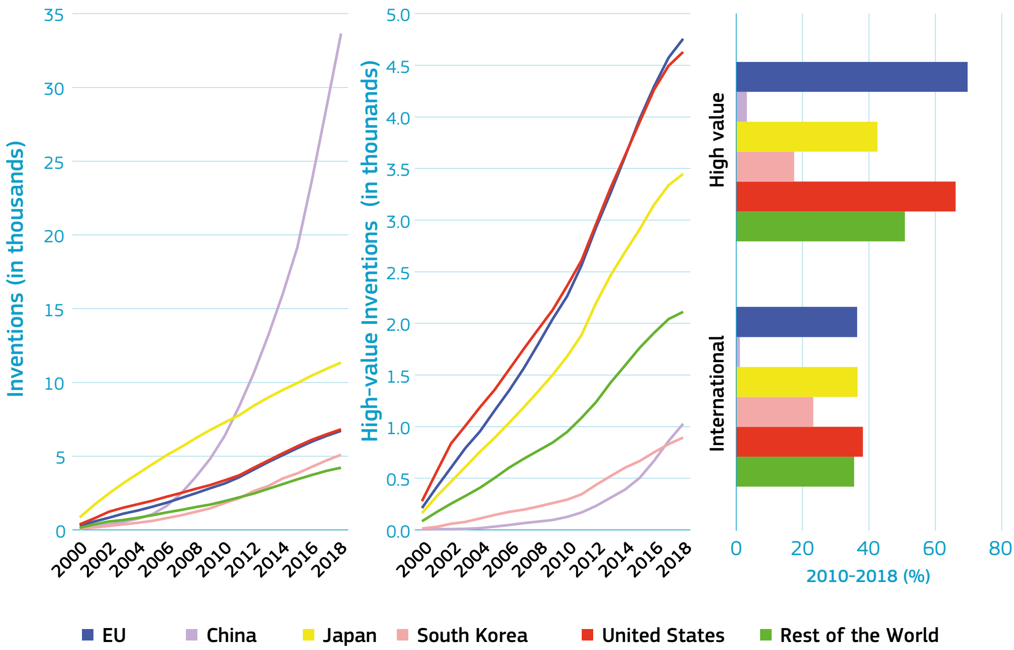


Source: European Commission (2020), Progress on competitiveness of clean energy technologies, COM(2020) 953 final.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-10.xlsx

Worldwide innovation output in low-carbon technologies has been increasing over time. At global level, the number of patents in low-carbon technologies has been rising over the past 20 years (EPO-IEA, 2021). Nevertheless, the pace at which new low-carbon energy patents have been issued has significantly decreased over time. Between 2000 and 2013, patents related to low-carbon technologies reported an annual growth rate of 12.5%, while annual growth rates reported in recent years are about three-quarters lower. This calls for intensified policy actions to accelerate clean energy innovation (EPO-IEA, 2021).

The EU leads the international scene in terms of clean energy innovation. The share of EU patents in low-carbon technologies has remained around 28% over the period 2010-2019 (EPO-IEA, 2021). Japan and the US follow closely with a share of 25% and 20% respectively, while China lags significantly behind with only 8% of the world share. Europe is particularly strong in the rail and aviation sectors, while Japan leads in electric vehicles, batteries and hydrogen. The US performs particularly well in technological fields related to biofuels and carbon capture, while China's greatest strength remains the ICT sector (EPO-IEA, 2021). When looking at green, high-value inventions (i.e. inventions protected by more than one patent office), the EU leads in areas related to renewable energies and energy efficiency (Figure 2.1-10). Furthermore, over the last 5 years, the EU has given home to around 25% of the top 100 companies with high-value patents in clean energy (European Commission, 2022e).

Figure 2.1-11: Trends in green inventions in energy-intensive industries, accumulated over 2000-2018 and 2010-2018

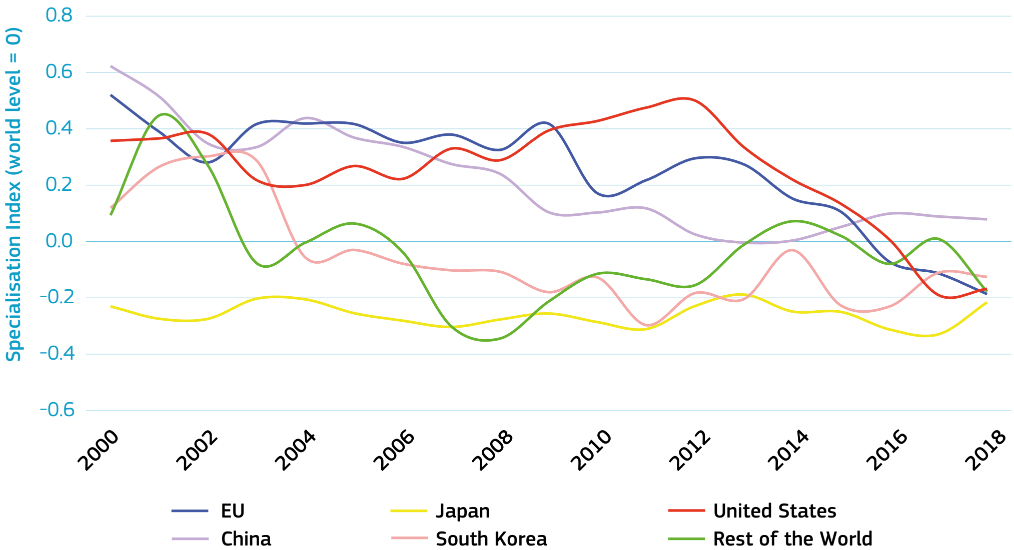


Source: European Commission (2020), Progress on competitiveness of clean energy technologies, COM(2020) 953 final.
Note: Cumulative inventions (left), high-value inventions (centre), and share of high-value and international inventions (i.e. patent applications protected in a country different to the residence of the applicant) (right) for major economies in the period 2010-2018.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-11.xlsx

The decarbonisation of energy-intensive industries (EIIs)[5] is critical to the achievement of the EU's climate goals. Between 2010-2018, 17 % of total green inventions implemented in the production and processing of goods came from EIIs (European Commission, 2022e). China ranks first in terms of overall inventions in EIIs. Nevertheless, the EU and the US lead in terms of high-value inventions[6], followed by Japan (Figure 2.1-11).

China surpassed the EU and US in terms of specialisation in EIIs. The EU and US reported the highest specialisation indexes in green innovations for EIIs until 2015 (Figure 2.1-12). Since then, both have lost their relative advantage in the field (with the specialisation index falling below the world average), and have been outperformed by China since 2016 (Figure 2.1-12).

Figure 2.1-12: Specialisation index in green inventions for energy intensive industries[(1)]



Science, Research and Innovation Performance of the EU 2022

Source: European Commission (2020), Progress on competitiveness of clean energy technologies, COM(2020) 953 final - Joint Research Centre elaboration based on EPO Patstat.

Note: [(1)]The figure reports the share of inventions relevant to EIIs within Climate Change Mitigation Technologies (CCMTs), for the production and processing of goods.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-1-12.xlsx

5 Energy Intensive industries include cement, chemicals, ceramics, steel and fertilisers industries

6 i.e. inventions protected by more than one patent office

4. Conclusions: R&I in a globally connected world

The COVID-19 crisis highlighted the importance for the EU to strengthen its resilience, and seize its role as a leader in the post-recovery global framework (European Commission, 2020a). In the context of the Green Deal implementation, it is essential for the EU to secure access to critical materials necessary for the production of advanced green technologies. In doing so, the EU must find a balance between its technological ambitions and the need to reduce its dependencies on international competitors. **Import portfolio diversification** is one of the possible strategies for the EU to mitigate reliance on a single supplier, along with the **implementation of recycling and substitution strategies** (Leonard et al., 2021). Furthermore, the EU has long relied on its **soft power to shape international standards and norms**. Leveraging the single market and its ability to build and enforce a solid regulatory framework, the EU has been able to exercise considerable influence at global level (UNESCO, 2021). In this regard, EU trade policy represents an important tool through which the EU can promote sustainability practices by setting both digital and green global standards (European Commission, 2020a). Thanks to its strong regulatory power, the EU confirms its key role in driving the transition towards a more circular economy and its capacity to lead by example, enforcing environmental norms and practices emulated by other regions (European Commission, 2020a).

Reducing EU strategic dependencies requires diversifying supply, notably by reshoring the production of some inputs, and increasing circularity. The EU would need to step up **commercialisation of its research results**. Although the EU is still strong in the production of scientific knowledge, challenges persist in translating scientific results into market products (see Chapter 6.3 - Innovation output, societal and market uptake and knowledge valorisation). Firms outside the EU often benefit from the EU's scientific results and successfully commercialise them (European Parliament, 2021). Furthermore, **the EU must play a leading role in the revival of multilateral governance structures**. In this regard, research and innovation will play a crucial role in realising the EU's global ambitions.

Furthermore, the Russian invasion of Ukraine has revealed the vulnerabilities of the EU energy sector. The new emphasis reducing EU dependency on Russian gas requires strengthening R&I investments and efforts to accelerate the development and deployment of energy efficient and clean energy technologies. Achieving this will **secure the green transition and the independence and competitiveness of the EU**. R&I policy can play a major role in shaping the direction of innovations and the portfolio of energy technologies. **The innovation policy of the future will have to be developed in a complex triangle of transformation policies, competitiveness policies and technology sovereignty considerations**. However, in doing so, the EU should avoid sacrificing international welfare gains through free trade and division of labour for shortsighted technology sovereignty policies driven by domestic interest groups (Edler et al, 2021).

To build 'a stronger Europe in the world', the European Commission aims to **reinforce the role of the EU as a leading actor to foster international cooperation**. With the Communication *Europe's global approach to cooperation in R&I*, the European Commission reaffirms EU's commitment to leading by example, preserving openness in international R&I cooperation, while promoting a level playing field and safeguarding fundamental EU values. Building on the lessons learned from the COVID-19 pandemic, **the new EU strategy on international R&I cooperation calls for a reinvigorated multilateral approach**, essential for achieving the SDGs and for establishing mutually beneficial relationships with international partners to deliver solutions to green, digital, health, social and innovation challenges (European Commission, 2021b). To strengthen the EU's open strategic autonomy, it is necessary to leverage the EU's capacity to develop and take up strategic technologies, thereby increasing EU competitiveness and avoiding future dependencies.

Box 2.1-1: Foreign interference

Research and innovation activities have become increasingly internationalised. Scientific research is a collaborative process, leveraging the relationships that researchers and scientists have built across disciplines over time. Nevertheless, research activities also embed a high level of competition between different actors. Europe's higher education institutions (HEI) and research performing organisations (RPO) have a strong record of internationalisation (European Commission, 2022a).

The EU strategy on international cooperation in R&I needs to balance the benefits of research collaboration with the risks related to foreign interference. International interference '*occurs when activities are carried out by, or on behalf of, a foreign state-level actor, which are coercive, covert, deceptive, or corrupting and are contrary to the sovereignty, values, and interests of the EU*' (European Commission, 2022a). Foreign interference may pursue different objectives, from the unlawful retrieval of information, to securing the power to influence decisions in favour of the foreign actor (European Commission, 2022a). Given the essential role played by HEIs and RPOs in fostering international research, and supporting knowledge creation and diffusion, the European Commission published a set of guidelines and best practices to support these entities in safeguarding their fundamental values (including academic freedom, integrity and institutional autonomy, as well as the protection of researchers, students and staff). As such, the Commission's *Staff Working Document on Foreign Interferences* informs HEIs and RPOs on the measures at their disposal to mitigate the risks of foreign interference and encourage the adoption of existing best practices.

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CHAPTER
2.2

ZOOM IN – REGIONAL ANALYSIS

KEY FIGURES

1 region
concentrates 9 % of total EU business R&I expenditure

43 %
of ICT patents filed in Europe are from 10 European regions

More than 3/4
of collaborations on patents were intraregional over 2012-2016

9 in 10
M&A innovative deals in Europe target a company in a more-developed region

56 of 73
less-developed EU regions increased their contribution to total EU scientific publications over 2010-2018

KEY QUESTIONS WE ARE ADDRESSING

- What are the R&I trends across EU regions?
- What is the regional specialisation pattern of R&I activities in the EU?
- What is the relationship between productivity and innovation at the regional level?

KEY MESSAGES

What did we learn?

- R&D expenditure, scientific publications and patent applications are concentrated in more-developed regions.
- The least-innovative regions recorded low and declining growth in patent applications over 2013-2018, putting into question technology production convergence across EU regions.
- Regions with lower or moderate innovation capacity rely more on the public sector for R&D investments than those with strong innovation capacity.
- About 75 % of patent collaborations in the EU have been intra-regional and only 3-5 % interregional across national borders.
- Patenting activity in health, ICT and climate mitigation technologies is highly concentrated in only a few EU regions.
- While most regions in central and eastern Europe (CEE) experienced significant catching up in productivity, much of the growth has been fuelled by a combination of factors such as rapid expansion of global supply chains and foreign direct investment. There has been a smaller role for innovation-driven productivity growth.
- Many transition regions are characterised by low R&I performance and have also not done well in productivity growth.

What does it mean for policy?

