European Commission

Horizon Europe
Strategic Plan 2025-2027
Analysis

Research and Innovation

Horizon Europe Strategic Plan 2025–2027 Analysis

European Commission
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Directorate-General for Research and Innovation
Horizon Europe

Contents

Foreword

Research and innovation (R & I) play a crucial role in shaping the future of our societies. Against the backdrop of recent crises, and the increasingly complex global landscape, the European Union (EU) has placed R & I at the heart of its policy agenda to foster a knowledge-based and innovation-driven economy and society. To realise the EU's objectives – notably an inclusive green and digital transition – R & I investments are essential.

Horizon Europe, the European Framework Programme (2021-2027) for R & I, is EU's flagship to support top quality, excellence-based R & I to deliver Europe's transitions and prepare our societies for future challenges. The outstanding R & I results achieved during the programme's first years are in line with the key strategic orientations of the first Strategic Plan covering the years 2021-2024, upon which we should now continue to build further.

This Horizon Europe Strategic Plan 2025-2027 Analysis underpins the development of the Strategic Plan for these years. It ensures that key strategic orientations are built on a solid evidence base. Being the result of an extensive co-design exercise, integrating a wide range of views and the main outcomes of the public consultation and citizen engagement, the analysis stresses the importance of the EU's investments in R & I to encourage the development of a vibrant and dynamic R & I ecosystem. Such investments are needed to address some of the most pressing challenges of our time, such as climate change, energy security, health, and the digital transformation. It also highlights the need for a coordinated and strategic approach to R & I at the EU level to ensure that resources such as skills and funds are effectively used, and the benefits of R & I are widely shared across all Member States and beyond.

The EU's R & I policy is not only about funding projects and initiatives, but also about offering an environment that fosters creativity, entrepreneurship, and collaboration. It is about empowering individuals and organisations to develop new ideas, products, and services that can improve our lives, drive competitiveness, and stimulate inclusive and sustainable economic growth.

The analysis provides a comprehensive overview of global developments and the EU's R & I strengths, limitations, objectives, gaps and needs. Such a thorough analysis is needed to ensure that R & I play its full part in shaping our societies and economies. I strongly believe this analysis will serve as a string and sound foundation for the next Strategic Plan, as well as an excellent resource for policymakers, researchers, innovators, and citizens across Europe and beyond.

Marc Lemaître
Director General,
Directorate General for Research and Innovation,
European Commission

PREFACE

The Horizon Europe Strategic Plan 2025–2027 will set out the key strategic orientations for the final years of the EU's largest research and innovation (R & I) programme to date – Horizon Europe. This Horizon Europe Strategic Plan 2025–2027 analysis underpins the development of the Horizon Europe Strategic Plan 2025–2027 by providing a solid evidence base, as set out in the legal basis of Horizon Europe ([1]).

In particular, the analysis shows developments since the first Strategic plan of Horizon Europe (2021–2024) ([2]). The analysis explores whether the changes in the context of EU policy, in the world, in society, economy and policy, in science, technology and innovation, and in our appreciation of future challenges and opportunities since the first strategic plan require a change of strategy regarding the plan's orientations, directions and activities.

Using tailor-made foresight and state-of-the-art analysis such as that in the *Science, research and innovation performance (SRIP) of the EU 2022* report ([3]), this analysis gives an overview of key political, socioeconomic and environmental drivers that are relevant for the EU and Member States' policy priorities, and challenges and opportunities we are facing as a European society, together with examples of the role R & I plays in addressing them.

This analysis provides orientations on society's demands for R & I, based on, among other sources, input gathered at a dedicated citizen engagement event on 1 December 2022 and from an online public consultation that concluded on 23 February 2023 after running for 12 weeks, with 2 258 respondents completing the section related to the Horizon Europe Strategic Plan 2025–2027.

Finally, the analysis provides an overview of current R & I activities and identifies gaps in the existing efforts by using analytics and data on the implementation of Horizon Europe, in particular related to pillar 2, which is the main focus of the Strategic Plan, and barriers to the take-up of results.

Focusing overall on the key themes of resilience and the just green and digital transition, this analysis has five sections (see Figure 1 for an overview).

1. Societal challenges and recent policies to address them

This section focuses on current global developments that affect the EU and the R & I landscape, including the consequences of the Russian invasion of Ukraine and the geopolitical context in a broader sense. It also highlights important recent EU policy initiatives that have implications for R & I efforts, the contribution of R & I to the realisation of the EU's policy objectives and approaches, and the main results from citizen engagement and the public consultation. Moreover, this section provides an overarching description of foresight considerations relevant to R & I and the considerations' implications.

2. The EU's research and innovation landscape within a global perspective

This section gives an overview of the EU and global R & I landscape, and implications for R & I priorities. By providing examples of areas where R & I activities are already strong, and where gaps exist, it aims to illustrate areas where Horizon Europe can add particular value in its final years, taking into account the activities at national level and in the rest of the world.

3. Possible new research needs and potentials arising from the global challenges

This section contains overarching orientations on the role R & I plays in addressing the major societal, environmental and economic challenges addressed by the European Green Deal, and the related transition over the next few decades towards the 2050 climate objectives. This section also covers the role R & I plays

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([1]) The legal basis of the Strategic Plan Analysis is stated in Article 6.4 of Council Decision (EU) 2021/764 establishing the specific programme implementing Horizon Europe – The framework programme for research and innovation, and repealing Decision 2013/743/EU (OJ L 167, 12.5.2021, p. 1), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021D0764&from=EN.

([2]) European Commission, Directorate-General for Research and Innovation (2021), *Horizon Europe – Strategic plan 2021–2024*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/083753.

([3]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

in the digital transition, and a more specific description of new research needs and potentials. In addition, it discusses the role of transformative R & I policies in boosting systematic change and R & I needs for increasing EU resilience.

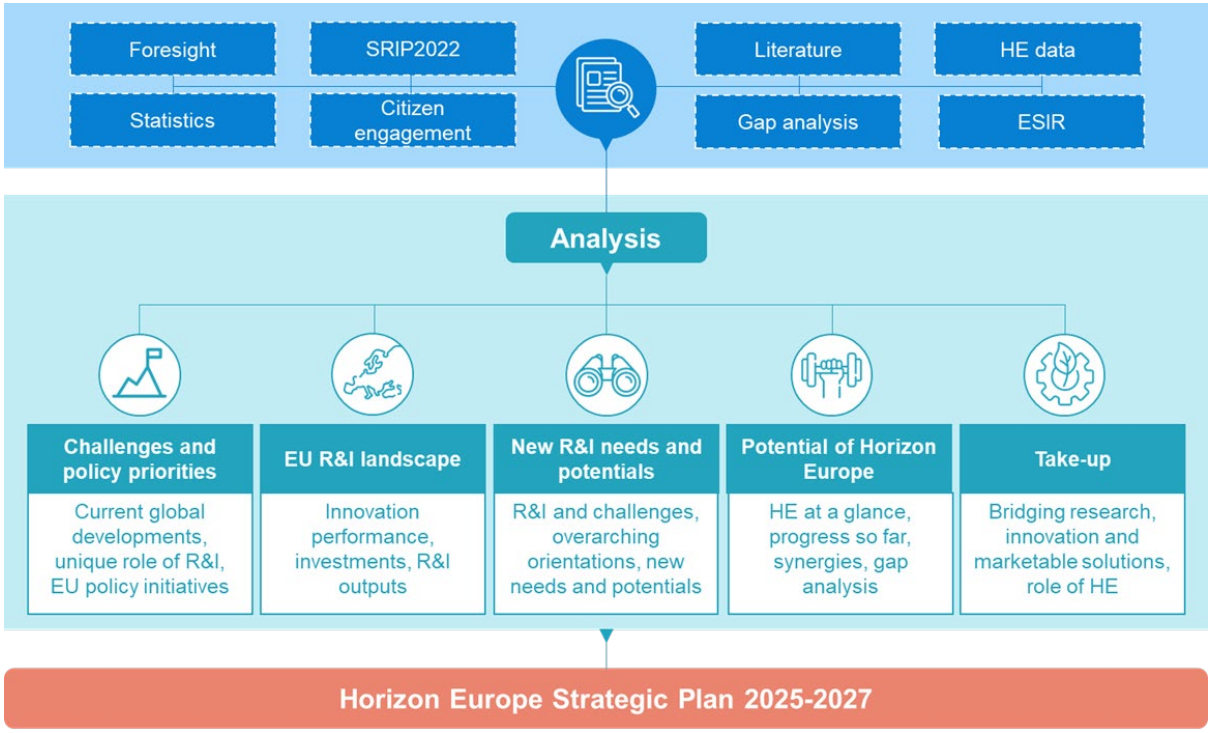
4. Potential of Horizon Europe to address important issues

This section provides orientations on relevant activities already supported by Horizon Europe, focusing on pillar 2, and on gaps in current efforts by using the gap analyses performed for each cluster. In addition, this section contains general data on the implementation and progress of Horizon Europe, and a subsection on synergies between Horizon Europe and other EU funds.

5. Considerations regarding potentials and limitations for take-up of results

This section contains orientations on relevant aspects concerning the valorisation of results and bridging the gap between basic research, innovation, and marketable solutions, including considerations regarding small and medium-sized enterprises and the role of Horizon Europe in supporting the take-up of results.

Figure 1. Overview of the Horizon Europe Strategic Plan 2025–2027 Analysis



NB: ESIR, Expert group on the economic and societal impact of research and innovation; SRIP2022, Science, research and innovation performance (SRIP) of the EU 2022 report.
Source: European Commission, Directorate-General for Research and Innovation.

EXECUTIVE SUMMARY

The past few years have been marked by global crises, including the COVID-19 pandemic, the Russian invasion of Ukraine, the energy crisis and high inflation, and the increased frequency of climate-related extreme events. These crises have resulted in greater uncertainties, increasing the urgency of progress on the EU's open strategic autonomy and resilience, and the revaluation of the EU's strategic alliances, dependencies, and international cooperation. These recent events – along with longer-term challenges such as climate change, biodiversity loss, pollution, decarbonisation, the green and digital transition, resilience, and competitiveness – provide an opportunity to 'build forward better'. Moreover, the new geopolitical context has placed the EU's just green and digital transition in the spotlight, requiring the reduction of strategic dependencies, for example on critical technologies, raw materials and finite critical minerals, and the speed-up of the net zero industrial transformation to strengthen the EU's resilience and foster its leadership in key technological domains and (global) value chains.

With the global geopolitical system expected to remain turbulent in the near future, the EU needs to be better equipped to respond to crises and developments through foresight and preparation, making use of new research and innovation (R & I) policies and initiatives. R & I play a crucial role in addressing current and future challenges, offering sustainable solutions, and driving economic growth, competitiveness, and transformative changes. Citizen engagement, along with social partners and civil society actors, is also a key focus of the EU's R & I policies to reinforce trust in science and facilitate the innovation process.

In this context, the EU remains a scientific powerhouse and has even improved its overall innovation performance in the past 7 years. However, it still lags behind the United States, Japan and China in terms of research and development expenditure as a percentage of gross domestic product. Despite producing 20 % of the world's scientific output in 2020, ranking second only to China, the EU falls behind in terms of the world share of the top 1 % most-cited scientific publications, ranking third (after China and the United States). In academic research, the EU specialises in humanities, the United States in health technologies and China in digital technologies. Scientific output in the EU is heterogeneous across regions and concentrated in a few areas, and the EU's scientific ecosystem is facing a brain drain issue, which could be addressed by offering more competitive wages, cutting-edge infrastructures, and fair promotion processes in academia. While the EU is a patenting leader, its position has been declining due to China's rise, with the EU's share of the world's patent applications declining from 31 % to 19 % between 2000 and 2018. The EU excels in patenting in the fields of advanced manufacturing and green technologies but underperforms in digital technologies.

To deliver on the European Green Deal and preserve the EU's open strategic autonomy and sustainable economic growth, significant investments in R & I are necessary. Furthermore, the EU needs to target investments in R & I in both the short term and the long term to strengthen its resilience against future cross-border threats and disruptions. This includes boosting social and place-based multi-actor innovation, which brings people from diverse backgrounds together with a common purpose. It also calls for the alignment of R & I policy and other sectoral policies at all levels of governance through a whole-of-government approach towards the sustainability agenda. At present, both technological output (as measured by patents) and the production of high-quality publications continue to be highly concentrated in a limited number of regions, and regional disparities in technological innovation have been increasing. The EU's ability to contribute to and benefit from R & I will also be strengthened through actions to address the persistent innovation divide across Member States and regions, and the deficit of interregional collaboration. This will enhance internal cohesion and deliver wider economic and social benefits.

Horizon Europe, the largest European R & I funding programme to date, with a budget of EUR 95.5 billion for 2021–2027, has the potential to drive significant public and private investments. It aims to strengthen societal and economic impacts through funding excellent and impactful investments in R & I. It also encompasses new and revitalised features such as the EU missions, an increased budget for innovators, the incorporation of the social sciences and humanities, and a new approach to European partnerships. In addition, Horizon Europe places greater emphasis on citizen engagement and international cooperation in R & I. Although 71 % of high-quality proposals go unfunded due to the programme's limited budget, the success rate of proposals under Horizon Europe (15.9 %) is higher than that under Horizon 2020 (11.9 %). To fund all high-quality proposals, an additional EUR 34 billion (approximately) would have been needed in the years 2021 and 2022. The legal framework of Horizon Europe seeks to maximise the impact of R & I policies by creating and strengthening synergies with other EU funds. Preliminary estimates show that Horizon Europe is almost on track in terms of climate mainstreaming and its commitment to spend at least 35 % of resources on climate action.

Despite the EU's strong scientific system and its leadership in applying open science, the take-up of R & I results remains a challenge. The EU struggles to match other major economies in terms of exports and job

creation in knowledge-intensive services. Improving the EU's ability to translate scientific discoveries into market solutions is a priority. To boost competitiveness, the EU's R & I policies must move beyond knowledge transfer and focus on knowledge valorisation and value creation through multi-actor approaches. This requires a more agile, transparent, and innovation-friendly regulatory framework, reducing the EU's skills shortage, promoting standardisation, and enhancing financing opportunities for innovative enterprises. Horizon Europe plays a crucial role in supporting the EU's R & I ecosystem through, for example, its missions, European partnerships, the European Innovation Council, the European Innovative Ecosystems programme and the European Institute of Innovation and Technology. Horizon Europe is also key to and promotes open science through its European Research Council, research infrastructures, along with the Marie Skłodowska-Curie actions and the European Research Area.

1. SOCIETAL CHALLENGES AND RECENT POLICIES TO ADDRESS THEM

Key messages from this chapter

- The past few years have been dominated by global crises such as the COVID-19 pandemic, the Russian invasion of Ukraine, the energy crisis and high inflation, and increasingly frequent climate-related extreme events. These crises have resulted in more uncertainties and increased the urgency of progress on the EU's open strategic autonomy and resilience, and the revaluation of the EU's strategic alliances, (technological) dependencies and international cooperation. These recent events are in addition to the longer-term challenges facing Europe, such as accelerating climate change, the pollution and biodiversity crisis, and the need for further – more inclusive and responsible – digitalisation, providing a window of opportunity to 'build forward better'.
- The new geopolitical context has placed the ambition of the EU's just green and digital transition in the spotlight. There is consensus regarding the urgency for Europe to foster its leadership in key technological domains and (global) value chains: the reduction of strategic dependencies, for example on raw materials and finite critical minerals, is necessary to keep the pace and direction of the transition, and to strengthen the EU's competitiveness and resilience to current and future crises and developments. Part of the effort is to speed up the EU's net zero industrial transformation. Moreover, it is important to make the transition just by, for example, providing support to affected sectors, adapting social and labour market policies, and using the right educational frameworks to close occupation shortages and skill gaps.
- Research and innovation (R & I) is at the forefront of the EU's preparedness, resilience, security and crisis response, as R & I activities have a specific capacity to offer (new) sustainable solutions to many societal, economic, environmental and political challenges facing Europe (and the world). The framework programme for research and innovation, with its dedicated instruments and objectives, has a direct impact on both the shorter-run crises and the longer-run challenges. Each euro invested by Horizon Europe potentially generates a return of up to EUR 11 in gross domestic product (GDP) over 25 years. R & I efforts produce economic and societal benefits that are many multiples of the investment costs, and that are key engines through which to foster Europe's (sustainable) productivity growth and competitiveness, and the transformative changes of the economy and society.
- Foresight is needed for the EU to be better equipped to respond to present and future crises and developments, and to start preparing for them through new policies and initiatives. There is a general appreciation that the global geopolitical system, and the EU within this, will remain subject to turbulence in the near future, due to a confluence of political, economic, ecological, social and environmental challenges. This turbulence increases the importance of the EU's ability to act globally and of the relationships between the EU and other parts of the world.
- Citizen engagement, and the engagement of social partners and civil society actors, are key focuses of the EU's R & I policies because such engagement is critical to reinforce trust in science, and to facilitate and secure the innovation process and its uptake.
- According to the majority of the respondents from the public consultation, the Horizon Europe 2025 - 2027 Strategic Plan should update and further elaborate some specific themes. Improvements are required especially with regard to international cooperation, key enabling technologies, and dissemination and exploitation. Moreover, respondents underlined the need to simplify the structure of the Strategic Plan, for example by reducing the number of layers, use more accessible language, and make the Plan more concrete.

1.1. Crises, global developments and long-term challenges

'Our Union as a whole has risen to the occasion.' These words spoken by President von der Leyen during the 2022 State of the Union address describe the testing times Europe is going through, and how Europe has found joint and just ways to tackle the recent crises ([4]). This response is also expected and needed in the years to come, because Europe is experiencing fierce geopolitical challenges that pose new uncertainties in terms of economic and social developments in Europe and globally.

The past year has been marked by the Russian invasion of Ukraine. While the outcome is still uncertain, the war has come with immense consequences. In addition to the human losses and suffering in Ukraine, and the unprecedented refugee movements in Europe, the war has generated social, economic, environmental and (geo)political distress in the EU, and it is expected to have significant implications in the coming years. Many of the implications have an impact on the EU, including its R & I landscape, such as the impact on the possibilities for scientific collaboration with Ukraine and Russia; the negative impact on the vibrant tech ecosystem in Ukraine; the upheaval of the energy, fertiliser and food value chains; the direct and indirect impacts for EU companies regarding energy costs, competitiveness and employment; and the impact of migration flows from Ukraine to the EU. Businesses, in general, are affected by the invasion through the more unstable economic environment, increased energy costs and disruption of supply chains, which may affect their R & I activities. The agile EU R & I community reacted quickly to help Ukrainian researchers and innovators, for example by setting up a EUR 20 million action to support the Ukrainian innovation community through the European Innovation Council (EIC), access to the European Research Area for Ukrainian researchers, and targeted tenders, traineeships, and jobs ([5]). A €25 million dedicated scheme under the Marie Skłodowska-Curie actions (MSCA) was launched to support displaced doctoral candidates and post-doctoral researchers from Ukraine, allowing them to continue their research activities in Europe as well as to re-establish themselves in Ukraine to rebuild the country's research and innovation capacity when conditions allow ([6]). Another example is the initiative of the European Research Council (ERC), which appealed to its grantees to provide temporary employment to refugee researchers and support staff, such as technician and laboratory managers, from Ukraine ([7]).

At the same time, the war in Ukraine has highlighted the importance of R & I to meeting other challenges, such as the provision of (clean) energy and (sustainable) food, medicines, defence and infrastructure, and socioeconomic resilience, security, and the protection and enhancement of democracy. R & I is already contributing to addressing the fast-evolving challenges related to critical infrastructure with cross-border relevance, but many other challenges are also expected in the future. The Council recommendation on a Union-wide coordinated approach to strengthen the resilience of critical infrastructure encourages Member States to make best use of the results of relevant projects under research programmes such as Horizon Europe ([8]). Accelerating the sustainable development of clean energy technologies is instrumental in alleviating existing energy dependencies ([9]). The Group of Chief Scientific Advisors advised EU institutions to develop a systemic approach for crisis management to increase the overall resilience of society; to provide rapid, flexible, and cross-sectoral responses; and to consider both short- and long-term perspectives in crisis management ([10]). Finally, through the European democracy action plan ([11]), the Commission stated that, since the beginning of its current mandate, its intention has been to continue to support research to strengthen the democratic resilience of our societies.

R & I has played a key role throughout the COVID-19 pandemic, in particular by channelling scientific knowledge into evidence-based policymaking with topical, relevant research outcomes and foresight. R & I policies, investments, short-time work schemes supporting employment and income stability,

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([4]) European Commission, Directorate-General for Communication, von der Leyen, U. (2022), *State of the Union 2022*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2775/95046.
([5]) European Commission (n.d.), *EU Solidarity with Ukraine*, https://eu-solidarity-ukraine.ec.europa.eu/index_en.
([6]) MSCA4Ukraine (n.d.), https://sareurope.eu/msca4ukraine/
([7]) ERC (n.d.), *ERC for Ukraine*, https://erc.europa.eu/apply-grant/erc-ukraine; and ERC (2022), *Statement by the ERC Scientific Council in support of Ukraine and its research community*, https://erc.europa.eu/news/statement-erc-scientific-council-support-ukraine-and-its-research-community.
([8]) Council recommendation of 8 December 2022 on a Union-wide coordinated approach to strengthen the resilience of critical infrastructure (OJ C 20, 20.1.2023, p. 1), https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32023H0120(01).
([9]) European Commission, Directorate-General for Research and Innovation, Ravet, J., Di Girolamo, V., Mitra, A., Peiffer-Smadja, O., Canton, E. and Hobza, A. (2022), *EU research and innovation and the invasion of Ukraine – Main channels of impact*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/54321.
([10]) European Commission (2022), *Strategic crisis management in the EU : improving EU crisis prevention, preparedness, response and resilience* Publications Office of the European Union, https://data.europa.eu/doi/10.2777/517560
([11]) European Commission (2020), On the European democracy action plan, COM(2020) 790 final, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0790&from=EN.

and international cooperation were central elements in tackling the COVID-19 crisis ([12]). The EU had invested considerably in infectious disease projects and initiatives before the crisis hit. These investments, coupled with additional funding calls ([13]), facilitated the development of COVID-19 vaccines when the pandemic started, and underline the importance of (basic) research and its potential outcomes, which can be valuable at any time and in different fields. For example, a number of tools used throughout the EU to contain the pandemic stemmed from the outputs of EU-funded security research. In addition, the EU played an important role in ensuring the adoption of a just and joint approach among its Member States during the crisis. Examples in this sense are the joint purchasing of vaccines; the European instrument for temporary support to mitigate unemployment risks in an emergency ([14]); and the Recovery and Resilience Facility part of NextGenerationEU, which was designed to help prevent and repair the economic and social damage caused by the COVID-19 pandemic and kick-start the recovery. Building on the COVID-19 experience, and with the creation of the European Health Emergency Preparedness and Response Authority (HERA), the Commission will further strengthen R & I for pandemic preparedness, with a key focus on medical countermeasures. In addition, the European Group on Ethics in Science and New Technologies (EGE) pointed to the importance of human dignity and solidarity in crisis management. As public, common and individual interests are intertwined, the EGE outlined how values should direct the prioritisation of scarce resources, highlighting the importance of data, good communication, the fight against disinformation and public trust ([15]).

R & I has contributed to the preparedness for and response to recent climate-related extreme events such as floods and wildfires. In particular, EU-funded R & I has been instrumental in creating platforms for forecasting, early warnings and real-time information sharing (integrating data from different sources, such as Copernicus Earth observation), and in developing advanced technologies (such as machine learning and drones) that directly support local decision-makers, improve the coordination between first responders and authorities, and help us to understand the impact these events have on our health. Other tools developed through R & I include mobile applications that allow emergency managers to support and empower citizens to report and carry out initial response actions. The war in Ukraine started at a time when the climate and biodiversity crises had intensified, and the impacts were felt more than ever by EU citizens in their daily lives. In 2022, heat and drought affected significant parts of Europe, leading to, among other impacts, further stress on health, biodiversity and ecosystems; forest fires; and conflicts related to water supply. Economic activities directly depending on natural capital, in particular agriculture, were directly affected.

R & I is key to preserving and restoring the Earth's natural carbon sinks, such as healthy soils (particularly on farmed land), plants (particularly forests), wetland, seas and oceans, and to substantially reducing greenhouse gas (GHG) emissions from the agricultural sector (notably by supporting the transition to agroecology) and transforming the food system. The pressure on land and marine resources is increasingly taking into account the requirements for biodiversity and ecosystem service protection, and the need for settlements, infrastructures and recreation. This requires re-evaluating the concept of a single best use of land optimising towards land use systems that fulfil several functions simultaneously. R & I is delivering solutions to foster the sustainability of the agriculture and aquaculture, forestry, bioeconomy and fishery sectors, which have profound environmental impacts and, at the same time, are particularly affected by global environmental changes; yet systemic changes need to be underpinned by policy and societal consensus. Similarly, innovative solutions also help to better manage natural resources including water, which are becoming scarce in many parts of the EU. Innovation is needed to develop the circular sustainable bioeconomy to foster sustainable management of biological resources for sustainable food systems and renewable bio-based products ([16]). Bioeconomy governance, based on sound understanding and application of all dimensions of sustainability, can help to identify, assess and address trade-offs between policy targets and competing uses of land, sea and biomass to optimise the use of material resources and services,

([12]) European Commission, Directorate-General for Research and Innovation, Borunsky, L., Correia, A., Martino, R., Rakic, R. and Ravet, J. (2020), *Can R&I Save the Day? A fair, green and digital recovery from COVID-19*, R & I Paper Series, working paper 2020/05, Publications Office of the European Union, Luxembourg.

([13]) European Commission (n.d.), *Coronavirus Research and Innovation*, https://research-and-innovation.ec.europa.eu/research-area/health/coronavirus_en.

([14]) European Commission (n.d.), *SURE*, https://commission.europa.eu/strategy-and-policy/eu-budget/eu-borrower-investor-relations/sure_en.

([15]) European Commission, Directorate-General for Research and Innovation, and EGE (2022), *Values in Times of Crisis – Strategic crisis management in the EU*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/39416607-6bc5-11ed-9887-01aa75ed71a1/.

([16]) European Commission, Directorate-General for Research and Innovation, Group of Chief Scientific Advisors, (2020). *Towards a sustainable food system : moving from food as a commodity to food as more of a common good: independent expert report*, Publications Office, 2020, https://data.europa.eu/doi/10.2777/282386

including ecosystem services. This allows the identification of win–win solutions that generate economic gains, preserve the environment, and increase resilience and capacity for recovery ([17]).

R & I contributes to the resilience of critical infrastructure, such as energy, transport and telecommunication networks, against hybrid threats. Security research will support the implementation of the recently adopted directive on the resilience of critical entities (CER directive) ([18]). On 8 December 2022, the Council adopted a recommendation on an EU-wide coordinated approach to strengthening the resilience – both physical and cyber – of critical infrastructure ([19]). In this context, the Commission will support the uptake of results of relevant EU-funded R & I projects. Many past security research projects can contribute to proposals to the Member States for scenario planning and for the methodology on stress tests.

Recent crisis events have taken place in the context of long-term challenges facing Europe, such as achieving the just twin – green and digital – transition, providing a window of opportunity to 'build forward better' ([20])**.** Europe also faces long-term challenges such as accelerating climate change; pollution and biodiversity loss; the need for further – more inclusive and responsible – digitalisation; decarbonisation; increasing resilience; ensuring security of supply and industrial competitiveness; ageing populations and related comorbidities; the increased burden of non-communicable diseases; diminishing productivity growth; growing inequalities, with the potential for social instability; and pressure at the EU's borders. The recent crises interact with these challenges, often making them more pronounced. At the same time, the crises provide the possibility to 'build forward better', creating windows of opportunity to address some long-standing challenges through bold transformative policies. Policies that aim to tackle these crises and challenges can be expected to create structural changes in the economy and society, affecting sectors and regions. Hence, it is important to make the transition just by, for example, providing support to affected sectors, adapting social and labour market policies, and using the right educational frameworks to close occupation shortages and skill gaps. Furthermore, the crises have magnified important dimensions such as Europe's dependencies and vulnerabilities in a globally interconnected world. It is likely that we will face a more uncertain and fragmented world. As the challenges we face are shared, joint actions and a coordinated approach at EU level are needed, but we also need to work together with our international partners.

1.2. Geopolitical nature and consequences of recent developments

The new geopolitical context has placed the ambition of the EU's energy transition in the spotlight. The European Green Deal ([21]) is expected to contribute to solving the EU's energy security problems related to the EU's dependence on its current main energy suppliers, notably Russia. REPowerEU aims to reduce Europe's dependency on Russian fossil fuel through short- and medium-term measures ([22]). As the transition of European industry to climate neutrality continues, the reliance on available fossil fuels will progressively be replaced with reliance on non-energy raw materials and finite critical minerals that are essential to the functioning and integrity of a wide range of industrial ecosystems. These priorities are also reflected in the Green Deal industrial plan for the net zero age, outlining the need to massively increase the technological development, manufacturing production and installation of net zero products, and increase the energy supply, in the next decade ([23]). More precisely, the proposed Critical Raw Materials Act ([24]), part of the Green Deal industrial plan, proposes to introduce legislative measures to secure sustainable access to critical raw

([17]) European Commission (2022), EU bioeconomy strategy progress report – European bioeconomy policy: Stocktaking and future developments, COM(2022) 283 final.

([18]) Directive (EU) 2022/2557 of the European Parliament and of the Council of 14 December 2022 on the resilience of critical entities and repealing Council Directive 2008/114/EC (OJ L 333, 27.12.2022, p. 164); see Council of the European Union (2022), *EU Resilience: Council adopts a directive to strengthen the resilience of critical entities*, https://www.consilium.europa.eu/en/press/press-releases/2022/12/08/eu-resilience-council-adopts-a-directive-to-strengthen-the-resilience-of-critical-entities/.

([19]) Council recommendation of 8 December 2022 on a Union-wide coordinated approach to strengthen the resilience of critical infrastructure (OJ C 20, 20.1.2023, p. 1), https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32023H0120(01).

([20]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 (SRIP)*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/38888.

([21]) European Commission (2019), The European Green Deal, COM(2019) 640 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN.

([22]) European Commission (2022), REPowerEU plan, COM(2022) 230 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN.

([23]) European Commission (2023), A Green Deal industrial plan for the net-zero age, COM(2023) 62 final.

([24]) European Commission (2023). Establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020. https://op.europa.eu/en/publication-detail/-/publication/ea1a446b-c704-11ed-a05c-01aa75ed71a1/language-en/format-PDF/source-283620205

materials for European industry. The proposal for a NetZero Act ([25]) seeks to ensure EU's strategic autonomy concerning net-zero technologies. Both the Green Deal and the changing geopolitical context call for a reduction of strategic dependencies in industrial ecosystems and a strong circular economy. This can be achieved through diversification of sources of primary raw materials; material efficiency; substitution; and better application of the circular economy principles, with new business models for the intensified use of products and components, along with the full use of secondary materials' resources; and a shift from use of fossil-based resources towards the sustainable use of biological resources. These innovation pathways require more attention. The manufacturing and energy-intensive industries, combined with advances in materials, the data economy and artificial intelligence (AI), are also expected to play a pivotal role in the circular economy.

The need to strengthen European leadership in key technological domains has become more urgent as a result of the recent crises and geopolitical tensions. It is therefore important to continue strengthening the EU's capacity to ensure adequate reskilling/upskilling of the workforce; to support socioeconomic transformations in a fair manner; to develop and implement advanced materials, technologies and processes; and to stay competitive and avoid future strategic dependencies. 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 and open strategic autonomy. To preserve and strengthen the EU's technological leadership, efforts are needed to increase R & I expenditure, which is critical to developing innovative solutions, improving access to materials along strategic global value chains, and creating a more efficient regulatory framework to develop and deploy advanced technologies. In addition, innovations bringing together the physical, digital and biological sciences and technologies will deliver on sustainability and generate significant new sources of economic value. Increasing R & I cooperation with strategic, like-minded partner countries will contribute to preserving and strengthening the EU's technology base. At the same time, there is a need to reduce strategic dependencies, including dependencies on our main international partners. In *Shaping Europe's Digital Future*, published in February 2020, the European Commission renewed its commitment to the creation of a stronger digital Europe, one able to withstand competitive pressure from its international partners and competitors, while protecting EU values and fundamental rights ([26]). In a communication from February 2022 ([27]), the European Commission set out the internal and external policies to implement decent work worldwide, putting this objective at the heart of inclusive, sustainable and resilient recovery from the pandemic. Through the declaration on digital rights and principles ([28]), which the Commission proposed in January 2022, the Council of the European Union and the European Parliament signed up to a common approach for a human-centred digital transformation that Europe promotes and defends across the world.

Reducing strategic dependencies in key technological areas and value chains is necessary to strengthen EU resilience. While the EU shows strengths in technological areas related to advanced manufacturing, green technologies and advanced materials, its technological sovereignty is at risk in fields such as AI, big data, cloud computing, cybersecurity ([29]), robotics and microelectronics (chips) ([30]). Moreover, the EU is heavily dependent on trading partners in non-EU countries such as Brazil, China and Vietnam for several strategic products, such as critical raw and processed materials and components (e.g.

([25]) European Commission (2023). Establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act). https://single-market-economy.ec.europa.eu/publications/net-zero-industry-act_en

([26]) European Commission, Directorate-General for Communications Networks, Content and Technology (2020), *Shaping Europe's Digital Future*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2759/091014.

([27]) European Commission (2022), On decent work worldwide for a global just transition and a sustainable recovery, COM(2022) 66 final, https://ec.europa.eu/social/BlobServlet?docId=25260&langId=en.

([28]) European Commission (2022), European declaration on digital rights and principles for the digital age, COM(2022) 28 final, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0028.

([29]) See also the advice of the Group of Chief Scientific Advisors to make systems more secure, using the latest cryptographic standards and avoiding backdoors; establish a 'duty of care' to anticipate and prevent risks for users; empower users to have control over their personal data shared on the internet; strengthen the European cybersecurity industry; and improve coordination and sharing across Europe of cybersecurity incidents. European Commission, Directorate-General for Research and Innovation, (2017). *Cybersecurity in the European digital single market*, Publications Office, 2017, https://data.europa.eu/doi/10.2777/466885

([30]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 (SRIP)*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/38888.

semiconductors/chips), chemicals, and health and medical products, and for renewable energy production, green mobility and digital/electronic products ([31]).

The changing geopolitical context has increased uncertainties linked to the global and security outlook, and this calls for a reduction of industrial dependencies in strategic sectors through economic restructuring. For this, EU industry plays an important role in realising the EU's global ambitions, safeguarding essential elements of EU strategic value chains. Moreover, the implementation of the European Green Deal will produce significant changes in the EU's energy system, energy dependencies, the manufacturing and process industries, the labour market, and our societies and daily lives overall. This involves both challenges (such as the need to foster industrial competitiveness and resilience, enhance sustainability and strengthen circularity and local sourcing, and the need for critical minerals and raw materials) and opportunities (such as leads in green technologies and manufacturing of net zero products, and additional employment based on new job profiles and skill requirements). As the need for oil and gas decreases, EU imports from oil- and gas-producing countries in the EU neighbourhood will also decline ([32]). This will, positively, change the EU's energy resource trade relationships. Therefore, R & I investments and efforts should be strengthened to accelerate the development and deployment of energy-efficient and clean energy technologies ([33]), and safe and sustainable chemicals and materials ([34]), thereby helping both EU independence and competitiveness.

In the EU, governments, industrial companies, research organisations and societal actors in general need to be prepared to respond to the challenges and take advantage of the opportunities of a future in a more turbulent world. Current developments in innovation systems involve two key trends: a trend towards functionalising the innovation systems towards particular challenges and goals, and a trend towards societal governance of innovation that is more inclusive and has greater public involvement. The first is underpinned by a strong assumption in these efforts that there is broad agreement on the end state of these transformations, and that coordination problems will be resolved and institutions will adapt and adjust. This assumption overestimates the extent of shared goals and visions across Europe – and this is why many argue that extraordinary measures are required, comparing the current polycrisis to wartime situations ([35]). The second trend recognises the inherent unpredictability of the societal developments accompanying evolving technologies, with a view to instilling responsibility for future evolutions in the governance of R & I processes. This requires institutional adaptations in the research system that could challenge its efficiency and effectiveness in considerably transformative innovation processes ([36]).

It is in the context of these two, partly contradictory, trends, that the future aspirations of the EU in relation to R & I must be seen. Of particular importance here is the long-term trend towards the decreasing share of global R & D associated with the EU. A strategically autonomous EU accounting for 30 % of global R & D is a very different prospect than a strategically autonomous EU responsible for 20 % of global R & D ([37]). Strengthening the EU's global role by simply contributing to a more coordinated approach to the governance of R & I in the EU is a potentially important strategic target for the EU framework programme. The global agency of the EU depends on its internal politics, and its control over global resources in the context of the systems used to coordinate the global distribution of resources, wealth and income. While the latter is partly a consequence of global demography and therefore likely to decline in the medium term, the former can be improved through EU policies, including in the field of R & I.

([31]) European Commission (2021), Strategic dependencies and capacities, SWD (2021) 352 final, https://op.europa.eu/en/publication-detail/-/publication/8f76a6dd-ae95-11eb-9767-01aa75ed71a1/language-en/format-PDF/source-213710188.

([32]) Leonard, M., Pisani-Ferry, J., Shapiro, J., Tagliapietra, S., and Wolff, G. (2021), 'The geopolitics of the European Green Deal', *Policy Contribution*, 04/2021, Bruegel.

([33]) European Commission, Directorate-General for Research and Innovation (2022), *ERA industrial technology roadmap for low-carbon technologies in energy-intensive industries*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/c9f70ebf-b48e-11ec-9d96-01aa75ed71a1/.

([34]) European Commission, Directorate-General for Research and Innovation (2022), *Strategic research and innovation plan for safe and sustainable chemicals and materials*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/9f04603f-534b-11ed-92ed-01aa75ed71a1/.

([35]) Dixson-Declève, S., *et al*. (2023), *Transformation in the Poly-crisis Age*, ESIR, draft March 2023.

([36]) See, for example, Oldervoll, J. A., Asenova, D., Dimova, A., Dreyer, M., Drivdal, L. E., Sikma, T., Schweizer, P.-J., De Smedt, K., Thornvig, J., Holm, N.-K. T., Trescher, D. and Vos, E. (2022), *Guidance on the application of the precautionary principle in the EU*, Reconciling science, innovation and precaution through the engagement of stakeholders, https://recipes-project.eu/sites/default/files/2022-07/2814_RECIPIES_Guidance_Book_final.pdf.

([37]) Organisation for Economic Co-operation and Development (OECD) (n.d.), *Research and Development Statistics (RDS)*, https://www.oecd.org/innovation/researchanddevelopmentstatisticsrds.htm. See also Dehmer, S. P., Pardey, P. G., Beddow, J. M. and Chai, Y. (2019), 'Reshuffling the global R & D deck, 1980-2050', *PLOS ONE*, 14 (3): e0213801, https://doi.org/10.1371/journal.pone.0213801.

1.3. Unique role of research and innovation

R & I is at the forefront of the EU's preparedness, resilience and crisis response, as R & I activities have a specific capacity to offer (new) solutions to many social, economic, environmental, political and security challenges faced by Europe (and the world). Hence, R & I policies can help build an inclusive, sustainable, fair, competitive and resilient Europe by leveraging the essential role of R & I as a source of prosperity and a catalyst for sustainability. The role of 'science for policy' interfaces is crucial in translating scientific results into advice for policy. In the EU, different science for policy interfaces exist, such as the Joint Research Centre and the EU decentralised agencies ([38]). Moreover, the Group of Chief Scientific Advisors, informed by a systemic analysis of all scientific literature in the field, and EGE provide the Commission with policy recommendations to inform further policymaking ([39]).