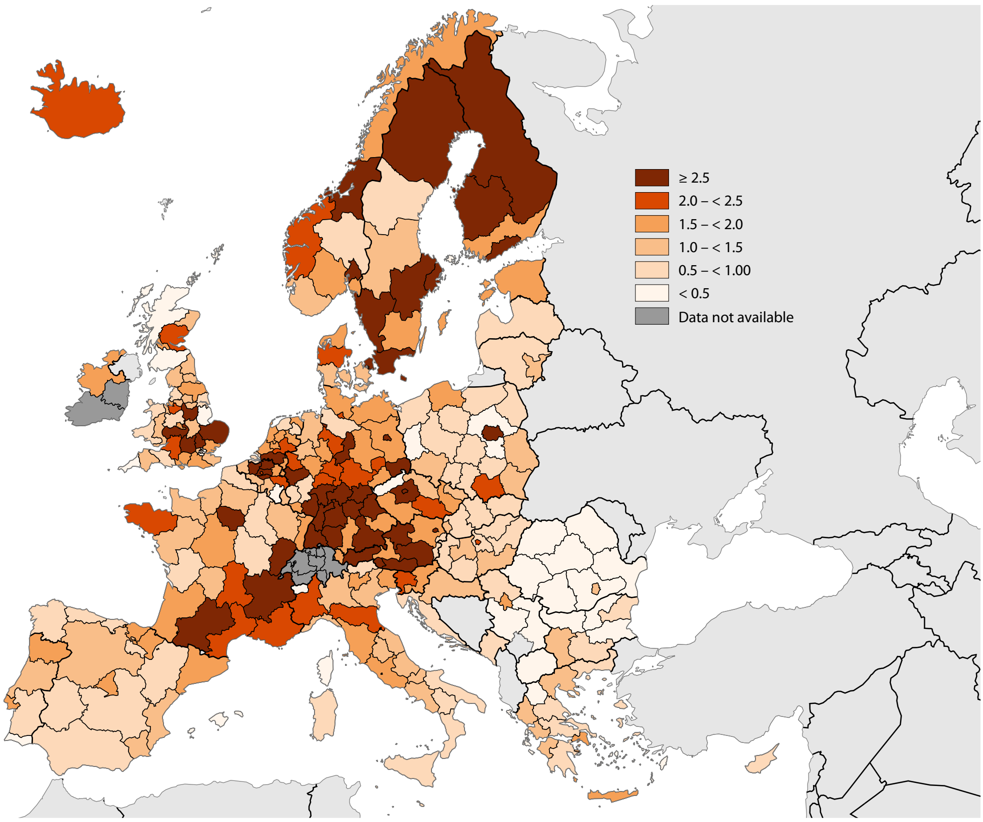
- Promoting innovation diffusion and transfer in less-developed and transition regions to trigger economic dynamism would help to close the innovation divide and increase the competitiveness of the EU as a whole.
- European R&I policies could target different types of innovation (product, process, social, ecological, etc.) according to territorial specificities, local needs and assets.
- Cross-border collaboration on R&I activities could optimise efforts and accelerate joint learning for the twin transition.
- Complementarities in R&I activities between EU regions in terms of industrial specialisation and knowledge transfer could be also strengthened at EU level to ensure a smooth integration of the latest research inputs and inventions across regions and countries.
- To maintain growth, regions, in particular less-developed ones, could shift to a knowledge-based and innovation-driven growth model in order to continue catching up.

1. EU regional disparities and trends in R&I

State of play of R&I dynamics at regional level

There is a pronounced regional concentration of R&D investments in the EU (Figure 2.2-1). In particular, western and northern Europe feature high R&D intensity, although well-performing regions can be found in other parts of Europe, too. Within countries, there is a concentration of R&D expenditure per capita in a few regions, typically capital regions or regions with large urban agglomerations. In the last decade, some regions with high R&D intensity continued to increase their R&D expenditures further. Only some regions with lower R&D intensities managed to catch up, and the gap with the top-performing regions remains significant.

Figure 2.2-1: R&D intensity (Gross R&D investment as % of GDP), 2019 or latest year available



Science, Research and Innovation Performance of the EU 2022

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

Note: BE, 2017; FR, 2013; NL, 2012; IE, ME, UK, NO, 2018.

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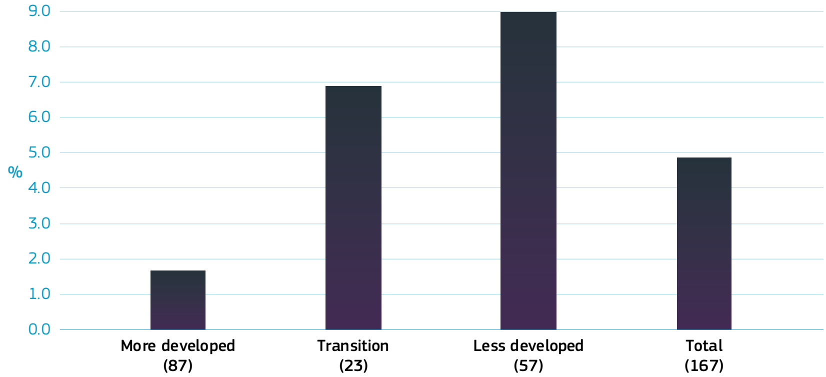
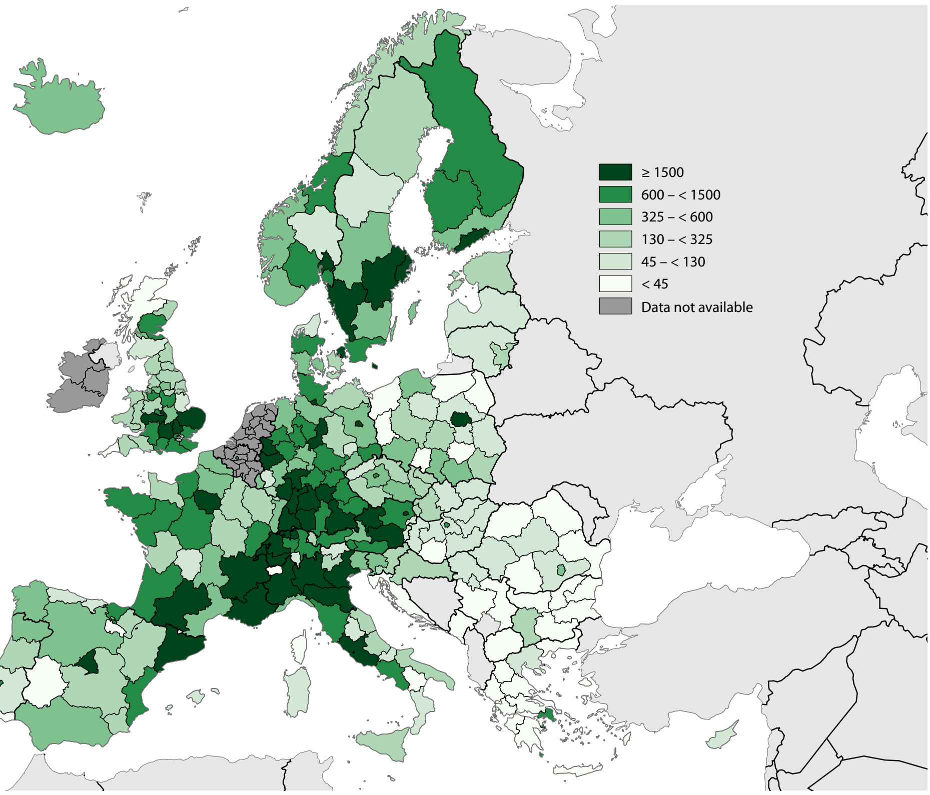
1 R&D investments as percentage of GDP

Figure 2.2-2: Business R&D investment in million euros, 2019 or latest year available, and Business R&D intensity annual growth 2010-2019 by type of region





Science, Research and Innovation Performance of the EU 2022

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

Note: No data for BE and NL; FR, 2013; UK, ME, 2018; AT, BG, DK, DE, EL, ES, HR, IT, HU, PL, PT, SI, RO, FI, SE, IS, NO, MK, 2019; CZ, EE, LV, CY, LU, MT, SK, RS, 2020.On the map, no data for FR, NL, BE, and per-capita GDP as the criteria adopted by regional Cohesion Policy in the 2014-2020 EU programming period has been used to classify regions in most developed (more than 90% of EU28 average per-capita GDP), transitioning (between 70% and 90%) and less developed regions (less than 70%).

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Business R&D expenditures are key in boosting the competitiveness of regions, promoting local job creation and reducing the EU's innovation gap (European Commission, 2014, 2017a and 2020). **Business R&D expenditures are also geographically concentrated, although they are sizeable in some transition regions**[3]. The latest data suggest a persisting concentration of business R&D expenditure in more-developed central locations (Figure 2.2-2).

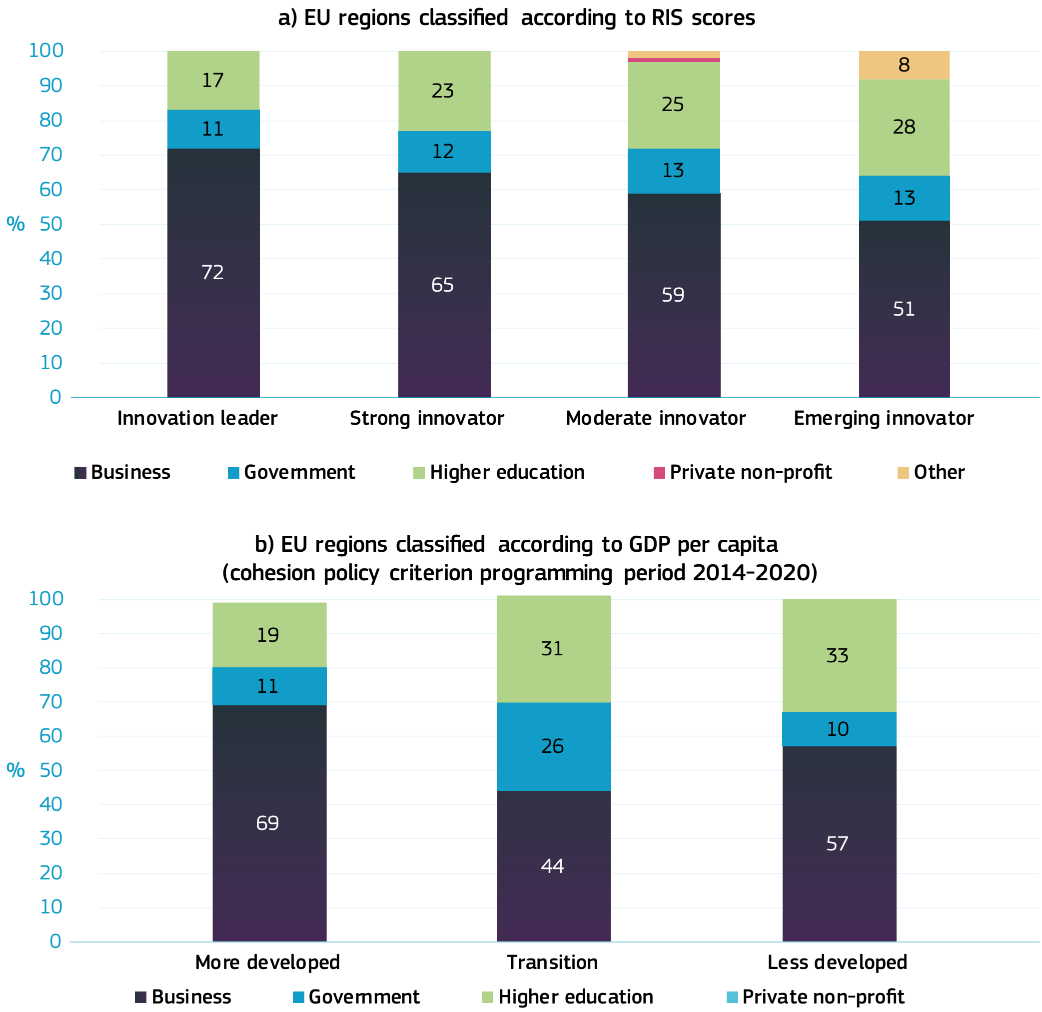
An example is Baden-Württemberg, which has about 2% of the EU population but boasts 9% of the EU's business R&D. In many regions of eastern and southern Europe, R&D expenditures have also increased, linked to a structural shift to more knowledge intensive activities and expected returns on R&D investment, but also linked to an increase in public R&D boosted by EU funds. Furthermore, the ultimate objective is to accompany the transition of those regions and workers most affected by globalisation and industrial developments and to facilitate the transition to a low-carbon and circular economy (JRC, 2018). Over the past decade, less-developed regions have shown a higher annual growth in terms of business R&D intensity, in particular in Cyprus, Poland, Bulgaria and Greece, than in transition and more-developed regions.

The regional impact of the COVID-19 pandemic on R&D investments has been driven by sectoral specialisation of regions. Throughout the crisis, many of the top R&D-investing companies in Europe active in, e.g., the information and communication and the health sectors have actually increased their R&D spending. Others, such as the automotive and the aerospace and defence sectors, have reduced it (JRC, 2021). As a result, we might expect R&D investments in regions to be affected by the crisis according to local specialisation in their industrial landscape.

Regions with lower innovation capacity tend to rely relatively more on government and higher education sectors for R&D investments, whereas strong/leading innovators benefit more from business-enterprise R&D investments. Interestingly, it seems that innovation leaders are also characterised by the highest share of R&D investment from the government, but with less from the higher education sector (Figure 2.2-3). When classifying regions according to their GDP per capita, it seems that regions in transition (i.e. those between 70% and 90% of the EU average) have relatively low business R&D investment: only 44%, compared to 69% for more-developed regions and 57% for less-developed regions. The development of R&D activities in transition regions relies relatively more on the government sector than it does in other regions as the share of R&D investments made by the government in transition regions is close to 26%, compared to 10% in less-developed regions and 11% in more-developed regions.

3 GDP per capita as the criteria adopted by regional Cohesion Policy in the 2014-2020 EU programming period has been used to classify regions as more-developed (more than 90% of EU-28 average GDP per capita), transitioning (between 70% and 90%) and less-developed regions (less than 70%).

Figure 2.2-3: Share of R&D investment per sector across EU regions classified according to RIS scores, 2019 and per GDP per capita (cohesion policy criterion programming period 2014-2020)



Science, Research and Innovation Performance of the EU 2022

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

Note: No data for BE, FR and NL. GDP per capita as the criteria adopted by regional Cohesion Policy in the 2014-2020 EU programming period has been used to classify regions as more-developed (GDP per capita more than 90 % of EU-28 average), transitioning (between 70 % and 90 %) and less-developed regions (less than 70 %).