Box 1. Science for EU policy

Science is at the core of EU policymaking ([40])**.** Policies developed with insufficient or poor science are less likely to solve the underlying issue and more likely to give rise to unintended consequences. Science can help policymakers to understand the policy problem; explore the system's complexities, interdependencies and synthesis; assess different policy options; design solutions that work; and distinguish facts from opinions in public debate. These principles are why the Commission has put scientific evidence at the heart of its policymaking processes; part of this involves use of robust science for policy interfaces in some EU policy areas. Moreover, to address complex crises, such as the triple planetary crisis and the COVID-19 pandemic, improved scientific advice and science for policy capacity in the Member States and across Europe are needed ([41]). Scientific evidence is therefore also explicitly described as a 'cornerstone' of better regulation, vital to establishing an accurate description of the problem, a real understanding of the main underlying factors and, therefore, the intervention logic, and to evaluating impact ([42]).

In relation to this theme, the Group of Chief Scientific Advisors mentioned, in their guidelines for good scientific advice under conditions of complexity and uncertainty, the importance of separating scientific advice from interests, beliefs or opinions through dialogue and agreements. Scientists and policymakers should engage at an early stage of the policymaking process and regularly to anticipate and design action. The need to consider all good science, disciplines and multidisciplinary expertise must be borne in mind, as must the need to ensure rigorous expert consultation and evidence synthesis that is comprehensive, transparent and iterative. As a matter of public policy, the Commission must refine its approach to conflicts of interests and develop a single code of good practice advising that the Commission analyse, assess and communicate uncertainties more effectively ([43]).

Source: European Commission, Directorate-General for Research and Innovation.

([38]) European Union (n.d.), *Types of Institutions, Bodies and Agencies: Decentralised agencies*, https://european-union.europa.eu/institutions-law-budget/institutions-and-bodies/types-institutions-and-bodies_en#:~:text=Decentralised%20agencies%20are%20spread%20across%20Europe%20and%20work%20on%20issues,drug%20addiction%20and%20the%20environment.

([39]) European Commission, Directorate-General for Research and Innovation (2022), *Europe needs better, more strategic crisis management, according to independent scientific and ethics advisors*, https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/europe-needs-better-more-strategic-crisis-management-according-independent-scientific-and-ethics-2022-11-22_en.

([40]) European Commission (2022), Supporting and connecting policymaking in the Member States with scientific research, SWD(2022) 346 final, https://knowledge4policy.ec.europa.eu/sites/default/files/SWD_2022_346_F1_STAFF_WORKING_PAPER_EN_V6_P1_2288249.PDF.

([41]) European Commission (2021), Drawing the early lessons from the COVID-19 pandemic, COM(2021) 380 final, https://commission.europa.eu/system/files/2021-06/communication150621.pdf.

([42]) European Commission (2021), Better regulation: Joining forces to make better law, COM(2021) 219 final, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2021:219:FIN#:~:text=COM%20%282021%29%20219%20final%20COMMUNICATION%20FROM%20THE%20COMMISSION,Better%20regulation%3A%20Joining%20forces%20to%20make%20better%20laws. In the same sense, the Group of Chief Scientific Advisors, the consortium of networks of European science academies (SAPEA) and EGE produced advice supporting and informing this process, drawing on insights from research and scholarship, and taking European values and respect for fundamental rights as critical guidelines. See the Group of Chief Scientific Advisors, SAPEA and EGE advice documents available at European Commission (n.d.), *COVID-19, future pandemics and other crises in the global context,* https://research-and-innovation.ec.europa.eu/strategy/support-policy-making/scientific-support-eu-policies/group-chief-scientific-advisors/covid-19-future-pandemics-and-other-crises-global-context_en.

([43]) European Commission, Directorate-General for Research and Innovation, Group of Chief Scientific Advisors, (2019). *Scientific advice to European policy in a complex world*, Publications Office, https://data.europa.eu/doi/10.2777/80320

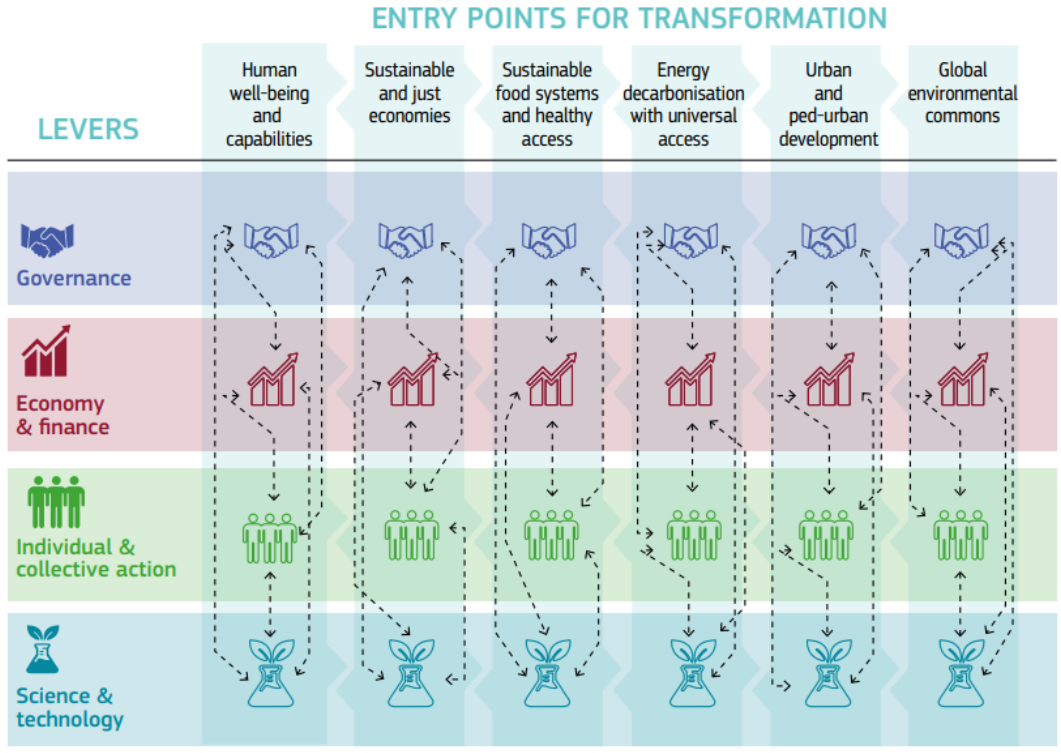
R & I is a key engine through which to foster Europe's (sustainable) productivity growth, competitiveness, inclusiveness and fairness, and transformative changes of the economy and society. Human capital, combined with research and development (R & D) investments, drives companies' abilities to design, create, absorb and diffuse innovation. Improved productivity, fairly distributed, while respecting planetary boundaries, is an important means of achieving inclusive (sustainable) growth and desirable outcomes for society as a whole. Productivity (also thanks to adequate design of products, services and processes) can be an ally in achieving the twin transition, providing the required resources to invest in new green and digital technologies necessary to tackle the societal challenges of the modern era. (Sustainable) productivity growth entails more (equal) output with the same (or fewer) resources. Such an improvement in the efficiency of production systems is necessary to reduce the impact of production on planetary boundaries. At the same time, productivity is not a solution to all our problems, as political consensus is necessary to direct the fruits of productivity towards desirable outcomes and to share productivity gains fairly ([44]). For this, Europe needs to focus on transformative policies to make it fit to address challenges such as climate change, biodiversity loss and pollution, and to deliver on the fundamental objective of providing inclusive well-being to citizens as embedded in the European Green Deal, the European Pillar of Social Rights and the UN's sustainable development goals (SDGs).

R & I policies play an important role in bringing together actors within the R & I ecosystem and beyond. These actors include industry, researchers, innovators, universities, social partners, small and medium-sized enterprises (SMEs), higher education, national and regional authorities, and civil society at large ([45])**.** However, to achieve the EU's objectives and increase the effectiveness of R & I policies, other policies also need to be taken into account. For example, in addition to R & I policies, other policies aim to boost the shift towards more sustainable and resilient systems. EU and other countries have put in place environmental regulations and agreed policy frameworks for a just transition to fulfil such objectives, and these policies can create incentives for businesses to implement structural changes and upgrade global value chains. Hence, R & I will need to interact with other levers, such as governance, economy and finance, and individual and collective action, in order to bring about the transformations required to address the SDGs (Figure 2).

([44]) European Commission, Directorate-General for Research and Innovation (2020), *Science, research and innovation performance of the EU 2020 – A fair, green and digital Europe*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/534046; European Commission, Directorate-General for Employment, Social Affairs and Inclusion (2020), *Employment and Social Developments in Europe 2020 – Leaving no one behind and striving for more: Fairness and solidarity in the European social market economy*, Publications Office of the European Union, Luxembourg.

([45]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 (SRIP)*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/38888.

Figure 2. Entry points for transformation and the key role of R & I



Source: United Nations (2019), *Global Sustainable Development Report 2019 – The future is now: Science for achieving sustainable development*, United Nations, New York, NY, https://sdgs.un.org/sites/default/files/2020-07/24797GSDR_report_2019.pdf.

R & I efforts produce economic benefits that are many multiples of the investment costs. As an example, Jones and Summers (2020) found a multiplier of R & D of between 4 and 20 ([46]). In addition, each euro invested by Horizon Europe potentially generates a return of up to EUR 11 in GDP over 25 years, an estimated average GDP increase of 0.08 % to 0.19 % for Horizon Europe overall. EU investments in R & I are also expected to directly generate an estimated gain of up to 100 000 jobs in R & I activities in the investment phase (2021–2027) ([47]). R & D affects employment positively, particularly in the medium- and hi-tech sectors, with positive spatial spillovers.

Economic, social and environmental benefits from R & I investments can come at different paces. Sometimes benefits come very quickly, building on previous R & I efforts (e.g. with COVID-19 vaccines), and sometimes they come more gradually, such as with the mapping of the human genome or tackling industrial and agricultural GHG emissions. It is therefore important for policies to present a mix of agility on the one hand, and stability and predictability on the other.

1.4. Future trends, disruptions, challenges and opportunities: foresight for the Horizon Europe Strategic Plan 2025–2027

The objective of the foresight exercise for the Horizon Europe Strategic Plan 2025–2027 was to inform political processes using possible and plausible predictions of future developments. In the context of more traditional R & I policy, where there is considerable uncertainty about both the directions of and the

([46]) Jones, B. F. and Summers, L. H. (2020), *A Calculation of the Social Returns to Innovation* (No w27863), National Bureau of Economic Research, Cambridge, MA, https://www.nber.org/system/files/working_papers/w27863/w27863.pdf.

([47]) European Commission (2018), Impact assessment, SWD(2018) 307 final, https://research-and-innovation.ec.europa.eu/system/files/2018-06/swd_2018_307_f1_impact_assesment_en_v7_p1_977548.pdf. In the impact assessment, the budget size and allocation are assumed to be the same as in Horizon 2020 in constant prices, minus the contribution from the UK (assumed to be 15 % of the budget). The budget for Horizon Europe increased from that of Horizon 2020, and therefore an even bigger impact can be expected. The multiplier is based on simulations performed using the Nemesis model and is consistent with figures provided in the interim evaluation of Horizon 2020 (calculated over 17 years) and in the *ex post* evaluation of the seventh framework programme. The average GDP gain depends on the model used: in Rhomolo, it is 0.08 %; in QUEST, it is up to 0.14 %; and in Nemesis, it is 0.19 %.

expectations from R & I, the questions are about the materiality of the objectives, the extent to which there are trade-offs between them, and the extent to which such trade-offs are determined by infrastructures and widely used existing technologies. How much space is given to alternative approaches is a question that reaches the heart of the strategy for an R & I programme. How do the alternative approaches relate to existing stakeholders, to industry incumbents and new enterprising start-ups, and to customers (prosumers) and citizens? The questions about stakeholders and distribution are inherently political in nature, and relate to how programme co-design and co-creation processes are managed in Horizon Europe.

The Horizon Europe Strategic Plan 2021–2024 was written against the background of the pursuit of the SDGs as an important area in which the EU can play a leadership role in a world of fragmenting globalisation, and rising populism and authoritarianism. What has changed in our appreciation of the future since the adoption of the first strategic plan of Horizon Europe? Are there any good reasons to revise our strategy, or its goals, objectives, practices and tactics? Since then, the Commission has published three strategic foresight reports signalling its concerns with:

- resilience – stimulated by new threats ([48]);
- the EU's ability to act in the world ([49]) – the decline of which has been a core concern for the EU since the Gonzales report ([50]) of 2010;
- the EU's pursuit of the joint/twin green and digital transition and how this pursuit can be compatible with the EU's sustainability objectives ([51]).

While desirability is important when it comes to the future, an equally important strategic concern is control over the circumstances that create this future. The three abovementioned reports set in motion debates about normative, desirable versions of the future, which also relate to the deliberations of the Conference on the Future of Europe ([52]).

The EU is a powerful actor in the world, and its actions are very influential, but its leadership is not completely within its sphere of control. EU leadership requires support from its constituent parts – its Member States, industry, social partners, institutions and society at large – and often support from existing and new world powers outside it. The evolution of this context, within which the EU pursues its objectives, in the medium term has been the subject of an important dedicated foresight exercise that included reflections on global developments and explorations of specific future disruptions. The content of the reflections of specific future disruptions is depicted in Figure 3 below.

([48]) European Commission, Secretariat-General (2020), *2020 Strategic Foresight Report – Charting the course towards a more resilient Europe*, European Commission, Brussels, https://commission.europa.eu/system/files/2021-04/strategic_foresight_report_2020_1_0.pdf.

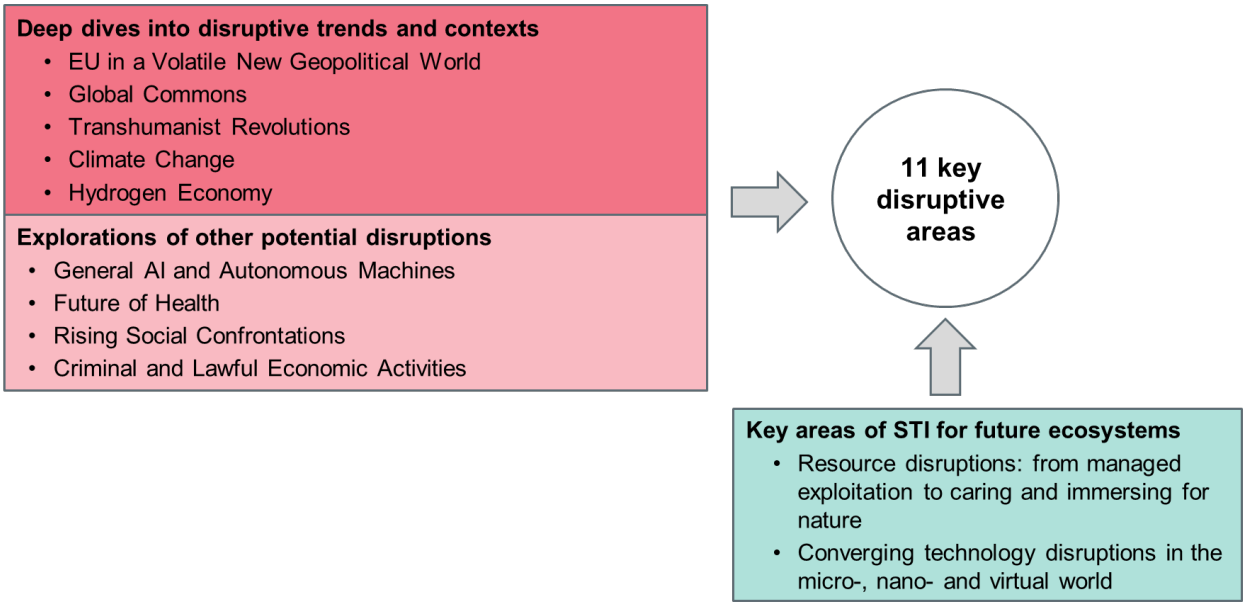
([49]) European Commission (2021), 2021 strategic foresight report – The EU's capacity and freedom to act, COM(2021) 750 final. See also Cagnin, C., Muench, S., Scapolo, F., Stoermer, E. and Vesnic Alujevic, L., *Shaping and securing the EU's open strategic autonomy by 2040 and beyond*, Publications Office of the European Union, Luxembourg, https://publications.jrc.ec.europa.eu/repository/handle/JRC125994.

([50]) Reflection Group on the Future of the EU 2030 (2010), *Project Europe 2030 – Challenges and opportunities: A report to the European Council by the Reflection Group on the Future of the EU 2030*, Publications Office of the European Union, Luxembourg, https://espas.secure.europarl.europa.eu/orbis/sites/default/files/generated/document/en/Project%20Europe%202030.pdf.

([51]) European Commission (2022), 2022 strategic foresight report – Twinning the green and digital transitions in the new geopolitical context, COM(2022) 289 final; and Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M. and Scapolo, F. (2022), *Towards a Green and Digital Future*, Publications Office of the European Union, Luxembourg, https://publications.jrc.ec.europa.eu/repository/handle/JRC129319.

([52]) See European Commission (n.d.), *Conference on the Future of Europe*, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/new-push-european-democracy/conference-future-europe_en.

Figure 3. Exploring potential futures in key areas of change



Source: European Commission, Directorate-General for Research and Innovation, based on own research and Futures4Europe (n.d.), *Futures4Europe*, http://www.futures4europe.eu/.

A summary of the reflections and views that were developed in this foresight exercise are presented in this section. The resultant implications and considerations for the 2025–2027 strategic plan are presented below. In view of the usually long-term impact of R & I, the time horizon applied was 2040 or – in the case of global sustainability issues – even 2050. The sources of the views are conversations in workshops, literature reviews, scenario-building work and other exploratory work that can be found on the website http://www.futures4europe.eu/, together with a sense-making event with around 260 experts from all over the world, the results of which fed into a broad survey – with 943 experts giving their views on what should be the EU's R & I priority topics in the light of the future disruptions explored in this study.

1.4.1. Multilevel global context scenarios

Several recent developments strongly suggest that a new world order is evolving. This new world order is likely to be a multipolar one, but we cannot know yet how these poles would behave. Therefore, three types of multipolar worlds are explored:

- a world with poles genuinely collaborating when tackling global challenges;
- a world with antagonistic groups of countries that are nevertheless willing to engage in limited cooperation;
- a world with at least one pole that is openly hostile towards others ([53]).

Thus, these multipolar scenarios explore two variants of how the EU might evolve:

- a dynamic and resilient variant;
- a destabilised and vulnerable variant.

Considering these two futures for the EU in each of the three global multipolar scenarios creates a set of six scenarios in total (Figure 4).

([53]) The OECD considers just one type of multitrack world, composed of several 'clusters' – that is, groups – of countries, which follow their own tracks (paths of development). These countries are not necessarily located in the same region, which is why they are clusters as opposed to world regions.

Figure 4. Six context scenarios exploring potential futures in key areas of change for future R & I policy

Global / EU	Genuine collaboration	Limited co-operation	Open hostility
Dynamic, resilient EU	A "Thriving in collaboration"	B "Respected partner"	C "Deterring fortress"
Declining, destabilised, vulnerable EU	D "Decline, despite collaboration"	E "Negligible partner"	F "Frail fiefdom"

Source: European Commission, Directorate-General for Research and Innovation.

With the explicit consideration of multiple development paths at both global and EU levels, a multilevel architecture of scenarios is obtained. This multilevel nature is what distinguishes this set of scenarios from other recent scenario projects that were sources of inspiration. The notion of a multitrack scenario, a term coined by the recent Organisation for Economic Co-operation and Development (OECD) project 'Global Scenarios 2035' ([54]), stresses the idea of the autonomous developments paths of clusters (groups) of countries. This idea is shared by the Commission's strategic intelligence foresight system for EU R & I scenarios ([55]), which also proposes almost autonomous future pathways of different world regions. The global dimension of our scenario matrix further differentiates the multitrack idea into three variants of how groups of countries might relate to each other: genuine collaboration, limited cooperation or open hostility ([56]).

The Joint Research Centre's science for policy report ([57]) that supports the Commission's 2021 strategic foresight report places its emphasis on the concept of open strategic autonomy, and so does not distinguish multiple development pathways at both global and EU levels. Yet this distinction is important for future EU R & I policies because the **EU's room – and need – for manoeuvre depends on global opportunities and constraints, and on the collaboration and disparities between the national innovation systems of EU Member States.** Of course, other factors that are important to the EU's R & I policies also influence the EU and global landscapes, such as the emergence of new types of non-state actors, or growing concerns about global challenges that are shared by all countries.

Considering several types of multipolar world offers an opportunity to think about different types of political and policy stances vis-à-vis China, Russia and the United States, which is important in order to derive future-proof implications and devise a future-proof EU R & I policy strategy. For example, the EU can make cognisant, well-considered preparations for a hostile, limited or genuinely collaborative relationship with Russia in the coming decades. While the last of these may seem difficult to imagine in spring 2023, it should not be discarded in the longer term. This structure highlights that greater emphasis on the security of the EU is needed, and its cohesion is very important in this. The structure also implies the need for the EU to **(continue to) take, where necessary, a more pronounced value-based and ethical stance when considering various options, actual and potential internal tensions, and external threats and challenges**. In view of how global relations might evolve in the three possible future worlds, the EU needs to take a position that is both robust with regard to these worlds and, at the same time, compatible with its basic values.

([54]) OECD (2021), *Global Scenarios 2035: Exploring implications for the future of global collaboration and the OECD*, OECD Publishing, Paris, https://search.oecd.org/economy/global-scenarios-2035-df7ebc33-en.htm. We use 'multipolar' and 'multitrack' scenarios as synonyms in this analysis.

([55]) European Commission, Directorate-General for Research and Innovation (2021), *Foresight – Strategic intelligence foresight system for European Union research and innovation (R & I) framework programme (SAFIRE)*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/e436b4b6-fa50-11eb-b520-01aa75ed71a1/language-en/format-PDF/source-222702137.

([56]) We could consider a fourth type of multipolar world, between limited cooperation and open hostility, in which the poles – the various groups of countries – operate in splendid isolation. In that world, there is hardly any global trade, international cooperation in investment, or research, technology development and innovation activities. There are no efforts to set up global governance mechanisms to tackle critical issues, and thus luck is needed to avoid major conflicts. To keep the number of scenarios lower, however, we do not elaborate on those scenarios here.

([57]) Cagnin, C., Muench, S., Scapolo, F., Stoermer, E. and Vesnic Alujevic, L., *Shaping and securing the EU's open strategic autonomy by 2040 and beyond*, Publications Office of the European Union, Luxembourg, https://publications.jrc.ec.europa.eu/repository/handle/JRC125994.

1.4.2. *Anticipating emerging disruptions: foresight implications for the Horizon Europe Strategic Plan 2025–2027*

The foresight work identified 11 key disruptive areas over a time perspective of 20–30 years. In the following three subsections, they are described and analysed for their implications for R & I policy.

A world of tensions

The Russian invasion of Ukraine brought home the realisation that the world system is at a crossroads, and may evolve towards a new bipolar or multipolar configuration, with important implications for global governance and its institutions ([58])**.** The EU's relationship with the United States and the extent to which the United States engages with global issues and in global governance institutions are critical for the EU's future. Our foresight activities explored scenarios with high and low levels of global engagement from the United States, and high and low levels of global agency for the EU. These scenarios put the EU's pursuit of digital leadership into context, as the United States is the de facto leader in many such technologies, followed by China. The EU faces a critical investment gap – in which, for example, the annual R & D budget of Amazon is more than four times that of the EU framework programme ([59]).

The very important digital transition of the EU's economy and society could be framed as a battle for leadership or as participation in a global digital and sustainable transition. The choice of strategic frame affects the chosen approach to key policy directions for R & I, especially as regards international cooperation and global regulatory frameworks. Framing the EU as, at least partly, a potential price-taker or participant, rather than a global leader in a number of areas, could make the strategic orientations more conducive to global collaborations for global challenges.

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

Box 2. Priority areas for EU R & I – geopolitical reconfiguration scenarios

Regarding geopolitical reconfiguration scenarios, the expert survey generated the following potential priority areas for EU R & I:

- evolution of critical dependencies in energy, food and trade,
- circular economy and material-recycling system with reduced import dependence,
- sustainable, secure and resilient food supply systems (e.g. agroecology, aquaculture and fisheries),
- development of global natural resource governance (see UN International Resource Panel reports([60])),
- engagement of autocracies in a win–win dialogue,
- societal and geopolitical impacts of climate change,
- global governance models for biosecurity.

Source: Foresight expert survey.

Tensions are not only the prerogative of geopolitics; they are also rising within societies, often leading to social confrontations ([61])**.** Key phenomena in the rising number of social confrontations are social media and their effects on identity politics. It is important to note here that social media are not 'the root cause' of social confrontations – the appearance of which predates social media by thousands of years. However, the creation of powerful community bonds in social media has liberating effects for groups of like-minded people and provides ample opportunities for controlling narratives, which amplify the power of

([58]) Futures4Europe (n.d.), *Geopolitical Reconfiguration*, https://www.futures4europe.eu/geopolitical-reconfiguration.
([59]) Macrotrends (n.d.), *Amazon Research and Development Expenses 2010–2022 | AMZN*, https://www.macrotrends.net/stocks/charts/AMZN/amazon/research-development-expenses#:~:text=Amazon%20annual%20research%20and%20development,a%2018.95%25%20increase%20from%202019.
([60]) The International Resource Panel (n.d.), Resource panel reports. https://www.resourcepanel.org/reports
([61]) Futures4Europe (n.d.), *Rising Social Confrontations and their Implications for Transitions – Rapid exploration*, https://www.futures4europe.eu/social-confrontations.

oppressive regimes and radical groups, leading to new, more intense, social confrontations. These raise new challenges for the regulation of online spaces, for the good functioning of democratic public spheres and for governance in general. Exploring trends in social confrontations and their management raises fundamental issues about truth, trust in science and free speech, and emphasises the importance of education.

Box 3. Priority areas for EU R & I – social configuration scenarios

Regarding social configuration scenarios, the expert survey generated the following potential priority areas for EU R & I:

- sources of social fragmentation and tensions, and the role of social media,
- effective methods for sociocultural integration and tolerance of diversity,
- pilot of new mechanisms for managing and resolving conflict in society (new forms of mediation on major decisions of public interest),
- development of cross-cultural communication and governance,
- evidence-based and normatively informed policy advice,
- new forms of public–private community governance.

Source: Foresight expert survey.

In a world of tensions, there are signals of increasing attention being paid to the relationships between legitimate and illegitimate, legal and illegal, and morally just and unjust actions and their economic importance. There is also rising concern with and incidence of economic and financial crime, and crime involving technology: from cyberattacks against citizens and infrastructures to manipulating opinions and sentiments ([62])**.** Technology could fall into the wrong hands (e.g. perpetrators of transnational organised crime who use it to escape the consequences of their actions and benefit in the legal economy). There are important responsibilities to restrict access to and use of advanced technology for specific criminal uses, and to prevent economic benefits from crime.

Box 4. Priority areas for EU R & I – lawful and unlawful economic activities

In the light of rising concern with the interpenetration of lawful and unlawful economic activities, the expert survey generated the following potential priority areas for EU R & I:

- crimes against nature,
- social innovation for community security,
- ways of detecting and detecting new forms of crime,
- technological traceability,
- monitoring systems for new types of illegitimate activities,
- ethics and law – new tendencies,
- design for radical transparency,
- new forensic technology and methods.

Source: Foresight expert survey.

Technology and society

The relationship between technology and society is of paramount concern for the framework programme, and is especially sensitive as regards the fair digital transition and health. Three areas of potential disruptions were explored: the drive towards general AI, transhumanist revolutions (the merging of the physical and digital spheres associated with human functions and enhancements) and broader health challenges.

General AI may emerge out of evolutions in domains of narrow AI, or directly out of programmes aiming to widen the potential of AI that are associated with global competition between nations ([63])**.** General AI entails major risks for humanity and needs to be appropriately regulated. A global cooperation

([62]) Futures4Europe (n.d.), *The Interpenetration of Criminal and Lawful Economic Activity – Rapid exploration*, https://www.futures4europe.eu/criminal-lawful-activity.
([63]) Futures4Europe (n.d.), *General AI*, https://www.futures4europe.eu/general-ai.

programme on regulating and creating the conditions for general AI to be beneficial and not a risk to humanity and nature is an important pursuit.

Box 5. Priority areas for EU R & I – general AI

In the light of the rising concern regarding general AI, the expert survey generated the following potential priority areas for EU R & I:

- AI improvements for specific applications,
- the nature of AI and human intelligence,
- AI in medical applications,
- understanding of cooperation between humans and general AI systems,
- ethical standards and AI regulatory sandboxes,
- pilot of rule sets for general AI applications in specific areas of application,
- understanding of threats and opportunities associated with general AI,
- AI supporting continuous learning and collaborative problem-solving,
- interpretable AI.

Source: Foresight expert survey.

Transhumanism, leveraging the broad appeal of the visions of extended lifespans, eternal youth and enhanced bodies and minds for individuals and communities in physical and virtual immersive spaces, is a major driver of technological developments in a broad array of domains including biology, digital technologies and health ([64])**.** The extension of humanity towards machines entails important risks and potential benefits for society and nature, and requires new perspectives, processes and values at its foundations.

Box 6. Priority areas for EU R & I – transhumanist revolutions

Regarding transhumanist revolutions, the expert survey generated the following potential priority areas for EU R & I:

- understanding of ageing and disease,
- rigorous criteria to assess, and regulate, the impact of technologies on humans, considering both psychological and physical health,
- ethical aspects in the context of digitalisation – industry of the future,
- psychological consequences of immersive worlds,
- productive, caring communities in connected spaces,
- molecular anti-ageing therapies,
- regulations to avoid inequalities and discrimination following human augmentation and enhancement.

Source: Foresight expert survey.

The COVID-19 pandemic has raised awareness of the individual, social, economic and political risks associated with health threats, even ones that are well predicted and understood ([65])**.** The rising tide of non-communicable diseases due to the demographic ageing of the baby boom generation is beginning, while another tide of health threats associated with antibiotic-resistant microbes is also rising. A future with so many threats is an important socioeconomic challenge in relation to appropriately directing the resources of healthcare systems and pharmaceutical industries to ensure fair and socially desirable outcomes. With new threats and increasing medical possibilities, society's expectations from healthcare systems are increasing, in terms of both effectiveness and speed of innovation and change.

Box 7. Priority areas for EU R & I – future health threats

Regarding future health threats, the expert survey generated the following potential priority areas for EU R & I:

- understanding of health and its value,

([64]) Futures4Europe (n.d.), *Transhumanist Revolutions*, https://www.futures4europe.eu/transhumanist-revolutions.
([65]) Futures4Europe (n.d.), *The future of health between new threats and new opportunities – Rapid exploration*, https://www.futures4europe.eu/the-future-of-health.

- extension of personalised medicine to self-diagnosis and self-medication/treatment,
- new testing modes and models – speeding up medicine approval without compromising safety,
- early detection of non-communicable diseases,
- interlinkage between health (humans, animals and the environment) and climate change,
- real-world evidence-based health system strengthening through implementation science,
- non-antibiotic treatments for bacterial infections.

Source: Foresight expert survey.

Research and innovation for flourishing ecosystems

Ecosystem restoration is very important for the EU and the world, while debates over what an appropriate and desirable level of restoration is, are ongoing. The foresight work broadly identified three perspectives on flourishing ecosystems based on the values associated with the relationship between humans and ecosystems, see Table 1 ([66]):

1. protecting and restoring ecosystems, concerned with the preservation of ecosystems by managing the impact of human activities;
2. co-shaping socioecological systems, concerned with the simultaneous development of social practices and ecological processes towards resilience and sustainable renewal;
3. caring within hybrid collectives, concerned with the establishment of caring relationships in new collectives with humans and other entities on an equal level.

Table 1. Overview of perspectives on flourishing ecosystems

Perspective	Notion of ecosystems	Motivation to promote ecosystem flourishing	Proposed attitude towards ecosystem flourishing
Protecting and restoring ecosystems	Distinctive nature sphere interacting with the human sphere (natural capital)	Costs and benefits of (in-)action regarding limiting effects on the environment	Manage the impact of human activities to reach a desired target; fix existing problems
Co-shaping socioecological systems	Complex adaptive socioecological systems with no clear boundaries	Steer system dynamics towards long-term survival	Move specific socioecological systems towards more beneficial dynamics; design, experiment and scale up solutions
Caring within hybrid collectives	Pluriverse of hybrid entities with agency emerging out of relations with each other	No other choice for humans, and ethics of care	Negotiate with other inhabitants of critical zones to allow all to flourish on their own terms; adapt to nature and its diversity

Source: Futures4Europe (n.d.), *Futures4Europe,* https://www.futures4europe.eu/.

Foresight work included an expert survey to identify future scientific and technological developments that can radically improve ecosystem performance from a perspective reaching to 2050. The survey addressed the 21 most dynamic domains of science and technology, within which respondents were asked to identify key developments. The survey had 2 275 respondents, who identified the developments shown in Table 2.

Table 2. Most important science, technology and innovation developments contributing to flourishing ecosystems

Domain	Science, technology and innovation development
Ecology and environmental health	Understanding better the impact of human activity on ecosystems

([66]) Futures4Europe (n.d.), *S&T&I for 2050 – Science, Technology, and Innovation (STI) for Ecosystem Performance: Accelerating sustainability transitions*, https://www.futures4europe.eu/sti2050.

	Understanding better the environmental impact of climate change Interventions to mitigate human impacts
Biotechnology, biochemical engineering, chemical engineering and organic chemistry	Bioenergy and biofuel Personalised/precision medicine New renewable and recycled raw materials
Environmental planning and environmental engineering	Circular economy Global nature conservation and restoration areas Carbon capture and storage
Agriculture science and agriculture engineering	Sustainable farming Increased water use efficiency Reduced nitrogen and phosphorus leakage
Data science and statistics	Scientific disciplines and fields reconfigured as big data sciences Environmental modelling and simulations Web applications and tools for decision-making
AI, pattern recognition, machine learning, natural language processing and computer vision	AI for healthcare AI for control of technical dynamical systems AI for renewable energy
Water resource management	Monitoring, modelling and forecasting Ecohydrological approach Water decontamination
Food science	Sustainable, circular food production Promoting healthy diets Food safety
Composite material, nanotechnology and metallurgy	Renewable energy storage Nanocomposites Nanomedicines
Waste management	Integrated waste management systems Recycling of plastics into new products Reduction of food waste and spoilage
Socioeconomics, social psychology and law	Cultural politics of environmentalism and inequality New practices in governance and policy Psychology of decisions in environmental behaviour and beyond
Natural resource economics, physical geography and regional science	Natural resource management Mapping and sensing Adaptation to climate change
Computational biology and bioinformatics	Bioinformatics for health Bioinformatics for genomics Applications in agrifood
Mechanical, process and manufacturing engineering, and risk analysis	Energy-efficient product and manufacturing engineering Energy storage and mix Nuclear power for electricity and heat production
Computer engineering and human–computer interaction	Smart systems Augmented and virtual reality AI and augmented/virtual reality in healthcare
Architectural, civil construction, geotechnical and structural engineering	Sustainable and carbon-neutral construction materials Sustainable structures Green architecture
World wide web	Greener data centres Education to combat misinformation and monitoring of misinformation Solutions for digital commons
Mining engineering, petrology and geochemistry	Sustainable/green mining Automation of mining Non-territorial and off-Earth mining
Transport engineering	Green transportation policies Green energy vehicles Rethinking of urban mobility
Theoretical physics and engineering physics	Quantum electronics Renewable energy

	Nuclear fusion
Marine engineering	Ocean clean-up solutions Marine renewable energy Marine aquaculture

Source: Futures4Europe (n.d.), *Futures4Europe*, https://www.futures4europe.eu/.

The status of the exploitation of the planet's resources – be it through agriculture and industry, mining, or waste disposal and emissions – is such that crises and shortages are likely to become frequent, resulting in an important concern for planetary health and a shift of attention from human performance to a more inclusive performance of flourishing ecosystems ([67]). Developing deep understanding of and empathy for elements and inhabitants of flourishing ecosystems is an important item on the agenda, as is developing an understanding of ecosystems that could transform our economy from linear through circular to regenerative, while enhancing the symbiotic interactions between human and non-human ecologies. Here it is important to note that such transformations should be means to achieving flourishing ecosystems rather than simply economic pursuits. New understandings of environmental damage, protection and repair, new means to pursue such activities, and new processes for governing ecosystems and technologies are important pursuits.

Box 8. Priority areas for EU R & I – future resource crises

Regarding future resource crises, the expert survey generated the following potential priority areas for EU R & I:

- nature-based solutions,
- use of high tech in recycling and material decomposition (including the design and manufacturing stage),
- laws for nature (legal status and representation of nature, for example animals, plants, landscapes),
- sustainable soil management practices, in line with agroecological principles,
- resource management – environmental and social baseline data acquisition.

Source: Foresight expert survey.

Environmental issues are often associated with hi-tech and micro- and nano-level interventions. Humanity now uses converging microtechnologies, nanotechnologies, biotechnologies and data technologies that intervene at the smallest and most fundamental level of nature, ecosystems and species, with the objective of increasing human performance and standards of living ([68])**.** Virtual worlds are built to represent or even replace reality. Sometimes interventions are far more pertinent than anticipated, and they are changing the nature of the world in often challenging ways. Biodiversity loss, weedkiller-resistant plants, omnipresent microplastics and (pseudo-)oestrogen, antibiotic resistance, pandemics, digital divides and digital monopolies, threats to democracy and human rights, or – though still fictional – self-replicating nanobots getting out of control are some of the challenges associated with converging technologies and their improvement of human performance. **To overcome such challenges, there is a need for new ecological understandings of human performance and planetary health as a coherent whole, where one should not advance without the other.**

Box 9. Priority areas for EU R & I – future ecosystem disruptions related to converging technologies

Regarding future ecosystem disruptions related to converging technologies, the expert survey generated the following potential priority areas for EU R & I:

- big data, environmental modelling and simulations, web applications and tools for decision-making,
- environmental impact assessment procedures for micro- and nano-level interventions,
- monitoring techniques for the micro, nano and virtual cosmos,
- biocentric/geocentric ethics,
- safety and testing regulation for nanotechnologies and microtechnologies,

([67]) Futures4Europe (n.d.), *S&T&I for 2050 – Science, technology, and innovation (STI) for ecosystem performance: Accelerating sustainability transitions*, https://www.futures4europe.eu/sti2050.

([68]) Futures4Europe (n.d.), *S&T&I for 2050 – Science, technology, and innovation (STI) for ecosystem performance: Accelerating sustainability transitions*, https://www.futures4europe.eu/sti2050; See also European Environment Agency (2001), *Late Lessons from Early Warnings: The precautionary principle 1896–2000*, Environmental issue report No 22, Office for Official Publications of the European Communities, Luxembourg.

- decentralisation of resource and data interchanges between technologies and ecosystems.

Source: Foresight expert survey.

Global commons are given increasing importance in the pursuit of sustainability ([69]). Five global commons are already recognised by international law: the atmosphere, outer space, Antarctica, the deep seabed and the high seas. These domains are necessary for and accessible by all, yet are beyond the jurisdiction of national governments. Other natural phenomena such as the permafrost and tropical rainforests share characteristics and ecological significance with global commons, but they do not have the legal recognition. Domains such as scientific knowledge and digital space also share characteristics with the geophysical commons listed above. By 2040, the combined impact of geopolitical instability caused by climate change, growing strategic sovereignty and breakdown of international order, multiple crises and the scarcity of resources will reduce the prospect of effective global and local governance of global commons with important effects on the biosphere.