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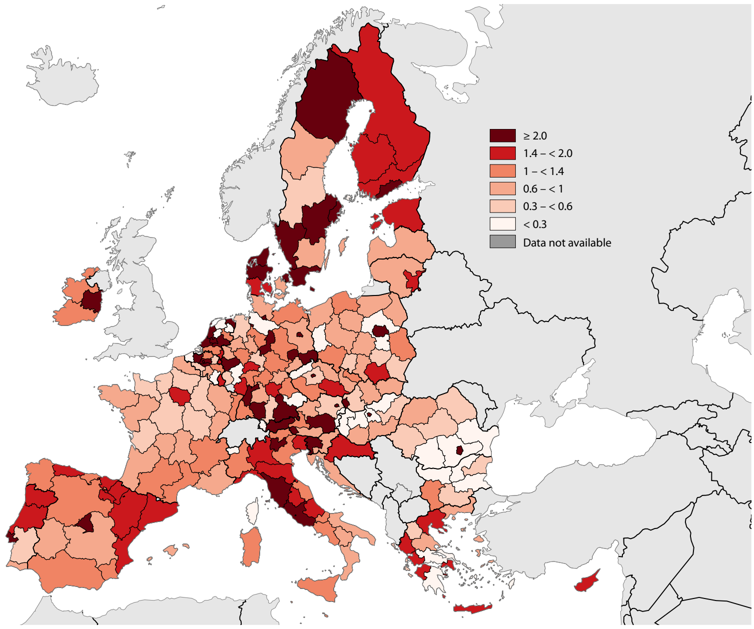
Scientific production measured by publications shows a relatively dispersed pattern across EU regions, with signs of convergence across regions. There are important regional differences in scientific publications per capita in the EU, although there is not as clear a divide as, for example, in overall innovation capacity (Figure 2.2-4). Moreover, many lagging regions, mostly in eastern and southern Europe, showed an improvement in scientific-output performance over 2010-2020. In contrast, the European regions that have the highest rate of scientific publications per capita did not record increases and in some cases, their relative contribution to the EU total number of scientific publications declined over the decade. Besides, the dispersion between European regions increased sharply during 2020, possibly due to the impact of the COVID-19 crisis on scientific production (see Chapter 1 – COVID-19, recovery and resilience).

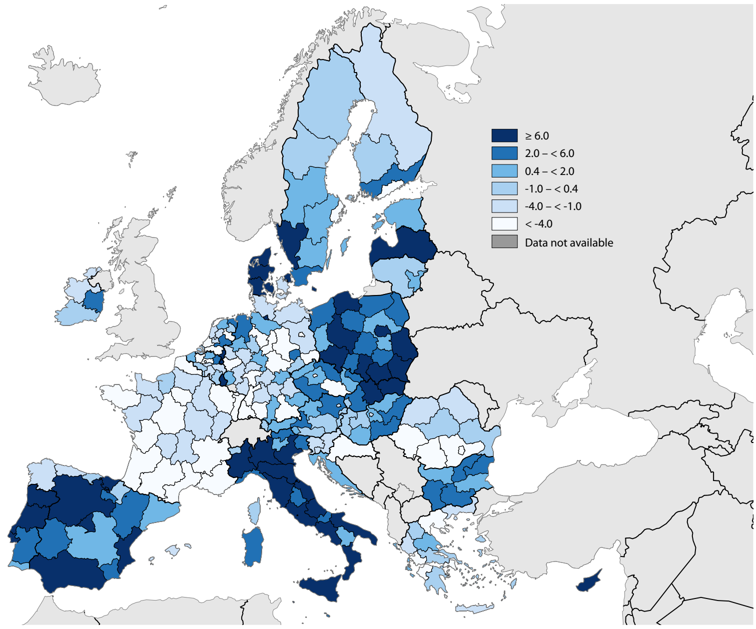
However, the production of high-quality publications continues to be highly concentrated in a relatively few regions. Hence, the 10% top cited publications are mostly produced in western Europe, with a dominance of Dutch and Nordic regions (Figure 2.2-5). Central and eastern European regions still show lower performance. If the positive trend in quantity of scientific publications translates into higher quality, we could experience some catching up in the future. However, this catching-up process tends to take longer and is conditional upon overall improvement in framework conditions for scientific production.

Figure 2.2-4: Scientific publications per 1000 inhabitants, 2020 and evolution of the contribution to EU total publications between 2010 and 2020

a) Scientific publications per 1000 inhabitants, 2020



b) Evolution of the contribution[1] to EU total publications between 2010 and 2020



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

Note: [1]The contribution of each region to the EU total has been calculated for both 2010 and 2020 and regions have been allocated in 6 different classes according to the percentage increase of this share between both years. Fractional counting used.

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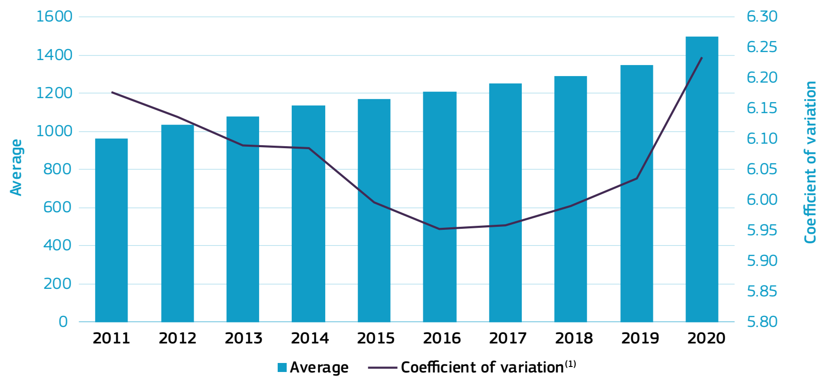
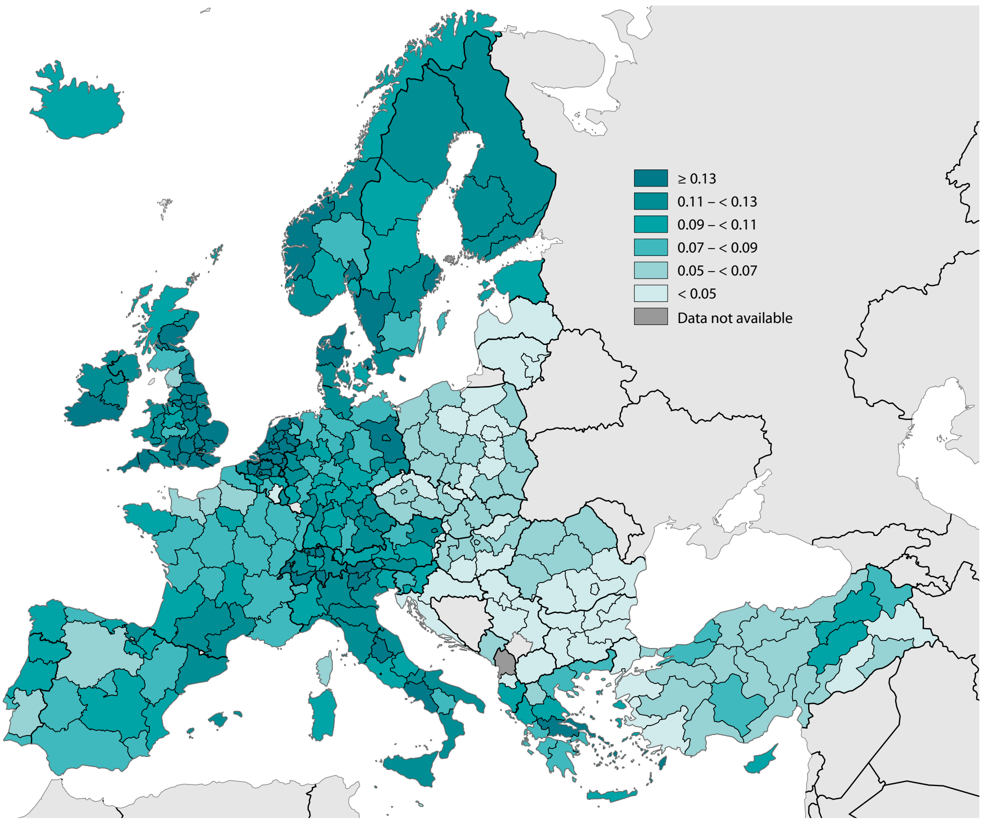
Figure 2.2-5: Percentage of highly cited publications (top 10%) in 2018 per NUTS2 level (map) and evolution of regional disparities in publications per million inhabitants (graph)





Science, Research and Innovation Performance of the EU 2022

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

Note: [1]The coefficient of variation (CV) is the ratio of the standard deviation to the mean, which shows the extent of variability of data in a sample in relation to the average value. The higher the coefficient of variation, the greater the level of dispersion around the mean.

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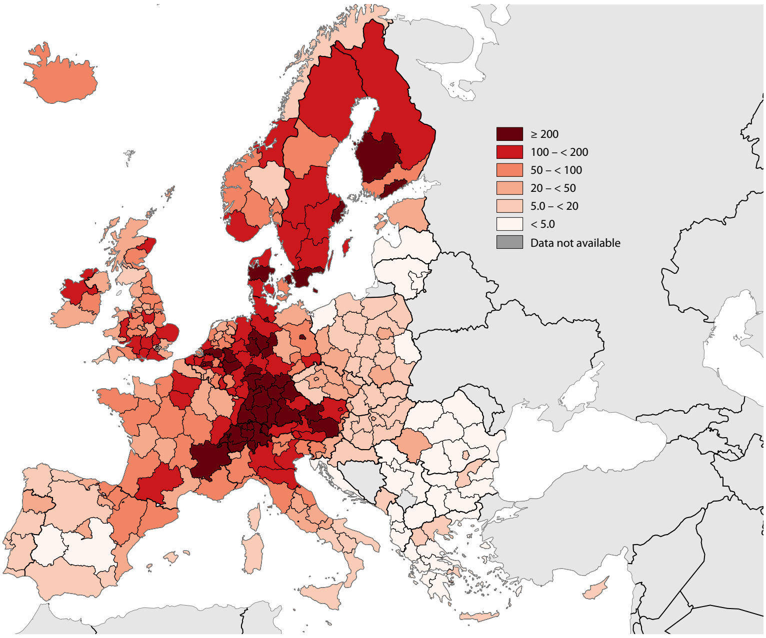
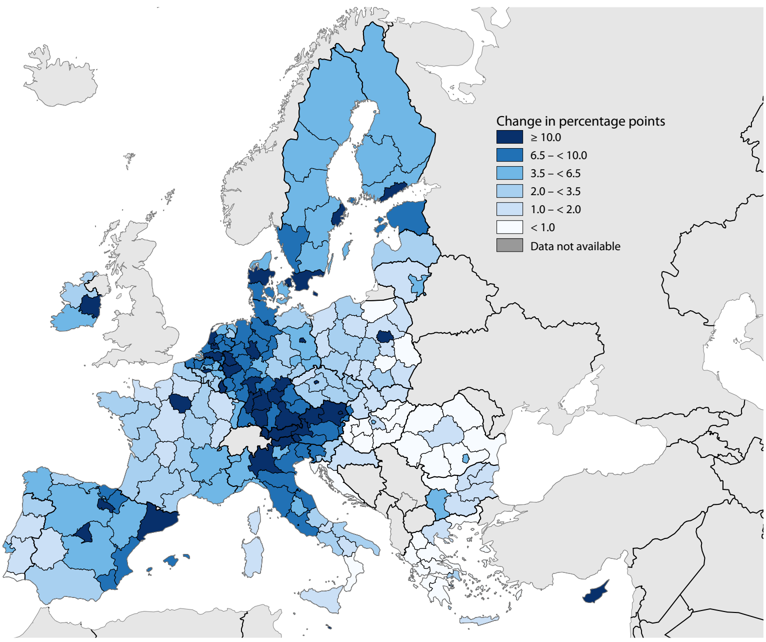
The regional pattern of technological production is driven by the existing innovation divide. The divide between regions located in western and northern Europe and those in central and eastern Europe, as well as with some southern countries, continues to be pronounced. The technological output as measured by patents is still concentrated in regions with a high share of manufacturing and with headquarters of large companies, such as southern Germany, Austria, Denmark and the Rhone-Alpes region in France or some capital city regions. However, a look at **trends across European regions reveals that some regions in eastern and southern Europe have increased their contribution to EU total patent applications over the past decade** (Figure 2.2-6), in terms of European Patent Office (EPO) applications. Some of the least innovative regions, in Portugal and Greece, have increased their contribution to EU total patent applications over 2010-2018. However, the regions that experienced the highest increases in their contribution to EU total patents are in Austria, Belgium and Germany, which are already among the top innovative regions.

Overall, the pattern for **design and trademark applications is similar to that for patent applications**. However, the emergence of specialisation in less technologically intensive fields covered by designs and trademarks could point to growth in service innovation or design-based innovation in lagging regions. Better performance in designs can be found, for example, in the Polish regions of Małopolskie (PL21) and Wielkopolskie (PL41), while trademarks play a prominent role in Andalucia (ES61) and in many Bulgarian regions (Figures 2.2-7 and 2.2-8). Bulgaria already outperforms the EU average in design and trademark applications per unit of GDP.