The legal recognition of global commons emphasises the importance of scaling up well-performing local models of commons management. Systems for monitoring the state of global commons, diagnosing problems and carrying out corrective interventions and improvements are certainly important for such governance. Science is related to global commons and global problems in three ways: (i) it acts as a public good in dealing with global problems; (ii) it acts as a spokesperson for global commons and related goods that have no voice; and (iii) it can be considered a part of the global commons itself. The framing of R & I activities (by research agencies and institutions, intellectual property regimes, etc.) and the role of institutions therein has important implications for the governance of global commons.

Box 10. Priority areas for EU R & I – global commons

In the light of the rising importance of emerging global commons, the expert survey generated the following potential priority areas for EU R & I:

- alternative forms of governance and ownership models to manage global/local commons,
- science and scientific knowledge as global commons,
- substitutes and alternative sources of materials to combat over-exploitation of global commons,
- ways to abandon the dominant framing of goods as private (market) or public (state) and instead recognise their value as common goods,
- upscaling from local to global governance of commons – infrastructures and management systems.

Source: Foresight expert survey.

There is possibly no global common more important than the climate ([70])**.** Humans are changing the climate, though unwittingly, through their lives, practices, lifestyles and infrastructures. Understanding the perils of climate change means that citizens can become responsible for the consequences of their actions, and decide to change their practices or to try compensating for their implications in different ways. Technological solutions directly addressing climate change mitigation entail significant risks, and their assessment and undertakings need governance structures and methods that require considerable development. Most technological solutions are only indirectly dealing with climate change, which leaves important questions about their relative performance.

Box 11. Priority areas for EU R & I – climate change

In the light of the need for responses to climate change, the expert survey generated the following potential priority areas for EU R & I:

- biodiversity and climate change,
- nature-based solutions,
- circular design and material use in climate technologies,
- integration of climate impacts in environmental impact assessments,
- behavioural change and ways to increase people's capacity to react to climate change,

([69]) Futures4Europe (n.d.), *The Emergence of Global Commons – A new opportunity for science, business, and governance: Deep dive*, https://www.futures4europe.eu/global-commons.
([70]) Futures4Europe (n.d.), *Climate Deep dive*, https://www.futures4europe.eu/climate.

- adaptation to climate change.

Source: Foresight expert survey.

Climate change and the limitations of fossil fuels call for a decarbonisation of the economy that involves advances in renewable energy technologies and scaling up their deployment, which includes expanding electrification, energy efficiency and the use of fuels and other energy carriers that contain no carbon, of which an important one is hydrogen ([71])**.** With the importance of energy in current global geopolitical structures and with the level of government involvement in energy systems worldwide, progress in the hydrogen economy is a very political issue. Some of the infrastructures of the fossil energy era can be used in a green hydrogen economy, although its energy systems could, and probably would, be very different from those of fossil fuels and nuclear power stations. The technologies used to form green hydrogen and integrate it into a carbon-free energy system are already available. Scale-up, demonstration and deployment of hydrogen-based systems are needed, in sync with appropriate regulatory reform to take advantage of European technological leadership. It is also necessary to ensure that the relative energy abundance caused by renewables and hydrogen does not imperil the drive for energy efficiency.

Box 12. Priority areas for EU R & I – hydrogen economy

In the light of the need for responses to a possible hydrogen economy, the expert survey generated the following potential priority areas for EU R & I:

- opportunities and challenges of an increasing variety of energy options,
- resilience, security and vulnerability of the new energy system,
- large-scale storage systems for hydrogen,
- upscaling of H_2 production technologies, including the process of synfuel production (e.g. binding H_2 to C or N, yielding methanol or ammonia),
- hydrogen as a fuel for long-range transport (e.g. ships, trains, planes, rockets).

Source: Foresight expert survey.

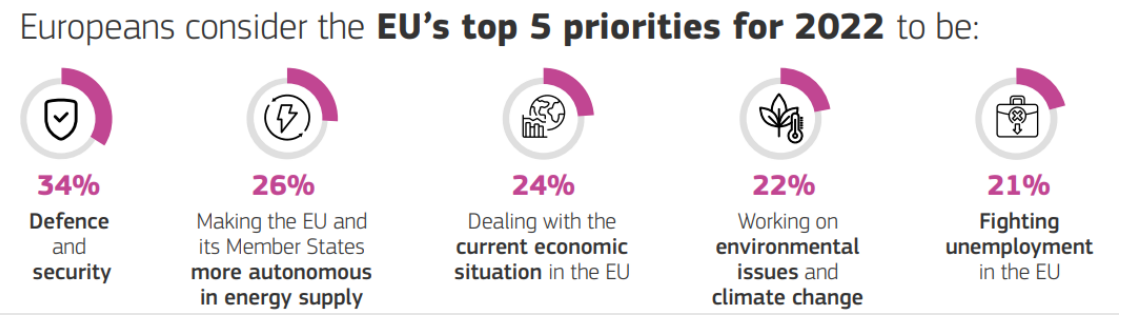
1.5. EU policymaking together with stakeholders from the research and innovation ecosystem, citizens and society at large

1.5.1. Priorities resulting from citizen engagement

Citizen engagement and the engagement of industry, social partners and civil society actors are critical to reinforce trust in science, and to facilitate and secure the innovation process and its uptake. Without citizen engagement, or without integration of the needs of social partners and their buy-in for uptake and deployment, even the best-designed strategies and activities would not achieve the highest impact, and would be unable to support the economic and social transformations and green and digital transition in a way that includes all EU communities or regions. Social innovations have also shown their worth as new tools, ideas and methods leading to active citizen engagement, enabling and promoting the effective uptake of technological innovations, and as drivers of social change and social ownership. The current crises and challenges are also at the forefront of EU citizens' minds. According to the results of a Eurobarometer survey on the key challenges of our times (Figure 5), the top five priorities for EU citizens in 2022 were (i) defence and security, (ii) more autonomy in energy supply, (iii) dealing with the current economic situation, (iv) environmental issues / climate change and (v) fighting unemployment ([72]). This should be reinforced with actions addressing the entanglement of complex issues, with the involvement of as many actors as possible ([73]).

([71]) Futures4Europe (n.d.), *The Hydrogen Economy: A radical alternative – Deep dive*, https://www.futures4europe.eu/hydrogen.
([72]) European Commission (2022), *Key Challenges of Our Times*, https://europa.eu/eurobarometer/surveys/detail/2694.
([73]) The New European Bauhaus is an example of such an action, as it addresses multifaceted challenges while actively involving stakeholders, citizens and communities in the design, creation and implementation of solutions. See European Union (n.d.), *New European Bauhaus*, https://new-european-bauhaus.europa.eu/index_en.

Figure 5. Top five EU priorities for 2022, according to European citizens



NB: Multiple answers could be given.
Source: European Commission (2022), *Key Challenges of Our Times*, https://europa.eu/eurobarometer/surveys/detail/2694.

The Conference on the Future of Europe illustrates how citizens and society at large can be engaged in EU policymaking ([74])**.** The final report provides 49 proposals that reflect the expectations of European citizens on nine topics: a stronger economy, social justice and jobs; education, culture, youth and sport; digital transformation; European democracy; values and rights, rule of law, and security; climate change and environment; health; the EU in the world; and migration ([75]). Moreover, according to EU citizens, in order to face major global challenges, the EU should prioritise the environment and climate change, social fairness and equality, and health and safety (cf. the Eurobarometer 'Future of Europe' ([76])). There is also wide agreement that tackling climate change can bring a range of benefits, including health and well-being benefits ([77]).

As a contribution to Horizon Europe Strategic Plan 2025–2027, a citizen engagement event took place on 1 December 2022, in the context of the Conference on the Future of Europe. One important general takeaway from the event was that citizen engagement (as, for example, seen at this event) is a valuable way to hear from EU citizens – about their views and opinions on how EU policy affects them, the challenges they face and what matters to them, and the solutions that they propose to tackle these challenges. Moreover, citizen engagement is a continuous effort, and the European Commission is committed to pursuing similar efforts on a regular basis ([78]). In this particular case, the event generated a lot of rich content to be used for developing the Strategic Plan 2025–2027. Table 3 shows the priorities resulting from the event separated into the three thematic groups, based on the proposals from the Conference on the Future of Europe report.

Table 3. Overview of prioritised proposals and key discussion points of the citizen engagement event for Horizon Europe Strategic Plan 2025 – 2027

Proposal	Desired knowledge or innovation	Barriers to or opportunities for implementation
Session on the digital and technological transition	• More literacy, knowledge and innovation so that citizens can better navigate the media landscape, access in-depth news	• Bureaucracy • Missing insight into the efficiency of research projects that have already been funded by the EU

([74]) The task of the conference was the organisation, for the first time, of a transnational, multilingual and interinstitutional exercise of deliberative democracy, involving thousands of European citizens, as well as political actors, social partners, civil society representatives and key stakeholders in accordance with Article 16 of the Rules of Procedure of the Conference on the Future of Europe.
([75]) Conference on the Future of Europe (2022), *Conference on the Future of Europe – Report on the final outcome*, Conference on the Future of Europe, https://futureu.europa.eu/rails/active_storage/blobs/redirect/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaHBBK1ZCQVE9PSIsImV4cCI6bnVsbCwicHVyIjoiYmxvYl9pZCJ9fQ==--fd6431aecc848f82a01218686dc7c6396b238e7c/Book_CoFE_Final_Report_EN_full.pdf?locale=en.
([76]) European Commission (2022). Eurobarometer ' 'Future of Europe' https://ec.europa.eu/commission/presscorner/detail/en/IP_22_447.
([77]) European Commission (2022), *Future of Europe: Europeans see climate change as top challenge for the EU*, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_447.
([78]) See European Commission, von der Leyen, U. (2022), 2022 State of the Union address by President von der Leyen, SPEECH/22/5493, https://ec.europa.eu/commission/presscorner/detail/ov/speech_22_5493.

27: Media, fake news, disinformation, fact checking and cybersecurity 31: Access to digital infrastructure 35: Digital innovation to strengthen the social and sustainable economy	coverage, and clearly see who sponsors what news stories • Information on better protecting children and vulnerable groups • Find a balance between the right to free speech and protection from hate speech or misinformation • Need to develop digital solutions with user needs at the centre (include all groups in society) • Explore innovation ecosystems (e.g. digital innovation incubators) that can harmonise infrastructures for digitalisation across the EU, so knowledge is shared, opportunities are the same across the EU and we achieve more equal digitalisation across the EU • Maintain a balance between digital and non-digital solutions, so that being digital remains a choice • Request for further discussion on whether rural areas need to be digitalised and what criteria can be used to define the development of rural areas • Citizens are frustrated with slow process of digitalisation regarding digital identities • Need to ensure citizen rights and security • Disease prevention an area of priority for digital development • Psychological and emotional effects of social media • Education of public administration officials and private actors	• Digital solutions are not user friendly, nor developed with user needs in mind • Citizens have different needs: some would like to choose between different digital solutions, others do not want to have to choose, and some would like to have a choice between using digital tools or not • Education on using digital tools is missing • Dominance of big tech companies • Inequalities between EU countries in terms of infrastructures for digitalisation and other inequalities • Safety concerns, concerns on protection of vulnerable groups • Mental health concerns
Session on the green transition 1: Agriculture, food production, biodiversity and ecosystems and pollution 6: Information, awareness, dialogue, and lifestyle 11: Sustainable growth and innovation	• New or effective tools to measure carbon emissions • Explore smart solutions towards eating more plant-based food, with minimum levels of laboratory produced food and with readjusted subsidies towards more sustainable farming practices • Consumer education is important in the whole ecosystem, not least in the schools • Explore new technologies for improving holistic and sustainable farming. Knowledge is missing on the potential of infra-red technologies and the use of sensor technologies	• Citizens' willingness to engage in innovation and to adapt to new green lifestyles • Need for better collaboration between many actors and sectors • Local authorities to be much more involved in engaging with citizens on sustainable change • Need for more and better communication and dissemination of research and insights that already exist

	• Need for an EU-level discussion on how we prioritise our land use • Explore how social and technological innovation would develop in harmony • Need for education and awareness programmes on lifestyle changes	
Session on resilience 10: Equal access to health for all 18: Reducing the EU's dependency on foreign actors in energy 25: Rule of law, democratic values and European identity	• Knowledge about the opportunity, advantages and limitations of having a common database of health data that would allow for a lot of useful research but presents some limitations in terms of privacy • Need for the EU to ensure fair and equal access to health services • Better tools to assess the possibility and usefulness of waste recycling for energy use • Focus on sustainable transportation solutions to achieve the goal of reducing dependency and understand what motivates behavioural change • Development of stronger connections between identity and democracy to strengthen democracy • Culture and cultural heritage to substantially contribute to keeping the EU connected/united and reinforce solidarity by helping build a common and strong EU identity • Need to make EU values and the rule of law respected across the EU • Need to raise awareness among the public of ongoing European research projects and the results of finalised ones	• Access to health to be equal across the EU and equally affordable • Barriers to a shift towards a more sustainable energy system poorly understood; need to understand those barriers better, hence the need to focus on behavioural research • Need to carefully and confidently navigate researching European identity, and foster and strengthen it against populist voices, while in parallel promoting intercultural understanding and without this being perceived as a propagandist effort • Demography (support families) and migration (access to health, integration, war in Ukraine) as serious challenges for the resilience of our societies • Need for EU to increase its digital capacities to be resilient and autonomous in the digitised world • Need for EU to increase its preparedness for future crises (war, health, etc.)

Source: VO Europe, teknologiradet and Mission Publiques (2022), *Report on citizen engagement event Horizon Europe Strategic Plan 2025–2027 – 1st of December 2022*.

Box 13. Overview of possible research needs based on the citizen engagement event for Horizon Europe Strategic Plan 2025 – 2027

Looking at the input from the citizen participants, possible areas of research could include:

- regarding the digital and technological transition:
  - researching users' needs for digital solutions;
  - engaging with populations in rural areas to understand their needs and discuss the value and desired developmental directions for rural areas;
  - researching dynamics of media landscapes, and how to create more transparency and provide access to all groups in society;
  - better understanding how to protect children, vulnerable groups and citizens' rights;
  - looking into how we can digitalise while keeping digitalisation optional;
  - understanding how to increase equality among Member States and on what parameters;

    - experimenting with research infrastructures, and evaluating the efficiency of research projects and communication of information;
    - better understanding which groups have difficulties using digital tools and why, and what/if education is needed;
    - diversifying the media landscape and countering the influence of big tech companies;
- regarding the green transition:
    - supporting the transition towards plant-based foods;
    - researching the effects of subsidies in food production industries, and what measures should be adjusted, how, why and when;
    - investigating what new technological tools have potential for what purposes (e.g. tools such as carbon measures, infrared, sensors);
    - investigating what is needed to improve holistic and sustainable farming;
    - better understanding the interaction between social and technological change in the context of the green transition, how one influences the other, and how the two can develop together and reinforce each other;
    - better understanding education needs regarding behaviour and lifestyle changes, and the effects of different types of education;
    - strengthening efforts to formulate and communicate research and knowledge regarding research insights that could make a difference in moving towards a more sustainable society;
- regarding resilience:
    - increasing knowledge about the opportunities, advantages and limitations of having a common database of health data;
    - undertaking research to define equal access and standards of health outcomes (making sure that patients with the same/similar diseases have the same health outcomes) at EU level, and combining health systems and welfare systems;
    - understanding motivations for more sustainable behaviours;
    - understanding mechanisms of identity creation in relation to democratic activities and societal coherence.

Source: VO Europe, teknologiradet and Mission Publiques (2022), *Report on citizen engagement event for Horizon Europe Strategic Plan 2025–2027 – 1st of December 2022*.

1.5.2. Priorities resulting from the public consultation

A public consultation on the past, present and future of the European Research & Innovation Framework programmes 2014-2027 that concluded on 23 February 2023 after running for 12 weeks. The consultation had five sections:

- Section A asked for information about the respondent's profile.
- Section B focused on the past programme Horizon 2020 (2014 – 2020) and aimed to collect feedback and evidence to draw lessons from the past. This part of the consultation will feed into the ex-post evaluation of Horizon 2020.
- Section C focused on the current programme Horizon Europe (2021 – 2027) and aimed to take stock of what stakeholders are currently experiencing to possibly adapt current actions. This part of the consultation will feed into the mid-term evaluation of Horizon Europe, covering the period 2021 – 2023.
- Section D collected views and opinions for the upcoming Strategic Plan of Horizon Europe (2025 – 2027). The questionnaire concerned societal challenges that should shape future EU research and innovation activities, the strengths and weaknesses of the European R&I system, EU Missions, European partnerships, synergies with other EU programmes etc.
- Section E asked about the key lessons learned and messages for the future.

This section presents an extract of the full analysis report, which is published as followed: European Commission, Directorate-General for Research and Innovation, Synopsis report : looking into the R&I future priorities 2025-2027, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2777/93927

108 position papers commented on topics relevant for section D of the consultation. The input from the position papers was integrated within the report under the relevant topic. Among the 108 position papers, 40

were written by academic or research institutions, 17 by public authorities ([79]), 12 by non- governmental organisations, 7 by business associations, 5 by companies or business organisations, 2 by EU citizens, 1 by a trade union. 24 position papers were submitted by "other" respondents including innovation agencies, networks, and consortia of universities. The largest number of position papers came from Belgium (33), France (12) and Finland (11).

Responses were reviewed manually to identify campaigns and potential duplicates in the position papers submitted and in the open questions of the questionnaire. Overall, **21 campaigns** were identified, with a number of identical contributions ranging from 2 to 8. The 21 identified campaigns include responses by **78 respondents**, representing **3%** of all responses.

Overview of the respondents

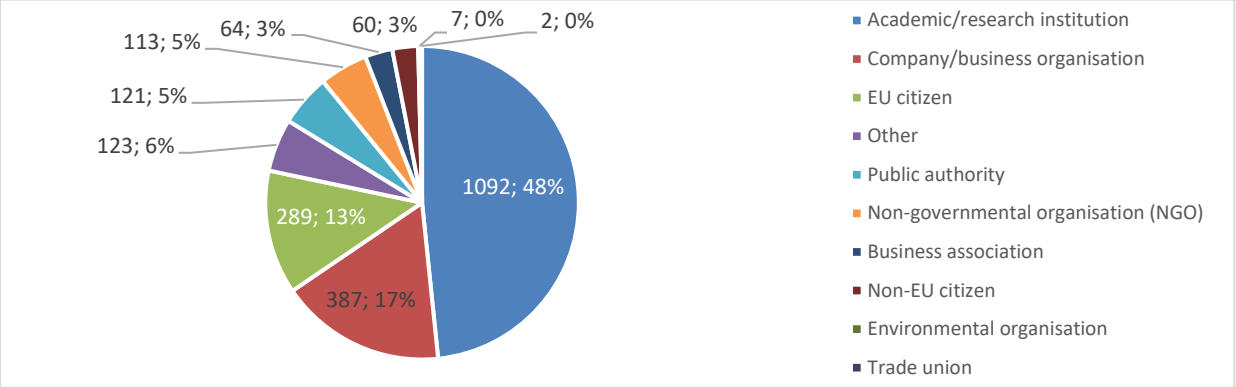
This section describes the profiles of the respondents that have contributed to section D of the consultation.

i. Types of respondents

In total, **2 258** respondents completed section D. The respondents could choose to answer all the questions or only some of them. Because of that, the total number of respondents for each question may vary.

A wide range of actors contributed to this section. Around half of the respondents (48%; 1 092) are part of academic or research institutions, 17% (387) are companies or business organisations, and 16% (349) are citizens (EU and not EU). The remaining respondents (19%; 430) include different types of stakeholders: 121 are public authorities, 113 are NGOs, 64 are business associations, 7 are environmental organisations and 2 are trade unions. 123 respondents selected the category "other". Among the 121 (5%) public authorities that contributed to sections D, 51 work at the national level, 34 at the international level, 24 at the regional level and 12 at the local level.

Figure 6. Types of respondents (N=2 258)

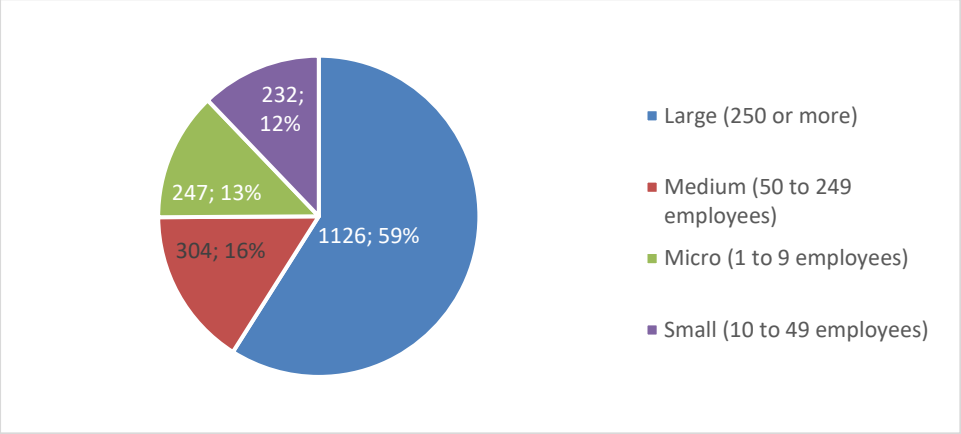


Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

62% (1 397) of respondents provided personal views, while 36% (811) contributed as a member of an institution or organisation and 2% (50) did not indicate this information. More than half (59%; 1 126) of the organisations that contributed are large, whereas 16% (304) are medium size, 13% (247) are micro and 12% (232) are small.

([79]) 12 position papers were submitted by public authorities at national level, 3 by public authorities at regional level and 2 at international level.

Figure 7. Size of the organisations participating in the consultation (N=1 909)

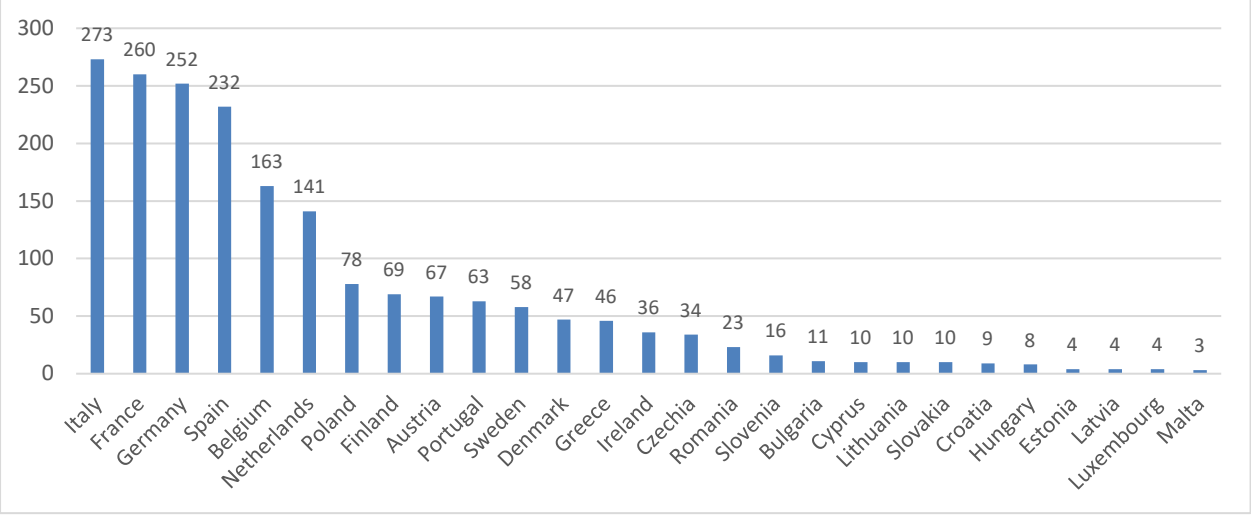


Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

ii. Geographical coverage

The consultation gathered responses from **75 different countries**. 86% (1 931) of respondents came from EU-27 countries, 7% (148) from the EU Associated Countries ([80]), and 8% (179) from third countries ([81]). The countries with the largest number of respondents are Italy (273), France (260), Germany (252) and Spain (232).

Figure 8. Number of respondents by EU27 Member State (N=1 931)

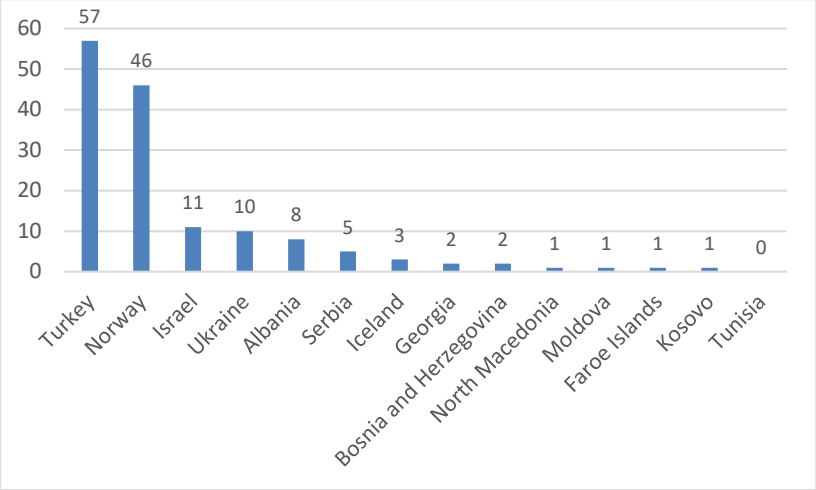


Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

([80]) Associated countries include Turkey (57), Norway (46), Israel (11), Ukraine (10), Albania (8), Serbia (5), Iceland (3), Georgia (2), Bosnia and Herzegovina (2), North Macedonia (1), Moldova (1), Faroe Islands (1), and Kosovo (1). Switzerland was not included.

([81]) United Kingdom, Switzerland, United States, Brazil, China, Colombia, India, Philippines, Ethiopia, Belarus, Australia, Jordan, Venezuela, Uruguay, South Africa, Nigeria, El Salvador, Uganda, Antigua and Barbuda, Indonesia, Egypt, Bangladesh, Japan, Taiwan, Kenya, Senegal, Russia, Laos, Rwanda, Singapore, Palestine, Sri Lanka.

Figure 9. Number of respondents by EU Associated Country (N=148)

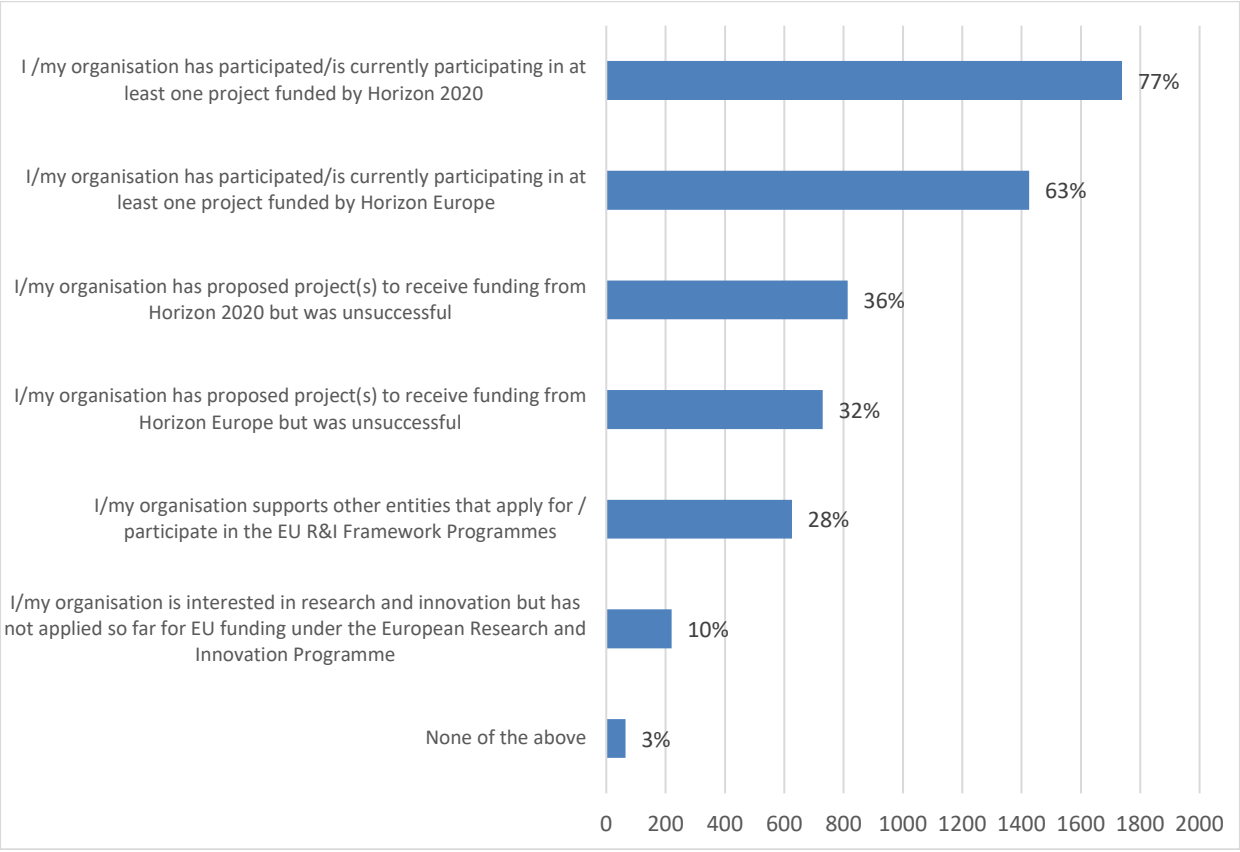


Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

iii. Experience with the framework programmes

More than three-quarters (77%; 1 739) of all the respondents that contributed to the part of the consultation on the Horizon Europe Strategic Plan 2025-2027 were beneficiaries of Horizon 2020, and 63% (1 426) of them are beneficiaries of Horizon Europe. Respondents include also organisations supporting other entities that apply for or participate in the EU R&I framework programmes (28%; 626) and organisations that have never applied for funding but are interested in R&I (10%; 220).

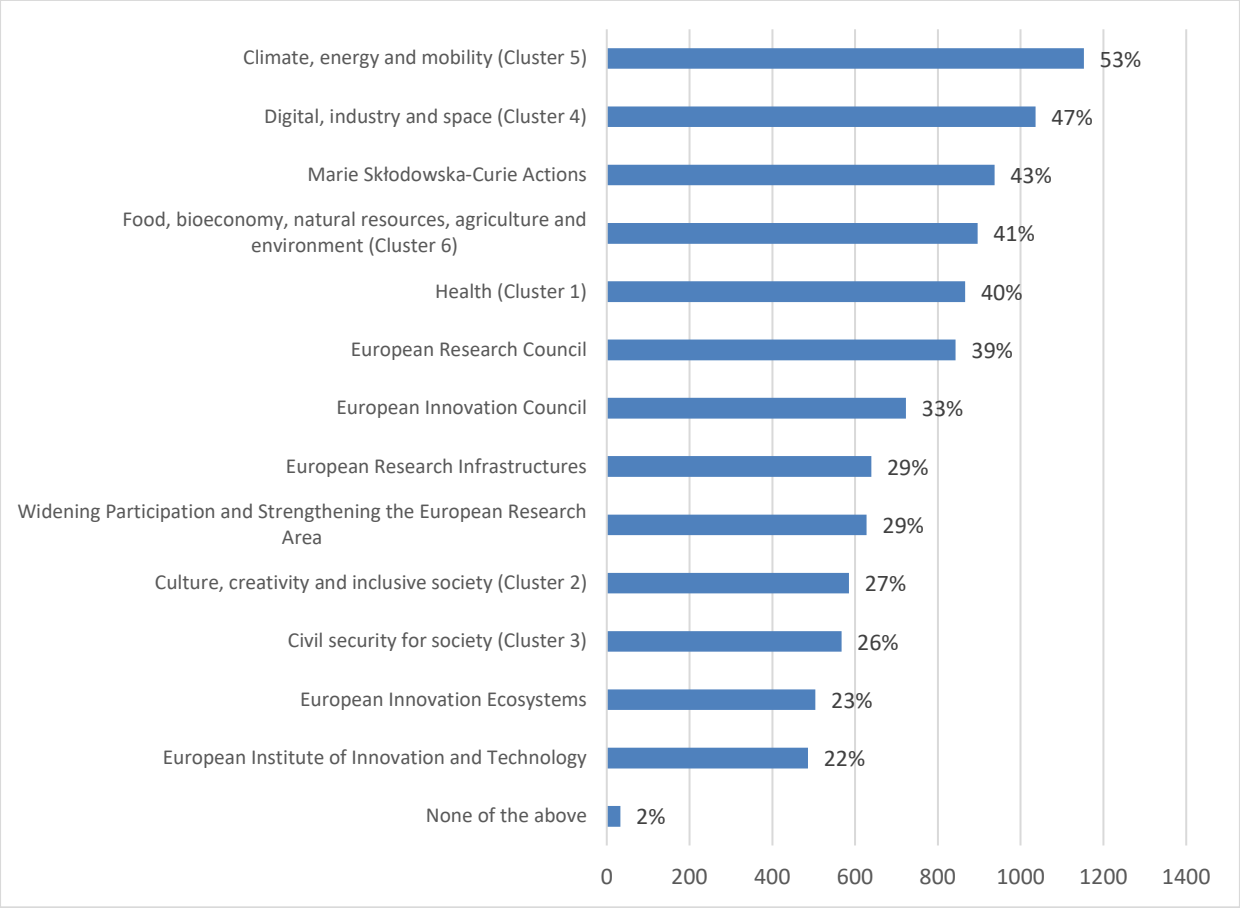
Figure 10. Please select the option(s) that best describe(s) your experience with the European Union Research and Innovation programmes (N=2 258; multiple answers possible)



Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

The respondents were active or interested in all the parts of Horizon Europe ([82]). The highest number of respondents were interested in **cluster 5** "Climate, energy and mobility" (53%; 1 153), **cluster 4** "Digital, industry and space" (47%; 1 036), **Marie Skłodowska-Curie Actions** (43%; 937), **cluster 6** "Food, bioeconomy, natural resources, agriculture and environment" (41%; 896), and **cluster 1** "Health" (40%; 866).

Figure 11. In which of the following areas of Horizon Europe are you or your organisation mainly active / interested in? (N=2 186; multiple answers possible)

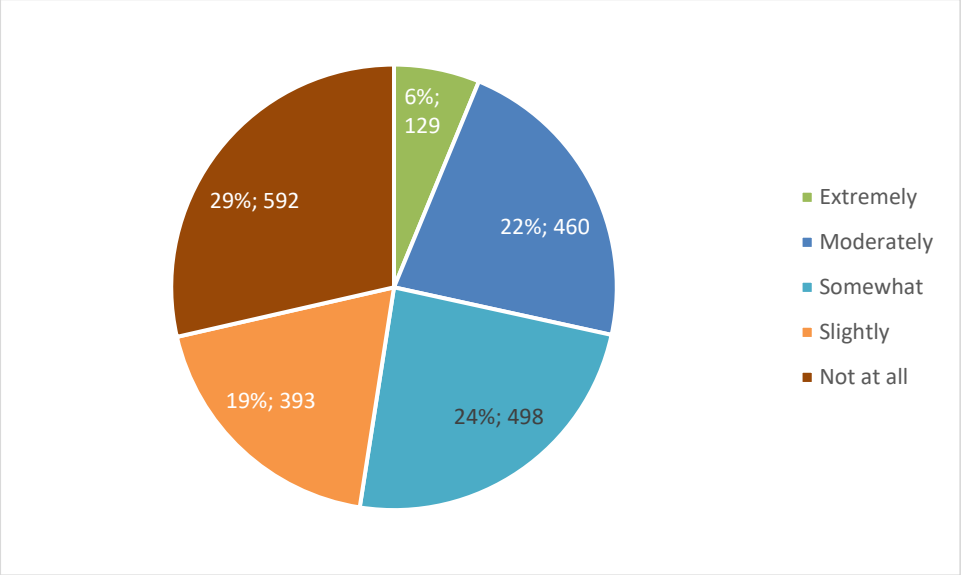


Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

Around half of the respondents are at least somewhat familiar with the strategic planning process for Horizon Europe, whereas one third of them is not familiar with it at all.

([82]) Question: In which of the following areas of Horizon Europe are you or your organisation mainly active / interested in? Please select all that apply.

Figure 12. How familiar are you with the strategic planning process for Horizon Europe? (N=2 072)



Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

Results of the consultation

Identifying priorities and societal challenges for the future

i. The most important R&I solution over the next 10 years

The respondents were asked to "name the most important R&I solution that would help [them] in [their] life over the next 10 years". This open question received 1 110 responses, of which 1 105 were valid after filtering "I don't know", N/A, "No opinion". The answers span different fields, some of them are more specific (e.g., referring to certain technologies or applications), others indicate broad areas of research.

The word cloud below gives an overview of the most recurrent words used in the responses. **Thematic areas such as health, energy, climate, sustainability and digitalisation** stand out.

Figure 13. Name the most important R&I solution that would help you in your life over the next 10 years (N=1 105)

Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

The table below reports the key topics for each area of research ([83]).

Table 4. Examples of the most important R&I solutions mentioned in the consultation

Thematic area	Key topics ([84])
Health	Cancer (prevention, cure, treatment, personalised medicine, vaccine development, targeted therapies, aggressive cancers) Rare diseases (diagnostics, cure) Dementia (prevention, treatment) Cardiovascular diseases (prevention, cure) Autoimmunity and degenerative diseases (prevention, treatment) Infectious diseases (prevention, cure, viral control) Chronic diseases (new remedies) Development of new diagnostics, vaccines, and therapeutics against neglected diseases Alzheimer's disease (cure) Antimicrobial resistance Multidisciplinary approach to health research, including AI-assisted medical diagnosis
Aging population and elderly care	Solutions to improve the quality of life for elderly people Prevention of loss of autonomy Solution to provide appropriate care for elderly people
Energy	R&I solutions for clean, sustainable and affordable energy production Solutions to substitute fossil fuel dependency from external countries, making the EU self-sufficient for energy Development of renewable energy solutions (e.g., wind energy) R&I solutions for clean mobility (e.g., in aviation and shipping), energy storage solutions for mobility. Energy-efficient solutions for advanced manufacturing and industrial processes Sustainable energy solutions for the construction industry Development of zero-emission solutions for the defence industry R&I solutions to use green gases (hydrogen, biomethane).
Climate	R&I solutions for climate change adaptation and mitigation R&I solutions for sustainable agriculture R&I solutions for water management and cleaning water from pollutants Protection of seas and oceans R&I solutions for preparedness to respond to threats and disasters Carbon capture technologies
Food	Food security Sustainable production of food systems (e.g., crop and tree improvement for climate change adaptation and mitigation) Plant-based and cellular agriculture research to increase the number of plant-based products Promotion of plant-based food The role of food, healthy diets, and personal nutrition in disease prevention and cure Digital solutions for food systems (e.g., digital technologies to shorten the food supply chain) Sustainable production of mass-produced goods, addressing social inequalities, protection of seas and oceans, and preparedness to respond to threats and disasters
Circular economy	R&I solutions for circular economy in manufacturing industries R&I solutions to introduce circular business models and processes R&I solutions for waste management and recycling Implementation of circular economy principles in building materials, components and systems
Digitalisation	R&I solutions for the digitalisation of industry Digital solutions for mobility Digital solutions for the construction industry

([83]) The topics were identified using a mix of automatic and manual techniques, through the following steps: 1) Identify the comments referring to a certain area using text clustering (automatic) and / or content analysis (using keywords highlighted by the text clustering). 2) Use artificial intelligence to extract the key topics from a homogenous group of comments in the same area. 3) Perform manual checks to validate the results.

([84]) The order does not indicate any ranking of prevalence.

	Digital infrastructures and networks Digital governance Cybersecurity
Technologies	Artificial intelligence solutions for: migration management, administrative practices, communication, automated driving, healthcare, chatbot AI for research Ethical use of technologies Advanced computing Advancement of Microfluidics and Lab-on-a-Chip technology Photonics technology (in sensing, telecom and other application fields) Electric battery technology Quantum technologies Microelectronics Industrial internet-of-things Digital twins for industrial products and processes Next generation of internet
Societal issues	Inclusivity in R&I Research to strengthen democratic societies (e.g., on cultural heritage, history, law, human and civil rights) Research addressing ethical concerns and democratic risks of an IT-driven (AI, IoT, robotics, etc.) society Platforms for democratic participation Solutions to increase the resilience of society (e.g., post-pandemic) Climate justice Social justice Solutions to restore/ maintain peace Migration and integration

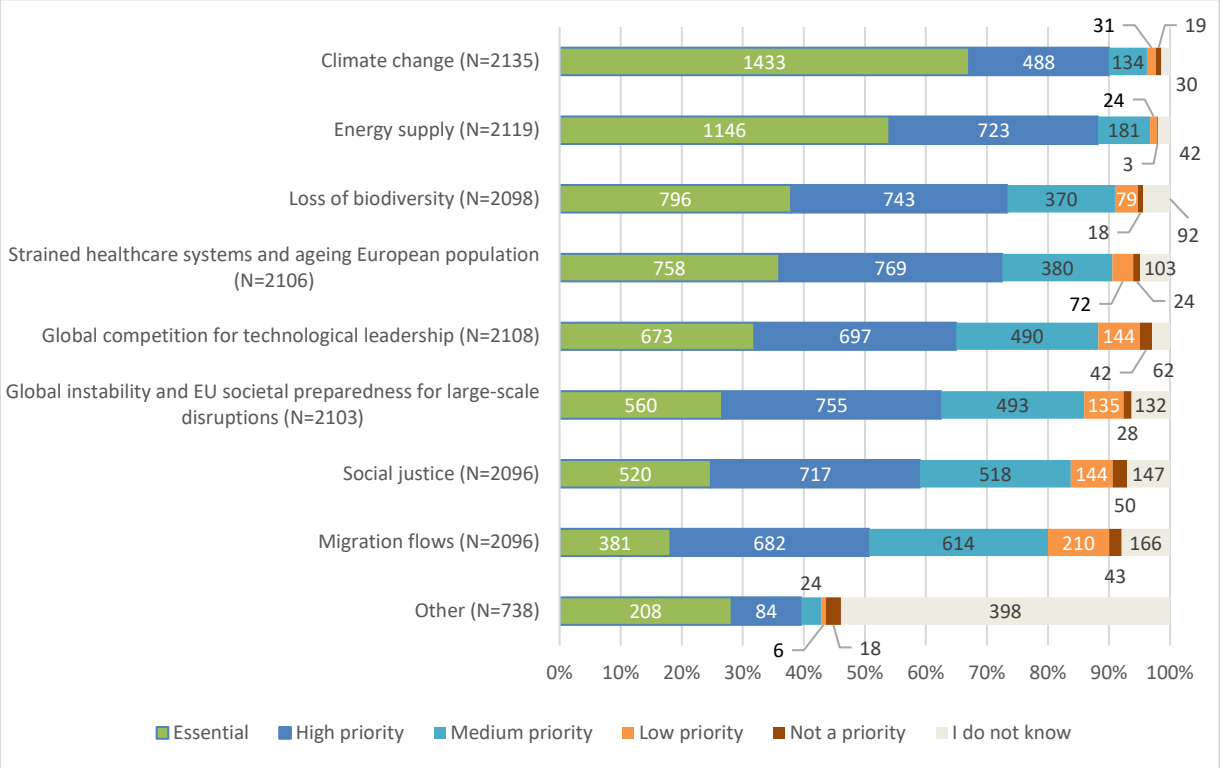
Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

ii. The most important societal challenges in the next 10 years

Respondents indicated “climate change”, “energy supply” and “loss of biodiversity” as the three most important “societal challenges that should be the focus of EU investments for research and innovation” in the next 10 years. **Almost all the respondents rated “climate change” (90%; 1 921) and “energy supply” (88%; 1 869) as an essential or high priority for the next 10 years**. All the societal challenges listed in the consultation were classified as essential or high priorities by more than 50% of participants. Respondents also reported other challenges not listed in the consultation. These challenges include food security, access to natural resources (e.g., drinking water) and critical raw material, transformation of work (e.g., mismatch between skills and work opportunities), transformation towards sustainable entrepreneurship and business in Europe, preserving and enhancing democracy, fight against disinformation, preserving peace ([85]).

([85]) 331 respondents provided comments in the open box where it was asked to specify other societal challenges. Most of the comments however refer to the societal challenges already listed and, in many cases, rather than answering the question about the societal challenges, the respondents provided input on the R&I solutions that should be prioritised.

Figure 14. In the next ten years, which societal challenges should be the focus of EU investments for research and innovation activities?



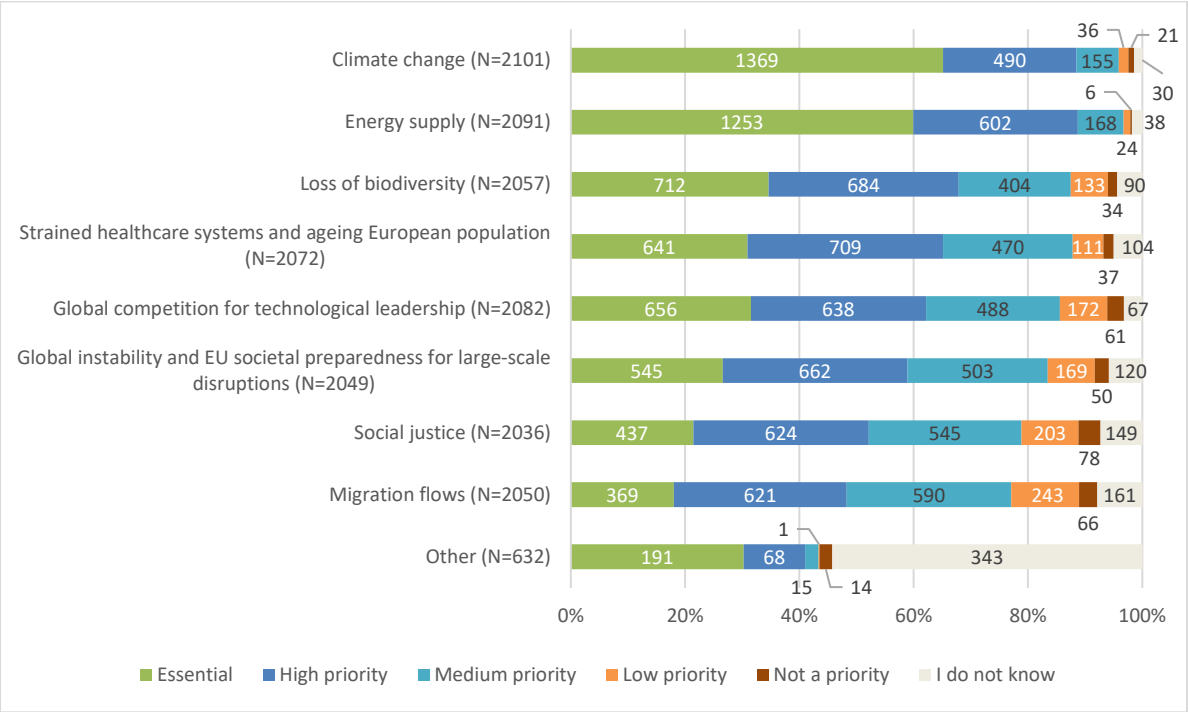
Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

iii. The most important challenges in the next 3 years

The respondents' opinion on the most important societal challenges for the next three years was the same as for the next 10 years. All the challenges were considered as "essential" or "high priority" by at least half of the respondents. The comments concerning other possible societal challenges were more focused on the possible solutions rather than on the challenges. In many cases, the respondents repeated the same comment provided in the previous question ([86]).

([86]) 459 respondents provided comments in the open box where they were asked to specify other societal challenges. 114 respondents provided an identical answer as to the previous question and 5 respondents explicitly referred to the answer given to the previous question. The analysis of the responses does not highlight any additional societal challenge (i.e., all the responses provide comments that can be associated to any of the challenges listed in the matrix). In many cases, rather than answering the question about the societal challenges, the respondents provided input on the R&I solutions that should be prioritised.

Figure 15. In the next three years, which societal challenges should be the focus of EU investments for research and innovation activities?



Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

iv. The Horizon Europe clusters addressing the societal challenges

As regards the capacity of the Horizon Europe clusters to address societal challenges, stakeholders from different groups (i.e., academia, NGOs, public authorities) underlined in their position papers that a **multidisciplinary and collaborative approach** including different types of actors is essential to tackle societal challenges. Some universities and research organisations maintained that all clusters have the potential to address current and upcoming societal challenges. However, in their opinion, to fully exploit their potential, clusters should fund more research at lower technology readiness level, combining a top-down and a bottom-up approach. In this way, the applied research and innovative solutions could benefit from new, exploratory knowledge.

The following chart shows the responses to the question “In your opinion, which Horizon Europe cluster(s) contribute(s) to addressing the societal challenges?”. Although all the clusters were selected for all the societal challenges (by at least 5% of respondents), certain clusters seem to have a more prominent role in addressing some societal challenges:

- “Climate change” is addressed by cluster 5 and cluster 6 according to respectively 95% and 70% of respondents.
- “Energy supply” is addressed by cluster 5 according to 93% of respondents.
- “Migration flows” is addressed by cluster 3 and cluster 2 according to respectively 76% and 70% of respondents.
- “Social justice” is addressed by cluster 2 and cluster 3 according to respectively 82% and 62% of respondents.
- “Loss of biodiversity” is addressed by cluster 6 and cluster 5 according to respectively 93% and 56% of respondents.
- “Strained healthcare systems and ageing European population” is addressed by cluster 1 according to 95% of respondents.
- "Global competition for technological leadership” is addressed by cluster 4 and cluster 5 according to respectively 93% and 58% of respondents.
- "Global instability and EU societal preparedness for large-scale disruptions” is addressed by cluster 3 according to respectively 75% of respondents.

EU Missions and specific issues

i. The EU Missions added value

Around 750 consultation participants replied to the question on the "added value" EU Missions can bring to European, national, regional and local programmes and initiatives ([87]). The comments provided were diverse: most of the respondents shared opinions, suggestions and criticisms on the EU Missions in general. Several respondents remarked that the added value of the EU missions is still unclear and difficult to assess.

The points below summarise the main messages on the EU Missions from the analysis of the answers ([88]) and the content of the position papers.

On the added value of the EU Missions:
- EU Missions provide a holistic, multidisciplinary and multisectoral approach to solving some of the greatest societal challenges, supporting the alignment of R&I policy with other sectoral policies.
- Missions can be an important instrument to increase the impact and visibility of European research and innovation and foster a spirit of European collaboration between different disciplines, stakeholders and sectors.
- EU Missions put research and innovation into a new role, combined with new forms of governance and collaboration.
- EU Missions create a new way to bring concrete solutions to societal challenges, engage citizens, and deliver impact.
- EU Missions can indicate prioritisation of policy and funding for European citizens.
- The EU Missions can mobilize and activate various public and private actors, but it remains to be seen if they can make a real impact.
- The EU Missions have contributed to enhanced international collaboration between European cities and regions, also beyond the Horizon-funded projects.
- The EU Missions might have a strong leverage effect on private, national and regional funding.
- The EU Missions may lead to more innovation uptake by stakeholders on local and regional levels.

On the Missions design:
- As EU Missions are funded by the EU Framework Programme for Research and Innovation, research and innovation activities should be the core of the Missions (not procurement of technologies).
- EU Missions can help bring focus to EU R&I funding programs, but it is important to ensure they are broad enough not to inhibit important R&I. At the same time, they should have clear operational priorities.
- Industry, as well as some regional and local stakeholders, do not feel that they have been included enough in the co-creation process.
- Better integration with clusters to deliver on overarching objectives would reduce the risk of duplication.
- More resources would help achieve more impacts.
- The Missions' calls should also address lower TRL (1-5) to allow fundamental research to nurture further ground-breaking developments and ultimately the goals of the EU Missions.
- It is important to have a clear plan for evaluation and feedback for the Missions before introducing new Missions or continuing the current Missions in the next Framework Programme. A possible proliferation in the number of missions could undermine the effectiveness of initiatives already undertaken.

On the Missions implementation:
- The Mission instrument is still unclear to many stakeholders.
- Research and Technology Organisations and industrial beneficiaries advocate for greater involvement in the Missions implementation.
- Finding an entry point to the EU Missions has been challenging for industry/ business stakeholders.
- Better collaboration is needed between academia, public sector and industry.
- The success of Missions depends on the implementation and governance at the national and regional levels, and there is a need for real coordination between Missions and regional policies to make them work.

([87]) Excluding answers as "I don't know", "no opinion", N/A, etc.

([88]) The analysis was carried out using an artificial intelligence software and manual checks.

- Universities, research institutions, and researchers do not feel involved enough in the implementation of the EU Missions.

ii. Specific issues in the Strategic Plan

According to the majority of the respondents, the 2025 - 2027 Strategic Plan should further elaborate some specific themes. Improvements are required especially with regard to international cooperation (70%; 1,367), key enabling technologies (69%; 1,362), dissemination and exploitation (62%; 1,209). Asked about additional themes that could be integrated as specific themes in the 2025 – 2027 Strategic Plan, 392 consultation participants left a comment. However, 169 of these comments were not in scope as they did not answer the question. The remaining comments refer to the following issues (some of them are already considered in the Strategic Plan):

- International cooperation
- Diversity and inclusiveness (category broader than gender)
- Climate/sustainability/biodiversity/circular economy
- Digitalisation/enabling digital technologies
- Health and well being
- Reciprocity & scientific collaboration
- Security (protecting knowledge and research infrastructures) & EU strategic autonomy
- Ethics and integrity
- Skills and education
- Open science (e.g., more emphasis on sharing data across borders)
- Citizen engagement, R&I valorisation
- Interdisciplinarity/Social Science and Humanities (SSH)
- Communication (disseminating scientific information to wider audiences, bridging the gap between science and society, and fighting against misinformation and disinformation)

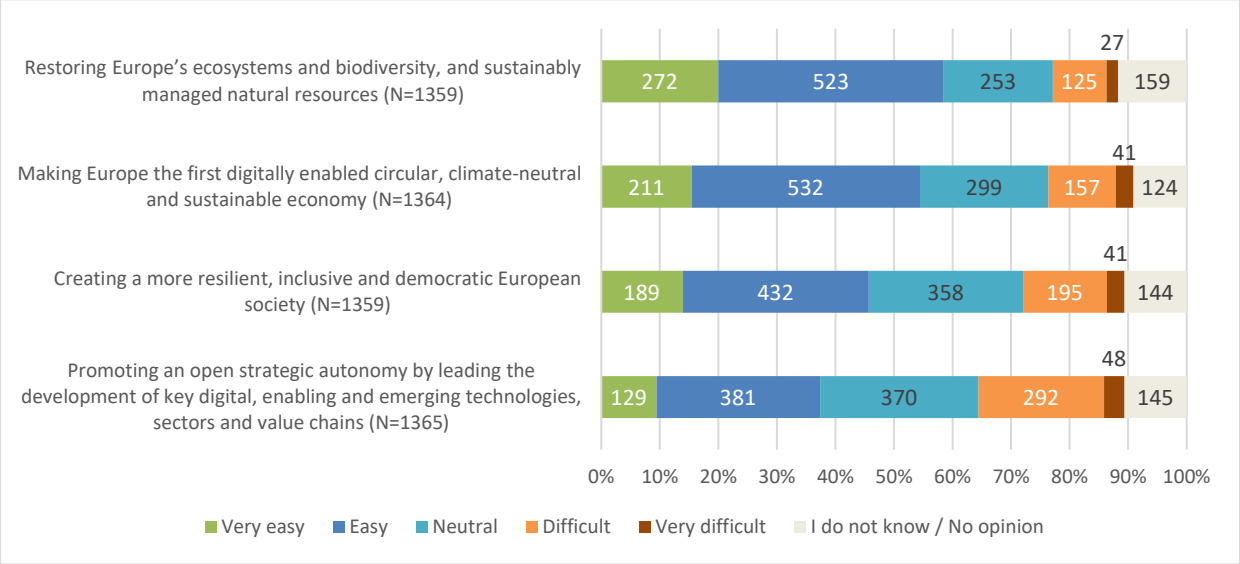
The Horizon Europe Strategic Plan structure

Two of the Key Strategic Orientations (KSOs) of the Horizon Europe's Strategic Plan 2021-2024 were "easy" or "very easy" to understand for the majority of the respondents: "restoring Europe's ecosystems and biodiversity, and sustainably managed natural resources" (58%; 795), and "making Europe the first digitally enabled circular, climate-neutral and sustainable economy" (54%; 743). Also, 46% (621) of respondents confirmed that understanding the KSO of "creating a more resilient, inclusive, and democratic European society" was "easy" or "very easy". Conversely, 25% (340) of respondents found it "difficult" or "very difficult" to understand the KSO on "promoting an open strategic autonomy". Different stakeholders confirmed in their position papers that the four KSO remain highly relevant for the coming years of Horizon Europe. Others pointed to some specific issues in the current KSO structure, such as:

- The KSOs are difficult to understand because they are too broad and merge too many, sometimes not strongly linked concepts. Limiting the number of KSOs is a positive objective but it should not harm the understanding of their meaning.
- The KSOs encompass too many impacts, making it difficult to understand the link with the work programmes.
- The four KSOs partially overlap, which makes it difficult to understand what should be covered by one or the other.
- The formulations of the KSOs are too complex and abstract and make the overall comprehension challenging.
- In the documents of the European Commission, different formulations are used for the 4 KSOs, which makes it difficult to recognise them and apply them in the proposal.
- The first KSO on strategic autonomy could be explained in a simpler way.
- The fourth KSO on resilient, inclusive and democratic European society needs a clear definition of "resilient."
- Some respondents would like to remove the 4 KSOs since multiple EU policies already give strategic indications.

Conversely, different stakeholders confirmed in their position papers that the four KSO remain highly relevant for the coming years of Horizon Europe.

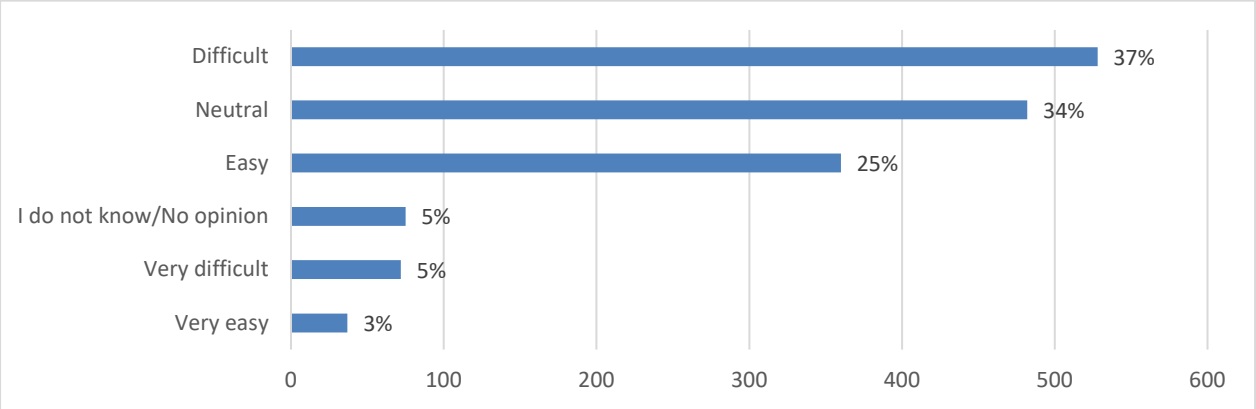
Figure 16. How easy is it to understand the four Key Strategic Orientations (KSOs) of the Horizon Europe's 2021-2024 Strategic Plan?



Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

More than one third of respondents (37%; 528) found difficult to understand the 2021-2024 Strategic Plan's structure. Only one quarter (25%; 360) found it easy while 5% (72) reported that understanding this structure was very difficult.

Figure 17. How easy is it to understand this structure the Horizon Europe's 2021-2024 Strategic Plan's structure? (N=1 554)



Source: European Commission (2023), *Synopsis Report - Looking into the R&I future priorities 2025-2027*, Directorate-General for Research and Innovation, Publications Office of the European Union, 2023.

The respondents provided feedback or suggestions for improving the structure, language and presentation of the Strategic Plan. They underlined the **need to simplify the structure reducing the number of layers** (KSO, clusters, impacts, etc.), use more accessible language, and make the Plan more concrete. Suggestions for improvement include:

- Better describe impact areas and expected impacts
- Reduce the number of impacts / prioritise the importance of the expected impacts
- Better explain the difference between impact/results, outputs/deliverables
- Provide definitions of the terms used
- Avoid using official or technical jargon
- Use the same terminology in the Strategic Plan as in the work programmes
- Add charts to help to understand the structure
- Add infographics / visuals to summarise the main messages

- Provide explanatory videos as supporting materials
- Communicate to different audiences and sectors to ensure the rationale is understood.

Different stakeholders suggested including specific references in the work programme topics or in the calls for proposal to relevant descriptions in the Strategic Plan so that applicants familiarise with it and are able to link the Strategic Plan concepts with concrete action.

1.5.3. Approaches for stakeholder consultation and citizen engagement for Horizon Europe work programmes

The regulation for the Horizon Europe framework programme demands that '[t]he Programme shall promote co-creation and co-design through the engagement of citizens and civil society' (Article 7(11) of Regulation (EU) 2021/695 on the principles of the programme ([89])). While 'co-creation' denotes the process of different Commission services coordinating in the drafting of topics, citizens and civil society shall contribute to the development of strategic plans, work programmes and topics through co-design. A brief recap of the co-creation and co-design actions during the first part of Horizon Europe is presented below.

- For the 2021–2024 strategic plan and the first (2021–2022) work programme, the 'research and innovation days' in autumn 2019 provided a large forum for stakeholders to provide inputs to the strategic orientation of clusters and missions. The COVID-19 pandemic disrupted the further development of ambitious co-design for the 2021–2022 and 2023–2024 work programmes. The research and innovation days for 2020–2022, which were to be crucial for co-design, moved into the virtual space, and, while they still attracted approximately the same number of participants as the in-person days, the intensity of interaction diminished.
- Since 2019, the Expert group on the economic and societal impact of research and innovation (ESIR) has engaged a number of interested parties from civil society in strategic discussion on the future orientation of the framework programme and R & I policy. The group's reports are appreciated for the depth of their reflection on future challenges and the identified needs of civil society stakeholders to address the green and digital transition.
- The different clusters interact with stakeholders in very diverse formats, including, notably, the work on the sectoral strategic research and innovation agendas (SRIAs). These most directly influence the design of activities in work programmes and partnerships. The work on SRIAs often includes public consultations of interested stakeholders.
- An increasing number of public consultations related to policy initiatives, such as the consultation on a Critical Raw Materials Act in autumn 2022, include sections on the role of R & I. While not directly linked to the development of the work programme, these consultations guide the strategic development and priority setting.
- Stakeholders and wider civil society were invited to respond to the public consultation linked to the *ex-post* evaluation of Horizon 2020, the midterm evaluation of Horizon Europe and the second strategic plan (1 December 2022 – 23 February 2023). Conclusions related to the R & I of the Conference on the Future of Europe were discussed with around 70 citizens in a workshop on 1 December 2022 (see Section 1.5.1).

In summary, **stakeholder and civil society consultation and co-design are well developed to help create strategic orientations, but their use is limited in later phases such as the drafting of concrete topics for the work programme**. Deeper involvement in these later phases is challenging as it might create uneven ground for the drafting of proposals in response to calls. The ongoing evaluations of Horizon 2020 observe that public stakeholder consultations provided little room for concrete contributions to topics in the subsequent work programmes and were designed for affirmation or generic criticism of a specific work programme.

At the same time, stakeholders demand more time between the official publication of the work programme and the first deadlines of the biannual work programmes so that they can prepare proposals. The Horizon 2020 Green Deal call (prepared during the COVID-19 lockdowns in Q1–Q3 2020) demonstrated how public feedback can be collected and provide orientations on topics. Stakeholders do not need all the details of topics to start preparing ambitious proposals – they need reliable information on orientations and the expected outcomes of a topic to start engaging with potential partners. For the 2025 work programme, an experimental consultation of stakeholders and civil society is planned. This consultation might be based on

(89) Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the framework programme for research and innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013 (OJ L 170, 12.5.2021, p. 1).

‘orientations paper’ (i.e. a portfolio of anticipated topics describing expected impacts and outcomes). Stakeholders’ input in this consultation might more directly influence the formulation of topics and become an important element of co-design.

2. THE EU'S RESEARCH AND INNOVATION LANDSCAPE WITHIN A GLOBAL PERSPECTIVE

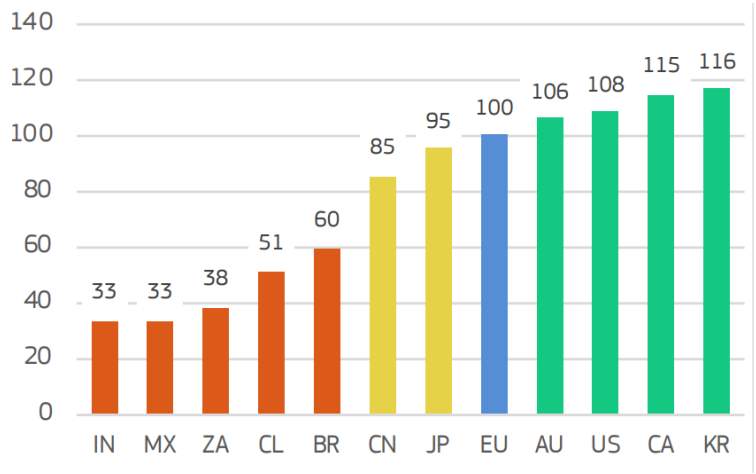
Key messages from this chapter

- The EU's overall innovation performance has improved over the past 7 years; however, the EU still lags behind the United States, Japan and China in terms of research and development expenditure as a percentage of GDP.
- In 2020, the EU produced about 20 % of the world's scientific output, second only to China, which produced 22 %. However, the EU's performance worsens when looking at the world share of the top 1 % most-cited scientific publications, ranking third (after China and the United States).
- In academic research, the EU specialises in humanities, the United States in health technologies and China in digital technologies.
- The EU is a patenting world leader; however, its position has been declining due to China's rise. The EU accounted for 31 % and the United States accounted for 38 % of the world's patent applications in 2000. Their shares declined to 19 % and 22 %, respectively, in 2018. China's share reached 21 % in 2018.
- In patenting, the EU shows strengths in areas related to advanced manufacturing and green technologies, while it underperforms in digital technologies.
- Scientific output and excellence are very heterogeneous across EU regions and remain very concentrated in a few areas. Regional disparities in R & I performance remain deep across the EU, and this innovation divide has been increasing.
- The diffusion of innovations and the uptake of breakthrough technologies, including through interregional linkages, remain suboptimal, and there is also unexploited potential in regional innovation ecosystems.
- The EU's scientific ecosystem is suffering from a brain drain to the rest of the world. More competitive wages, cutting-edge infrastructures and fair promotion processes in academia are required to address this issue.

2.1. Overall innovation performance

At global level, between 2015 and 2022, the EU overtook Japan and closed part of the performance gap between it and some other competitors, according to the European innovation scoreboard ([90]). South Korea is the most innovative country, and Australia, Canada and the United States also outperform the EU. The EU outperforms Brazil, Chile, China, India, Japan, Mexico and South Africa (Figure 18). Within the EU, almost all EU Member States have increased their innovation performance since 2015, but the lowest-performing countries are falling further behind.

Figure 18. Global innovation performance



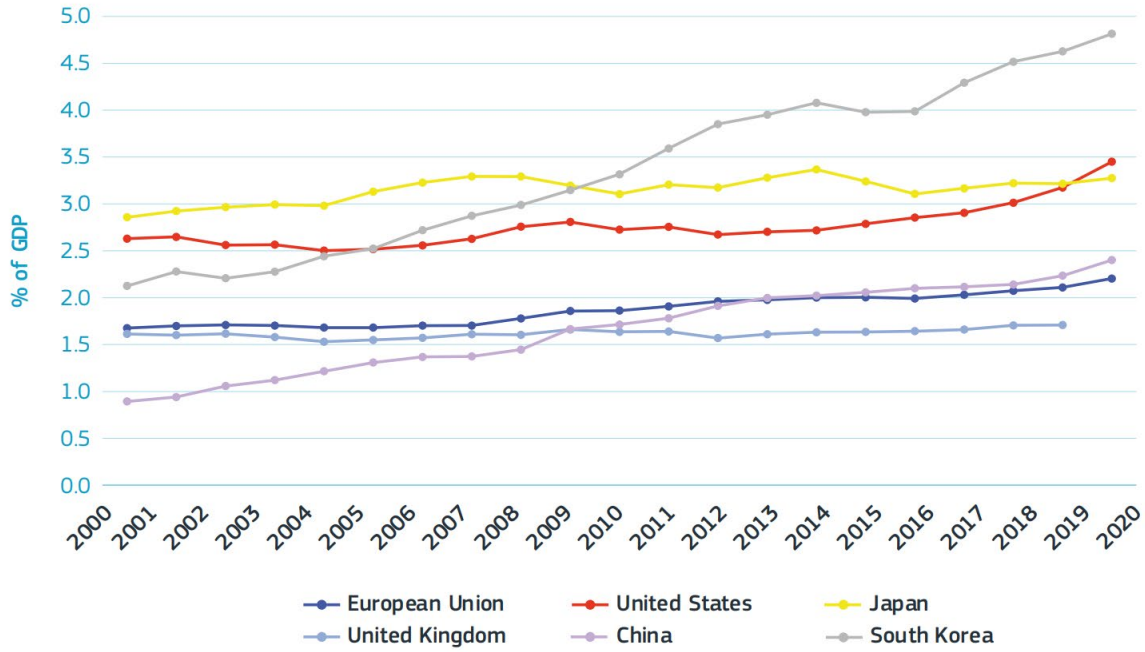
Source: European Commission, Directorate-General for Research and Innovation and Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2022), *European Innovation Scoreboard 2022*, Publications Office of the European Union, Luxembourg, https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en.

2.2. Research and development investments

Europe has intensified its R & D investments over the past two decades, but there remains a gap in terms of its R & D intensity compared with some of its main competitors. The EU's R & D intensity increased from 1.81 % of GDP to 2.32 % of GDP over 2000–2020. However, in 2020, it is still below that of South Korea (4.81 %), the United States (3.45 %) and Japan (3.27 %) (Figure 19). China experienced steady growth in its R & D intensity, reaching the EU's level in 2013 (2.32 %).

([90]) The European innovation scoreboard measures overall innovation using 32 indicators that can be grouped into four sections: framework conditions, investments, innovation activities and impacts. See European Commission, Directorate-General for Research and Innovation and Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2022), *European Innovation Scoreboard 2022*, Publications Office of the European Union, Luxembourg, https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en.

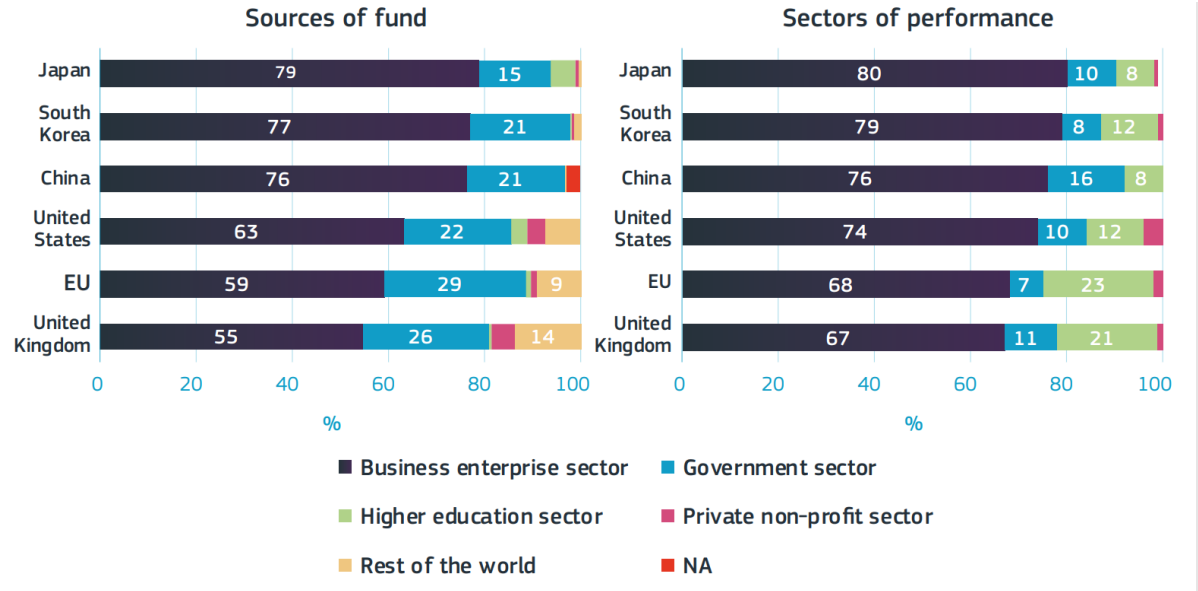
Figure 19. R & D intensity (R & D expenditure as a percentage of GDP), 2000–2020



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826, based on the OECD's main science and technology indicators.

The EU has a much lower rate of R & D investments from the business sector than its international competitors. The business sector funds 59 % of R & D investments in the EU, while it funds 63 % in the United States, 76 % in China, 77 % in South Korea and 79 % in Japan (Figure 20). The higher education sector is much more involved as sector of performance in the EU (23 %) and in the United Kingdom (21 %) than it is in the United States and South Korea (both 12 %) or in China and Japan (both 8 %). It is also interesting to note that China has the highest share of R & D investment performed by the government (16 %), followed by the United Kingdom (11 %).

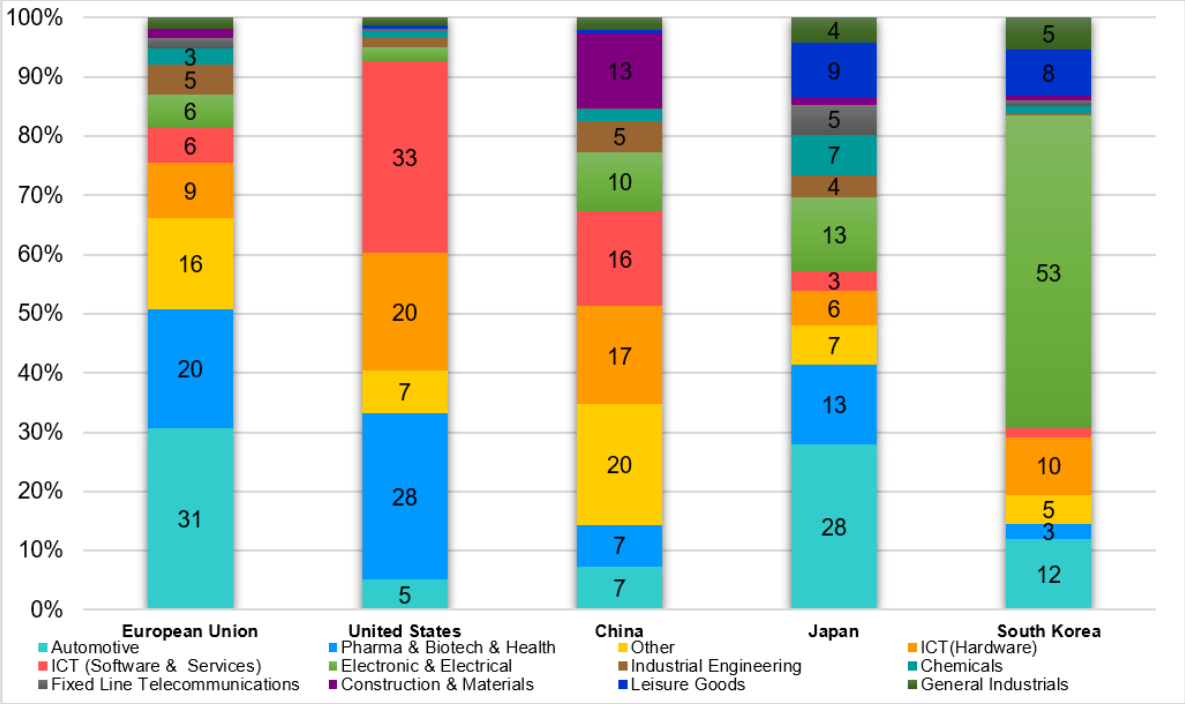
Figure 20. Gross expenditure on R & D by source of funding (left) and sectors of performance (right), by country/region, 2019 (%)



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826, based on Eurostat (online data code:rd_e_ gerdfund).

The EU's lower rate of R & D investment is partially driven by the structure of the EU economy. Less than 40 % of the EU's corporate R & D expenditure is in the sectors with high R & D intensity (e.g. ICT producers, ICT services, health industries) and around 40 % is in the sectors with medium-high R & D intensity (e.g. automobiles and other transport) (Figure 21) ([91]). Conversely, based on the 2021 EU industrial R & D investment scoreboard, which covers more than 90 % of business spending on R & D worldwide, circa 80 % of R & D investment by US companies and more than half in China is in the sectors with high R & D intensity. Over the past 10 years, the United States and China have increased their specialisation in ICT sectors, and the United States has increased its proportion in the health sector. In terms of R & D intensity, in 2019, China had already caught up to the European level. According to the R & D investment trend for the top investors worldwide, we might expect China to surpass the EU in terms of business R & D investment within 2–3 years.

Figure 21. Sectoral distribution of R&D investment by country/region, considering the top 2500 R&D investors worldwide, 2021

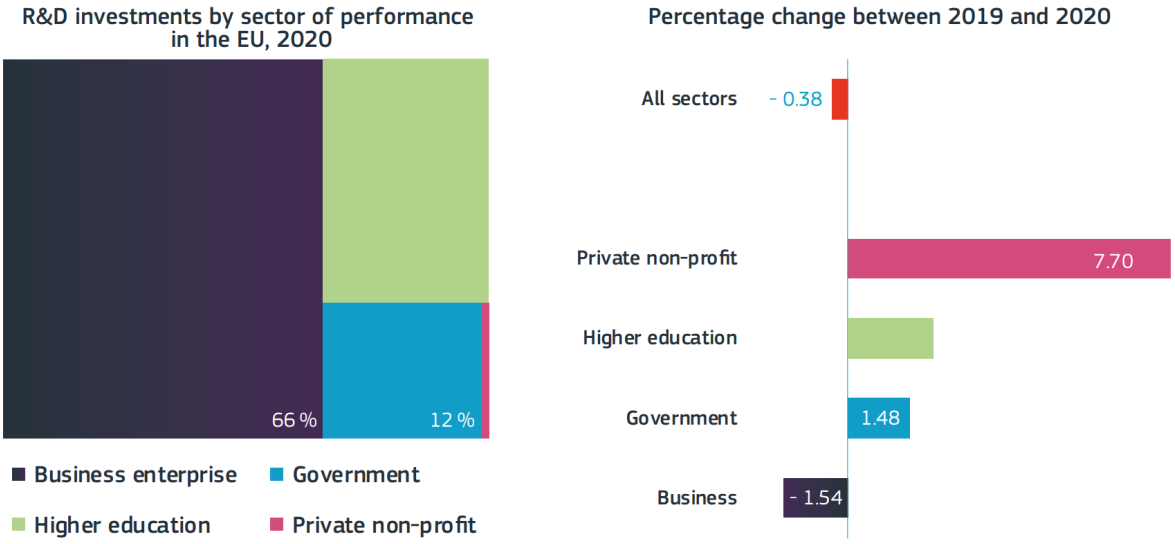


NB: The sectoral distributions are calculated using only the R & D investments of the top 2 500 companies investing in R & D worldwide, distributed according to the location of their headquarters (China, the EU, the United States, Japan or South Korea) and not the country/regions of the world where investments are used.
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on the 2021 EU Industrial R&D Investment Scoreboard.