Figure 2.2-6: Total patent applications to the EPO (fractional counting) in 2018 per million inhabitants at NUTS 2 level (red map) and evolution of the contribution of each region to EU total patents applications to the EPO between 2010 and 2018 (blue map)





Science, Research and Innovation Performance of the EU 2022

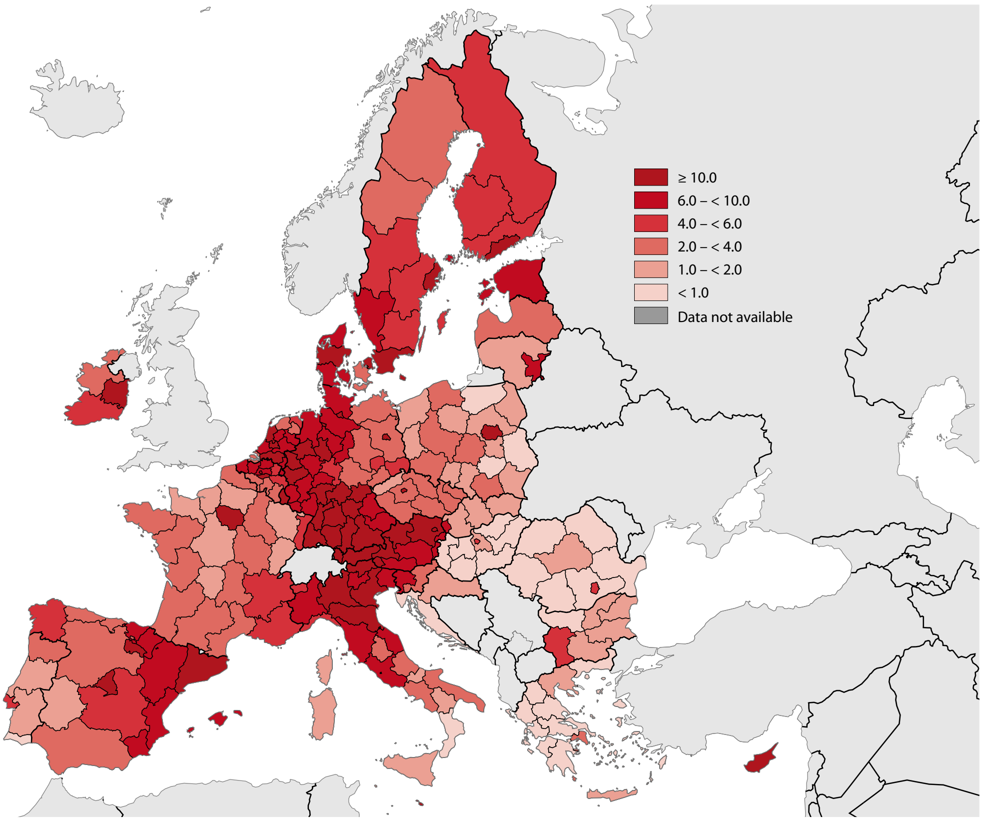
Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO REGPAT database.

Note: [1]The contribution of each region to the EU total has been calculated for both 2010 and 2018 and regions have been allocated in 6 different classes according to the percentage increase of this share between both years.

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

Many less-developed regions are too far away from the technological frontier and do not have the necessary capabilities, including human capital, to make effective use of additional R&D investments (Aghion and Griffith, 2008). These types of area, which are often economically lagging-behind, are regarded as less able to generate, import and absorb knowledge for innovations (Rodríguez-Pose, 2001). For example, in many regions in southern countries, such as Greece and Spain, around 20% of the labour force are employed in science and technology, with the exception of the capital regions (Figure 2.2-9). In stark contrast, this share is more than 40% in some northern European regions in Finland and

Figure 2.2-7: Cumulated volume of trademark applications (fractional counting) at NUTS2 level, 2003-2020



Science, Research and Innovation Performance of the EU 2022

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

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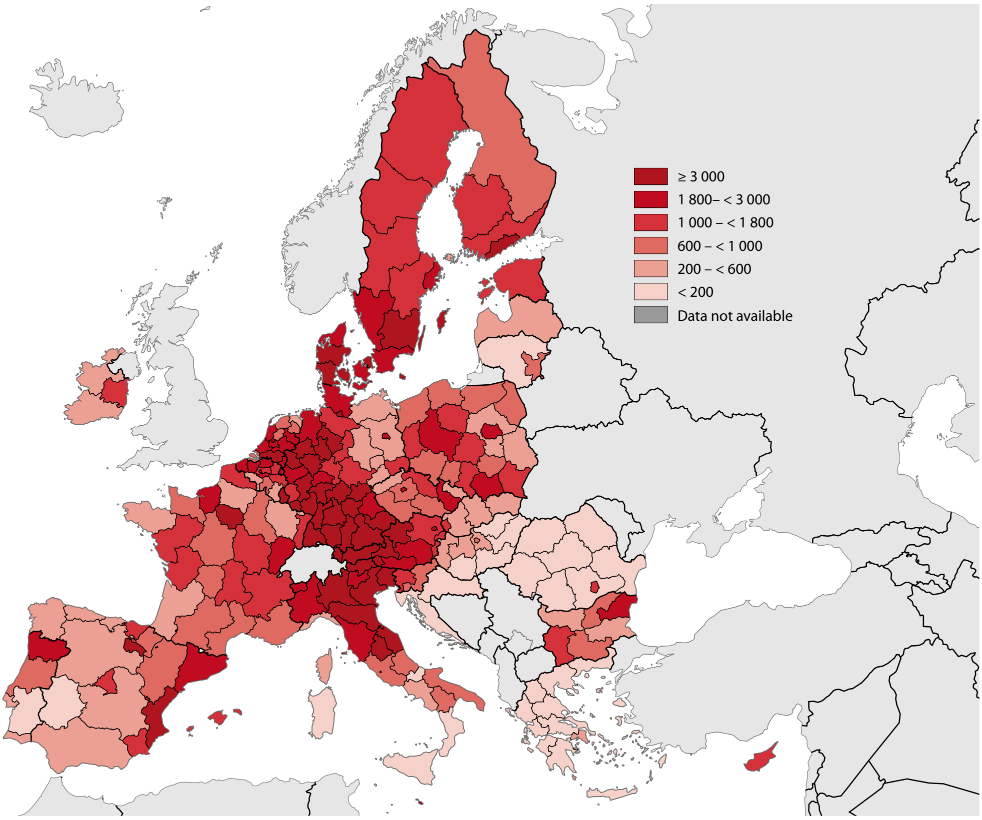
Figure 2.2-8: Cumulated volume of design applications (fractional counting) at NUTS2 level over 2003-2020



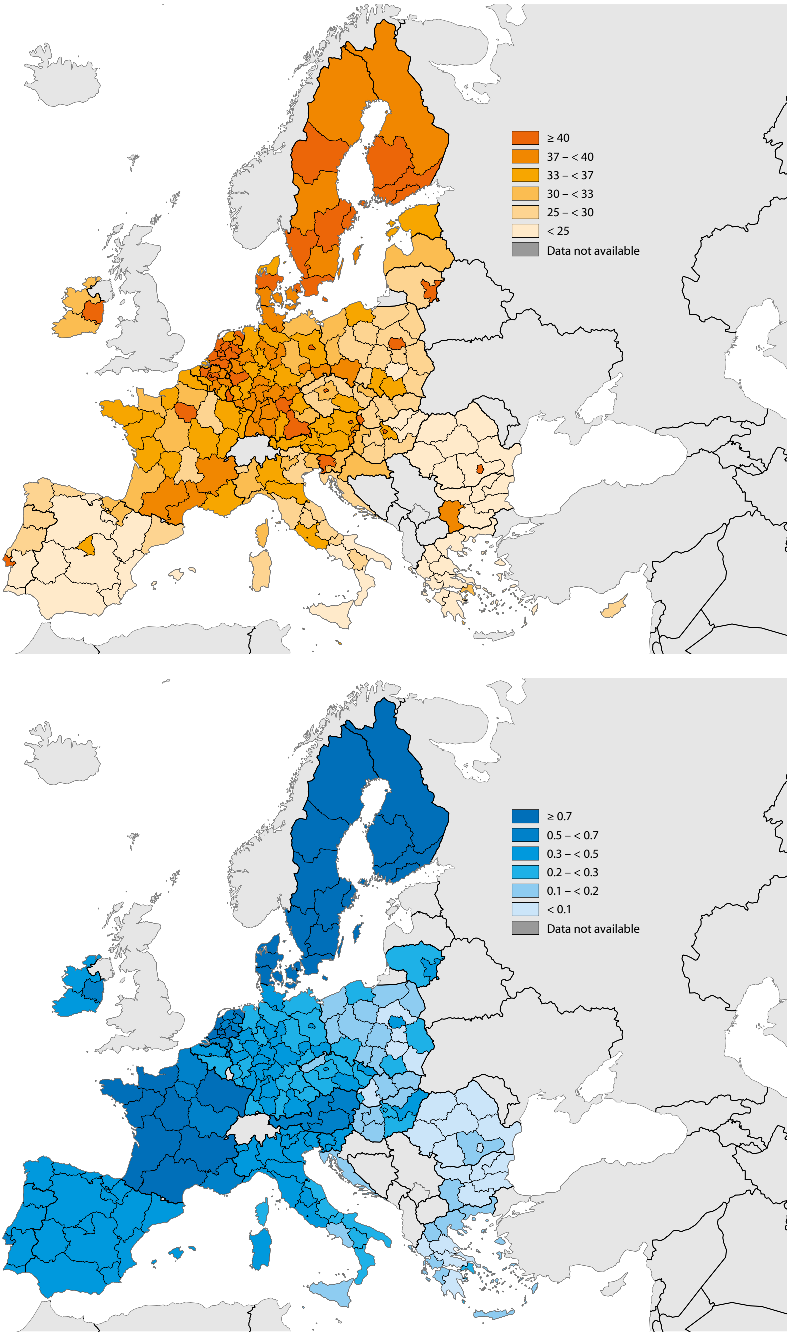
Science, Research and Innovation Performance of the EU 2022
Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EUIPO database.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-2-8.xlsx

Sweden or in the Netherlands, which have specialised in science and technology. It also appears that leading regions in terms of human capital devoted to science and technology have strengthened their position, such as regions in France, Sweden and Finland. On the other hand, the catching-up process has not been very strong in some countries, such as Greece or Spain, although other regions in Portugal, Poland and Austria have witnessed an increase of 11-20% since 2020.

The regional innovation divide

Agglomeration externalities are a key driver of geographical concentration of innovation. For example, spatial proximity allows firms to share specialised suppliers or to facilitate recruitment amongst a shared labour pool (Klepper, 2010; Ponds et al., 2010). Individuals and firms also benefit from localised knowledge spillovers as proximity facilitates the diffusion and adoption of innovation (Audretsch, 2003; Sonn and Storper, 2008). Better social interaction and networking opportunities in more densely populated regions facilitate the exchange and diffusion of new knowledge

Figure 2.2-9: Percentage of people employed in Science and Technology in 2020 over the total labour force across regions (orange map) and share of population engaged in Lifelong learning in 2021 at NUTS 2 level (blue map)



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

Note: Lifelong learning is defined as the share of population aged 25-64 enrolled in education or training aimed at improving knowledge, skills and competences.

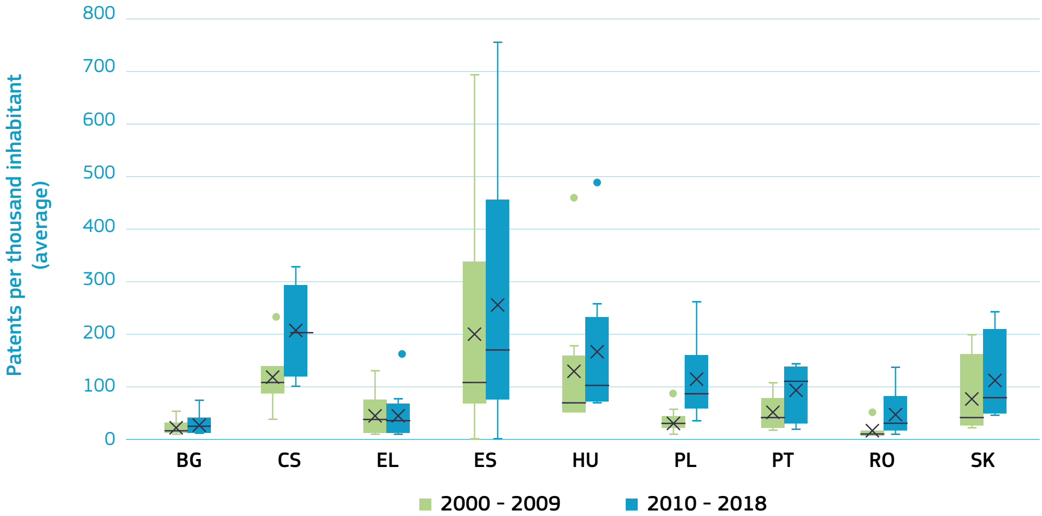
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-2-9.xlsx

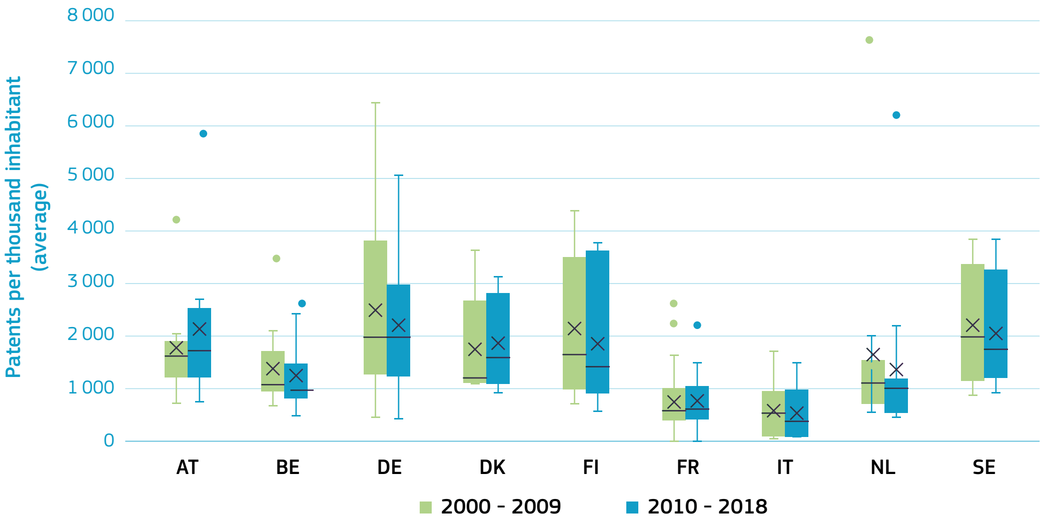
(Fujita et al., 2001). Isaksen et al. (2016) describe 'thick innovation ecosystems', found in metropolitan and technologically advanced regions, that host a variety of industries and knowledge- and innovation-supporting organisations. Indeed, Figure 2.2-10 documents that **innovative activities are increasingly concentrated in metropolitan regions**[4]. Some countries have much higher regional concentration of innovation and feature a large difference in patent applications filed between their metropolitan and non-metropolitan regions, e.g. Finland, Sweden, Germany, Denmark or France. In contrast, countries such as the Netherlands, Austria, Czechia, Italy, Latvia, Slovenia and Lithuania showed a smaller gap between metropolitan and non-metropolitan regions over 2000-2018.

Rural and urban areas differ in the intensity of innovation as well as in the type of innovation. As illustrated in Table 2.2-1, urban regions are much more active in patenting and publication activities than rural or intermediate regions. In Europe, metropolitan regions gathered 74 % of patent applications in 2018, 84 % of scientific publications in 2020, and 87 % of highly cited publications in 2020. When it comes to the types of innovation, it appears that high-density areas are characterised by a higher degree of unconventionality in innovation, meaning that **research activities and product innovations tend to be concentrated in higher-rank cities** or more agglomerated settings, **while process innovations and less technology-intensive activities tend to be more distributed in space** (Duranton and Puga, 2001; Lee and Rodríguez-Pose, 2013; Berkes and Gaetani, 2020). Besides, while rural regions more rarely produce learning related to R&D activities ('learning by searching') they **have a fundamental role in the other dimensions of learning** (by doing, by using, and – in particular – by interacting).

4 Except in Bulgaria, where non-metropolitan regions tend to concentrate innovative activities.

Figure 2.2-10: Difference between metropolitan and non-metropolitan regions in average patent applications to EPO (fractional counting) per 1 000 inhabitants across EU, 2000-2018.





Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO REGPAT database.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-2-10.xlsx

Table 2.2-1: Urban-rural innovation divide in Europe

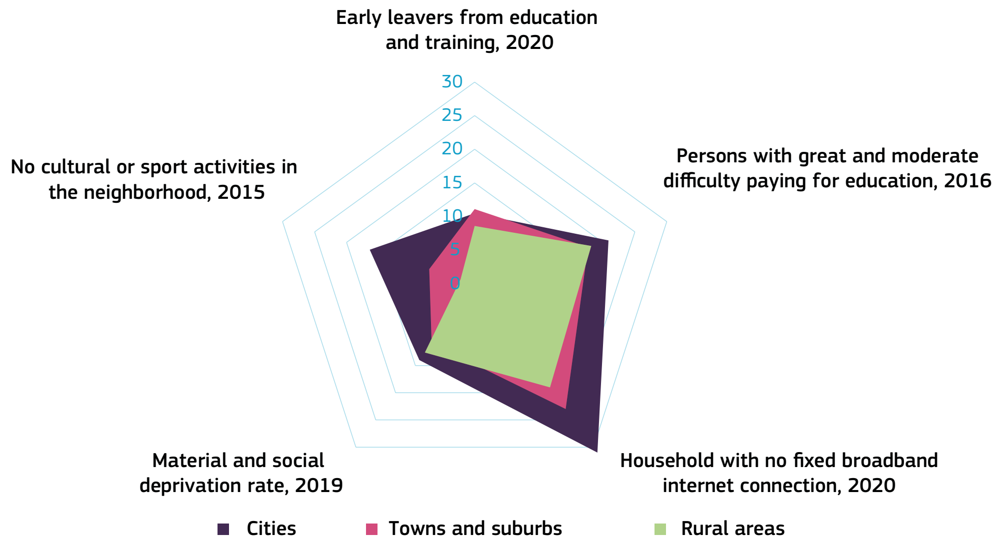
Type of regions	Predominantly urban regions	Intermediate regions, close to a city	Intermediate regions, remote	Predominantly rural regions, close to a city	Predominantly rural regions, remote
Number of regions in Europe	240	464	48	265	150
Publications per million inhabitants 2020 (frac. counts), % change 2014-2020	2 078.9 +6.46 %	1 145.2 +9.3 %	400.5 +19.2 %	397.7 +14.4 %	302.9 +44.5 %
Share of publications 2000-2020	63.7 %	30.5 %	0.6 %	4.2 %	1.0 %
Average of highly cited publications (top 10 %) over total publications 2000-2020	0.09 %	0.07 %	0.06 %	0.05 %	0.06 %
Average of highly cited publications (top 1 %) over total publications 2000-2020	0.01 %	0.01 %	0.01 %	0.00 %	0.01 %
Patents per million inhabitants 2018, % change 2014-2018	132.4 -14.6 %	104 -14.5 %	31.3 -29.8 %	65.8 -4.7 %	30.7 -15.2 %
Share of patents 2000-2018	52.8 %	36.1 %	0.8 %	8.6 %	1.7 %
Share of patents cited at least one time in total patents 2000-2018	17.4 %	19.5 %	14.8 %	20.0 %	21.6 %

Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Eurostat and Science-Metrix using EPO REGPAT and Scopus databases.

Access to education, science and infrastructure is unequal across territories (Figure 2.2-11), which may stoke the cultural divide between urban and rural settings and calls for increased infrastructure and facilities across Europe. Besides, populations in towns, suburbs and rural areas are more subject to material and social deprivation than populations of cities. It leads to a 'geography of discontent' (McCann, 2019), which is becoming apparent in many European countries and beyond as communities and localities display a sense of despair and being left behind, often manifested in anti-system voting. Urban-rural divergence is still growing in countries such as France, Sweden and Austria, with powerful political movements emerging from both formal and informal contexts, and rural areas remaining distant, both physically and technologically, from urban centres (Cowie et al., 2020). Rural individuals are underrepresented in science at all levels, and their absence from these processes skews the priorities and ethical considerations of science (O'Neal and Perkins, 2021). Furthermore, populations living in periphery and rural areas face difficulty in paying for education and training (Figure 2.2-11) as going to higher learning institutions often also means moving into urban centres, where housing prices are high. It also hinders labour mobility as people who lose their jobs because industries have either been displaced or closed may not be able to attend training and support facilities, often localised in urban centres. Rural and peripheral areas have a much higher share of their population with no fixed broadband internet connection. In turn, this can result in the loss of important perspectives that lead to innovations, and it propagates large-scale societal problems such as science scepticism, susceptibility to misinformation and lack of support for science funding.

Figure 2.2-11: Territorial disparities in access to education and connectivity in the EU, 2020 or latest year available



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Eurostat.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-2-11.xlsx

The convergence process: challenged over recent years

A process of convergence in research outputs (patents and publications) that happened across the EU in the beginning of the 2000s due to high annual growth of the least performant regions and low annual growth for the most performant regions. This process **reduced over time and finally stopped from the middle of the 2010s**. Table 2.2-2 demonstrates that the least performant regions in terms of patents per million inhabitants and number of patents had been catching up over 2001-2005 (at a very high rate) then 2009-2013 (at a slower pace), but that this convergence stopped over 2013-2018. In contrast, the most performant regions had a lower growth rate in the beginning of the 2000s but ended up with a higher annual growth rate than the least performant regions over 2013-2018. **For scientific publications, it appears that the pronounced convergence process in the beginning of the 2000s was still valid over the 2016-2020 period, but at a much slower pace than previously**. These results are similar to regional performance as mapped by the Regional Innovation Scoreboards, which also demonstrated that over 2016-2021 the share of emerging innovators (the least innovative class) has increased in the less-developed regions. Less-developed regions indeed face more difficulties in translating research results into innovation, and the returns on additional R&D investment in terms of patenting tend to be lower than in other regions (Sterlacchini, 2008). Although there is convergence for scientific publications, many disadvantages prevail in less-developed regions of Europe and these are less capable of generating innovation from R&D inputs (Rodríguez-Pose and Ketterer, 2020).

Due to the high concentration of innovation, the vast majority of regions lag behind, even in the most innovative EU countries. In 2018, the majority of French (80%), Belgian (70%), Italian (85%), Dutch (60-80%) and Finnish (50-70%) regions filed fewer patents per capita than the EU average per region (Table 2.2-3). Moreover, **the disparities have been on an increasing trend** and these regions experienced a severe drop in the number of patents filed per capita over 2010-2018. In the Netherlands in particular, while 60% of regions had a patent per capita rate below the EU average in 2010, in 2018 more than 80% of regions were below the EU average in terms of technological production per capita. Most of these regions were also characterised by declining patent productivity during the last decade, as was the case in the Netherlands, Finland and Ireland. In contrast, Sweden, Austria, Ireland and Finland experienced a decreasing rate of regional disparities within their borders in terms of technological production per capita.

Table 2.2-2: **Annual growth 2001-2018/2020 for research outputs (patent applications and scientific publications – fractional counting) by groups of regions**

	Annual growth			
Patents per million inhabitants	**2001-2005**	**2006-2010**	**2011-2014**	**2015-2018**
Most performant regions (1st tercile)	1.1	-0.6	0.3	-3.6
Middle performers (2nd tercile)	4.5	0.6	0.7	-4.7
Least performant regions (3rd tercile)	16.2	1.7	5.3	-11.8
Patents	2001-2005	2006-2010	2011-2014	2015-2018
Most performant regions (1st tercile)	2.4	0.06	-0.1	-2.8
Middle performers (2nd tercile)	5.5	1.6	1.3	-2.4
Least performant regions (3rd tercile)	16.7	1.6	4.1	-12.6
Publications per million inhabitants	2001-2005	2006-2010	2011-2015	2016-2020
Most performant regions (1st tercile)	4.1	2.9	1.4	0.9
Middle performers (2nd tercile)	6.0	4.3	2.6	1.7
Least performant regions (3rd tercile)	10.0	9.7	4.0	2.1
Publications	2001-2005	2006-2010	2011-2015	2016-2020
Most performant regions (1st tercile)	4.6	3.3	2.1	1.2
Middle performers (2nd tercile)	6.5	4.6	2.4	1.3
Least performant regions (3rd tercile)	11.2	9.2	4.1	2.6

Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Eurostat and Science-Metrix using EPO REGPAT and Scopus databases.

Table 2.2-3: Regions with total patent applications to the EPO per capita (fractional counting) below the EU average, 2010 and 2018

Patents per million inhabitants [1]						
	EU average 2010: 136.1 patents per million at regional level (NUTS3)			EU average 2018: 116.5 patents per million inhabitants at regional level (NUTS3)		
	No. and percentage of regions with patents per capita below the EU average	Average patents per capita for these regions	Average increase in patents per capita for these regions 2010-2018	No. and percentage of regions per capita below the EU average	Average patents per capita for these regions	Average increase in patents per capita for these regions 2010-2018
AT	15/35 (43%)	84	+21 patents per capita	10/35 (29%)	77	+8 patents per capita
BE	31/44 (70%)	77	-3 patents per capita	30/44 (68%)	61	-23 patents per capita
DE	122/401 (30%)	78	-1 patents per capita	124/401 (30%)	62	-44 patents per capita
DK	3/11 (27%)	76	+10 patents per capita	4/11 (36%)	79	-49 patents per capita
FI	10/19 (53%)	59	-9 patents per capita	14/19 (74%)	57	-33 patents per capita
FR	80/100 (80%)	58	-8 patents per capita	79/100 (79%)	44	-17 patents per capita
IE	8/8 (100%)	70	-10 patents per capita	7/8 (88%)	43	-18 patents per capita
IT	92/110 (84%)	42	-6 patents per capita	94/110 (85%)	36	-10 patents per capita
NL	24/40 (60%)	81	-18 patents per capita	33/40 (83%)	66	-39 patents per capita
SE	7/21 (100%)	89	-27 patents per capita	11/21 (52%)	59	-64 patents per capita

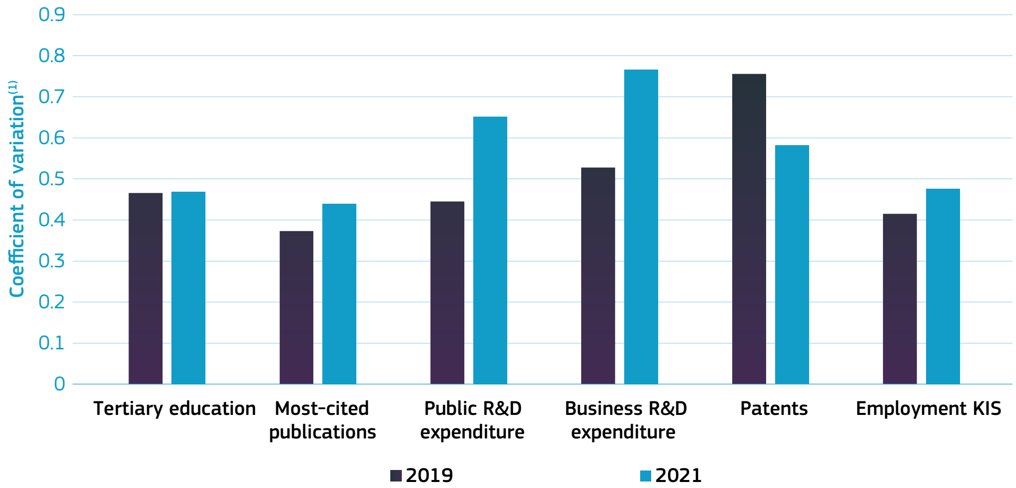
Science, Research and Innovation Performance of the EU 2022

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

Note: [1]Only countries where at least one region has a number of patents per capita above EU average are represented in this table.

Since the onset of the COVID-19 pandemic, it appears that the dispersion across EU regions has increased for several R&I indicators other than technological production, including R&D expenditures, employment in knowledge intensive sectors and most cited publications (Figure 2.2-12). This reflects that some regions are failing to catch up with the best-performing regions, which continue to improve their innovative capacity and to produce scientific knowledge. It may accentuate the dispersion observed since 2017 and put a definitive halt to the convergence patterns, not only in terms of research outputs, such as patents, but also in terms of R&D investments.