The COVID-19 pandemic has led to a decrease in R & D investments in the EU. In 2020, for the first time since 2010, business R & D investments decreased in the EU (Figure 22). In contrast, performance in the public sector increased (+ 1.48 % for the government sector and + 2.04 % for higher education from 2019 to 2020). The private non-profit sector experienced the highest growth rate, with a 7.7 % increase from 2019 to 2020. As the business sector is the main R & D performer, the overall effect is a decrease in R & D investments in 2020 from the 2019 level. However, it is worth noting that, due to the decline in GDP linked to the COVID-19 pandemic, the EU's total R & D intensity increased to 2.32 % of GDP in 2020.

([91]) European Commission, Joint Research Centre (2022), *The 2021 EU Industrial R & D Investment Scoreboard*, Publications Office of the European Union, Luxembourg.

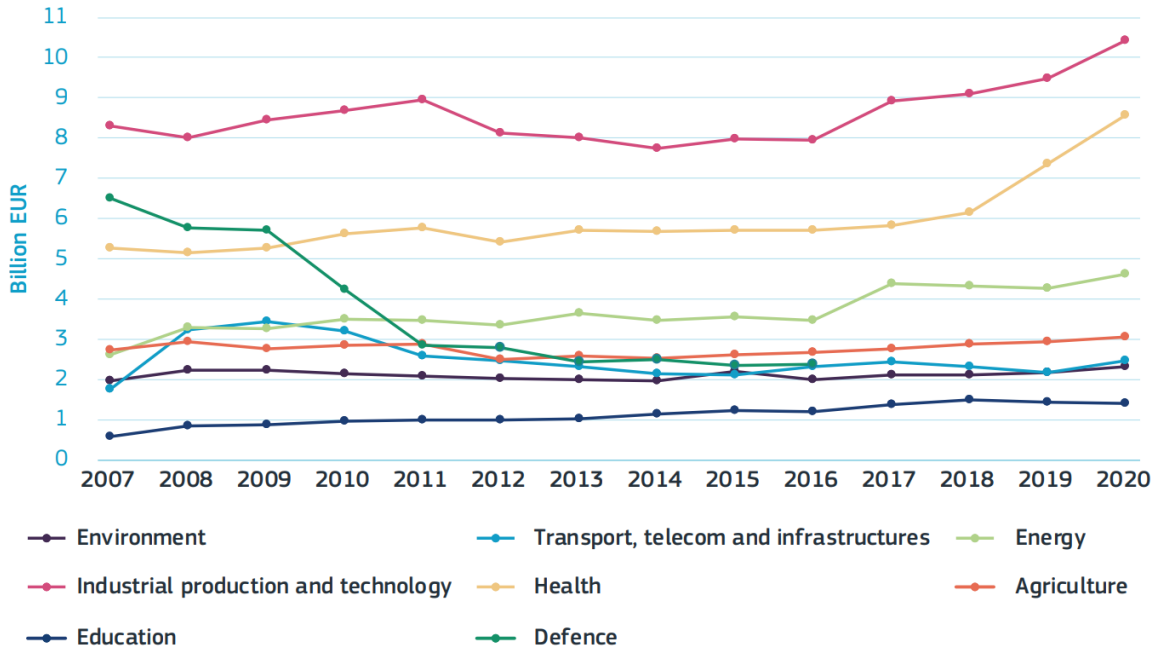
Figure 22. R & D investments by sector of performance in the EU in 2020 (left) and percentage change between 2019 and 2020 (right)



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826, based on Eurostat (online data code:rd_e_ gerdfund).

When it comes to national public budget allocations for R & D, Member States are also slowly steering investments towards societal and environmental challenges. Figure 23 shows an increase in health, industrial production and technology, and energy-related government budget allocations for R & D at European level. Growth in the total budget allocations for agriculture and environment R & D investments are more modest. The R & D budget for transport, telecommunications and infrastructures increased mainly from 2007 to 2009, but then slowly decreased and stagnated from 2011 onwards. In contrast, the R & D budget for defence has decreased significantly in recent years, but this trend is likely to be reversed.

Figure 23. Evolution of government budget allocation for R & D by thematic area in the EU, 2007–2020



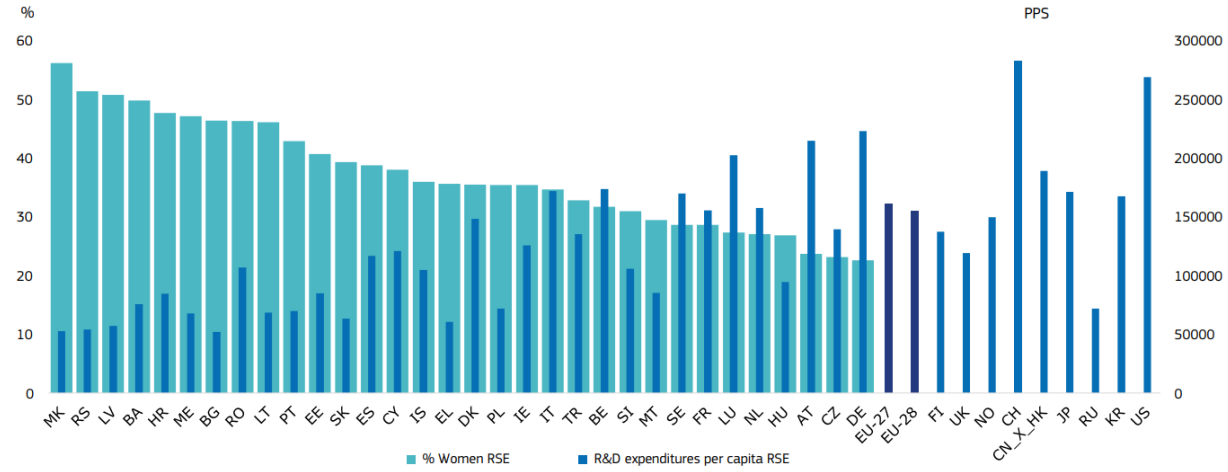
Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications

Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826, based on Eurostat (online data code: gba_nabsfin07)

At European level, the EU sustainable finance framework has been revised to foster private sustainable and responsible investments, including R & D investments. The 2020 EU taxonomy ([92]) establishes a list of environmentally sustainable economic activities and should create security for investors, protect private investors from greenwashing, help companies to become more climate friendly, mitigate market fragmentation and help to shift investments. In 2021, the European Commission also proposed a regulation for a European green bond standard to facilitate the issuance of green bonds by enhancing the transparency, comparability, and credibility of the green bond market for both borrowers and investors.

The proportion of women researchers is negatively associated with research and development (R&D) expenditure per researcher. Figure 24 shows how in countries where the research workforce comprises 40% or more women, expenditure was typically under 100,000 PPS, with only one country having expenditure over this threshold. On the other hand, in countries where the research workforce comprises less than 40% women, only five of 21 countries had expenditure under 100,000 PPS. Furthermore, in three EU-27 countries with the highest levels of expenditure (DE, AT, LU), women represent only around one-quarter of researchers. This may indicate a greater exclusion of women from research in countries where research attracts more expenditure (and is, therefore, a more attractive career option). It may also indicate a lower valuation of research in countries where it is 'feminised' (i.e. where the workforce is comprised of a higher proportion of women).

Figure 24: Proportion (%) of women among researchers (in FTE) and R&D expenditure (in PPS) per capita researcher (in FTE), 2018



Source: European Commission, Directorate-General for Research and Innovation, She figures 2021 : gender in research and innovation : statistics and indicators, Publications Office, 2021, https://data.europa.eu/doi/10.2777/06090.

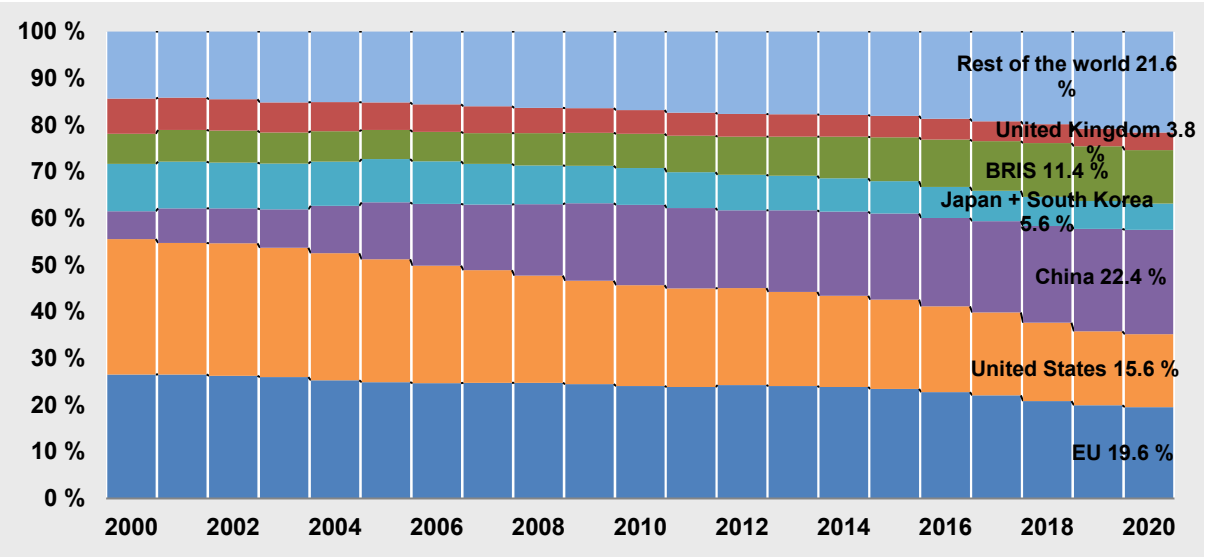
2.3. Publications and patents around the world

2.3.1. Quantity and quality of scientific publications

The EU remains a scientific powerhouse, as it produces about 20 % of the world's scientific output despite having just 6 % of the world's population. In 2020, China, the EU and the United States jointly produce about 60 % of the scientific output worldwide. This has been the case for the last 20 years, with China gaining the lead in recent years. China's significant increase affected the relative position of the United States, which has lost 13 percentage points since 2000, and to a lesser extent the EU, with a decline of 7 percentage points (Figure 25). One reason why the rise of China has been more at the expense of the United States than the EU could be due to the EU's specialisation in fields such as health and social sciences, where China's output is still lagging.

([92]) Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (OJ L 198, 22.6.2020, p. 13).

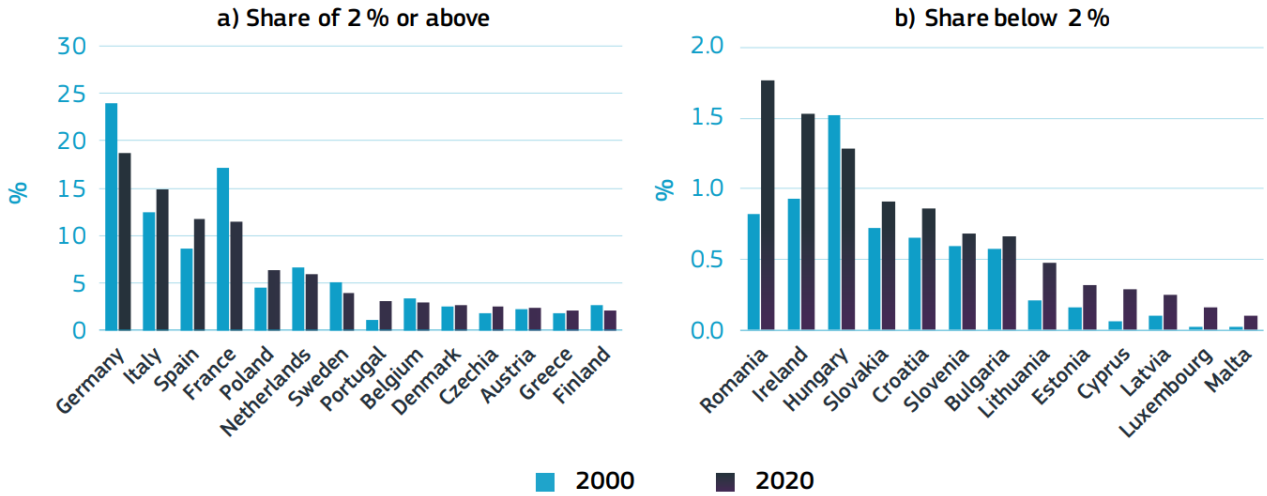
Figure 25. World shares of scientific publications, 2000–2020



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

The EU's scientific output is strongly driven by the larger Member States. However, other Member States are catching up in terms of scientific output and scientific quality. Four large EU Member States (Germany, Italy, Spain and France) together produced almost 60 % of the EU's total publications in 2020. Within the EU, the shares of scientific publications vary significantly, and to a large extent depend on the size of the country. At the same time, southern and eastern European countries have increased their share from 2000 to 2020, in contrast to some of the most populated countries such as Germany and France (Figure 26).

Figure 26. Share of scientific publications of each EU Member State within the EU, split into countries with shares of 2 % or above (left) and shares below 2 % (right), 2000 and 2020

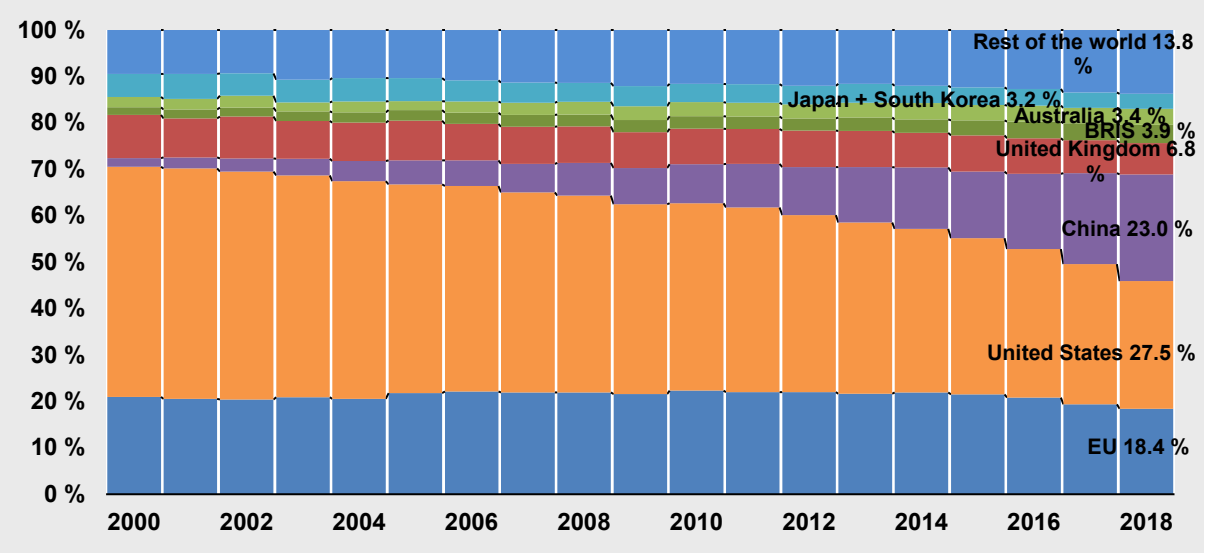


Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

Looking at scientific excellence (top 1 % most-cited publications), the rise of China is still evident (Figure 27), yet not as striking as for the rise in quantity of scientific output (see Figure 25). China overtook the EU in the world share of the top 1 % most-cited publications, while the United States preserved its leading position (Figure 27). The EU is in third position, with a global share of 18.4 %, followed by the UK, with a share of 6.8 %. Germany has the highest share among the EU Member States with 4.0 %, followed by Italy (2.6 %), which climbed up one position, overtaking France (2.2 %). Australia also stands out, with a share of

3.4 %, which is above the shares of Japan and South Korea combined. Brazil, India, Russia and South Africa, despite their small shares, have been improving over time.

Figure 27. World share of top 1 % most-cited scientific publications, 2000 (citation window: 2000–2002) to 2018 (citation window: 2018–2020)

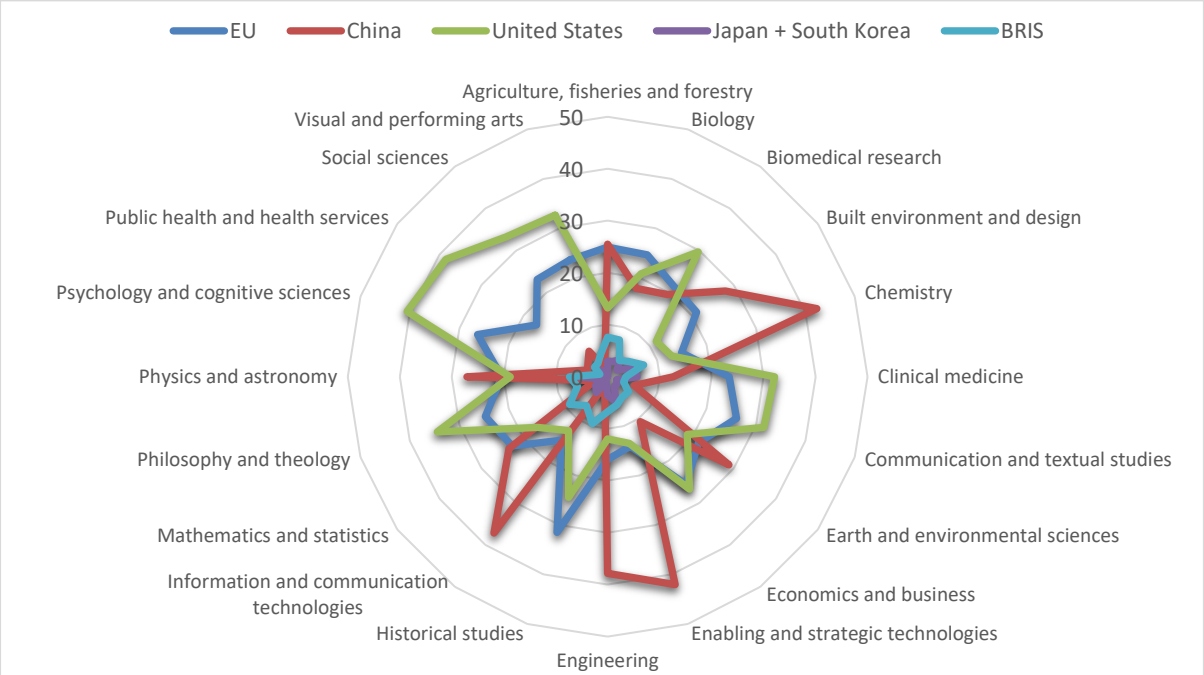


Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times,* Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

2.3.2. Scientific specialisation

Looking at the scientific field of specialisation, China focuses on digital technologies, the EU focuses more on humanities and the United States on health technologies. In 2020, the EU was the global leader in the domains of historical studies and biology. The United States led in the domain of health sciences, particularly in the fields of public health and health services, clinical medicine and biomedical research. In contrast, China led in applied and natural sciences, especially in the fields of engineering, enabling and strategic technologies, chemistry and ICT (Figure 28).

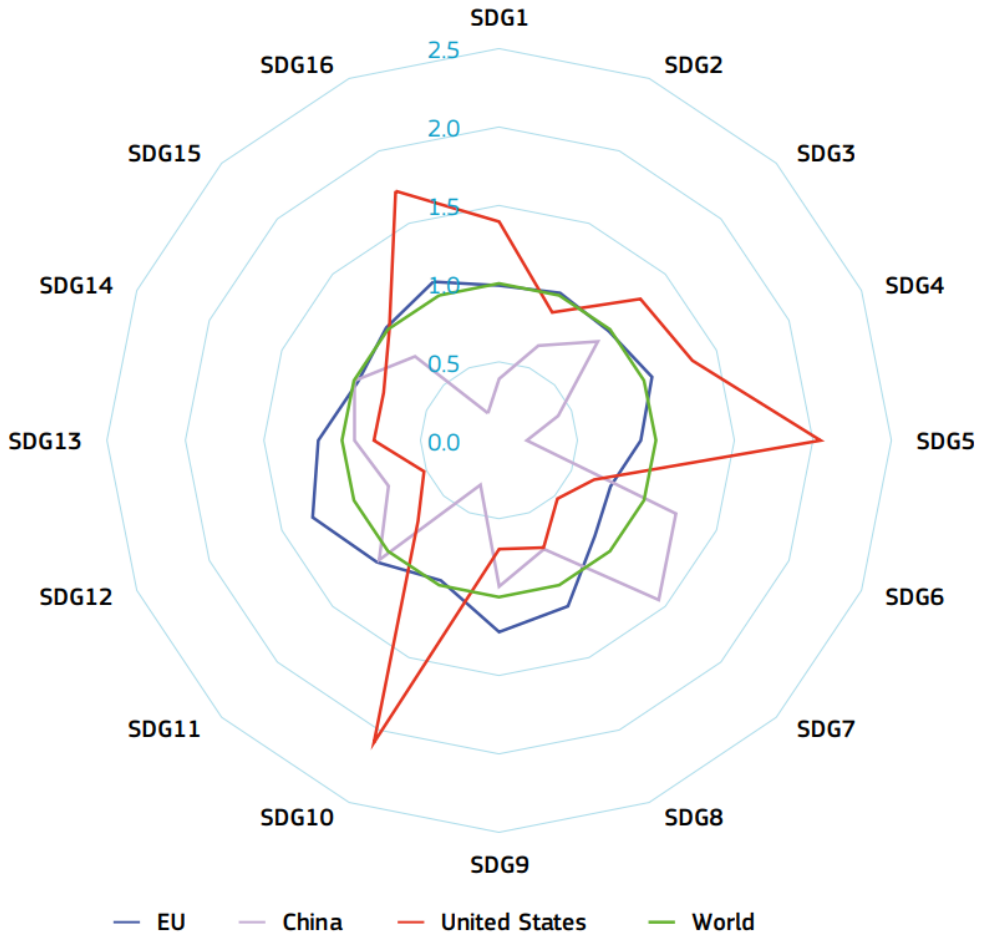
Figure 28. World shares of the top 10 % most-cited publications by country/region and scientific field, 2020



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

The EU presents a balanced specialisation across all SDGs, while publications from China and the United States are more focused and overperform in some SDGs, neglecting others. Overall, the EU does not present very low specialisation indexes in any of the SDGs, while the US and China do for several of them. At the same time, the EU never reaches very high specialisation indexes, with China and the United States reaching very high specialisation indexes for some SDGs. The EU is more specialised in terms of scientific output in SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 12 (responsible consumption and production) and SDG 13 (climate action). The United States has the lead in SDG 1 (no poverty), SDG 3 (good health and well-being), SDG 4 (quality education), SDG 5 (gender equality), SDG 10 (reduced inequalities) and SDG 16 (peace, justice and strong institutions). Finally, China is more specialised in SDG 6 (clean water and sanitation) and SDG 7 (affordable and clean energy) (Figure 29).

Figure 29. Specialisation index of scientific output for each SDG, 2020



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

The under-representation of women in research teams is a persistent issue in Europe and worldwide, especially in Natural Sciences and Engineering & Technology fields. Women are better represented in Medical & Health Sciences, Agricultural & Veterinary Sciences, Social Sciences, and Humanities & Arts. Women's representation within authorship teams has increased over time, with the highest growth rates observed in Engineering & Technology and Social Sciences. The growth rate at the European level was higher than the world level in most fields of R&D, except in Engineering & Technology and Humanities & Arts.

Table 5. Average proportion of women among authors on publications, by field of R&D, 2010-2014 and 2015-2019

Country	Natural sciences		Engineering and technology		Medical and health sciences		Agricultural and veterinary sciences		Social sciences		Humanities and the arts	
	2010-2014	2015-2019	2010-2014	2015-2019	2010-2014	2015-2019	2010-2014	2015-2019	2010-2014	2015-2019	2010-2014	2015-2019
WLD	0.2	0.2	0.1	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4
EU-27	**0.2**	**0.3**	**0.2**	**0.2**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
EU-28	**0.2**	**0.3**	**0.2**	**0.2**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
BE	0.2	0.2	0.2	0.2	0.3	0.4	0.3	0.3	0.3	0.4	0.3	0.4
BG	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.5
CZ	0.2	0.2	0.2	0.2	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.4
DK	0.2	0.2	0.2	0.2	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.4
DE	0.2	0.2	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
EE	0.3	0.3	0.2	0.2	0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.5
IE	0.2	0.2	0.2	0.2	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4
EL	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.4
ES	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
FR	0.2	0.2	0.2	0.2	0.4	0.4	0.3	0.4	0.3	0.4	0.4	0.4
HR	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
IT	0.3	0.3	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
CY	0.2	0.2	0.1	0.2	0.3	0.4	0.3	0.3	0.3	0.3	0.4	0.5
LV	0.3	0.4	0.3	0.3	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.6
LT	0.2	0.3	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.4
LU	0.2	0.2	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
HU	0.2	0.3	0.2	0.2	0.4	0.4	0.3	0.3	0.3	0.4	0.4	0.4
MT	0.2	0.2	0.1	0.2	0.3	0.4	0.3	0.3	0.3	0.3	0.2	0.3
NL	0.2	0.2	0.1	0.2	0.3	0.4	0.3	0.3	0.3	0.4	0.3	0.4
AT	0.2	0.2	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
PL	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5
PT	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.4	0.5	0.4	0.5
RO	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SI	0.3	0.3	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.5
SK	0.3	0.3	0.2	0.3	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4
FI	0.2	0.3	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
SE	0.2	0.2	0.2	0.2	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4
UK	0.2	0.2	0.1	0.2	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4
IS	0.2	0.3	0.1	0.2	0.4	0.4	0.3	0.4	0.4	0.5	0.3	0.4
NO	0.2	0.2	0.2	0.2	0.4	0.4	0.3	0.3	0.3	0.4	0.4	0.4
CH	0.2	0.2	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
ME	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.4	0.4	0.4	p	0.5
MK	0.3	0.4	0.4	0.4	0.5	0.5	0.4	0.4	0.5	0.4	p	0.4
AL	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.4	0.6	0.5
RS	0.4	0.4	0.3	0.3	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.5
TR	0.3	0.3	0.2	0.2	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.4
BA	0.3	0.3	0.2	0.2	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4
GE	0.2	0.2	0.2	0.2	0.5	0.4	0.4	0.3	0.4	0.5	p	0.5
AM	0.2	0.2	0.2	0.2	0.4	0.4	0.3	0.3	0.4	0.3	p	0.3
MD	0.2	0.3	0.2	0.3	0.4	0.4	p	0.5	0.3	0.4	p	0.3
TN	0.2	0.3	0.2	0.2	0.4	0.4	0.3	0.4	0.3	0.3	0.3	0.3
IL	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3
UA	0.2	0.3	0.2	0.3	0.4	0.5	0.4	0.4	0.5	0.5	0.3	0.5
AR	0.4	0.4	0.4	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
AU	0.2	0.2	0.1	0.1	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.5
BR	0.3	0.3	0.3	0.3	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
CA	0.2	0.2	0.1	0.1	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4
CN_X_HK	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
HK	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
IN	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.4
JP	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MX	0.3	0.3	0.2	0.2	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4
RU	0.3	0.3	0.2	0.3	0.4	0.5	0.4	0.4	0.4	0.5	0.5	0.5
ZA	0.2	0.3	0.2	0.2	0.4	0.4	0.3	0.3	0.4	0.4	0.3	0.4
KR	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
US	0.2	0.2	0.1	0.2	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.4

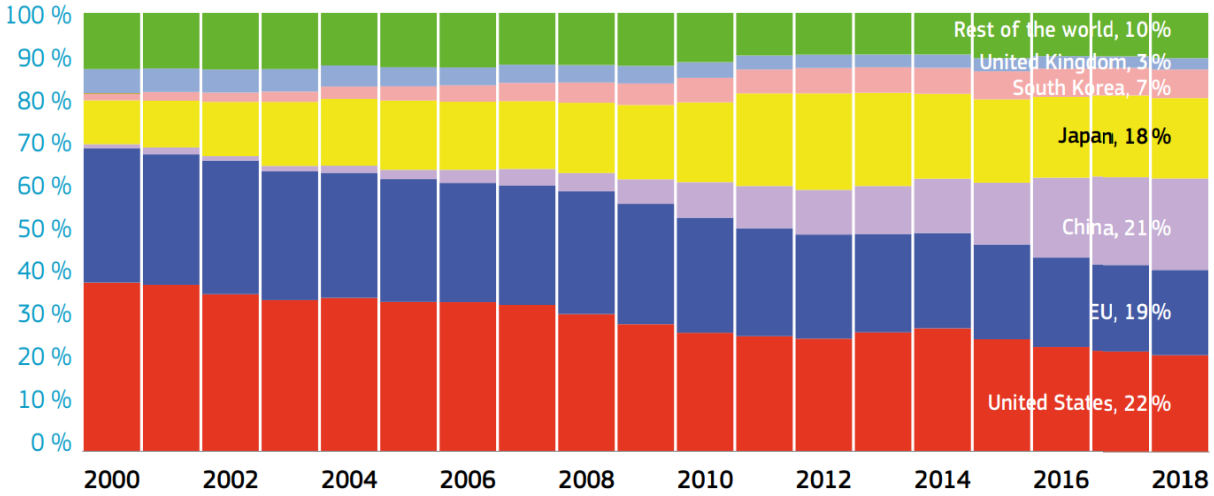
Source: European Commission, Directorate-General for Research and Innovation, *She figures 2021: gender in research and innovation: statistics and indicators,* Publications Office, 2021, https://data.europa.eu/doi/10.2777/06090.

2.3.3. *Technological output*

The EU is a patenting world leader; however, its position has been decreasing due to the rise of China. Around 80 % of the patent applications filed under the Patent Cooperation Treaty (PCT) worldwide come from China, the EU, Japan and the United States. Yet the distribution of the share of applications among them has changed over time (Figure 30). While the EU accounted for 31 % and the United States accounted for 38 % of the world's patent applications in 2000, their shares declined to 19 % and 22 %, respectively, in 2018. In contrast, China has the largest increase over time, especially after 2008, overtaking both the EU and Japan in 2017. If the present trend continues, China will overtake the United States in the coming years. Unlike in the case of scientific publications, for which the rise of China was mostly at the expense of the United States, for patent applications the rise of China and Japan came at the expense of both the United States and the EU.

The EU applies for proportionally more patents in the medium- and low-tech sectors, such as the automotive and machinery sectors. China and the United States apply for proportionally more patents in hi-tech fields such as the pharmaceutical and other chemistry sectors (polymers, materials or nanotechnology) and in knowledge-intensive services such as information technology.

Figure 30. World shares of patent applications filed under the PCT, 2000–2018

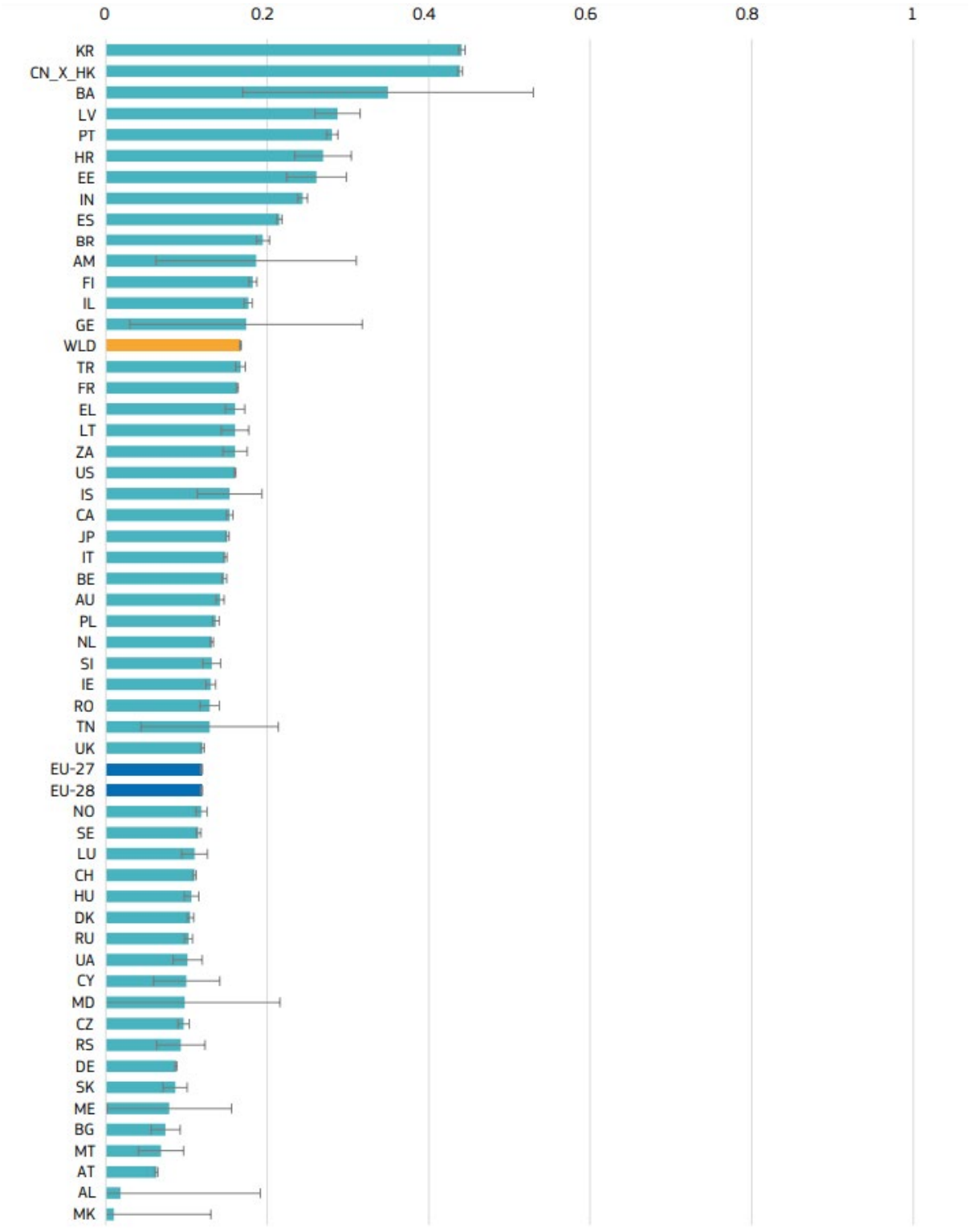


Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

Women are severely underrepresented among inventors. Figure 31 shows the number of inventorships, calculated based on the number of patent applications and the corresponding number of inventors (for example, a team of 10 inventors for a given patent application would each be attributed a tenth of that invention). A ratio of women to men inventorships of greater than 1.0 would indicate that women produced a larger share of inventions than men, whereas a value of less than 1.0 would indicate the opposite (and a value of 1.0 would indicate gender parity, with women and men producing an equal number of inventions).

The data show that between 2015-2018, women were very under-represented among inventors, both at European level and worldwide. At European level, the ratio was 0.12, indicating that for every 10 inventorships held by men, just over one (1.2) was held by women. Notably, economies in the G-20 region had the highest ratios of women to men inventorship, indicating that the EU is lagging behind some of its main competitors. For example, in China except Hong Kong and South Korea, for every five inventorships held by men, there were over two inventorships held by women.

Figure 31: Women to men ratio of inventorships, 2015-2018



Source: European Commission, Directorate-General for Research and Innovation, *She figures 2021: gender in research and innovation:* statistics and indicators, Publications Office, 2021, https://data.europa.eu/doi/10.2777/06090.

2.3.4. Technological specialisation

While the EU shows strengths in technological areas related to advanced manufacturing and advanced materials, it underperforms in digital technologies. The changing geopolitical context

increases the need to reduce strategic dependencies in key technological areas and value chains, as these are necessary to strengthen the resilience of the EU. When compared with other economies, the EU underperforms, positioning itself well below China and the United States, especially in the areas related to digitalisation, such as audiovisual technology, telecommunications, computer technology and digital communication (Table 6).

Table 6. 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	↗↗
	Biotechnology	PCT Patent Applications (world share %)	2018	19.0	↘	35.2	↗	13.9	↗↗	13.0	↗↗	6.1	↗↗
	Chemical engineering	PCT Patent Applications (world share %)	2018	26.0	↗	23.2	↗	13.4	↗↗	14.3	↗↗	6.5	↘↘
	Environmental technology	PCT Patent Applications (world share %)	2018	23.6	↘	19.0	↘	19.0	↗↗	14.5	↘	7.6	↗↗
	Food chemistry	PCT Patent Applications (world share %)	2018	24.2	↘	17.3	↘↘	9.7	↗↗	18.5	↗	11.6	↗↗
	Macromolecular chemistry, polymers	PCT Patent Applications (world share %)	2018	21.9	↗	18.2	↗	10.9	↗↗	33.1	↗↗	8.1	↗↗
	Materials, metallurgy	PCT Patent Applications (world share %)	2018	22.0	↗	14.9	↗	13.0	↗↗	29.7	↗↗	9.4	↗↗
	Micro-structural and nano-te	PCT Patent Applications (world share %)	2018	21.2	↗	30.8	↘	13.5	↗↗	15.6	↗↗	4.0	↘↘
	Organic fine chemistry	PCT Patent Applications (world share %)	2018	21.8	↘↘	28.7	↘	15.1	↗↗	12.7	↘	5.3	↗↗
	Pharmaceuticals	PCT Patent Applications (world share %)	2018	17.5	↘	39.8	↗↗	8.8	↗↗	8.6	↗	8.2	↗↗
	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	↗↗
	Audio-visual technology	PCT Patent Applications (world share %)	2018	10.1	↘	11.8	↗	40.1	↗↗	22.2	↗	5.8	↗↗
	Basic communication process	PCT Patent Applications (world share %)	2018	17.8	↗	24.2	↗	18.7	↗↗	24.2	↗↗	4.0	↗↗
	Computer technology	PCT Patent Applications (world share %)	2018	9.6	→	30.3	↗↗	31.7	↗↗	12.1	↗	5.6	↗↗
	Control	PCT Patent Applications (world share %)	2018	17.2	↗↗	19.3	↗↗	24.9	↗↗	23.9	↗↗	3.4	↗↗
	Digital communication	PCT Patent Applications (world share %)	2018	14.3	↗	24.4	↗↗	40.3	↗↗	5.3	↗↗	6.6	↗↗
	Electrical machinery, apparatus, energy	PCT Patent Applications (world share %)	2018	20.6	↗↗	12.9	↗	18.5	↗↗	28.2	↗↗	8.9	↗↗
	IT methods for management	PCT Patent Applications (world share %)	2018	7.3	↗↗	27.0	↗↗	29.0	↗↗	13.3	↗↗	8.5	↗↗
	Measurement	PCT Patent Applications (world share %)	2018	23.2	↗	22.6	↗↗	14.9	↗↗	20.2	↗↗	4.9	↘↘
	Medical technology	PCT Patent Applications (world share %)	2018	17.8	↗	35.6	↗↗	10.2	↗↗	14.8	↗↗	5.7	↗↗
	Optics	PCT Patent Applications (world share %)	2018	12.8	↗↗	17.4	↗↗	26.6	↗↗	27.7	↗↗	6.5	↗↗
	Semiconductors	PCT Patent Applications (world share %)	2018	9.4	↘↘	18.8	↘	27.8	↗↗	27.7	→	8.6	↗↗
	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	↗↗
	Handling	PCT Patent Applications (world share %)	2018	29.1	↗	17.4	↗	13.6	↗↗	20.0	↗↗	4.8	↘↘
	Machine tools	PCT Patent Applications (world share %)	2018	30.7	↗	14.1	↗	15.6	↗↗	23.4	↗↗	4.6	↗↗
	Mechanical elements	PCT Patent Applications (world share %)	2018	34.5	↗	14.8	↗	11.7	↗↗	23.8	↗↗	3.4	↗↗
	Other special machines	PCT Patent Applications (world share %)	2018	30.5	↗↗	21.6	↗↗	9.6	↗↗	17.7	↗↗	4.9	↗↗
	Textile and paper machines	PCT Patent Applications (world share %)	2018	24.5	→	21.2	↗↗	13.2	↗↗	25.5	↗↗	4.3	↗↗
	Thermal processes and apparatus	PCT Patent Applications (world share %)	2018	23.9	↘	13.5	↘	14.9	↗↗	29.3	↗↗	5.5	↗↗
	Transport	PCT Patent Applications (world share %)	2018	34.4	↗↗	12.8	↗↗	13.9	↗↗	24.0	↗↗	3.6	↘↘

→	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%

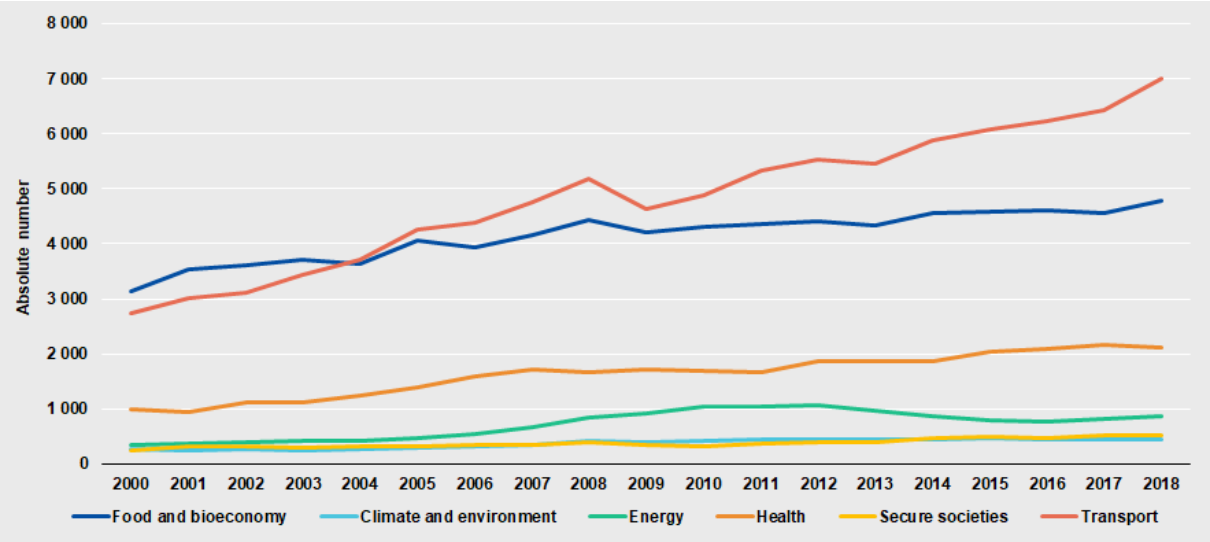
Best … Worst

NB: Trend is defined by calculating the average annual growth between 2010 and the latest available year.
Source: European Commission, Directorate-General for Research and Innovation, Common R & I Strategy & Foresight Service, Chief Economist Unit, based on Science-Metrix using the European Patent Office's worldwide patent statistical database.

2.4. The EU's research and innovation outputs tackling global challenges

The EU has remained stable over time in terms of number of patent applications filed per societal grand challenge (SGC) (Figure 32) ([93])**, but its world share has declined** (see Figure 31 and the paragraph following it). Stable numbers of applications are seen more in the fields of food and bioeconomy, climate and environment, and energy ([94]). The only exception is transport, which continued to increase significantly, overtaking food and bioeconomy in 2004. When we calculate the evolution in numbers of patents, however, four fields (energy, health, secure societies and transport) have more than doubled their numbers of patent applications. Moreover, we find that food and bioeconomy increased by 53 % and climate and environment increased by 55 % between 2000 and 2018.

Figure 32. Total number of patent applications filed under the PCT in the EU, by SGC, 2000–2018



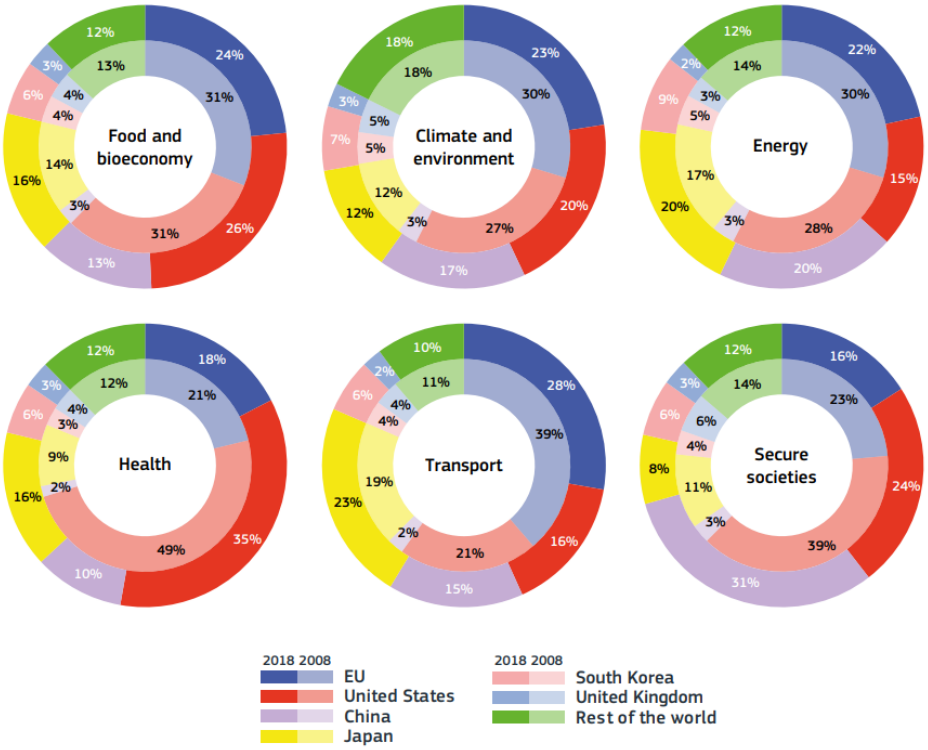
NB: Covers PCT patents at the international phase designating the European Patent Office. Fractional counting method used; inventor's country of residence and priority date used.
Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826, based on Science-Metrix using the European Patent Office's worldwide patent statistics database.

The EU is still the top worldwide patent applicant in the fields of climate and environment (23 %), energy (22 %) and transport (28 %). However, the analysis per SGC, displayed in Figure 33, shows that the EU experienced significant losses in its world shares of all fields between 2008 and 2018. The biggest decline was in transport, with – 11 percentage points, despite an increase in the absolute number of patent applications over the same period. The United States, while maintaining leadership in the fields of health, and food and bioeconomy, followed the same pattern, with even stronger declines, especially in secure societies (– 15 percentage points), health (– 14 percentage points) and energy (– 13 percentage points). China increased its world shares in all fields. However, unlike scientific production, where it leads in almost all fields, China is only top in the field of secure societies, where it had an impressive increase of 28 percentage points, from 3 % in 2008 to 31 % in 2018. China's performance also improved significantly in the energy sector, with an increase of 17 percentage points. Japan, despite being weak in scientific production, stands out strongly in technology output, with important shares in the health, energy and transport SGCs.

([93]) To analyse the performance of the EU in delivering sustainable and responsible research and innovation, six key SGCs have been defined as priorities under Horizon 2020 (health, demographic change and well-being; food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the bioeconomy; secure, clean and efficient energy; smart, green and integrated transport; climate action, environment, resource efficiency and raw materials; and secure societies – protecting freedom and security of Europe and its citizens).

([94]) Note that publications and patents are indicators of outputs and that research impacts can take many shapes and forms (social innovation, etc.).

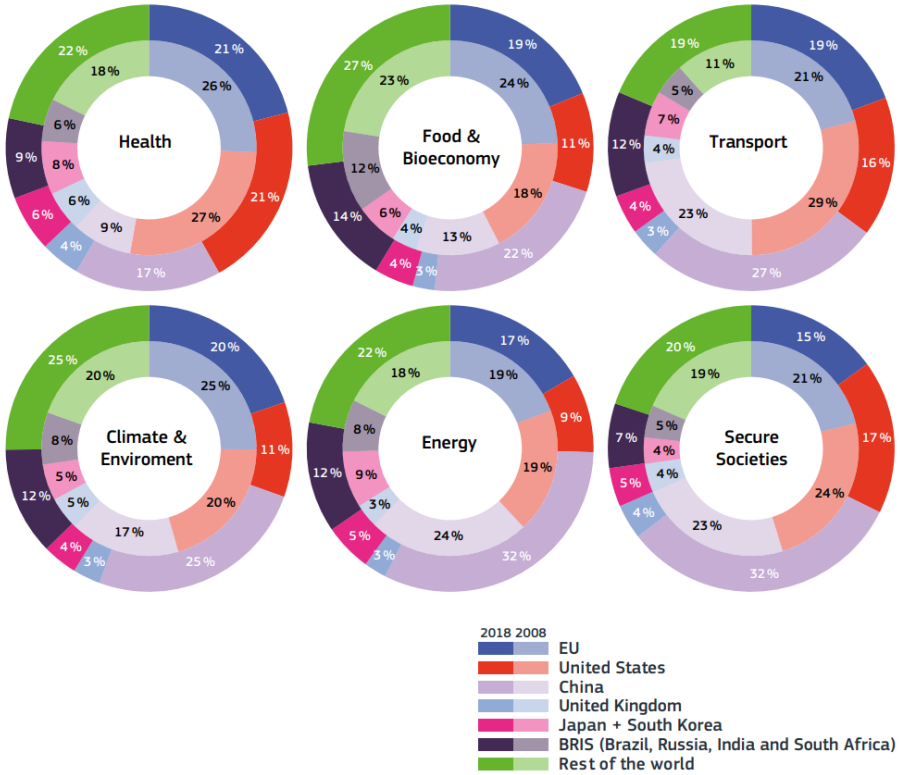
Figure 33. World shares (%) of patent applications filed under the PCT, by country/region and SGC, 2008 (interior ring) and 2018 (exterior ring)



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826, based on Science-Metrix using the European Patent Office's worldwide patent statistics database.

In terms of scientific output, China is leading in all SGCs except for health, where the 8-percentage-point increase over 2010–2020 was not sufficient to overtake the United States and the EU (Figure 34). EU researchers are the authors of about 20 % of scientific publications for all the SGCs worldwide, except for energy (17 %) and secure societies (15 %). The United States' publication share has declined substantially for all SGCs in the last 10 years.

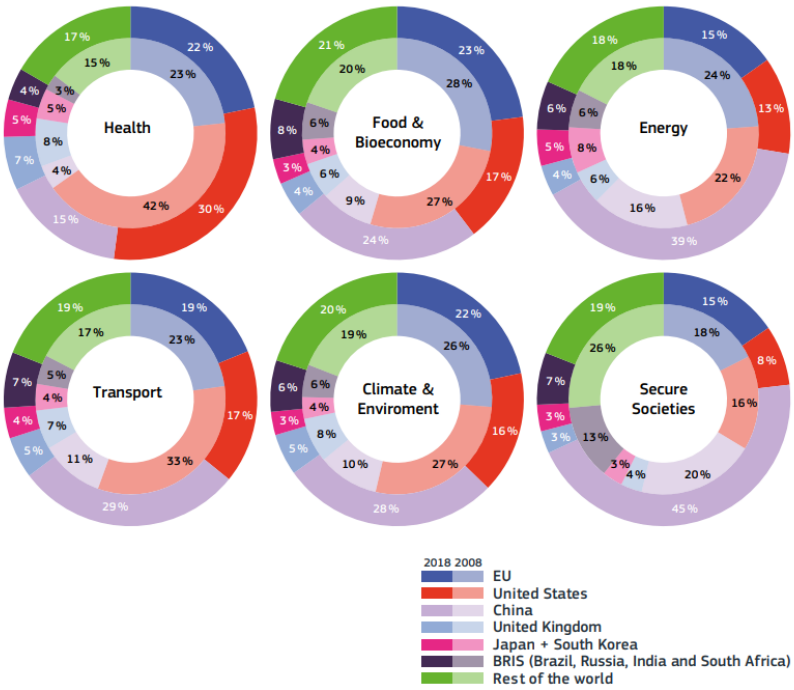
Figure 34. World shares (%) of scientific publications, by country/region and SGC, 2010 (interior ring) and 2020 (exterior ring)



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826, based on Science-Metrix using Scopus data.

In terms of the quality of research output, the EU has the second highest world share of the top 10 % most-cited publications in all SGCs. Ten years ago, the EU was leading in energy and in food and bioeconomy (Figure 35). The massive improvement in the quantity and quality of the Chinese output in these fields has forced the EU into second position. Chinese researchers are leading regarding the most-cited publications related to energy (with a 39 % share). The United States is undoubtedly the global leader in most-cited publications in the health field, with a 30 % share, despite losing 12 percentage points since 2008.

Figure 35. World shares (%) of the top 10 % most-cited scientific publications, by country/region and SGC, 2008 (interior ring) and 2018 (exterior ring)



NB: Fractional counting method used.
Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826, based on Science-Metrix using Scopus data.

2.5. EU regional dimension

Overall innovation performance ([95]) **increased** from 2014 to 2021 for 225 out of 240 European regions ([96]). Performance has decreased for only 15 regions, including four regions in France, three in each of Denmark and Germany, two in Romania, and one in each of Czechia, Slovakia and Switzerland. The most innovative region in Europe is Stockholm (SE11) in Sweden, followed by Helsinki-Uusimaa (FI1B) in Finland, and Oberbayern (DE21) in Germany. Hovedstaden (DK01) in Denmark is in fourth place, and Zürich (CH04) in Switzerland is in fifth place.

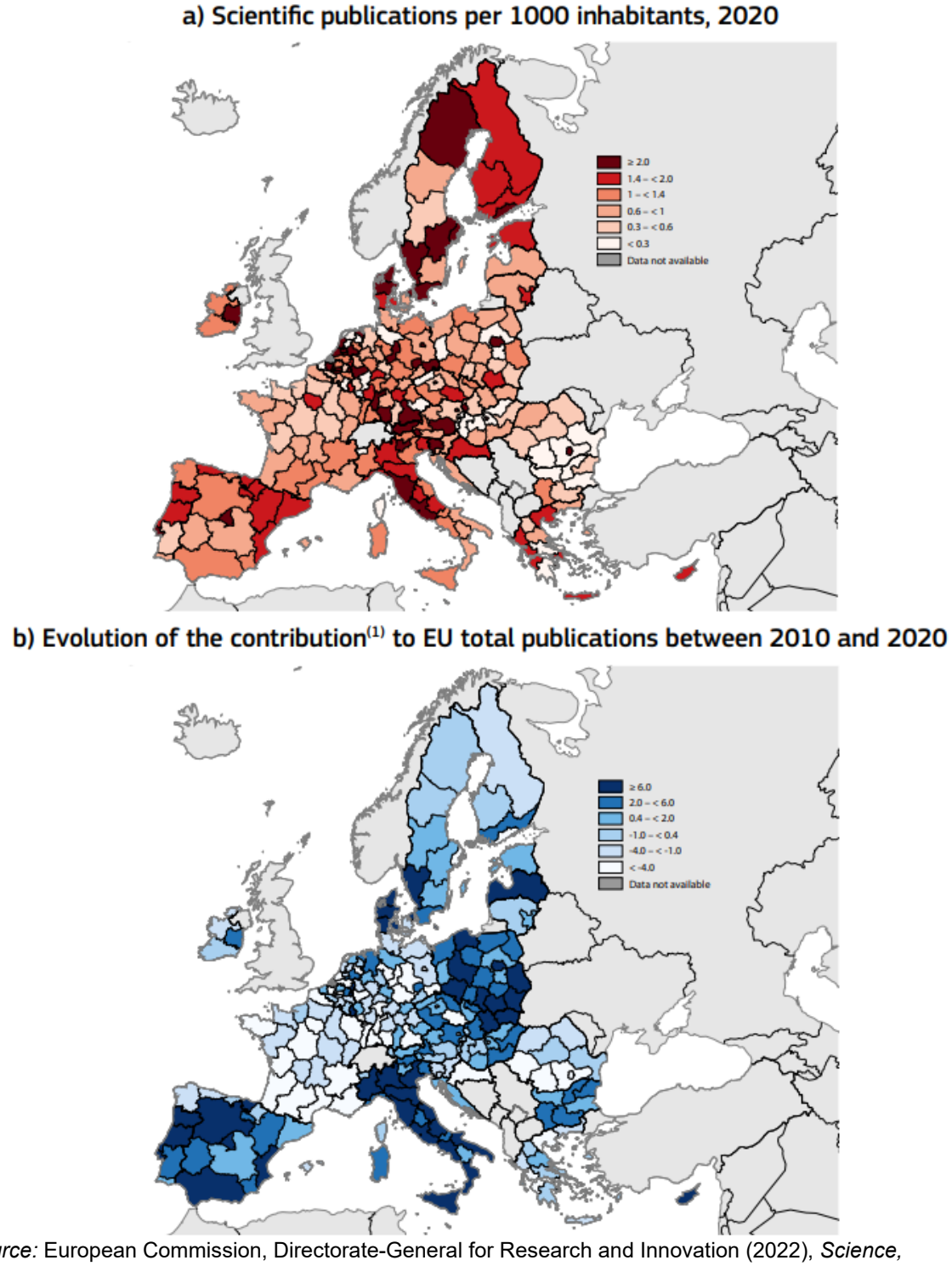
Scientific output shows a relatively dispersed pattern across EU regions, and, over 2015–2018, regional disparities in technological innovation have been increasing. The EU experienced a convergence process in patenting activity in the beginning of the 21st century, but, since 2015, the gap between the most and the least innovative regions in terms of patent applications has widened. There are important regional differences in scientific publications per capita in the EU, although there is not such a clear divide as in the case of, for example, overall innovation capacity (Figure 36). 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 rates of scientific publications per capita did not record an increase and, in some cases, their relative contributions to the EU's total number of scientific publications declined over the decade. In addition, over 2016–2021, the share of emerging innovators (the least innovative class) increased in the less developed regions, meaning that more regions were lagging

([95]) Measured according to the regional innovation scoreboard. The regional innovation scoreboard is a regional extension of the European innovation scoreboard, and assesses the innovation performance of European regions on 32 indicators. These indicators are grouped into four main categories: framework conditions, investments, innovation activities, and impacts. See European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2021), *Regional Innovation Scoreboard 2021*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2873/674111.

([96]) Covers the NUTS 2 regions for Austria, Belgium, Bulgaria, Croatia, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Norway, the Netherlands, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom. Cyprus, Estonia, Latvia, Luxembourg and Malta are included at country level.

behind in 2021 than in 2016. The dispersion between European regions also increased sharply during 2020, possibly due to the impact of the COVID-19 crisis on scientific production.

Figure 36. Scientific publications per 1 000 inhabitants, 2020 (top), and evolution of contributions to the EU's total publications between 2010 and 2020 (bottom)

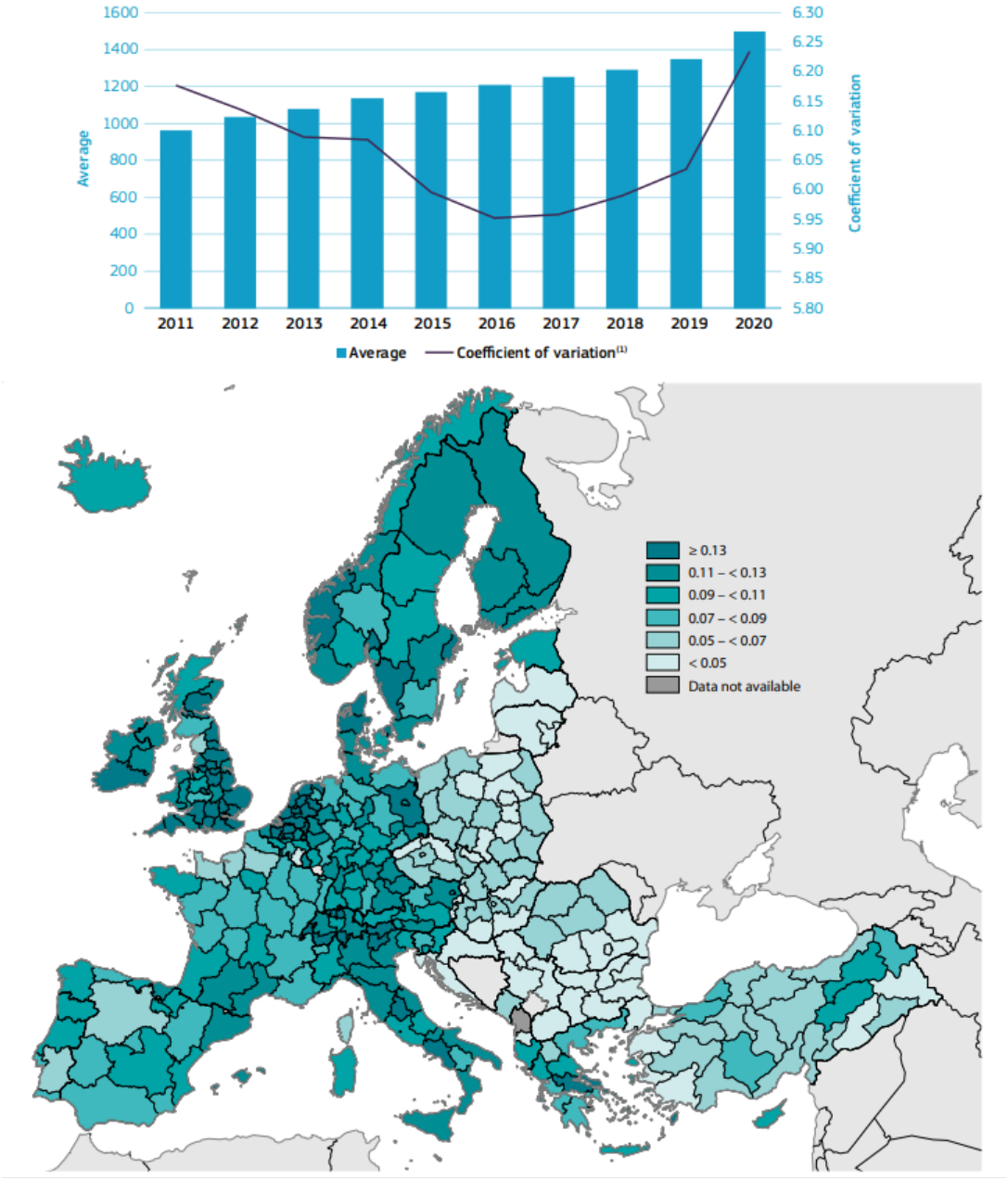


Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

At the same time, the production of high-quality publications (scientific excellence) continues to be highly concentrated in relatively few regions. Hence, the top 10 % most-cited publications are mostly produced in western Europe, with a dominance of Dutch and Nordic regions (Figure 37). Central and eastern

European regions still show lower performance. If the positive trend in the quantity of scientific publications translates into higher quality, then the EU could experience some catch-up from central and eastern regions in the future. However, this catch-up process tends to take longer and depends on overall improvement in framework conditions for scientific production.

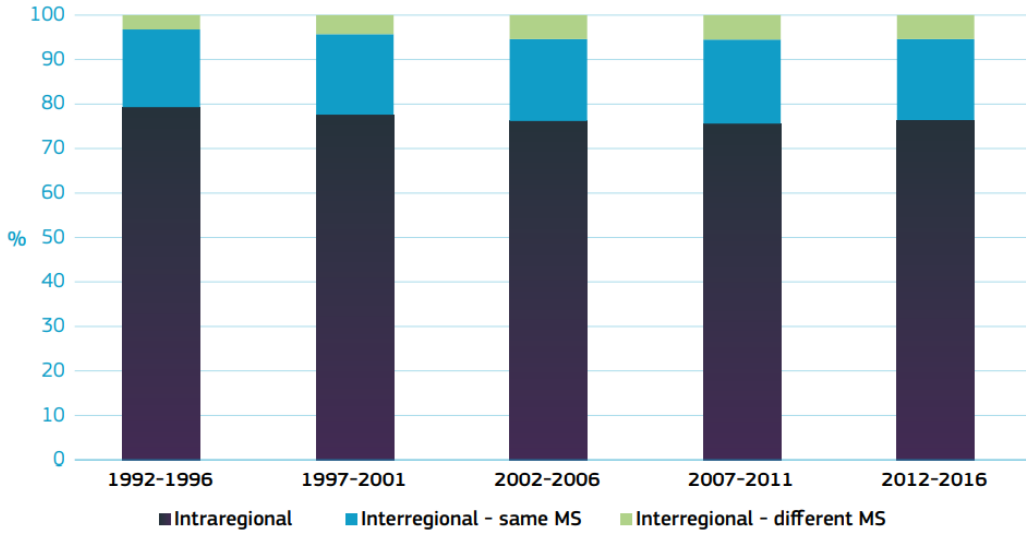
Figure 37. Percentage of highly cited publications (top 10 %) in 2018 per NUTS 2 level (map) and evolution of regional disparities in publications per million inhabitants (graph)



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

Interregional co-patenting remains very limited in the EU, even if it did slightly increase from 1992 to 2016. Over 75 % of collaborations on patents (co-patenting) take place within the same region; fewer than 20 % are interregional, with stakeholders in other regions of the same country; and only 3–5 % are interregional across national borders (Figure 38). 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 38. Interregional and intraregional co-patenting in Europe over 1992–2016



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826, based on Balland and Boschma (2019).

2.6. EU brain drain and drivers of scientific excellence

The mobility of researchers across countries is an important driver for international collaboration and optimal allocation of human capital. Cross-border research and collaboration among researchers are important channels of knowledge flow and knowledge transfer. International collaboration through scientific co-publications improves scientific quality since researchers are exposed to a diverse environment, while achieving greater impact and citations from their international collaborations. Overall, smaller countries and/or those performing better in R & I show a relatively high inflow of researchers and a higher share of researchers who obtained a Doctor of Philosophy (PhD) degree abroad. These results imply that the outflow of researchers is not necessarily a bad thing, as long as the innovation ecosystem is attractive so as to generate corresponding inflows of researchers from abroad ([97]). Several factors can affect the mobility of researchers, such as working conditions, career prospects, and cultural and linguistic aspects.

The mobility of researchers across jobs can be key for knowledge transfer and knowledge diffusion. If researchers can smoothly move from academia to the private and public sectors (and vice versa), competences and rare skills can flow through the economy with low friction costs. Furthermore, inventors' mobility can be an important source of learning for hiring organisations. At EU level, the share of job-to-job mobility has remained small at almost 7 %, despite an increase between 2010 and 2020. Within the EU, there are significant differences in the mobility patterns of human resources in science and technology. Overall, countries performing better in R & I present higher job-to-job mobility ([98]).

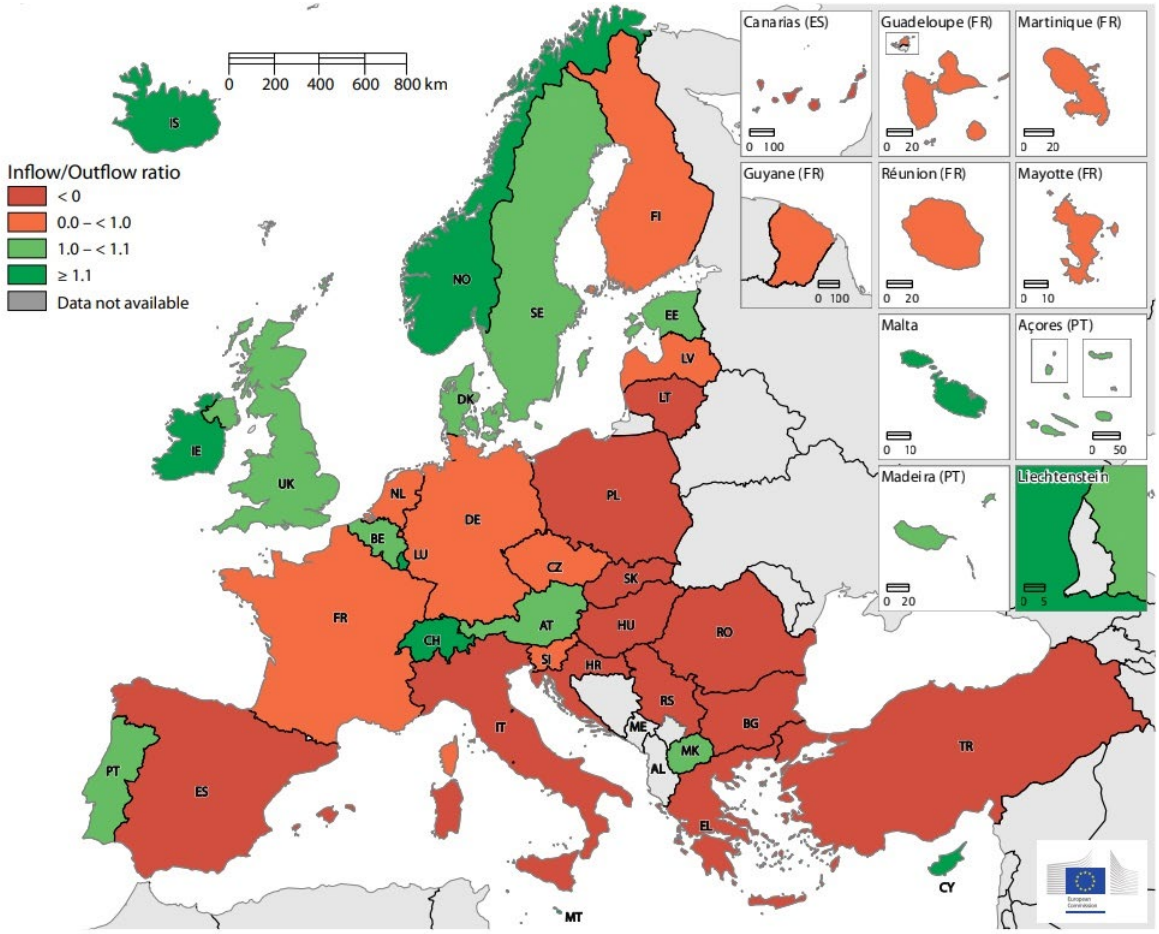
A current concern for the EU's scientific ecosystem is brain drain from some countries within the EU, and the EU as a whole, to outside the EU (outflow over inflow of researchers). This brain drain is particularly an issue for most eastern and southern European countries, such as Greece, Italy, Hungary and Poland, for which the outflow of researchers from Europe has outstripped the inflow of researchers from the rest of the world into Europe during the last 20 years (see Figure 39). These results might be explained by poor career conditions and unattractive research systems that have led researchers to look for better conditions abroad. In contrast, the inflow of researchers outpaces the outflow in most northern and western European countries (including Luxembourg, Norway, Switzerland and the United Kingdom). Most Member States report a ratio of researcher inflow over researcher outflow below 1 (i.e. more researchers left the

([97]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

([98]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

country than entered it over the period). This might be explained by the fact that, in most EU Member States, the top destination for European researchers is not another Member State but a country outside the EU such as the United States, which is a top destination overall. As highlighted previously, researchers' mobility is a positive feature of a research ecosystem; hence, instead of disincentivising outflows, it is important to increase the attractiveness of the R & I ecosystem (competitive wages, cutting-edge infrastructures, fair promotion processes) to obtain a more balanced flow of researchers in the EU by raising the inflow.

Figure 39. Map of researcher inflow and outflow ratios during 2001–2020 by country



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times,* Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

3. POSSIBLE NEW RESEARCH NEEDS AND POTENTIALS ARISING FROM THE GLOBAL CHALLENGES

Key messages from this chapter

- To deliver on the European Green Deal, R & I is needed to boost systemic change across our entire economy, all industry sectors, our ways of producing and consuming, and our infrastructure.
- The EU is among the world leaders of the green transition but is lagging behind China and the United States when it comes to the digital transition. At the same time, some of the other leading countries are seizing the net zero industrial opportunities; for example, China has increased its production of green patents by almost 20 times over the past 20 years.
- Transformative R & I policies, characterised by directionality, policy coordination, reflexivity and demand articulation, have the potential to act as leverage for transformation in the transition towards sustainable development.
- To preserve its open strategic autonomy and sustainable economic growth, the EU needs to increase its global leadership though public and private investments in R & I that deliver social, technological and organisational innovation. R & I is a key instrument in supporting the EU to increase its technological development, manufacturing production, net zero products and energy supply. The EU must also pursue reciprocal openness and a level playing field through strategic international R & I cooperation with like-minded partners.
- Stronger R & I are needed to develop and deploy net-zero technologies as outlined in the EU Green Deal. This is key for achieving the climate neutrality objectives at reduced costs. This includes the need for more funding for development, deployment and upscale of net-zero industrial value chains targeting strategic sectors, as outlined in the recently published proposal for a Net Zero Industry Act, a pillar of the Green Deal Industrial Plan, but also for ensuring the competitiveness of the European industry through more effective R&I investment in the net-zero technology products manufacturing ecosystem.
- Reduction, substitution, and the better application of the circular economy principles, with new business models for intensified use of products and components, along with the full use of secondary material resources and a shift from using fossil-based resources towards sustainably using biological resources, could also help to achieve a strong circular economy and reduce industrial dependencies in strategic sectors.
- The EU needs to target investments in research, development, and innovation in both the short term and the long term to strengthen resilience and preparedness against future cross-border health threats, climate risks, natural resource scarcity and degradation, and insecurity threats or critical supply chain disruptions, including those due to dependencies on critical raw materials from third countries.
- Building resilience also calls for boosting social and place-based multi-actor innovation, which has the potential to bring people from diverse backgrounds together with a common purpose through personal and collective commitment and joint actions.
- A whole-of-government, whole-of-society approach (i.e. horizontally and vertically coherent governance settings involving all relevant actors and stakeholders), nudging public and private sector actors, is also needed to ensure coordination and integration among stakeholders and levels of government, and policy domains. Through whole-of-government approaches, local public authorities can play a central role in creating optimal framework conditions for accelerating transformative R & I and for fast adoption of innovative solutions.

3.1. Transformative research and innovation policies: how research and innovation can boost systemic change

In 2019, the European Green Deal pointed out the need for the R & I agenda to take a systemic approach to achieving its ambitious targets. The problems we face today are indeed complex and interconnected, thus requiring solutions from multiple perspectives, disciplines and sectors. R & I policies are increasingly expected to provide novel instruments for and solutions to conflicting goals ([99]), implicating different policy domains and levels of governance (regional, national and European). Moreover, the novel solutions to address societal challenges, such as social innovation, transformative change, changes in practices and climate technologies, can require long lead times before showing effects. In addition, for technologies to reach maturity, there is a crucial need for a significant amount of capital throughout the funding life cycles of start-ups and for long-term investments in R & I. While many, if not all, sustainability-driven technologies promise positive outcomes, technological innovations, by their very nature, may have unintended adverse consequences when scaled up to system level (e.g. indirect land use change, loss of biodiversity, and increased competition for land and soil degradation resulting from bioenergy production or from the use of biomass in sustainable bio-based products) ([100]). Under these circumstances, innovation experts and scholars have put forward a strong claim for policymakers to provide an R & I policy mix that sets the direction of change and the framework conditions to navigate the transition process, notably spaces for experimentation (including living labs), with novel policy instruments and synergies between them, inclusive and coherent governance settings, and consultation and engagement with stakeholders (such as the multi-actor approach ([101])) throughout the R & I cycles.

R & I policies should then act as leverage for transformation in the transition towards sustainable development, empowering individuals and communities to meet societal needs and build sustainable, inclusive and resilient societies, and should also pay the necessary attention to needs beyond functionality, such as quality of experience or sense of belonging. A portfolio of strategies and tools can be adopted throughout the policymaking process to assist with designing ad hoc R & I policy mixes for leveraging societal transformations. For instance, ***ex ante* policy experimentation and real-time monitoring and evaluation could be more widely integrated into policymaking processes** to test, for instance, what kinds of novel combinations of policy instruments or governance settings and operations can best support the uptake and acceleration of the twin transition, or to evaluate different policy approaches during their implementation and adjust them to new evidence on actual impacts and best practices as needed ([102]). Living labs are an example of *ex ante* experimental interventions that promote delivering on manifold, locally adapted solutions. Moreover, experimentation could support formulating and implementing adaptive policy mixes, to which **policy instruments could be gradually introduced to support the different stages of the change**. A **whole-of-government, whole-of-society approach** (i.e. horizontally and vertically coherent governance settings involving all relevant actors and stakeholders), nudging public and private sector actors, is also needed to ensure coordination and integration among stakeholders and levels of government, and policy domains. Furthermore, **behavioural insights** could be further strengthened in various stages of policymaking processes to increase the impact of the processes. Finally, the *Science, research and innovation performance of the EU 2020* report ([103]) called for a **better alignment and synergy of R & I policies with sector-specific policies** (e.g. in energy, transport, agriculture, bioeconomy, aquaculture and fisheries, and forestry) that are key to providing focus, vision and ad hoc instruments for the deployment and diffusion of innovations (e.g. wind and solar photovoltaics, combined heat and power, sustainable agriculture, and land and soil management). This is also referred to as sustainability transitions governance ([104]).

Deep transformations require R & I policy support not only for disruptive and other types of innovations but also, and most importantly, for upscaling, replication and acceleration of these innovations – that is, when radical innovations become the new way of doing and thinking within markets,

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([99]) Kanger, L., Sovacool, B. K. and Noorkõiv, M. (2020), 'Six policy intervention points for sustainability transitions: a conceptual framework and a systematic literature review', *Research Policy*, 49 (7), 104072.

([100]) European Environmental Agency (2019), *The European Environment – State and outlook 2020: Knowledge for transition to a sustainable Europe*, Publications Office of the European Union, Luxembourg.

([101]) Agricultural European innovation partnership (2017), *Horizon 2020 Multi-actor Projects*, Agricultural European Innovation Partnership, eip-agri_brochure_multi-actor_projects_2017_en_web.pdf (europa.eu).

([102]) von Wirth, T., Fuenfschilling, L., Frantzeskaki, N. and Coenen, L. (2019), 'Impacts of urban living labs on sustainability transitions: mechanisms and strategies for systemic change through experimentation', *European Planning Studies*, 27 (2), pp. 229–257.

(103) European Commission, Directorate-General for Research and Innovation (2020), *Science, research and innovation performance of the EU 2020 – A fair, green and digital Europe*, Publications Office of the European Union, Luxembourg.