Figure 2.2-12: Regional disparities in key R&I components in 2019 and 2021 according to Regional Innovation Scoreboard

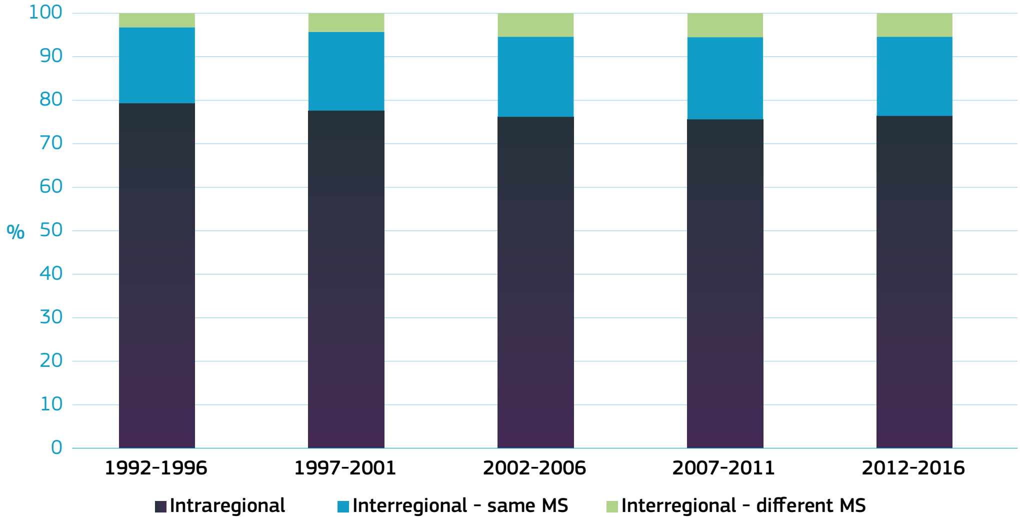


Source: DG Regional and Urban Policy, based on Regional Innovation Scoreboard 2021.
Note: [1]The coefficient of variation (CV) is the ratio of the standard deviation to the mean. which shows the extent of variability of data in a sample in relation to the average value. The higher the coefficient of variation. the greater the level of dispersion around the mean.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-2-12.xlsx

Collaboration on R&I activities at regional level

Interregional co-patenting remains very limited in the EU, even if it has slightly increased from 1992 to 2016. Over 75% of collaborations on patents (co-patenting) take place within the same region, somewhat less than 20% are interregional with stakeholders in other regions of the same country and only 3-5% are interregional across national borders (Figure 2.2-13). Still, there are some improvements in terms of interregional collaboration beyond national borders as the share increased from 3.2% over 1992-1996 to 5.4% over 2012-2016.

Figure 2.2-13: Inter- and intra-regional collaboration in patenting (co-patenting) in Europe over the period 1992-2016



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Balland and Boschma (2019).

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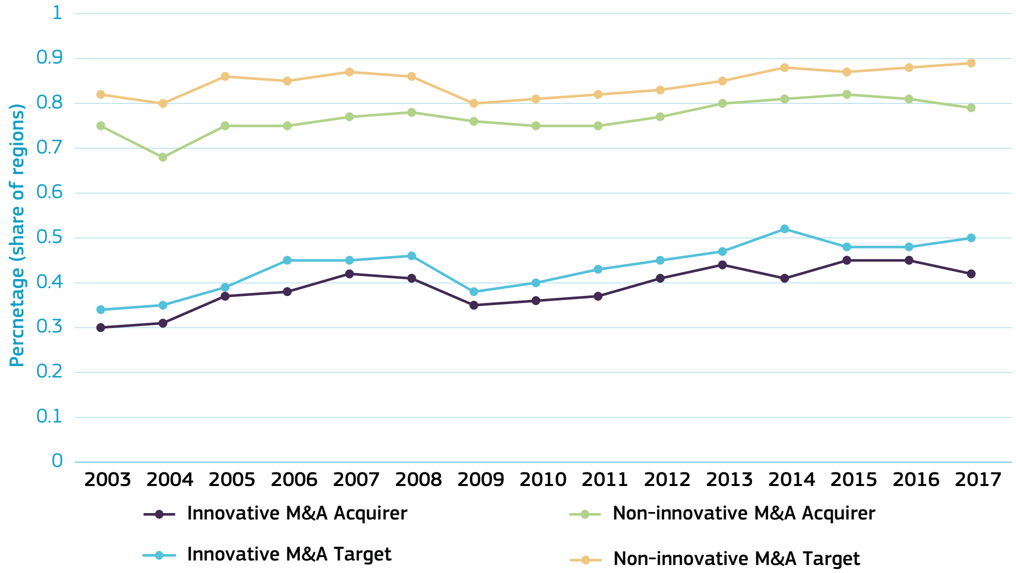
The importance of proximity goes beyond production of research and innovations as it seems that knowledge diffusion also remains mostly national. For example, the EIB (2021) used the cross-country citation index, which measures how often countries refer to one another in relative terms, to demonstrate **that most green knowledge stays within national borders or regions.** For both technological innovation and diffusion of knowledge, collaboration and circulation across regions and Member States is as critical to tackling global societal challenges as proximity can be. It ensures that inventions and knowledge benefit from work already done by others. Policy implications include strengthening the ties between regions across national borders, including through R&I policies at European level.

Innovative cross-regional merger and acquisitions (M&A) when the target company had filed patent applications prior to the deal **predominantly involve companies located in more-developed regions** (Figure 2.2-14). Integrating business units through M&A is usually to access new markets (new products or new locations), increase market power, efficiency or financial strength, take advantage of opportunities for diversification or acquire valuable assets such as technology or talented teams of workers (Andrade et al., 2001; Carpenter and Sanders, 2007; Gopinath, 2003). M&A that involve different locations are an important tool to promote mutual learning, collaborative knowledge-creation and diffusion across space.

Figure 2.2-14: Yearly share of regions involved in acquisitions[1] by deal type and company location, 2003-2017



Science, Research and Innovation Performance of the EU 2022

Source: Aquaro, Damioli and Lengyel (2020).

Note: [1]Acquisition is considered as innovative when the target company made one or more patent applications in the 20 years prior to deal completion.

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Companies located in less-developed and in transition regions show very low or negligible proportions of involvement in M&A deals. Table 2.2-4 illustrates that, in the case of innovative deals, 91.9 % of acquirers and 88.3 % of targets were located in more-developed regions 2003-2017. In comparison, when it comes to non-innovative deals, these shares were higher. About 81.9 % of acquirers and 88.4 % of targets were located in more-developed regions. **In total, more-developed regions were home to both acquirers and targets for 84.1 % of innovative acquisitions** and for 77.6 % of non-innovative ones (Aquaro et al., 2020). All deals involving companies in less-developed and transitional regions did not exceed 7 % of total deals.

Table 2.2-4: Number of M&A deals, both innovative and non-innovative, by category of European region, 2003-2017

	Innovative M&A deals					Non innovative M&A deals			
Targets / Acquirers	Less developed	Transition	More developed	All	Targets / Acquirers	Less developed	Transition	More developed	All
Less developed	2.9	0.3	1.6	4.9	Less developed	6.1	0.3	1.9	8.3
Transition	0.4	0.3	2.6	3.2	Transition	0.6	0.3	2.4	3.3
More developed	3.3	4.5	84.1	91.9	More developed	6.8	4	77.6	88.4
All	6.6	5.1	88.3		All	13.5	4.6	81.9	

Science, Research and Innovation Performance of the EU 2022

Source: Aquaro, Damioli and Lengyel (2020).

Note: An acquisition is considered as innovative when the target company made one or more patent applications in the 20 years prior to deal completion. GDP per capita as the criteria adopted by regional Cohesion Policy in the 2014-2020 EU programming period has been used to classify regions as more developed (more than 90% of EU-28 average GDP per capita), transitioning (between 70% and 90%) and less-developed regions (less than 70%).

2. Regional specialisation in R&I across different thematic areas

R&I in specific thematic activities is often concentrated in a relatively small number of regions. As regions gain reputation as hotspots for particular activities, they attract more talent working in these specific domains, resulting in local specialisation. This is particularly the case for more central regions. It appears that local concentration is more important for technological innovation than for scientific production. For technological production, there is indeed a need to reach a critical mass that might act as a catalyst for interaction between the different agents of the regional innovation system (Buesa et al., 2010).

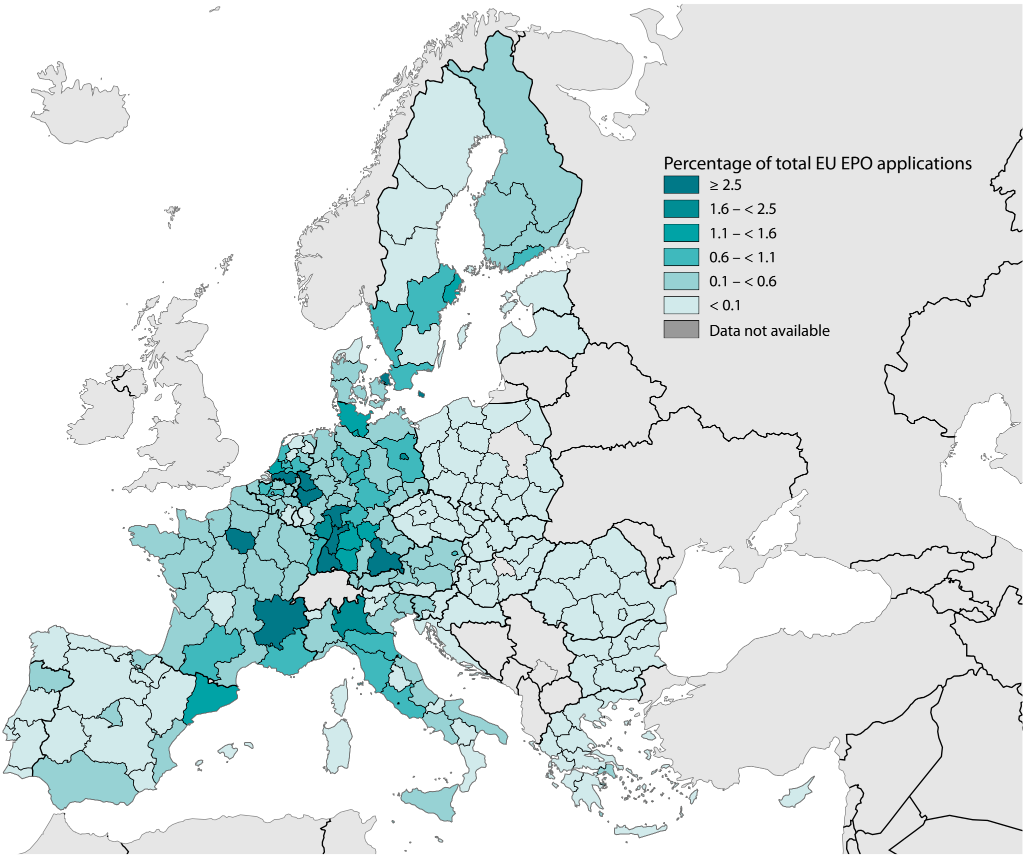
Health

There is a high degree of local specialisation in health when it comes to technological innovation (Figure 2.2-15). The top ten regions in Europe filed about 40% of the total patent applications between 2003 and 2018 (Table 2.2-5). The high degree of regional specialisation in health can partly be explained by the localisation of top pharmaceutical industrial clusters and ecosystems, such as the Biotech-Cluster Rhine-Neckar, with more than 100 members, including small and large companies. It can also be explained by the localisation of large research centres, such as the Karlsruhe Institute of Technology or the BioM-Munich Biotech Cluster located in Oberbayern (DE), with more than 255 members, including 200 SMEs and 50-70 start-ups, or Medicon Valley Alliance in Hovestaden (DK), also with more than 250 members, including 230 SMEs[5].

Top pharmaceutical companies are part of these clusters or are located in the top regions: Bayer, Janssen in Köln (DE) and Merck in Darmstadt (DE). Unlike other industries, pharmaceutical patents relate to products with particularly long development cycles. For example, a new drug requires on average 10-15 years of development, from the early stages of conception to the final approval by health authorities (Lansdowne, 2020). Besides, developing R&I in health requires significant investment, particularly in terms of infrastructure and research equipment. This can explain to some extent the local specialisation in technological production as not too many companies can afford to make such long-term investments in R&D.

5 Reference on industrial clusters: European Cluster Collaboration Platform

Figure 2.2-15: Contribution of each EU region to the total number of patent applications to EPO (fractional counting) in Health over the period 2003-2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, adapted from DG Regional and Urban Policy study The importance of scientific domains for technological diversification in European regions (Balland and Boschma, 2021).

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Table 2.2-5: Contribution of the top ten EU regions to the total number of patent applications to EPO (fractional counting) in Health over the period 2003-2018.

TECH LEADERS[1]	% patents	No. patents	Patents per 1 000 inhbts.	% population 2018	SCIENCE LEADERS [2]	% publications	No. publications	Publications per 1 000 inhbts.	% population 2018
Île de France (FR)	8.3	22 060	22.1	2.7	Île de France (FR)	5.2	266 743	22.1	2.7
Darmstadt (DE)	4.9	13 047	13.2	0.9	Lombardia (IT)	2.8	143 374	14.3	2.2
Oberbayern (DE)	4.8	12 601	23.9	1.0	Comunidad de Madrid (ES)	2.4	123 004	19.3	1.5
Hovedstaden (DK)	3.7	9 691	51.8	0.4	Cataluña (ES)	2.3	117 009	15.8	1.7
Noord-Brabant (NL)	3.6	9 431	8.0	0.6	Lazio (IT)	2.3	116 318	19.7	1.3
Düsseldorf (DE)	3.3	8 821	11.7	1.2	Oberbayern (DE)	2.1	107 915	23.9	1.0
Karlsruhe (DE)	3.1	8 151	30.7	0.6	Noord-Holland (NL)	2.1	107 664	39.0	0.6
Köln (DE)	2.7	7 167	19.4	1.0	Zuid-Holland (NL)	2.0	102 418	28.4	0.8
Rhône-Alpes (FR)	2.6	6 781	12.5	1.5	Berlin (DE)	2.0	101 218	29.2	0.8
Freiburg (DE)	2.5	6 674	17.9	0.5	Stockholm (SE)	1.8	94 430	43.0	0.5
Average all EU regions	0.43	1.15	0.52	0.42	Average all EU regions	0.43	22.3	10.67	0.42
Contribution top ten	39.4 %	104 424	----	10.4	Contribution top ten	25.0	1 280 093	---	13.3