([104]) Fagerberg, J. (2018), 'Mobilizing innovation for sustainability transitions: a comment on transformative innovation policy', *Research Policy*, 47 (9), pp. 1568–1576; Turnheim, B. and Sovacool, B. (2020), 'Exploring the role of failure in socio-technical transitions research', *Environmental Innovation and Societal Transitions*, 37, pp. 267–289.

businesses, society and the policy environment ([105]). In addition, these transformations also call for understanding the limits of and potentials in local natural and human capital, and the deployment of tailored transition pathways. That is why **R & I policy also needs to fully embrace** the principles underpinning transformative change towards sustainable development – **transformation, directionality, co-creation, diffusion and uptake**.

Furthermore, European R & I policy has a role to play in empowering the actors in the field of R & I and making sure that all relevant actors are involved, for instance the science producers, such as private and public knowledge institutions, whose independence needs to be safeguarded for them to be able to evolve and experiment with cutting-edge and out-of-the-box ideas ([106]). Furthermore, it is, for instance, also of key importance to involve social economy actors to develop partnerships building on the 'societal perspective' of R & I projects while fostering experimentation that could help the green transition. Since empowering actors involves providing spaces for wide cooperation, EU R & I will promote a multi-actor approach across entire value chains in the EU and beyond. Expert recommendations for that purpose involve prioritising the chains necessary to realise open strategic autonomy and the European Green Deal, and encouraging environmental and social governance across the value chains identified to support shared values ([107]).

Finally, experts have advised the EU to support the transition of its industrial systems from a **digital industry 4.0 to a transformative industry 5.0** ([108]), one able to innovate and contribute to the twin transition **while ensuring a fair transition, and full integration of the social and societal dimension, maintaining a social and societal dimension**, which is crucial to ensure that the transition is just, effective and leaves no one behind ([109]).

3.2. Research and innovation needs for delivering on the European Green Deal

Considering their positions on the transitions performance index (TPI) 2021, EU Member States are, overall, relatively well prepared for the transitions and challenges ahead. They show good performance overall, with progress in all Member States from 2011 to 2020 on the TPI 2021 (Table 7), which measures the performance of countries along four transitions: economic, social, environmental and governance. The 'ESG gap' column indicates, independently of the positioning on the TPI ranking, the extent to which an increased effort in the economic transition is particularly needed. Countries with a positive ESG gap need to do more on the economic transition. In contrast, countries with pronounced negative gaps are not sufficiently using their economic resources to speed up progress in the three other pillars ([110]).

([105]) European Commission, Directorate-General for Research and Innovation (2020), *Science, research and innovation performance of the EU 2020 – A fair, green and digital Europe*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/534046.

([106]) European Commission, ESIR (2021), *Transformation Post-COVID – The future of European universities*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/bc039241-c996-11eb-84ce-01aa75ed71a1/language-en/format-PDF/source-213424063.

([107]) European Commission, ESIR (2021), *Transformation Post-COVID – Global value chains: Harnessing innovation to protect and transform the backbone of global trade*, Publications Office of the European Union, Luxembourg,https://op.europa.eu/en/publication-detail/-/publication/c3bd86d6-c995-11eb-84ce-01aa75ed71a1/language-en/format-PDF/source-213423369.

([108]) European Commission, ESIR (2022), *Industry 5.0: A transformative vision for Europe – Governing systemic transformations towards a sustainable industry*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/17322.

([109]) European Commission, ESIR (2022), *Industry 5.0: A transformative vision for Europe – Governing systemic transformations towards a sustainable industry*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/17322. See also Council of the European Union (2022), Council recommendation of 16 June 2022 on ensuring a fair transition towards climate neutrality (2022/C 243/04) (OJ C 243,27.6.2022, p. 35), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022H0627(04); and European Commission (2021), Commission staff working document accompanying the proposal for a Council recommendation on ensuring a fair transition towards climate neutrality, SWD(2021) 452 final, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiA466j_O_9AhWCnVwKHeeuDqYQFnoECBgQAQ&url=https%3A%2F%2Fec.europa.eu%2Fsocial%2FBlobServlet%3FdocId%3D25029%26langId%3Den&usg=AOvVaw0dzymExom7mKU6zM8bnTMU.

([110]) European Commission, Directorate-General for Research and Innovation, Prevost, S., Benavente, D., Stevenson, A., Caperna, G. and Panella, F. (2022), *Transitions Performance Index 2021 – Towards fair and prosperous sustainability*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/09602.

Table 7. EU TPI ranking, pillar scores and transition groups

RANK		COUNTRY	2020 TRANSITIONS SCORES					PROGRESS	ESG GAP
REGION	TPI	NAME	TPI	ECONOMIC	SOCIAL	ENVIRONMENTAL	GOVERNANCE	2011-2020	(% OF TPI)
1	2	Denmark	78.4	73.4	85.5	73.1	84.0	6.0%	7.9%
2	3	Ireland	75.9	76.1	78.3	72.3	79.0	9.8%	-0.3%
3	4	Netherlands	73.6	66.7	84.8	64.7	82.5	7.2%	11.7%
4	6	Germany	73.1	70.7	82.0	65.0	79.1	5.1%	4.0%
5	7	Sweden	72.3	73.0	84.3	57.0	83.7	1.8%	-1.1%
6	9	Malta	70.7	55.7	80.1	74.4	70.1	7.2%	26.5%
7	10	Slovenia	70.4	62.5	85.9	60.9	77.7	5.0%	14.1%
8	11	Austria	70.4	70.2	80.6	59.1	78.0	4.6%	0.3%
9	12	France	69.6	58.9	81.0	66.8	73.2	4.6%	19.3%
		EU-27	69.0	61.1	77.5	65.0	74.0	4.9%	14.3%
10	13	Belgium	68.9	67.9	81.6	59.1	73.3	5.6%	1.9%
11	14	Czechia	68.8	60.4	83.9	59.0	77.3	7.6%	15.3%
12	15	Luxembourg	68.7	69.3	75.5	52.9	85.0	8.2%	-1.1%
13	16	Italy	67.6	56.7	70.2	73.8	65.7	7.0%	20.2%
14	18	Finland	67.4	68.2	84.1	47.9	80.7	1.7%	-1.6%
15	19	Spain	67.1	54.2	74.7	65.4	73.7	4.5%	24.1%
16	20	Portugal	67.0	50.3	76.9	66.4	73.1	5.1%	31.1%
17	21	Estonia	66.1	56.4	79.2	53.9	80.3	10.8%	18.3%
18	22	Slovakia	65.0	50.1	80.9	60.2	70.9	6.4%	28.7%
19	23	Latvia	64.4	47.9	72.2	68.4	66.0	3.8%	32.2%
20	24	Croatia	64.3	45.6	72.0	67.6	68.7	13.5%	36.5%
21	25	Poland	64.2	52.5	74.1	59.7	71.8	7.0%	22.7%
22	26	Hungary	64.0	53.0	75.3	66.2	60.5	-0.2%	21.4%
23	27	Lithuania	63.5	52.3	71.7	61.6	68.4	5.2%	22.0%
24	30	Greece	62.1	45.2	70.9	65.5	63.8	11.0%	34.0%
25	32	Romania	61.2	42.2	66.0	65.3	66.6	5.8%	38.7%
26	34	Cyprus	59.9	47.6	79.2	51.6	66.1	0.4%	25.8%
27	36	Bulgaria	59.3	40.8	65.3	61.2	66.7	4.9%	39.1%

Transition leader [75-100] Strong transition [65-75[Good transition [55-65[Moderate transition [45-55[Weak transition [0-45[

Notes: (1) 'ESG gap (% of TPI)' refers to the difference between the sum of the social, environmental, and governance (ESG) pillar weighted scores and the economic pillar score, as a percentage of the TPI score, in 2020. (2) 'Progress 2011-20' refers to the percentage growth of TPI scores from 2011 to 2020.

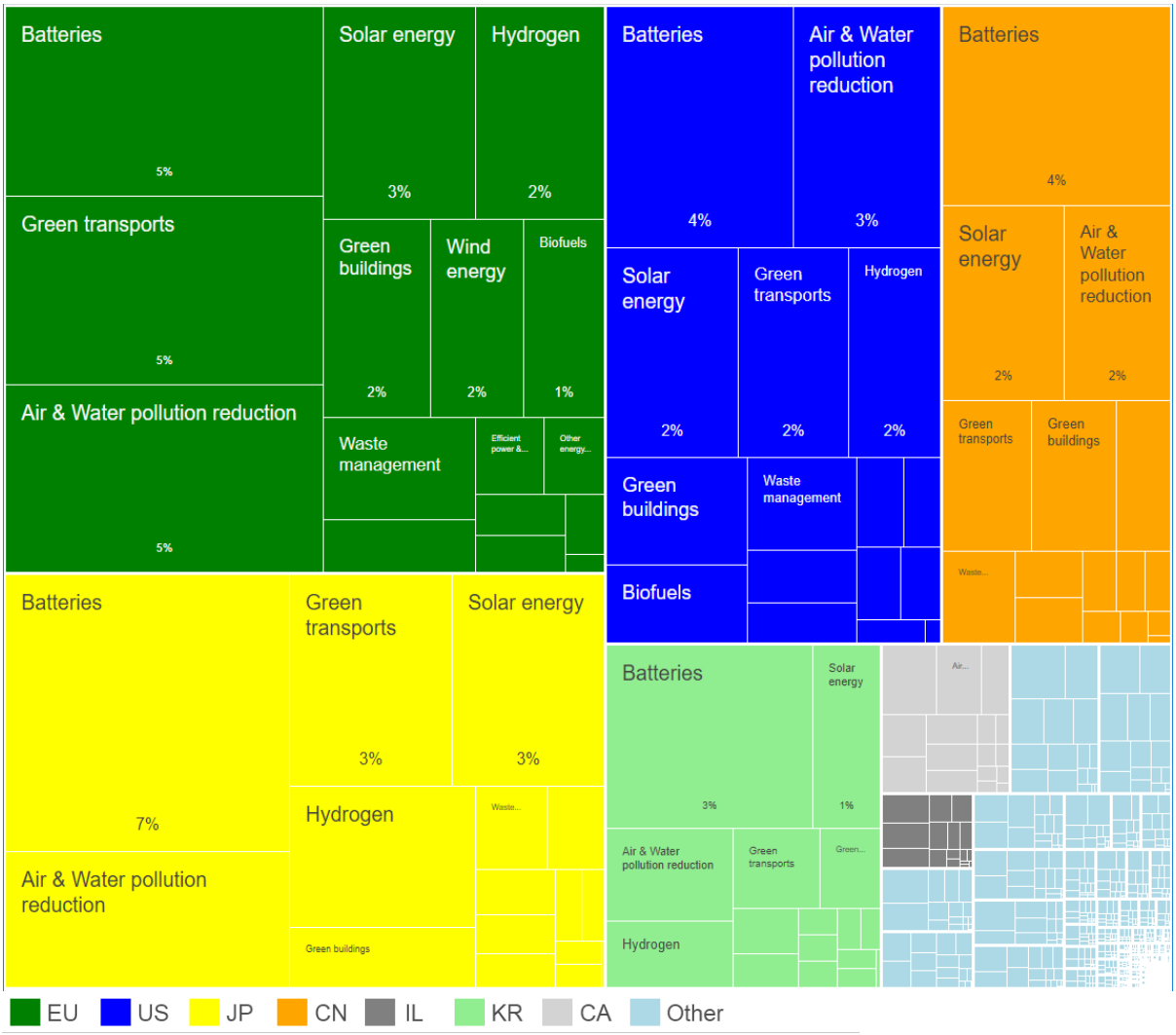
Source: European Commission, Transitions Performance Index 2021.

NB: 'ESG gap' refers to the difference between the sum of the following scores in 2020: (1) those weighted by the environmental, social and governance (ESG) pillar and (2) the economic pillar score, as a percentage of the TPI score. 'Progress' refers to the percentage growth of TPI scores from 2011 to 2020.
Source: European Commission, Directorate-General for Research and Innovation, Prevost, S., Benavente, D., Stevenson, A., Caperna, G. and Panella, F. (2022), *Transitions Performance Index 2021 – Towards a fair and prosperous sustainability*, Publications Office of the European Union, Luxembourg.

European countries ([111]) **are also among the leaders of the green transition.** From 2016 to 2021, Europe produced 30 % of all green inventions worldwide (Figure 40). Japan was second, with 21 %, followed by the United States (19 %) and China (13 %). The European lead is especially strong for domains such as green transport (41 %), biofuels (37 %) and wind energy (58 %). The production of solar energy technology or batteries is more evenly distributed among the largest and most innovative countries ([112]).

([111]) Understood as the group comprising the EU-27, the United Kingdom and the European Free Trade Association countries.
([112]) https://www.paballand.com/asg/esir/fow/green-transition.html.

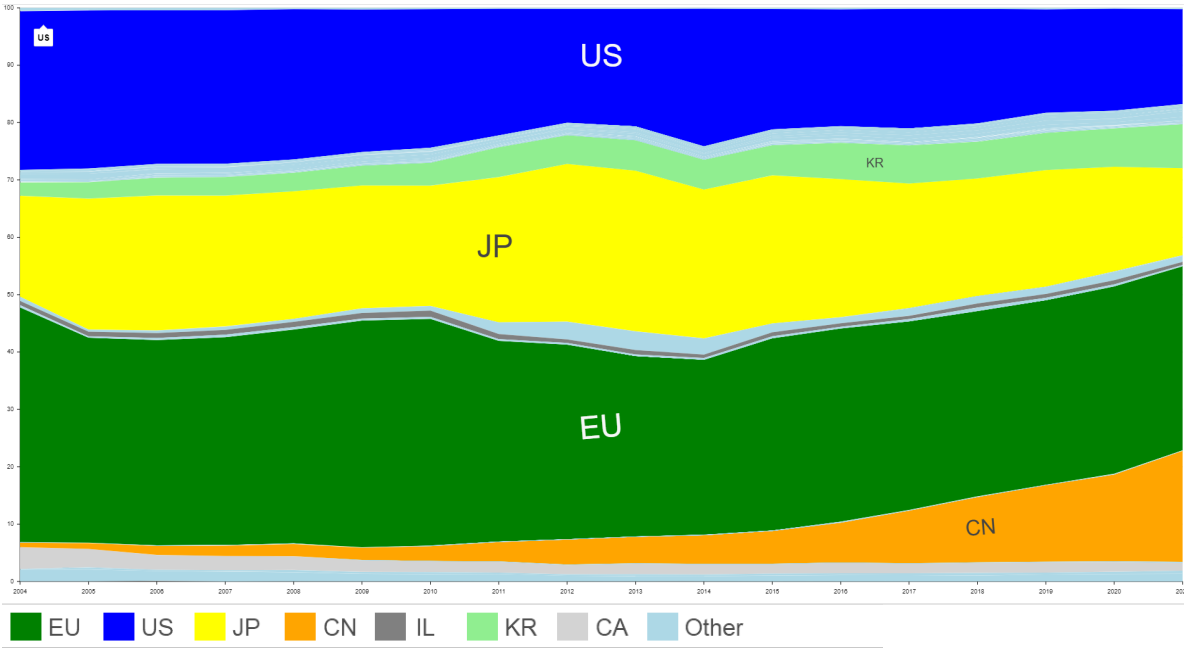
Figure 40. Percentage of green patents across world regions, 2016–2021



Source: European Commission, ESIR (forthcoming), *Industry 5.0 and the Future of Work – Making Europe the centre of gravity for future good-quality jobs*, Publications Office of the European Union, Luxembourg.

Europe has maintained a fairly stable position in the green transition since 2004 (Figure 41). In addition, although we can observe a slowdown during the 2007–2008 financial crisis, the rate of output of innovation has been relatively stable since 2014. This is remarkable, in the sense that this stability existed despite the meteoric rise of China. In less than 20 years, China has increased its production of green patents by almost 20 times. A significant decrease in terms of proportion is observed for the United States, from a global share of almost 30 % to about 20 %. Japan has also been on a declining trend since the financial crisis (Figure 39).

Figure 41. Evolution of the production of green patents across world regions (%), 2004–2021



Source: European Commission, ESIR (forthcoming), *Industry 5.0 and the Future of Work – Making Europe the centre of gravity for future good-quality jobs*, Publications Office of the European Union, Luxembourg.

However, even if the EU is positioned as a leader in terms of the green transition, R & I progress and uptake are still critical for implementing the European Green Deal ([113])**.** The EU is fully committed to ensuring prosperity within planetary boundaries. The European Green Deal, consisting of a set of policy initiatives covering several sectors and fields, aims to put the EU firmly on the path towards climate neutrality by 2050 and is the EU's new growth model ([114]). Fairness and solidarity are guiding principles of the European Green Deal, which pays particular attention to people and to leaving no one behind in the transition.

To deliver on the European Green Deal, systemic change should be fostered across our entire economy and all industry sectors, with a focus on energy-intensive industry, but also in our production and consumption, and in our large-scale infrastructure, transport, food and agriculture, construction and buildings. In order to enable such systemic changes, technological innovation should be accompanied by opportunities delivered through social and economic innovation.

Further R & I is needed to **protect and restore natural capital; decarbonise the economy; accelerate the transition to chemicals and materials that are safe and sustainable** ([115])**; achieve a circular economy and the zero pollution ambition; modernise our infrastructures, buildings and transport, and make them more resilient; protect the health and well-being of citizens and communities (including rural ones); design sustainable and resilient agriculture, forestry, fisheries and aquaculture, and food and water systems; and transform our ways of producing and consuming** ([116]).

([113]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 (SRIP)*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/38888.

([114]) European Commission (2019), The European Green Deal, COM(2019) 640 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN.

([115]) European Commission, Directorate-General for Research and Innovation (2022), *Strategic research and innovation plan for safe and sustainable chemicals and materials*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/9f04603f-534b-11ed-92ed-01aa75ed71a1/language-en/format-PDF/source-273210885.

([116]) European Commission (2019), The European Green Deal, COM(2019) 640 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN.

3.2.1. *Achieve climate neutrality*

The European Climate Law writes into law Europe's objective of climate neutrality by 2050 ([117]). The EU endorses a holistic and integrated approach for policies and initiatives, with sustainable development as an essential guideline. All the scenarios that limit warming to below + 1.5 °C or below + 2 °C rely heavily on research and technology progress and its uptake, along with profound changes in practices, behaviour and consumption patterns. Demand management, the phase-out of fossil fuels and a change in the functioning of the economic system will be required. In addition, the International Energy Agency estimates that half of the global reductions in CO_2 emissions by 2050 will have to come from technologies that are currently in the demonstration or prototype phase ([118]). Other significant reductions in emissions (not just CO_2) are expected to result from land and soil management. For example, while accounting for only 3 % of the Earth's land, peatland holds more than one quarter of all soil carbon – twice as much as the world's forests do. The degradation of peatland (e.g. through conversion to agricultural land) is causing about 5 % of the world's anthropogenic GHG emissions ([119]). Several policy packages have been adopted to ensure the EU achieves its emission reduction targets. One of the most prominent is the fit for 55 plan, which adapts existing climate and energy legislation to meet the new EU objective of a minimum reduction of GHG emissions of 55 % by 2030 compared with levels in 1990 ([120]). The proposed Nature Restoration Law ([121]) and the upcoming Soil Health Law ([122]) are expected to provide a solid framework for the protection of peatland and other organic soils. Finally, the Commission proposal for a regulation on carbon-removal certification aims to support the large-scale deployment of the carbon removals needed to achieve the 2050 target. R & I will be needed to ensure that the objectives of the future EU Nature Restoration Law are reached.

R & I is critical to achieving the clean energy transition and meeting the objective of climate neutrality by 2050. The production and use of energy across economic sectors account for more than 75 % of the EU's GHG emissions ([123]). A power sector must be developed that is largely based on renewable sources, complemented by the rapid phase-out of coal and decarbonisation of gas, and energy efficiency must be prioritised ([124]). **However, there has been a global decline, including in the EU, in clean and efficient energy patenting since the early 2010s, although more recently this trend has reversed (Figure 42).** Consequently, an acceleration in patenting activity on clean energy technologies is needed ([125]), particularly in sectors with high potential such as renewable hydrogen and offshore renewables. While solar and wind technologies have reached a certain relative level of maturity, this is not the case for other technologies such as energy storage, or hydropower, geothermal technologies and bioenergy, for which total installed costs have not significantly lowered ([126]). That said, R & I still plays a crucial role for even 'mature' renewable energy technologies such as electrification of high temperature processes and carbon capture and utilisation, solar photovoltaics, for which the International Energy Agency has identified specific areas that require further research efforts ([127]).

Further research is needed to develop and bring down the costs of both industrial and nature-based carbon removal technologies, including bioenergy-based and direct air-based carbon capture and storage. First, **stronger research and innovation are needed to develop and deploy net-zero technologies as outlined in the EU Green Deal**. This is key for achieving the climate neutrality objectives at reduced costs. This includes the need for more funding for development, deployment and upscale of net-zero industrial value

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([117]) Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law') (OJ L 243, 9.7.2021, p. 1), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1119&from=EN.

([118]) International Energy Agency (2021), *Net Zero by 2050 – A roadmap for the global energy sector*, International Energy Agency, Paris.

([119]) See, for example, Gewin, V. (2020), 'How peat could protect the planet', *Nature*, 578, pp. 204–208, https://www.nature.com/articles/d41586-020-00355-3.

([120]) European Commission (2021), 'Fit for 55': Delivering the EU's 2030 climate target on the way to climate neutrality, COM(2021) 550 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A550%3AFIN.

([121]) European Commission (2022), Proposal for a regulation of the European Parliament and of the Council on nature restoration, COM(2022) 304 final.

([122]) European Commission (2021), EU soil strategy for 2030 – Reaping the benefits of healthy soils for people, food, nature and climate, COM(2021) 699 final.

([123]) European Commission (n.d.), *Energy and the Green Deal*, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/energy-and-green-deal_en#documents.

([124]) European Commission (2019), The European Green Deal, COM(2019) 640 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN.

([125]) International Energy Agency (2021), *Patents and the Energy Transition – Global trends in clean energy technology innovation*, European Patent Office, Munich, and International Energy Agency, Paris; International Energy Agency (2023), *Hydrogen Patents for a Clean Energy Future – A global trend analysis of innovation along hydrogen value chains*, International Energy Agency, Paris.

([126]) European Commission (2022), Progress on competitiveness of clean energy technologies, COM(2022) 643 final.

([127]) International Energy Agency (2022), *Solar PV*, International Energy Agency, Paris.

chains targeting strategic sectors, as outlined in the recently published proposal for a Net Zero Industry Act,[128] a pillar of the Green Deal Industrial Plan,[129] but also for ensuring the competitiveness of the European industry through more effective R&I investment in the net-zero technology products manufacturing ecosystem. Second, more (and more effective) R & I investment in net zero technologies and in the uptake of innovation by industry is needed in order to preserve the competitiveness and attractiveness of the EU as an investment location for the net zero industry. This will reconcile the costs of achieving the Green Deal objectives with industrial competitiveness and job creation. Third, **R & I leading to strategic autonomy in clean technologies will help in achieving the objective of decreasing dependencies on third-party technologies and/or raw materials**. Therefore, more R & I investment targeting strategic sectors is also critical. The Green Deal industrial plan outlines the need to massively increase the technological development, manufacturing production and installation of net zero products, and increase the energy supply in the next decade.

While the evolution of low-carbon transitions for climate neutrality can deliver positive impacts on emission reduction and the restoration of natural ecosystem services, it may also have the oppositive effect, for example by leading to more pollution. Therefore, to understand how to support the protection and restoration of our ecosystems, **there is a need for more evidence on the link between adoption of low-carbon technology and environmental impacts that could increase the vulnerability of society and natural ecosystems to climate change**. For instance, scientific evidence is needed to analyse and monitor the effects of biohazards (e.g. discharge of biomaterials, nitrogen leakage on agricultural land), biomethane emissions and carbon loss on natural ecosystems. The biodiversity strategy ([130]) points to some research gaps that could be filled by better developing practices and solutions such as organic farming and agroecology to restore and protect ecosystems. Furthermore, the systemic drivers of biodiversity loss need to be addressed, as does how these drivers are linked to human activities from consumption to extraction, production and trade.

In addition to technical innovation and supply of renewable energies, demand-side mitigation pathways and policy options to avoid unnecessary consumption and GHG emissions, a shift to low-carbon alternatives and improved efficiency and adoption are also key in R & I meant to support climate neutrality. According to an Intergovernmental Panel on Climate Change (IPCC) report, '[t]he indicative potential of demand-side strategies to reduce emissions of direct and indirect CO_2 and non-CO_2 GHG emissions in three end-use sectors (buildings, land transport, and food) is 40–70 % globally by 2050 (*high confidence*)' ([131]). Behavioural demand-side changes are also found to be in line with higher levels of well-being ([132]). In addition, R & I is key to better understanding the unequal contributions to GHG emissions and pollution activities, which vary along the income distribution and between socioeconomic groups.

([128]) European Commission, Directorate-General for Communication (2023), *EU Net-Zero Industry Act : making the EU the home of clean tech industries*, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2775/010539

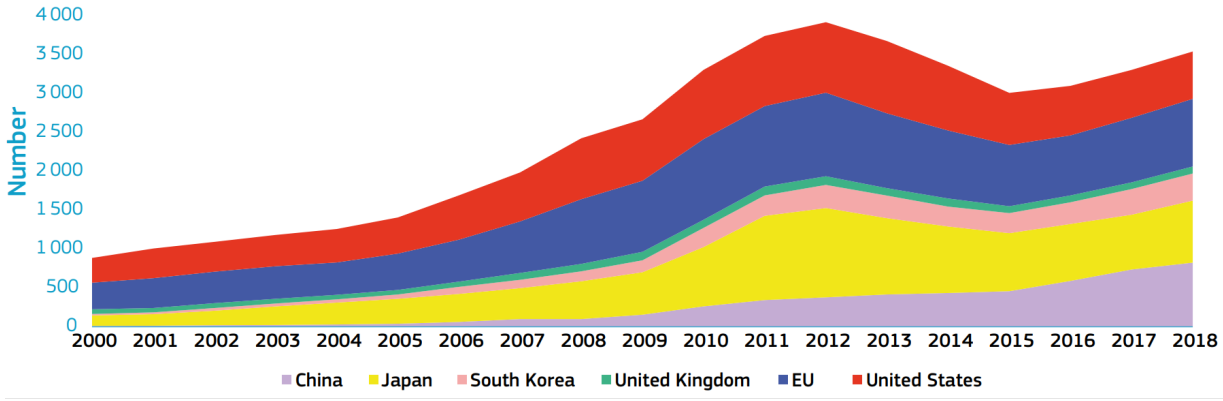
([129]) European Commission (2023). *A Green Deal Industrial Plan for the Net-Zero Age, COM(2023) 62 final. https://op.europa.eu/en/publication-detail/-/publication/4875f9b9-a2d8-11ed-b508-01aa75ed71a1/language-en/format-PDF/source-283620809*

([130]) European Commission (2011), Our life insurance, our natural capital: An EU biodiversity strategy to 2020, COM(2011) 244 final.

([131]) Creutzig, F., Roy, J., Devine-Wright, P., Díaz-José, J., Geels, F. W., Grubler, A., Maïzi, N., Masanet, E., Mulugetta, Y., Onyige, C. D., Perkins, P. E., Sanches-Pereira, A. and Weber, E. U. (2022), 'Demand, services and social aspects of mitigation', in IPCC, *Climate Change 2022 – Mitigation of climate change: Contribution of working group III to the sixth assessment report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom, pp. 503–612, https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter05.pdf; for more information on demand-side strategies, see Creutzig, F., Niamir, L., Bai, X., Callaghan, M., Cullen, J., Díaz-José, J., Figueroa, M., Grubler, A., Lamb, W. F., Leip, A., Masanet, E., Mata, É., Mattauch, L., Minx, J. C., Mirasgedis, S., Mulugetta, Y., Budi Nugroho, S. B., Pathak, M., Perkins, P., Roy, J., de la Rue du Can, S., Saheb, Y., Some, S., Steg, L., Steinberger J. and Ürge-Vorsatz, D. (2022), 'Demand-side solutions to climate change mitigation consistent with high levels of well-being', *Nature Climate Change*, 12, pp. 36–46, https://www.nature.com/articles/s41558-021-01219-y.

([132]) Creutzig, F., Roy, J., Devine-Wright, P., Díaz-José, J., Geels, F. W., Grubler, A., Maïzi, N., Masanet, E., Mulugetta, Y., Onyige, C. D., Perkins, P. E., Sanches-Pereira, A. and Weber, E. U. (2022), 'Demand, services and social aspects of mitigation', in IPCC, *Climate Change 2022 – Mitigation of climate change: Contribution of working group III to the sixth assessment report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter05.pdf.

Figure 42. Evolution of number of patent applications filed under the PCT in secure and clean energy, 2000–2018



NB: Fractional counting method used.
Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826, based on Science-Metrix using the European Patent Office's worldwide patent statistics database.

According to the 2022 REPowerEU plan, more support should be directed towards R & I aiming to reduce material consumption, enhance the recyclability of renewable energy equipment and substitute critical raw materials. Horizon Europe will dedicate EUR 200 million of renewable hydrogen projects ('hydrogen valleys'), with the EU aiming to take a lead role in international cooperation on **renewable hydrogen R & I**. Furthermore, the 2022 biomethane action plan also points out gaps in research, development and innovation, aiming to increase sustainable biomethane production and use, and facilitate its integration into the EU's internal gas market. In the medium term, the Commission has also identified the need for further energy innovation, including heat pumps, retrofitting and energy-efficient industrial processes. Digital transformation, technological innovation with rapid upscaling at meaningful market level, and research and development are also important drivers for achieving the climate-neutrality objective ([133]). Further research and innovation pathways are also needed when it comes to the development and uptake of the market shares of energy communities and cooperatives. Technological innovation matters, but innovation in terms of answering social needs and creating innovative partnerships (e.g. for financing or project management) are also very important.

Finally, **research infrastructures** underpin and strengthen research and allow testing of and acceleration of the deployment of new clean technology. Research Infrastructures are essential for basic science that can, for instance, develop new clean energy sources (nuclear fusion is a prominent example). But analytical services provided by research infrastructures can also transform industrial processes and products, and their potential in this sense needs to be fostered to support the green transition. Research and technology infrastructures also allow testing and accelerating the deployment of these new technologies and are a crucial part of the innovation pipeline. For these reasons it is **essential to secure access to world class research infrastructures for European researchers, innovators, and industry** so that Europe can deliver on the green deal while not compromising on the union's stance on open strategic autonomy.

3.2.2. Protect and restore our ecosystems.

Protecting and restoring nature is essential to maintain and increase the resilience of ecosystems, also contributing to climate change mitigation, among other important ecosystem services, and to combat drivers of biodiversity decline. In the long term, these actions will build Europe's resilience and open strategic autonomy, preventing natural disasters, reducing risks to food security and providing economic benefits for many sectors of the economy. In summer 2022, the Commission adopted the proposal for an ambitious Nature Restoration Law, which is a key deliverable of the EU biodiversity strategy for 2030 ([134]). The proposal includes binding targets to restore degraded ecosystems: by 2030, restoration

([133]) Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law') (OJ L 243, 9.7.2021, p. 1), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1119&from=EN.
([134]) European Commission (2022), Proposal for a regulation of the European Parliament and of the Council on nature restoration, COM(2022) 304 final.

measures will cover 20 % of the EU's land and sea, and by 2050 measures will be in place for all ecosystems in need of restoration, while building a truly coherent trans-European nature network. Other important initiatives were adopted in this area, including the **EU forest strategy for 2030** ([135]), announcing a proposal on forest observation, reporting and data collection, and strategic forest planning in Member States (planned for the first half of 2023); and the **EU soil strategy for 2030** ([136]), announcing the adoption of a proposal for a Soil Health Law (expected to come into force in 2023). The Commission communication on **a new deal for pollinators** was presented on 24 January 2023 ([137]). The EU also made important commitments at global level at the UN's 15th meeting of the Conference of the Parties to the Convention on Biological Diversity, which adopted the Kunming–Montreal **global biodiversity framework** on 19 December 2022. This framework sets out goals and targets for 2030 that concern the whole EU society and economy.

R & I will be key to providing knowledge and methods for the **protection and restoration of all ecosystems**, habitats and species targeted by the proposal for an EU Nature Restoration Law, including knowledge about biodiversity status and trends. **Drivers of biodiversity loss** are far from being fully understood, as are their impacts. More knowledge and innovative approaches to tackle them are needed. Developing scenarios towards **transformative positive change for biodiversity** requires improved modelling and more citizen engagement. Better assessments of the **economic benefits that nature protection and restoration bring**, and evaluation of the cost of inaction, are needed. **Nature-based solutions** should be scaled up, including through new business models. R & I to address the complex, multifaceted challenges of the green transition could include the more active involvement of citizens and communities, in synergy with the New European Bauhaus. More research is needed on the links between biodiversity and health. Shifting to an ecosystem-based approach in supporting research would be a great help to nature-based solutions, which are themselves crucial to rooting conservation and transition efforts in the local economy, supporting local employment and the development of ecological knowledge and skills.

A holistic multisectoral and multidimensional approach is needed to identify options where actors and sectors can work in synergy and to identify win–win solutions and possible trade-offs considering the multiple challenges at stake (water, food, health, finance, biodiversity, climate change adaptation and mitigation, energy need), paying particular attention to interlinkages between biodiversity and climate, including synergies and opportunities between activities related to ecosystem restoration and those addressing climate change adaptation and/or mitigation. There is also a need for more evidence on the links between adoption of low-carbon technology and the environmental impacts that could increase the vulnerability of society and ecosystems to climate change.

The **ocean** is being negatively affected by the **triple planetary crisis** – climate change, biodiversity loss and pollution. Responding to this **intertwined** crisis necessitates a **shared, systemic and multidisciplinary scientific understanding of the problem, and the design of appropriate, fit-for-purpose solutions and innovations**. Enhancing ecosystems and biodiversity in the ocean and the marine environment is paramount for the **integrity and resilience** of the Earth's system and continued delivery of the vital **ecosystem services** on which humanity depends. That is why the following research avenues are all important for Horizon Europe: restoring degraded ecosystems, reversing the loss of biodiversity and the associated ecosystem functions, reducing disaster risks and enhancing climate change mitigation and adaptation, preventing the **ocean and cryosphere (polar regions)** – **vulnerable elements of the Earth's systems** – from reaching a point of no return (tipping elements, cumulative and cascading elements, slow onset events, emerging threats) through observation, monitoring, risk-based assessment and forecasting capacities, integrated prediction systems that combine the Earth's system, ecosystem and social system models, and the **sustainable and circular management of natural resources at sea**, which includes developing nature-based solutions. Other important research avenues are innovation regarding **blue bioeconomy and biotechnology** sector value chains, which hold high promise for producing regenerative effects on marine ecosystems; innovation through the bioprospecting of the vast marine biodiversity for natural products with applications in fields such as pharmaceuticals, green chemicals, cosmetics and materials; applications of bioremediation such as antifouling management and control, degradation of aromatic pollutants, degradation of oil and removal of metals from sediments; a path to recovery for biodiversity in all sectors through better understanding, monitoring and tackling of its direct and indirect drivers, and through improvements to European and global policies and conventions; and enhancement of healthy ecosystems and biodiversity, including those that are indispensable to **sustainable aquaculture and fisheries**. Fish and seafood production will rely on sustainable fisheries and aquaculture, facilitated by digital and data technologies – including the development of a **digital twin of the ocean** in collaboration with the Destination Earth initiative of the European strategy

([135]) European Commission (2021), New EU forest strategy for 2030, COM(2021) 572 final.
([136]) European Commission (2021), EU soil strategy for 2030 – Reaping the benefits of healthy soils for people, food, nature and climate, COM(2021) 699 final.
([137]) European Commission (2023), A new deal for pollinators, COM(2023) 35 final.

for data. Excellent European research will support, among other things, the UN Decade of Ocean Science for Sustainable Development, the UN Decade on Ecosystem Restoration, the Kunming–Montreal global biodiversity framework, the Ocean and Climate Change Dialogue under the UN Framework Convention on Climate Change, the international ocean governance agenda, and the joint IPCC and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) global assessments.

Pollution is affecting the water system from source to sea, notably through plastics and microplastics, nutrients, chemicals and underwater noise. Litter is particularly pervasive worldwide. Plastic pollution has increased tenfold since 1980, and each year between 4.8 million and 12.7 million tonnes of plastic end up in the ocean, with microplastics becoming an increasing risk. The main drivers of point source pollution are insufficient waste and urban wastewater treatment, and stormwater overflow. Agriculture, on the other hand, is the major driver of diffuse pollution, with the highest inputs of nutrients and organic matter into aquatic environments. Overall, only 38 % of Europe's surface water bodies achieved good chemical status. Marine biodiversity is also affected by pollution from ships. Underwater noise, mainly from shipping traffic and impulsive noise sources, adversely affects the health of marine species and biological productivity. Wetland, peatland, mangroves and seagrass are vital for humanity and the climate. According to the International Union for Conservation of Nature, peatland covers as little as 3 % of our planet but stores around 30 % of all land-based carbon. Peatland also offers a food source for coastal communities, and helps protect them from floods and storms. Today, wetland is facing unprecedented challenges. Around 35 % of wetland has disappeared since the 1970s, at a pace three times faster than forests. Drainage for agricultural and urban development uses, overfishing, invasive species and pollution (both chemical and physical) are currently the biggest threats.

The EU, with its five sea basins, has massive potential for offshore wind and ocean energy. Renewable energy from the seas can be harnessed through a great variety of technologies, making it a cornerstone of the clean energy transition. To reach the European Green Deal energy and climate goals, and at the same time reduce our need for energy imports, the EU is speeding up the green transition and investing massively in renewable energy ([138]). The offshore renewable energy strategy set an ambitious target of installing 300 GW of offshore wind and 40 GW of ocean energy capacity in EU seas by 2050. However, knowledge about potential impacts of offshore energy on the marine environment needs to be improved, in particular around the effects of large-scale installations and multiple stressors, and the compatibility with several other ecosystem protection and restoration measures that are being put in place. The long-term perspective of offshore infrastructure development will need to include considerations around the circularity of the materials used, security and the reliability of the supply chains.

3.2.3. Deliver a circular economy and a zero pollution ambition for a toxic-free environment

A functioning circular economy is one of the key objectives of the European Green Deal. To foster this, the Commission recently proposed the circular economy package ([139]), which includes a framework for bio-based, biodegradable and compostable plastics to continue accelerating the plastic sector's transition towards a circular economy; a revision of the packaging and packaging waste directive aiming to reduce waste, and make packaging more recyclable and reusable; and a proposal on carbon-removal certification ([140]). The Commission also adopted several proposals to foster a circular economy in the EU, including the sustainable product policy initiative, proposing new rules to make almost all physical goods on the EU market more environmentally friendly, circular and energy efficient throughout their whole life cycle, from the design phase through to daily use, repurposing and end of life ([141]). This initiative includes a proposal for a new ecodesign for sustainable products regulation, providing for digital product passports. To support companies in their innovation processes the Commission issued a Recommendation establishing a European assessment framework for 'safe and sustainable by design' chemicals and materials ([142]). The Commission also adopted the first EU strategy for sustainable and circular textiles ([143]), addressing the entire life cycle of textile products to create a greener, more competitive sector that is more resistant to global

([138]) European Commission (n.d.), *EU Funding for Offshore Renewables*, https://energy.ec.europa.eu/topics/renewable-energy/financing/eu-funding-offshore-renewables_en.
([139]) European Commission, Timmermans, F. and Sinkevičius, V. (2022), Opening remarks by Executive Vice-President Timmermans and Commissioner Sinkevičius at the press conference on the circular economy package, SPEECH/22/7323.
([140]) European Commission (2022), *European Green Deal: Putting an end to wasteful packaging, boosting reuse and recycling*.
([141]) European Commission (2022), Proposal for a regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC, COM(2022) 142 final.
([142]) Commission Recommendation (EU) 2022/2510 of 8 December 2022 establishing a European assessment framework for 'safe and sustainable by design' chemicals and materials (OJ L 325 20.12.2022, p. 179, CELEX: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022H2510)
([143]) European Commission (2022), EU strategy for sustainable and circular textiles, COM(2022) 141 final.

shocks; the empowering consumers initiative ([144]); and a proposal for the revision of the construction products regulation ([145]), intending to create a harmonised framework to assess and communicate the environmental and climate performance of construction products.