Science, Research and Innovation Performance of the EU 2022

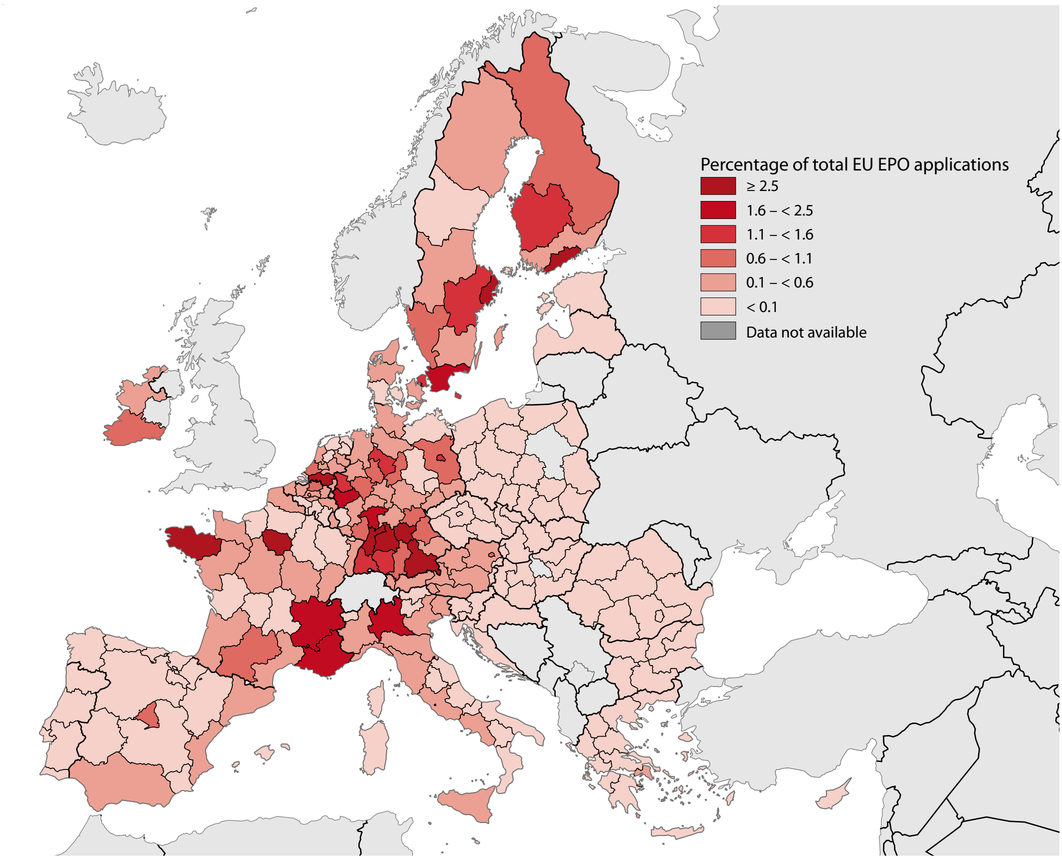
Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, adapted from DG Regional and Urban Policy study *The importance of scientific domains for technological diversification in European regions* (Balland and Boschma, 2021).

Note: [1]Tech Leaders: top ten regions in number of patents. [2]Science leaders: top ten regions in number of publications 2003-2018.

Information and communication

Information and communications innovations are highly concentrated, with the top ten regions filing more than 45 % of patents in the EU (Figures 2.2-16 and Table 2.2-6). The distribution of patents is consistent with the localisation of the largest industrial clusters in ICT and some of the most innovative companies in the world. Among such clusters and companies are the Baden Württemberg Connected e.V. cluster in Stuttgart (DE), the BICCnet Bavarian Information and Communication Technology Cluster in Oberbayern (DE), with close to 600 members, including 230 SMEs and Siemens, the CyberForum e.V.

Figure 2.2-16: Contribution of each EU region to the total patent applications to EPO (fractional counting) in the ICT sectors over the period 2003-2018



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, adapted from DG Regional and Urban Policy study *The importance of scientific domains for technological diversification in European regions* (Balland and Boschma, 2021).

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Table 2.2-6: Contribution of the top ten EU regions to the total patent applications to EPO (fractional counting) in the ICT sectors over the period 2003-2018

TECH LEADERS [1]	% patents	No. patents	Patents per 1 000 inhbts.	% population	SCIENCE LEADERS [2]	% publications	No. publications	Publications per 1 000 inhbts.	% population
Île de France (FR)	8.8	19 940	1.7	2.7	Île de France (FR)	5.3	57 381	4.7	2.7
Oberbayern (DE)	8.3	18 848	4.2	1.0	Cataluña (ES)	2.4	25 434	3.4	1.7
Noord-Brabant (NL)	5.5	12 505	5.0	0.6	Comunidad de Madrid (ES)	2.3	24 606	3.9	1.4
Stockholm (SE)	4.3	9 853	4.5	0.5	Rhône-Alpes (FR)	2.1	22 941	3.5	1.5
Stuttgart (DE)	4.0	9 177	2.3	0.9	Oberbayern (DE)	2.1	22 914	5.1	1.0
Mittelfranken (DE)	4.0	8 966	5.2	0.4	Lombardia (IT)	1.7	18 200	1.8	2.3
Helsinki-Uusimaa (FI)	3.1	7 059	4.4	0.4	Lazio (IT)	1.6	17 336	2.9	1.3
Bretagne (FR)	2.7	6 060	1.8	0.7	Berlin (DE)	1.6	17 046	4.9	0.8
Karlsruhe (DE)	2.6	5 816	2.1	0.6	Wien (AT)	1.6	16 966	9.4	0.4
Rhône-Alpes (FR)	2.3	5 229	0.8	1.5	Southeast Ireland (IE)	1.6	16 813	4.4	0.9
Average all EU regions	0.44	985.9	0.43	0.42	Average all EU regions	0.43	4704	0.42	0.43
Contribution of top ten	45.6	103 453	-------	9.3	Contribution of top ten	22.2	239 637	---	14.0

Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, adapted from DG Regional and Urban Policy study The importance of scientific domains for technological diversification in European regions (Balland and Boschma, 2021).

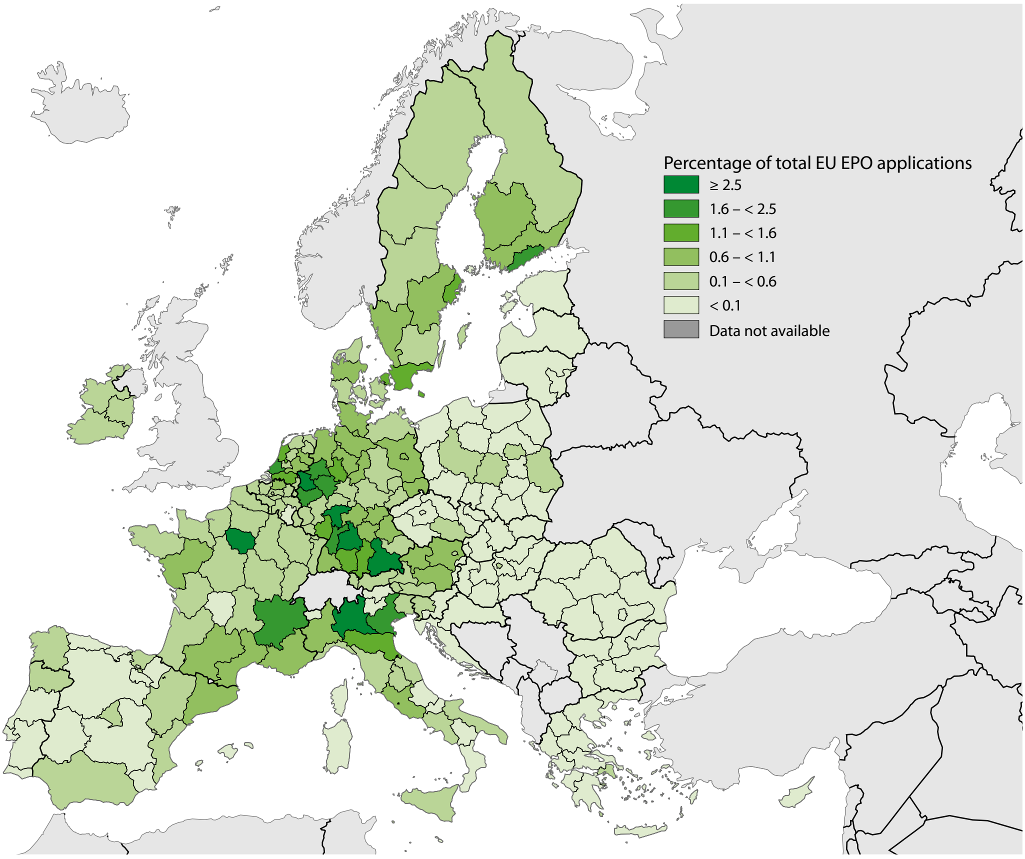
Note: [1]Tech Leaders: top ten regions in number of patents. [2]Science leaders: top ten regions in number of publications 2003-2018.

cluster, with more than 1 100 members, including 1 050 SMEs, in Karlsruhe (DE), Philips in Noord-Brabant (NL), Bosch in Stuttgart (DE), Nokia in Helsinki-Uusimaa (FI), the Cap Digital cluster, with more than 1 000 members, and the Systematic Paris-Region cluster, both in Ile-de-France (FR), and the Digital League cluster in Rhône Alpes (FR) (BCG, 2021). Public research institutions have also played a role, even if it is characterised by a lower propensity to file patents (Buesa et al., 2010). For example, Mittelfranken (DE) hosts the University of Erlangen-Nuremberg, ranked as the second most innovative university in Europe in 2019 (Reuters, 2019), while Rhone-Alpes (FR) and Bretagne (FR) both host large research labs of the France's National Centre for Scientific Research, one of the most innovative players in France (INPI, 2020).

Climate change, environment, resource efficiency and raw materials

Patenting in climate change. environment. resource efficiency and raw materials tends to be less concentrated across the different EU regions: the top ten regions filed about 30% of total patents applications (Figures 2.2-17 and Table 2.2-7). Among the top firms in the domain of energy and materials is Royal Dutch Shell in Zuid-Holland (NL), while among top innovative universities are the Technical University of Munich in Oberbayern (DE) and the Technical University of Denmark in Hovestaden (DK) (Reuters, 2019). Patenting in this area is, in absolute numbers, much less important than in the other domains. Due to a high rate of knowledge spillovers for green innovations and the existence of path dependence, green technological innovations may require more public support than other types of technological development (Roed Nielsen et al., 2016) (see Chapter 3 – R&I for sustainability).

Figure 2.2-17: Contribution of each EU region to the total number of patent applications to EPO (fractional counting) in climate change, environment, resource efficiency and raw materials over the period 2000-2018.



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, adapted from DG Regional and Urban Policy study *The importance of scientific domains for technological diversification in European regions* (Balland and Boschma, 2021).

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Table 2.2-7: Contribution of the top ten EU regions to the total number of patent applications to EPO (fractional counting) in climate change, environment, resource efficiency and raw materials over the period 2000-2018.

TECH LEADERS [1]	% publications	No. publications	Publications per m. inhbts.	% population	SCIENCE LEADERS [2]	% patents	No. patents	Patents per m. inhbts.	% population
Île de France (FR)	3.3	28 923	2 353	2.7	Île de France (FR)	5.2	465	38.1	2.7
Cataluña (ES)	2.4	20 713	2 707	1.7	Düsseldorf (DE)	3.2	286	55.0	1.2
Andalucía (ES)	2.1	18 471	2 179	1.9	Stuttgart (DE)	3.1	277	67.2	0.9
Comunidad de Madrid (ES)	2.1	18 032	2 673	1.5	Oberbayern (DE)	2.8	254	54.6	1.1
Lombardia (IT)	2.0	16 921	1 687	2.2	Lombardia (IT)	2.8	250	24.9	2.2
Lazio (IT)	2.0	16 918	2 939	1.3	Darmstadt (DE)	2.5	224	56.2	0.9
Oberbayern (DE)	1.6	13 581	2 883	1.1	Rhône-Alpes (FR)	2.3	210	31.7	1.5
Hovedstaden (DE)	1.5	13 186	7 143	0.4	Arnsberg (DE)	2.2	199	55.5	0.8
Zuid-Holland (NL)	1.5	13 164	3 516	0.8	Köln (DE)	2.2	195	43.7	1.0
Helsinki-Uusimaa (FI)	1.5	12 936	7 656	0.4	Karlsruhe (DE)	2.2	195	69.6	0.6
Average all EU regions	0.4	6 837	1 844	0.4	Average all EU regions	0.4	37.4	18.5	0.4
Contribution of top ten	20	172 844	---	14	Contribution of top ten	29	499		13

Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, adapted from DG Regional and Urban Policy study The importance of scientific domains for technological diversification in European regions (Balland and Boschma, 2021).

Note: [1]Tech Leaders: top ten regions in number of patents. [2]Science leaders: top ten regions in number of publications 2003-2018.

Table 2.2-8: Patent applications to EPO (fractional counting), 2000-2018. Percentage of total in the top ten regions per technologies

Regional specialisation	Nano-technologies	Micro- and nano-electronics	Advanced manufacturing technologies	Advanced materials	Photonics	Industrial bio-technology
Auvergne-Rhône-Alpes (FR)	13.30	11.20	6.17	4.61	3.64	3.78
Baden-Württemberg (DE)	11.56	9.66	8.52	6.00	11.65	6.00
Zuid-Nederland (NL)	7.38	10.37	6.79	3.81	13.51	
Ile-De-France (FR)	6.19	4.54	5.58	4.85	7.26	6.56
Bayern (DE)	6.06	18.42	10.79	7.41	11.22	8.15
Nordrhein-Westfalen (DE)	4.82	4.10	9.11	12.62	7.38	8.60
Vlaams Gewest (BE)	3.75	4.64	2.92		2.12	4.08
Hessen (DE)		3.26	3.42	5.34	2.83	4.00
West-Nederland (NL)	3.12		2.66			5.34
Nord-Ovest (IT)	3.04			3.37	3.67	
Södra Sverige (SE)	2.42					
Sachsen (DE)		3.47				
Südösterreich (AT)		2.77				
Östra Sverige (SE)			3.05			
Rheinland-Pfalz (DE)				5.15		
Westösterreich (AT)					3.56	
Berlin (DE)						3.51
Danmark (DK)						4.48
Région Wallonne (BE)				3.83		
Contribution of top 10 regions to EU total	61.6%	72.4%	57.1%	59.0%	67.0%	54.5%

Science, Research and Innovation Performance of the EU 2022

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

When it comes to patenting activity related to strategic areas and key technologies, European capital regions are not in the lead; there is also a high degree of concentration. Local specialisation is very high, with the top ten EU regions filing 55-72 % of patent applications related to nanotechnologies, micro- and nano-electronics, advanced manufacturing and materials, photonics and biotechnology (Table 2.2-8).

The high degree of regional concentration in technological development in some areas, such as health and ICT, demonstrates the importance of technology transfer across Europe and beyond. Regions capable of keeping pace with technological progress tend to be more resilient in times of structural change and better equipped to face new challenges and to compete globally. To profit from new opportunities, notably as regards digital technologies, firms need to have a sufficient level of absorptive capacity. This capacity is fundamental to making productive use of globally distributed knowledge networks (Asheim et al., 2019). Resilience at regional level will partly depend on the development of innovation systems and intermediaries that can encourage diffusion and absorption of productivity enhancing technologies, as well as the ability to build on national and regional capabilities to generate new knowledge.

Read more in Chapter 14 – Innovation policy for a complex world

(Pierre-Alexandre Balland, Utrecht University)

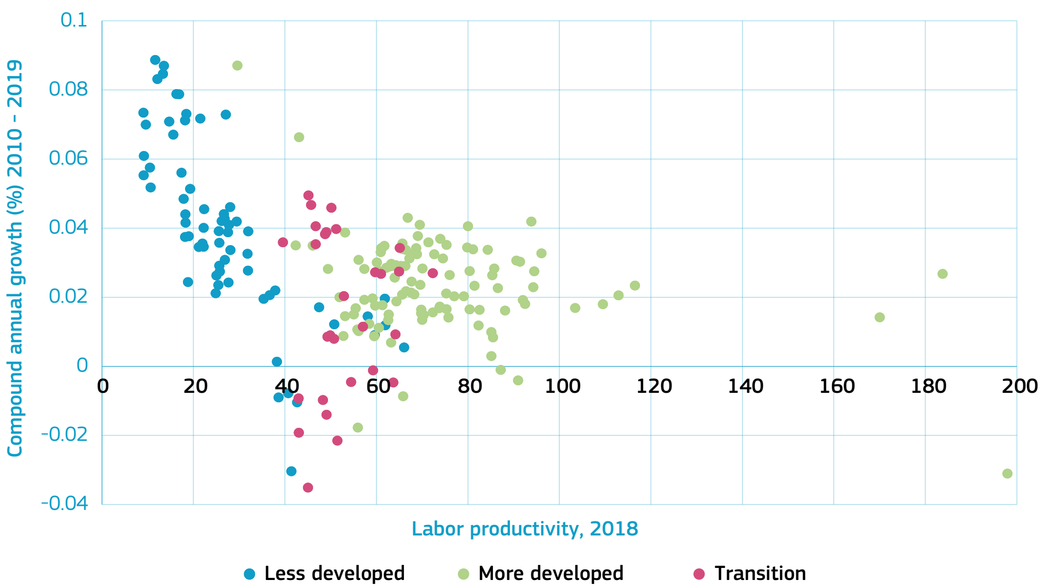
This chapter examines theoretically and empirically the spatial concentration of innovation in EU regional ecosystems. It proposes a detailed geography of patents in several strategic areas and key technologies such as artificial intelligence, blockchain, quantum computing, batteries, hydrogen, mRNA, and oncology diagnostics and treatments, and looks at the complementarities across EU regions.

The chapter focuses on the importance of leveraging regional ecosystems with human and artificial intelligence and shows how this approach can be used to assess potential new opportunities for collaboration across EU regions and to optimise knowledge sharing to increase EU competitiveness in strategic areas and some key technologies.

3. The impact of regional R&I disparities on productivity and growth

Regional disparities play a part in the European productivity story. In addition to the general drivers of the secular slowdown in productivity growth (see Chapter 4.1 – Productivity), regional divergencies are particularly pronounced in many Member States, driven inter alia by growing gaps between capital and other metropolitan and non-metropolitan regions. Overall, there seems to be some degree of convergence in productivity performance as witnessed by the negative relationship between productivity levels and productivity growth (Figure 2.2-18). It is driven mainly by regions in less-developed EU countries, especially in central and eastern Europe, which recorded relatively high productivity growth, albeit from low starting levels. However, **many European regions seem to face the middle-income trap and struggle to make the transition from middle-income to high-income status** (Borunsky et al., 2020). There is thus little correlation between productivity levels and growth in these transition regions. They often experience a problematic combination of moderate productivity levels and low productivity growth. A similar situation can even be observed in some more-developed regions. **Many regions in more-developed countries with average productivity levels, such as regions in the south of Europe or regions with industrial transition issues, are no longer catching up**. These trends hint at the risk of some kind of middle-income trap, jeopardising the convergence process.

Figure 2.2-18: Labour productivity[(1)], 2018 and compound annual growth, 2010-2018 by regional development



Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit, based on Eurostat.
Note: [(1)]GDP per worker in current PPS. FR and PL NUTS2 regions not included.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-2-2-18.xlsx

EU regions with good R&I performance also have high productivity. Indicators of R&I performance show strong performance in regions that have the highest productivity levels (Table 2.2-9). This positive link also holds for regions ranking high in productivity growth. However, the very top regions (80-100% quintile) in terms of productivity growth present slightly lower R&I indicators. This can be explained by the presence of many CEE regions, in particular Bulgarian and Romanian regions. All CEE Member States show levels of labour productivity that remain below the EU average. On the other hand, these regions show a tendency for stronger growth rates in countries that started from lower levels, such as Romania or Bulgaria, reflecting the convergence process (Correia et al., 2018). And **while there is**

Table 2.2-9: R&I indicators by regional quintiles[1] for productivity

		Labour productivity 2019					Productivity growth 2010-2019				
		0-20%	20-40%	40-60%	60-80%	80-100%	0-20%	20-40%	40-60%	60-80%	80-100%
R&D per capita 2019	Average	92.8	229.5	482.4	925.7	1 480.6	304.9	911.7	843.8	507.6	175.1
	Median	82.1	204.6	456.8	702.0	1 326.0	204.6	655.4	736	273.2	98.0
Business R&D per capita 2019	Average	56.7	120.0	264.5	637.8	998.1	156.3	620.4	585.2	342.3	109.2
	Median	41.3	100.5	227.2	561.8	697.6	80.7	373.7	566.4	183.5	35.4
Patents per m. inhbts. 2018	Average	8.8	19.9	73.3	134.6	210.9	30.7	119.3	170.1	84.9	42.6
	Median	6.3	13.4	47.9	100.6	178	15.7	99.4	140.4	31.8	30.9
Publications per 1 000 inhbts. 2020	Average	0.6	1.1	1.0	1.2	2.1	1.4	1.4	1.4	1.1	0.8
	Median	0.6	1.1	0.9	1.2	2.2	1.3	1.2	1.1	0.8	0.7
Highly cited publications (top 10%) per m. inhbts. 2020	Average	0.2	0.8	1.1	1.5	3.0	1.4	1.8	1.8	1.0	0.7
	Median	0.2	0.7	1.0	1.4	2.7	1.0	1.2	1.4	0.5	0.5

Science, Research and Innovation Performance of the EU 2022

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

Note: [1]Regional quintiles for productivity are based on GDP PPS per worker. The green gradient is applied by blocs so that the colouring only considers single indicator row for calculating the gradients thresholds.

substantial heterogeneity in the evolution of innovation performance across CEE regions, many remain modest innovators. One of the crucial reasons for their low innovation performances are the low levels of investment in intangible assets, such as R&D. As in the rest of the EU, CEE countries are not making sufficient strides to improve their R&D investment and continue to lag significantly behind in R&D intensity. However, the rapid economic growth and fast convergence process seem to keep productivity growth above the EU average (Borunsky et al., 2020). In such cases, much of the growth has been fuelled by a combination of factors, such as the rapid expansion of global supply chains and foreign direct investment, with a smaller role for innovation-driven productivity growth.

Regions that are catching up from low levels of productivity seem to profit from knowledge diffusion via international companies and capital deepening. In many less-developed regions, notably in Romania, Bulgaria and Poland, the high levels of productivity growth have not been underpinned by good performance of the corresponding R&I systems (Table 2.2-9). Prior to the crisis, CEE countries captured capital inflows, with foreign direct investment being the most important component. After the financial crisis, capital inflows to the regions slowed down and lower efficiency gains associated with them led to declines in productivity growth (Correia et al., 2018). At the same time, regional economies of southern European, notably Italy and Greece, experienced lower productivity growth, a trend that exacerbated after the economic crisis, halting the convergence process. **The fast pace of innovation dynamics poses new challenges to the production systems of many less-developed regions, which are often not sufficiently oriented towards knowledge intensive sectors, as mirrored in the lower performance of their regional R&I systems**. Many transition regions characterised by low R&I performance have also not done well in productivity growth. This implies that regions, in particular less-developed ones, should shift to a knowledge based and innovation-driven growth model to continue to catch up. This would help to avoid the middle-income trap that has affected the development of many transition regions in the recent past.

Box 2.2-1: The EU added value of support to location-based innovation

Transnational collaboration is deeply enshrined in the EU legal bases and can even be defined as the *raison d'être* of European R&I policy and programmes. However, are there arguments for substantial 'European added value' that supports activities largely taking place in one location?

The treaties on the functioning of the European Union[6] make several references to facilitating free movement of knowledge and the promotion of collaborative activities, notably in Article 180.

In pursuing these objectives, the Union shall carry out the following activities, complementing the activities carried out in the Member States:

(a) implementation of research, technological development and demonstration programmes, by promoting cooperation with and between undertakings, research centres and universities;[...]

Yet for the European research area to be achieved[7], the Union shall '[promote] all the research activities deemed necessary by virtue of other Chapters of the Treaties.' The European Green Deal as the EU's growth strategy embraces the green and digital transitions and guides environmental, agricultural, marine and industrial policy. All these domains recognise the role of local networks for innovation, including technical demonstration as well as social and governance innovation (e.g. in local innovation test beds). Different socio-economic, cultural and administrative environments lead to different innovative solutions to the same challenge. Analysing diverse environments in terms of what works where is an essential part of joint learning and contributes to 'dissemination and optimisation of results' (Article 180(c)).

The high value assigned to transnational cooperation is reflected in the Horizon Europe framework programme as it states that 'except in duly justified cases where the work programme otherwise provides, legal entities forming a consortium shall be eligible for participation…'[8]. It also defines certain action types for which support of single entities is justified, namely:

- ERC grants based on consideration of European excellence;
- the EIC, for which the argument was accepted in the negotiation of Horizon 2020.

If the green transition and achieving climate neutrality by 2050 is seen as an all-encompassing innovation project requiring joint learning, the experiences from local actors' networks, the multi-actor-approach, can be considered as a contribution to a European added value, even if a single project has no transnational nature. The (obligatory) contribution to the joint learning efforts would provide for this.

Acknowledging this argument could tremendously ease the creation of synergies between the framework programme for R&I and other EU programmes under indirect management, such as cohesion funds or the European Maritime, Fisheries and Aquaculture Fund, in particular in the context of European Missions. The framework programme would mobilise local innovation networks through competitive EU-level calls to create a portfolio of funded projects under diverse environments (i.e. excellence in terms of best in different classes versus excellence in terms of best in Europe). It would also provide a joint learning environment that includes horizontal scientific analysis. Excellent projects not fundable due to budget limitations would be awarded a seal of excellence and could easily be taken up by national and regional support schemes as the projects would not be based on transnational partnerships.

6 Article XIX 'Research and technological development and space', Articles 179 and 180

7 Article 179(1)

8 Article 22(2) of the Horizon Europe Framework Programme

4. Conclusions: a fragmented regional R&I ecosystem

This chapter proposes a state of play and dynamics of regional R&I in the EU. It demonstrates that R&I inputs and outputs are concentrated in more-developed regions, although the contribution to the EU total of the least-performing regions has increased slightly in the last decade in terms of research inputs (R&D investments, notably). **Besides, patenting activity in health, ICT and climate mitigation technologies is highly concentrated** in a few EU regions. European R&I policies could target **different types of innovation according to territorial specificities in terms of peripherality and economic structure to achieve a better match between competitiveness and inclusiveness goals**. European policies must put greater emphasis on promoting innovation combined with more focus on the local context to trigger economic dynamism in less-developed regions.

Recent developments have halted the convergence process across EU regions in terms of technological production as the least-innovative regions had a decreasing rate of patent applications over 2013-2018. Moreover, regions with lower or moderate innovation capacity still rely more on the public sector for R&D investments than those with strong innovation capacity. **Many European regions seem to face the middle-income trap and struggle to transition from middle-income to high-income status**. For less-developed regions, which tended to have stronger growth rates in countries that started from lower levels, **much of the growth has been fuelled by a combination of factors** such as the rapid expansion of global supply chains and foreign direct investment. **There has been a smaller role for innovation-driven productivity growth**. This tendency to higher dispersion across regions is well-documented and applies to many other characteristics (e.g. economic growth, wage developments), pointing at a rise in regional inequality in Europe (Rodríguez-Pose et al., 2018). This is not a uniquely European problem, but one common to many countries, both developed and developing (Ganong and Shoag, 2015).

The green and digital transitions pose different challenges to innovation policy than growth orientation alone. Integration into global value chains and (foreign) direct investment in sectors of recognised competences have been drivers for growth in many regions and were often the focus of R&I policies. **The green transitions of societies will be realised through location-based innovation, i.e. deeper interaction in local stakeholder networks enabled by digital technologies**. Societal transformation will redefine the role of local knowledge generation versus experimentation with the recombination of existing approaches and technologies. R&I activities are increasing, even in less-developed regions, as shown by the increasing number of publications. This is a strength and an encouraging signal in this respect.

Effective public support for innovation must **further identify and understand both specificities and local obstacles in the single market that could block the potential** of regional innovation to increase the competitiveness of the EU, address the innovation divide and leave no one behind. Europe's full economic potential will not be achieved without tackling the fragmentation of the European innovation ecosystem and enhancing the synergies and **coordination at all levels**. These include **R&I policies and Cohesion Policy**, together with education and training implemented through a broad range of instruments. A place-based approach to promoting innovation, especially the diffusion and commercialisation of existing innovation in lagging regions, is critical. This approach could be supported in line with the specificities of each region, and regions' current or possible comparative advantages as mapped in smart specialisation strategies.

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