Creating a toxic-free environment means reducing air, water and soil pollution to levels no longer considered harmful to health and natural ecosystems, and respecting the planet's boundaries. The first zero pollution package ([146]) adopted by the European Commission in April 2022 as part of the zero pollution action plan ([147]) included proposals to revise the industrial emissions directive ([148]) and the related regulation on the industrial emissions portal ([149]), reflecting the need to modernise the legal framework to accompany and provoke the necessary, deep industrial transformation by 2050. The second zero pollution package ([150]) from October 2022 included the Commission proposals to update the urban waste water treatment directive ([151]); revise the list of priority substances in surface and groundwater regulated under the environmental quality standards, groundwater and water framework directive ([152]); and revise the ambient air quality directives ([153]), aligning the EU air quality standards more closely with the latest 2021 recommendations from the World Health Organization. The Zero Pollution Monitoring & Outlook Framework ([154]), published in December 2022, showed that more efforts are required to achieve the 2030 targets defined in the zero pollution action plan. The framework also pointed out to significant knowledge and data gaps in some areas and highlighted the role of R & I to address these gaps. This calls for R & I to ensure the proper design and implementation of policies envisaged.

R & I is also critical to achieving a circular economy by fostering new safe ways of designing, producing, repurposing, reusing, repairing and recycling, and R & I will improve our resilience and strategic dependency by decoupling economic growth from resource use. The new 2020 European circular economy action plan calls for harnessing the potentials of R & I and digitalisation to drive this transition ([155]). The transition from a linear to a circular economy needs to be fair and just for all. Innovations and improvements in regenerative materials lead to better performance outcomes, and environmental and social outcomes ([156]). **European industries have not yet exploited the full potential of digital technologies for resource efficiency and productivity gains.** Cross-sectoral cooperation, supported by appropriate digital and data infrastructures, is also needed to enable actors across sectors to optimise research results, reach economies of scale, accelerate the uptake and widen the deployment of these

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([144]) European Commission (2022), Proposal for a directive of the European Parliament and of the Council amending Directives 2005/29/EC and 2011/83/EU as regards empowering consumers for the green transition through better protection against unfair practices and better information, COM(2022) 143 final.

([145]) European Commission (2022), Proposal for a regulation laying down harmonised conditions for the marketing of construction products, amending Regulation (EU) 2019/1020 and repealing Regulation (EU) 305/2011, COM(2022) 144 final.

([146]) European Commission (2022), *Press release: Green Deal: Modernising EU industrial emissions rules to steer large industry in long-term green transition*, https://ec.europa.eu/commission/presscorner/detail/en/IP_22_2238

([147]) European Commission (2021), *Pathway to a healthy planet for all – EU action plan: 'Towards zero pollution for air, water and soil*, COM(2021) 400 final.

([148]) European Commission (2022), *Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) and Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste*, COM/2022/156 final/3.

([149]) European Commission (2022), *Proposal for a Regulation of the European Parliament and of the Council on reporting of environmental data from industrial installations and establishing an Industrial Emissions Portal*, COM/2022/157 final.

([150]) European Commission, Timmermans, F. and Sinkevičius, V. (2022), Executive Vice-President Timmermans' and Commissioner Sinkevičius' remarks on the new legislative proposals: the zero pollution package, SPEECH/22/6412, https://ec.europa.eu/commission/presscorner/detail/en/speech_22_6412.

([151]) European Commission (2022), *Proposal for a Directive of the European Parliament and of the Council concerning urban wastewater treatment (recast),* COM(2022) 541 final.

([152]) European Commission (2022), *Proposal for a Directive of the European Parliament and of the Council amending Directive 2000/60/EC establishing a framework for Community action in the field of water policy, Directive 2006/118/EC on the protection of groundwater against pollution and deterioration and Directive 2008/105/EC on environmental quality standards in the field of water policy,* COM(2022) 540 final.

([153]) European Commission (2022*), Proposal for a Directive of the European Parliament and of the Council on ambient air quality and cleaner air for Europe (recast*), COM/2022/542 final.

([154]) European Commission (2022), *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, First 'zero pollution' monitoring and outlook 'Pathways towards cleaner air, water and soil for Europe',* COM/2022/674 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A674%3AFIN&qid=1670510444610

([155]) European Commission (2020), *A new circular economy action plan – For a cleaner and more competitive Europe*, COM(2020) 98 final.

([156]) European Commission, Directorate-General for Environment, White, O., Garnett, K., Zamparutti, T., Rolands, S. and Spela, K. (2022), *The EU Environmental Foresight System (FORENV) – Final report of 2020–21 annual cycle emerging issues impacting the delivery of a zero-pollution ambition by 2050: Emerging issues impacting the delivery of a zero-pollution ambition by 2050*, Publications Office of the European Union, Luxembourg.

technological pathways. Living labs could prove to be useful instruments in this regard. Circularity in the agrifood sector, especially in nutrient management, is also particularly important, and significant R & I is needed, notably in the light of the current food security crisis and skyrocketing fertiliser prices ([157]) Circularity from primary production, the starting point of numerous sustainable bio-based value chains, should be promoted at all levels. There is a need for R & I to shorten value chains.

Promoting grassroots initiatives and strategic partnerships with actors at local level (municipalities, clusters, social economy entities such as cooperatives, work integration enterprises, mainstream businesses) is critical to achieving these goals. For example, research and pilots could improve linkages between industries and the broad social circular economy networks that are known for collecting consumer waste and goods (e.g. electronics, plastics, textiles, biowaste). Finally, research is needed on the emergence of local circular value chains operated and managed by industry, for example research based on the model of social and ecological innovation clusters (quadruple helix).

3.2.4. Design a fair, healthy and environmentally friendly agrifood system with vibrant rural areas and protected forests

European food already sets a global standard for food that is safe, plentiful, nutritious and of high quality, but it should also set the global standard for sustainability ([158])**.** EU agriculture is the only major agriculture system in the world that has reduced its GHG emissions (by 20 % since 1994). However, this path has been neither linear nor homogenous across Member States. In addition, the processing, packaging, transportation, retailing, consumption and waste disposal of food are major contributors to air, soil and water pollution, and GHG emissions, and have a profound impact on biodiversity ([159]). Despite the recognition of their multifunctionality, and the progress made in defining and implementing their sustainable management, the condition of European forests is increasingly threatened by a growing number of social, economic and, above all, environmental and climatic pressures.

The development of sustainable agriculture and food systems is one of the main priority areas of action for the EU, in line with the farm-to-fork strategy ([142]), the biodiversity strategy ([160]) and the objectives of the common agricultural policy ([161]). The EU Forest strategy ([162]) paves the way for an improved landscape of forests in the EU. **Addressing R & I gaps is crucial to tackle the environmental, social and economic challenges faced by the agricultural, forestry and rural areas**, both in the EU and globally. R & I is also a key enabler of the green and inclusive transitions needed to deliver on the SDGs and the European Green Deal.

Farmers and foresters are the stewards of more than 80 % of the EU's territory. They are at the heart of the green transition, notably through commitments under the farm-to-fork strategy, EU forest strategy and the EU's climate ambitions. **Engaging these actors in the R & I cycle is fundamental in order to ensure both the design of impactful R & I activities and the uptake of their results.** Continued efforts in R & I, including tools for the deployment of solutions through the synergies between projects funded by Horizon Europe and the common agricultural policy network, are needed to equip the farming and forest-based sectors with the necessary solutions to adapt to rapidly changing environmental conditions, and use sustainable methods of production and land management.

In addition to ensuring the supply of nutritious and safe food and other products, and safeguarding animal health and welfare and plant health, **farmers and foresters have a major role in supporting the provision of ecosystem services**. Agriculture and forestry can significantly contribute to a climate-neutral, sustainable and circular bioeconomy. For example, carbon farming is emerging as a major area of activity in primary production for which R & I is needed to deliver on its potential. Such win–win solutions can also be an important source of income diversification for primary producers, and **boost local and rural economies** through investments in skills, knowledge and innovation. As recently acknowledged by the Food and

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([157]) European Commission, Directorate-General for Research and Innovation (2022), *ERA industrial technology roadmap for low-carbon technologies in energy-intensive industries*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/c9f70ebf-b48e-11ec-9d96-01aa75ed71a1/.

([158]) European Commission (2021), *EU Agricultural Outlook – For markets, income and environment 2021–2031*, Publications Office of the European Union, Luxembourg.

([159]) European Commission (2020), A farm to fork strategy – For a fair, healthy and environmentally-friendly food system, COM(2020) 381 final.

([160]) European Commission (n.d.), *Biodiversity Strategy for 2030*, .

([161]) European Commission (n.d.), *The Common Agricultural Policy at a Glance*, https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-glance_en.

([162]) European Commission (2021), *New EU forest strategy for 2030*, COM(2021) 572 final.

Agriculture Organization of the UN in its report on the future of food and agriculture ([163]), R & I is part of the solution, provided the innovation is also accessible to more vulnerable groups.

Policies and actions are required to stimulate dietary changes by **creating a more favourable food environment** in which a sustainable choice is the easy one. However, such policies cannot be successful unless consumers ultimately choose to buy healthy and sustainable products. The Group of Chief Scientific Advisors is currently developing a scientific opinion that will recommend what tools could be used to overcome the barriers preventing consumers from adopting sustainable and healthy diets, fostering the necessary change towards sustainability in the food environment.

The global food system is facing a growing list of challenges, from climate change, resource scarcity, biodiversity loss and soil degradation, to a growing and ageing population, urbanisation, increased food waste and food poverty. Exacerbating climate change impacts, Russia's war against Ukraine and the COVID-19 pandemic are unveiling the vulnerability of food systems and how pivotal functioning food supply chains are. R & I is a key driver in accelerating the transition to sustainable, healthy and inclusive food systems from primary production to consumption. The EU Green Deal and in particular the farm-to-fork strategy guide Horizon Europe to target key areas of research, including sustainable food consumption, and food loss and waste prevention, and also research on alternative proteins and the microbiome, among other things. Since 2016, the food 2030 policy ([164]) has convened around and fostered a systems approach to R & I policy that connects the land to the sea, and producers to consumers, from 'farm to fork to gut and back'. Along the food 2030 pathways, further R & I investments are required to foster the implementation of systemic approaches to deliver co-benefits and foster the deployment of solutions. Further R & I can indeed have a deep and manifold impact on accelerating the food system transformation to make the systems fair, healthy and environmentally friendly.

R & I is still needed in the agrifood, forestry and rural development sectors in order to meet the expectations of the EU Green Deal. While those specific needs would require a sectoral perspective, the definition of R & I priorities should be framed under their contribution to tackling EU and global environmental, social and economic sustainability challenges. In addition, the R & I needed should also address the wider systemic changes and cross-sectoral transformations that need to happen to achieve the Green Deal and just transition objectives.

3.2.5. Bioeconomy governance and sustainable bio-based innovation systems

Innovation in the bioeconomy lays the foundations for the transition away from a fossil-based economy. Sustainable bio-based innovation is an important segment and enabler of the overall bioeconomy and encompasses the sustainable sourcing, industrial processing and conversion of biomass from the land and the sea into bio-based materials and products, taking into account sustainability in all its dimensions: ecological, social, economic and cultural. This innovation also capitalises on the potential of living resources, life sciences, digitalisation and biotechnologies for new discoveries, products, services and processes. Bio-based innovation, including **industrial (bio)processes and technologies**, with an important role for the competitiveness of European SMEs, can bring new economic activities and employment to regions and cities, contribute to revitalising rural and coastal economies and communities, and strengthen the circularity of the bioeconomy. A fair economic return in the supply chain remains a challenge. To generate additional and diversified income, **primary producers need to be fully and effectively integrated into the new value chains**.

There is an uneven distribution of activity associated with the development of sustainable, circular bioeconomies across the EU Member States, affecting the potential to deliver on both the European Green Deal and national objectives. There is a need to ensure the **strategic development of the bioeconomy and of sustainable circular bio-based industry** in those parts of Europe where suitable conditions exist for bioeconomic activities.

Gaps remain on how to promote more **sustainable consumption patterns** to guarantee environmental integrity, namely in the field of textiles. Increased focus is required on how to better **manage land and**

([163]) Food and Agriculture Organization of the UN (2022), *The Future of Food and Agriculture – Drivers and triggers for transformation*, Food and Agriculture Organization of the UN, Rome, .

([164]) European Commission (n.d.), *Food 2030*, https://research-and-innovation.ec.europa.eu/research-area/environment/bioeconomy/food-systems/food-2030_en.

sustainable biomass demands, taking into account the waste hierarchy, to meet environment and economic requirements in a climate-neutral Europe.

Research and innovation should contribute to improving the circularity aspect of bio-based systems, with a particular focus on biowaste, waste management and valorisation, taking into account the whole life cycle of bio-based products and technologies. Moreover, the cross-cutting aspect of zero pollution in the bio-based sector should be further implemented. The reduction of **GHG emissions** should be considered, but so should the reduction of other important **pollutants** emitted during the production processes. There is a need to ensure the prevention, mitigation and control of these substances, and take a safe and sustainable design approach to the bio-based value chains.

Finally, youth participation and leadership, and societal acceptance of sustainable bio-based solutions need to be addressed in the context of the transition, as outlined in the European Green Deal. Major gaps persist in trust building within bioeconomy/bio-based sectors underpinned by the social sciences and humanities at social level, and mutual learning and social sustainability for inclusive participation of all stakeholders.

3.2.6. Climate-neutral, energy-intensive industries

Industrial activity is the second largest global source of the energy sector's CO_2 emissions, accounting for around 16 Gt of CO_2 or about 45 % of total energy system emissions today ([165])**.** Three key industries account for 70 % of those emissions: chemicals, steel and cement production. The materials produced by these industries form some of the fundamental inputs to buildings, infrastructures, vehicles, consumer goods and many other uses in thriving economies and our daily lives. Drastically reducing emissions from these energy-intensive industries is an important response to the climate challenge. However, these emissions are considered particularly hard to abate ([166]). There is a lack of market-ready, near-zero-emission technologies that can replace current industrial processes that are highly reliant on fossil fuels. Another important element of **the transition for the energy-intensive industry sector is timing**. Given the long lifetimes and expense of the key pieces of emission-intensive equipment used in this sector, the year 2050 is just one investment cycle away. In Europe, many industrial plants are relatively old and will face a major investment decision in the coming decade. This leaves a window of opportunity to address existing assets and address the issue of potential stranded assets. From 2030 onwards, all investment in both new and existing industrial capacity should be in plants that generate either zero or near-zero emissions. **Therefore, it will be very important to ensure that, by 2030, innovative near-zero-emission industrial technologies are at the large prototype and demonstration scale, ready to be deployed as soon as possible.** Progressing towards net zero industrial GHG emissions will only be enabled by the adoption of new energy-efficient production processes using low- and zero-GHG electricity, hydrogen, fuels and carbon management, supported by a regulatory and market environment that rewards such investments. To this end, the fostering of synergies between the EU's R & I framework programme and EU funding programmes that focus on the deployment of clean technologies (e.g. the Innovation Fund, InvestEU) is crucial.

As expressed in the processes for planet partnership roadmap for 2050 ([167]), **energy-intensive industries need to embrace the circular economy and restorative feedback loops, not as an afterthought but as a key pillar of the design of entire value chains**. To achieve this goal, energy-intensive industries have to engage in hubs for circularity ([168]) and adopt new cross-sectoral, collaborative, circular business models that exploit synergies and are anchored in the local ecosystem to optimise incoming resources, including investments. **The hubs will be key instruments to advance the R & I agenda of European industries far beyond what could be achieved if focusing on a single value chain.** Energy savings could reach 55 % of the primary consumption of energy-intensive industries, energy recovery could reach 80 %, freshwater savings could reach 40 % and material reuse could go up to 100 %. Hubs for circularity are first-of-their-kind, lighthouse demonstrator plants of (nearly) commercial size, implementing industrial and/or urban industrial symbiosis. Starting in existing industry clusters or heavily industrialised urban areas, the aim is to accelerate

([165]) International Energy Agency (2022), *Achieving Net Zero Heavy Industry Sectors in G7 Members*, International Energy Agency, Paris.
([166]) IPCC (2022), *Climate Change 2022 – Mitigation of climate change: Contribution of working group III to the sixth assessment report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom.
([167]) Aspire/Processes4Planet (2021), *Strategic Research and Innovation*. About Processes4Planet | A.SPIRE (aspire2050.eu)
([168]) European Commission, Directorate-General for Research and Innovation (2021), *A New Flagship Initiative – hubs for circularity' concept, opportunities & challenges for successful implementation*, https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/new-flagship-initiative-hubs-circularity-concept-opportunities-challenges-successful-implementation-2021-04-14_en#:~:text=The%20Hubs%20for%20Circularity%20%28H4C%29%20will%20be%20a,size%20implementing%20industrial%20symbiosis%20and%2For%20urban%20industrial%20symbiosis.

the twin transition of industry, collectively achieving and demonstrating at scale a leap towards circularity and carbon neutrality in the use of resources (feedstock, energy and water) in a profitable way involving all stakeholders (industry, SMEs, local authorities, educational institutions and civil society).

Finally, the Green Deal industrial plan aims to complement the circular economy action plan in order to fulfil the need to massively increase the technological development, manufacturing production and installation of net zero products, and increase the energy supply in the next decade.

3.2.7. Sustainable mobility

Mobility and transport account for approximately one third of Europe's total energy consumption and almost a quarter of Europe's GHG emissions. They are also the main causes of air pollution in cities. At the same time, transport is considered an essential service, as outlined in Principle 20 of the European Pillar of Social Rights ([169]). It enables individuals to satisfy basic needs, such as access to employment, education, health and care services. Recognising this, the European Green Deal makes a clear commitment that 'transport should become drastically less polluting', while the EU's sustainable and smart mobility strategy ([170]) sets a – 55 % emission reduction target for transport by 2030 and a – 90 % target by 2050. Furthermore, REPowerEU explicitly requires Europe's energy-intensive sectors, including transport, to reduce their dependency on fossil fuels. Simultaneously, the Social Climate Fund regulation proposal ([171]) and the Council recommendation on ensuring a fair transition towards climate neutrality ([172]) acknowledge the need for more data on the issue of transport poverty, while promoting sustainable alternatives, especially public transport networks.

In this context, further R & I in mobility and transport is key to delivering on the EU's ambitious policy objectives. This requires **urgent development and deployment of new technologies and solutions, decarbonised fuels and technologies, zero-emission vehicles/vessels, planes and drones, green infrastructures, logistics, traffic management and innovative services, with the aim of (i) decarbonising the energy input, (ii) enhancing the energy efficiency of transport and mobility, and (iii) fully integrating transport and mobility with decarbonised energy systems**. To this end, major transformations are needed in all modes of transport (road, rail, air, water), in urban and rural mobility. These transformations call for the development of an integrated, decarbonised and seamless multimodal network at system level, including long-haul transport options. Spatial planning (e.g. the 15 minute city) in urban and rural areas and business model innovation (for transport and other service sectors) have unexploited potentials to reduce the individual demand for transport. Such innovative solutions are also required in an ageing society. This also requires **extensive collaboration and a coordinated approach across multiple stakeholders in transport R & I; therefore, partnerships / joint undertakings are key to reinforcing the EU's strategic approach to maximise impact**.

3.2.8. Modernise our buildings

Construction is the **second-largest industrial ecosystem** in the EU in economic terms, employing close to 25 million people ([173]). It is dominated by microenterprises, and suffers from low productivity, low levels of digitalisation and low innovation uptake. **Construction also has a huge environmental impact**: it is responsible for half of Europe's extracted resources, and it represents the biggest source of Europe's waste generated per year, with 37.1 % of the total ([174]). The recovery rate for construction and demolition waste has improved very little over recent years, and much of the recovery consists of backfilling ([175]), rather than the actual substitution of primary material through reuse and recycling. In addition to the impact of the

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([169]) European Commission (n.d.), *European Pillar of Social Rights*, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/economy-works-people/jobs-growth-and-investment/european-pillar-social-rights_en.

([170]) European Commission (2020), Sustainable and smart mobility strategy – putting European transport on track for the future, COM(2020) 789 final.

([171]) European Commission (2021). Proposal for a regulation establishing a Social Climate Fund. COM/2021/568 final

([172]) COUNCIL RECOMMENDATION on ensuring a fair transition towards climate neutrality.2021/0421 (NLE). 7 June 2022. 9107/22

([173]) European Commission (2021), Annual single market report 2021, SWD(2021) 351 final, https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021SC0351.

([174]) Eurostat, Statistics Explained (n.d.), *Waste Statistics – Waste generation, 2020*, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics#Total_waste_generation. The proportion has increased from 2018, when it stood at 35.9 %.

([175]) Eurostat (n.d.), *Recovery Rate of Construction and Demolition Waste*, https ://ec.europa.eu/eurostat/databrowser/view/CEI_WM040/default/table?lang=en.

construction industry, the end result of its activities – the built environment – requires improvement to meet climate and energy goals. The built environment contains many hazardous substances, such as asbestos.

Most of the EU's existing buildings have poor energy performance, as they rely on fossil fuels for heating and cooling, and they use old technologies and wasteful appliances. Buildings are responsible for about 40 % of the EU's total energy consumption, and for 36 % of its GHG emissions from energy ([176]). In addition, GHGs are emitted during material extraction, manufacturing of construction products, on-site activities and end-of-life processes ([177]). As cities own a significant share of public building stock as well as energy, mobility, water and waste management and other infrastructures, they are major actors in the implementation of the European renovation wave. They can aid implementation by promoting neighbourhood-level approaches, introducing shorter and sustainable supply chains, and retrofitting public buildings and social housing, while setting up circularity and reuse of construction materials.

Research and innovation should support both the upgrade of the built environment and the modernisation of the construction ecosystem that delivers it. There is an opportunity for construction to operate in a more resource efficient way and make greater use of secondary materials, while avoiding the use of hazardous materials. Material use for buildings could potentially decrease by 30 % if used more efficiently ([178]). This means **supporting digital** technologies for a more productive, safer, cleaner and less wasteful construction ecosystem. Technologies are also needed for **energy and sustainability improvements across the whole life cycle** of the building work. R & I should facilitate a new way to build that is faster, cleaner, safer and less wasteful, and results in a higher-quality built environment. This implies new and circular business models, taking into consideration the specific conditions of every geographic region of Europe, and characteristics of buildings, such as cultural heritage or protected building status. In addition, in the Horizon Europe new European Bauhaus nexus report ([179]), experts recommended the substantial increase of wood-based construction to reduce emissions from the construction sector (by replacing concrete) and contribute to stable carbon sinks (the wood used in the construction). The recommendation applies differently to new construction and to renovation.

3.2.9. Environment, climate change, sustainability and health

R & I is key to understanding, preventing and reducing the health impacts resulting from environmental degradation. The triple planetary crisis (climate change, pollution and biodiversity loss) introduces unprecedented pressures and has significant consequences. Recent assessments have attributed 16 % of total global mortality to pollution-related disease, and estimate that around 350 000 premature deaths in the EU can be attributed to air pollution ([180]). Climate change is a global challenge that will exacerbate social inequalities, reduce food and water security, and increase the incidence of non-communicable diseases. The changing environmental conditions potentially create habitats for vectors of known disease such as dengue fever or malaria in Europe, but can also 'awake[n] dormant pathogens' ([181]) and lead to the transmission of pathogens. The impacts of biodiversity loss on health are largely unexplored. R & I can deliver evidence and tools to combat the serious impacts that these rapidly unfolding threats have on human health. In addition, the unequal health impacts that diverse forms of pollution, climate hazards and extreme weather stresses have on socioeconomically vulnerable groups need to be further addressed, also

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([176]) European Commission (2020), A renovation wave for Europe – Greening our buildings, creating jobs, improving lives, COM(2020) 662 final.

([177]) Eurostat has estimated the carbon footprint of construction and construction works across the EU-27 in 2019 to be 9.4 % of the total domestic final use. See Eurostat, Statistics Explained (n.d.), *Greenhouse Gas Emission Statistics – Carbon footprints*, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Greenhouse_gas_emission_statistics_-_carbon_footprints.

([178]) Material Economics (2018), *The Circular Economy – A powerful force for climate mitigation*, Material Economics, Stockholm, https://materialeconomics.com/material-economics-the-circular-economy.pdf?cms_fileid=340952bea9e68d9013461c92fbc23cae.

([179]) European Commission, Directorate-General for Research and Innovation, Schellnhuber, H. J., Widera, B., Kutnar, A., Organschi, A., Hafner, A., Hillebrandt, A., Murphy, O. and Nakicenovic, N. (2022) *Horizon Europe – New European Bauhaus nexus report: Conclusions of the High-level Workshop on 'Research and Innovation for the New European Bauhaus', jointly organised by DG Research and Innovation and the Joint Research Centre*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/9f9acd60-8aec-11ec-8c40-01aa75ed71a1/language-en#:~:text=The %20'Horizon %20Europe %2DNew %20European,the %20New %20European %20Bauhaus %20initiative.

([180]) Environmental Energy Agency (2020), *Report on Healthy Environment, Healthy Lives: How the environment influences health and well-being in Europe*, Publications Office of the European Union, Luxembourg.

([181]) Alempic, J.-M., Lartigue, A., Goncharov, A. E., Grosse, G., Strauss, J., Tikhonov, A. N., Federov, A. N., Poirot, O., Legendre, M., Santini, S., Abergel, C. and Claverie, J.-M. (2022), 'An update on eukaryontic viruses revived from ancient permafrost', *Viruses*, 15(2), 564.

taking into account that those affected the most by pollution and climate hazards are those contributing the least to GHG emissions.

In addition to the increased burden of illnesses and injuries related to environmental degradation, health and care systems will have to reckon with the increasing frequency and intensity of extreme weather events linked to climate change. These extreme weather events have particularly strong effects on older people, due to comorbidities and compromised physical health conditions. More R & I investment in person-centred health and care delivery, and in particular better-equipped primary care, could potentially have a positive effect on our climate ([182]). In parallel, the health and care sector has its own responsibility concerning environmental degradation. **The sector represents 4–5 % of global carbon emissions, making it the fifth-largest polluter in the world** ([183])**.** Health and care systems also contribute to significant amounts of waste, frequently related to a suboptimal use of resources. **The sector is already struggling with important challenges and the need for structural reforms, for example to increase financial sustainability and resilience. Environmental sustainability reforms should thus go hand in hand with these transformations.** Modernisation and the transition to greener practices will allow the sector to become resilient and comply with the European Green Deal's objectives.

The health and care sector must cut its emissions in care delivery, and in the production of medical and health-related products. The European Green Deal positions the EU at the forefront of the global environmental transformation and presents an opportunity for the future competitiveness of its health industry sector. Accordingly, and **to make sure the quality of care is not compromised, more R & I is needed**.

Finally, regarding carbon sinks in lands and forests, the EU co-legislators have agreed to increase the EU's target for net carbon removals by natural sinks to 310 million tonnes of CO_2 equivalent by 2030. This agreement sets ambitious and fair targets for each Member State to reverse the decreasing trend of the EU's carbon sink, including through forests. Member States will be responsible for caring for and expanding their carbon sinks to meet the new EU target. Member States have many measures at hand to improve their land management, including sustainable forest management or the rewetting of peatland, and should update their strategic plans under the common agricultural policy to reflect the higher ambition for the land sector. R & I has a key role in helping improve the effectiveness of enhanced sustainable forest management under changing climate conditions by, among other things, reinforcing the knowledge about climate change impacts, contributing to a greater diversity of forests and genetic resources, and providing evidence-based and operational guidance for climate change mitigation and adaptation in line with biodiversity objectives. A holistic approach to new and emerging pests and diseases is needed to reduce biotic disturbances and risks. Sound and site-adapted forest and soil restoration will be supported, including through the R & I mission on soil health and food. An improved understanding of primary and old-growth forests and of their biodiversity and climate functions will be sought.

3.2.10. Leave no one behind

R & I play an increasing role in ensuring that the green transition leaves no one behind and is a just transition for all, including disadvantaged groups. Workers in downscaling, polluting areas should be supported in their transition to related fields of work through reskilling and other support measures, and where international partners in low- and middle-income countries contribute to the R & I and benefit from the outcomes. In the Council recommendation on ensuring a fair transition towards climate neutrality ([184]), Member States committed to strengthening R & I actions at regional, national and EU levels, notably committing to enhancing the modelling and assessment of the macroeconomic, employment and social impacts of climate change and environmental policies. This should include distributional impact assessments along the lines set out in the Commission communication on better assessing the distributional impact of

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([182]) World Health Organization (2022), *The UN Decade of Healthy Ageing 2021–2030 in a climate-changing world*, Connection Series No 3, World Health Organization, Geneva, https://cdn.who.int/media/docs/default-source/decade-of-healthy-ageing/decade-connection-series-climatechange.pdf?sfvrsn=e926d220_3&download=true#:~:text=Climate%20change%20in%20an%20ageing%20world&text=The%20number%20of%20older%20people,are%20more%20likely%20(26).

([183]) Tennison, I., Roschnik, S., Ashby, B., Boyd, R., Hamilton, I., Oreszczyn, T., Owen, A., Romanello, M., Ruyssevelt, P., Sherman, J. D., Smith, A. Z. P., Steele, K., Watts, N. and Eckelman, M. J. (2021), 'Health care's response to climate change: a carbon footprint assessment of the NHS in England', *The Lancet*, 5(2), pp. E84–E92; Karliner, J., Slotterback, S., Boyd, R., Ashby, B., Steele, K. and Wang, J. (2020), Health care's climate footprint: the health sector contribution and opportunities for action, *European Journal of Public Health*, 30(Supplement 5), ckaa165.843.

([184]) Council recommendation of 16 June 2022 on ensuring a fair transition towards climate neutrality (OJ C 243, 27.6.2022, p. 35), https://op.europa.eu/en/publication-detail/-/publication/60233148-e66f-11ec-a534-01aa75ed71a1/language-en/format-PDF.

Member States' policies ([185]). The ecological transition will indeed reshape societies, including production, consumption patterns and employment structures, and geopolitics, including global economic, trade and security interests. The transition will create challenges for a number of Member States and societies, and the citizens and workers most vulnerable to the transition should be supported ([186]). R & I programmes should also enable the greening/reduction of the environmental footprint of social infrastructures operated by different stakeholders, including social economy entities.

Support should be delivered to businesses to decarbonise their production processes and adopt greener technologies in the context of the European Green Deal and the new industrial strategy ([187]). Enhancing upskilling and reskilling programmes is of pivotal importance to ensure that workers in the industries particularly vulnerable to the transition are equipped for the shifting task requirements in jobs or career transitions. Although lifelong training and education help shield workers from unemployment, **fewer than 40 % of adults participate in formal or non-formal education or training every year, and too many people only achieve low levels of key competences and basic skills, or do not reach upper-secondary-level education**. With the accelerated pace of the clean energy transition, the lack of a sufficient workforce with relevant skill sets, including but not limited to new competence skills in digitalisation, hybridisation and system optimisation, is becoming a key bottleneck. As accentuated by the Commission's initiative the European Year of Skills, streamlining the provision of relevant skills to the labour force across sectors is of key importance not only in the light of the twin transition, but also in the context of other demographic trends in the EU, such as migration integration and the ageing population. The European Pillar of Social Rights ([188]) points out that **R & I could support a just transition through development of innovative forms of work and flexible learning pathways** ([189]). Finally, women are underrepresented in manufacturing and science, technology, engineering and mathematics education. For example, in 2018, only 24 out of every 1 000 women with tertiary education degrees had studied an ICT-related subject ([190]).

Leaving no one behind and pursuing a just and inclusive transition also mean ensuring access to essential goods and services for all, in line with Principle 20 of the European Pillar of Social Rights ([191]). The green and digital transition can have an impact on social inclusion and households across the income distribution scale in different ways. For example, increasing the prices of energy and transport can aggravate existing barriers and create new forms of exclusion. At the same time, certain measures supporting the transition, such as investing in public transport and energy efficiency, have the potential to improve access to essential services for disadvantaged groups. The Council recommendation on ensuring a fair transition towards climate neutrality encourages Member States to ensure access to affordable essential services and housing for the people and households most affected by the green transition, particularly those in vulnerable situations, and to tackle energy and transport poverty. The Commission will also release the first EU report on access to essential services in Q1 2023, which will provide information on the state of play concerning access to the essential services listed in Principle 20 of the European Pillar of Social Rights, and on support measures available at both EU and Member State levels. The report will shed a light on existing knowledge gaps and on the main barriers that need to be addressed in order to ensure an inclusive green transition, informing future policy work in the area.

3.3. Research and innovation needs for addressing the digital and technological transformation

3.3.1. Digital technologies and productivity growth

R & I is a key engine through which to foster EU productivity growth, which in turn is important for boosting competitiveness and socioeconomic development, and tackling poverty and social exclusion. Yet despite the huge productivity enhancing potential of the ICT revolution, there is a secular

([185]) European Commission (2022), Better assessing the distributional impact of Member States' policies, COM(2022) 494 final, https://op.europa.eu/en/publication-detail/-/publication/831aab2e-408e-11ed-92ed-01aa75ed71a1/language-en/format-PDF/source-search.
([186]) European Commission (2019), The European Green Deal, COM(2019) 640 final.
([187]) European Commission (2021), Updating the 2020 new industrial strategy: Building a stronger single market for Europe's recovery, COM(2021) 350 final.
([188]) The European Pillar of Social Rights in 20 principles (europa.eu)
([189]) European Commission (n.d.), *European Pillar of Social Rights*, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/economy-works-people/jobs-growth-and-investment/european-pillar-social-rights_en.https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/economy-works-people/jobs-growth-and-investment/european-pillar-social-rights_en.
([190]) International Labour Organization, January 2021.
([191]) 'Everyone has the right to access essential services of good quality, including water, sanitation, energy, transport, financial services and digital communications. Support for access to such services shall be available for those in need.'

stagnation in productivity growth (Figure 43). This worrying phenomenon is likely explained by low technological diffusion, elevated human capital and organisational uptake costs for laggard firms, increasing productivity polarisation and declining business dynamism. Efforts directed at easing the access to productivity-enhancing technologies and ensuring the availability of the required skill base to facilitate the adoption of these technologies should be enacted throughout the EU to increase competitiveness while reducing inequality.

Research productivity also shows signs of decline ([192]), as the number of researchers required today to achieve the famous doubling of computer chip density is more than 18 times larger than the number required in the early 1970s. AI technology may provide a solution to the problem. AI may greatly increase the efficiency of the existing economy, but it may have an even larger impact by serving as a new general-purpose 'method of invention' ([193]). As an example, over 5 years, the multidisciplinary team of AlphaFold from DeepMind worked on an AI model that has now solved a problem that was at the core of biology for several decades. AlphaFold modelled the folding of all known proteins (200 million); previously, it had taken a PhD student several years to model a single protein. This means an increase in productivity by a factor above 1 million. That discovery has already led to an enormous amount of additional work and discoveries by the scientific community (more than 500 000 users, from 190 countries, and more than 3 000 citations). Generative AI-based tools such as ChatGPT and their rapid uptake by the general public raise further questions about the impact of such tools on the labour market, inequality and digital access, and about the skills required to make best use of them in personal and professional life.

R & I can play an increasing role in ensuring that the digital transition benefits everyone and that nobody is left behind. Supporting access to essential services, in particular digital communications, in line with Principle 20 of the European Pillar of Social Rights is key to addressing the digital divide and ensuring that the digital transition is just and inclusive. The Commission has proposed a declaration on European digital rights and principles to promote a sustainable, human-centric vision for a digital transformation shaped by European values ([194]). The Commission report on access to essential services highlights the barriers faced by people in vulnerable situations in terms of a lack of skills and broadband access, which need to be addressed in order to ensure an inclusive digital transition.

To safeguard innovation in the digital economy, it will also be a priority to mitigate the market power of data-rich incumbents and to safeguard the openness of the digital ecosystem for new entrants. The richness of data can lower the cost of innovation, as it is possible to develop better models and products when there are more information and less costly processes. At the same time, companies with many customers and the data collection infrastructure already in place will find it easier to develop new products or invade close markets than new entrants that lack the customer base to feed them with new data on a daily basis. The advantages data give to the incumbents are called data-driven network effects. Data-driven network effects are associated with high entry barriers for newcomers, resulting in a lack of innovative pressure for the incumbent firms ([195]). Besides, research infrastructures also underpin R&I in the digital technology space. The massive amounts of data generated by modern science and deep tech industry requires high performance computing systems for analysis. As they are costly, **leading high-performance computing systems could be shared technology infrastructures for R&I in the EU. Merely controlling the data (there is an ongoing policy to organise research data in the European Open Science Cloud) is not sufficient to safeguard European competitiveness and sovereignty. Europe must also be able to analyse the data. Europe must also safeguard its future position in AI and quantum computing, two strands of digital technology which will be formative in the digital and technological transformation.**

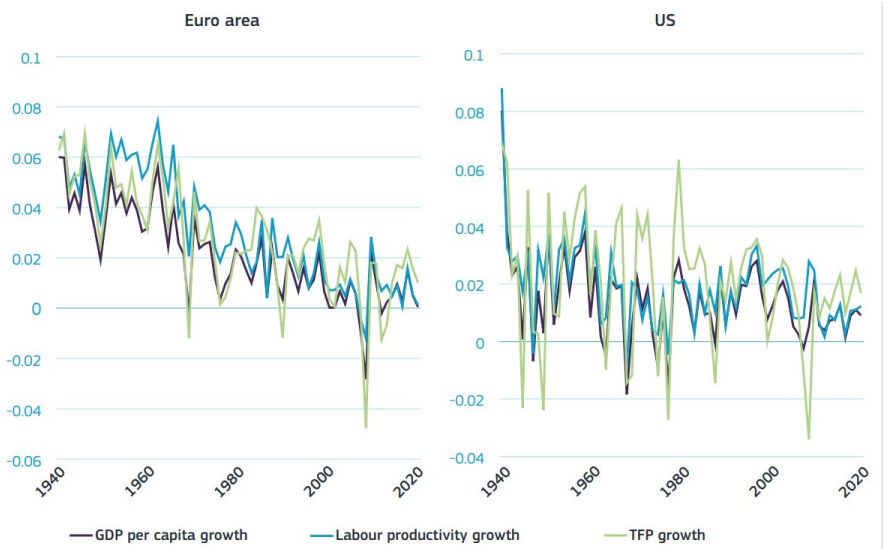
([192]) Bloom, N., Jones, C. I., Van Reenen, J. and Webb, M. (2020), 'Are ideas getting harder to find?' *American Economic Review*, 110(4), pp. 1104–1144.

([193]) Cockburn, I. M., Henderson, R. and Stern, S. (2019), 'The impact of artificial intelligence on innovation: An exploratory analysis', in National Bureau of Economic Research, *The economics of artificial intelligence: An agenda*, University of Chicago Press, Chicago, IL, 2019, pp. 115–146.

([194]) European Commission (n.d.) *Europe's Digital Decade: Digital targets for 2030 – Europe aims to empower businesses and people in a human-centred, sustainable and more prosperous digital future*, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_en.

([195]) Krämer, J. and Schnurr, D. (2022), 'Big data and digital markets contestability: Theory of harm and data access remedies', *Journal of Competition Law & Economics*, 18(2), pp. 255–322.

Figure 43. Productivity growth slowdown, 1940–2020



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

3.3.2. Technological sovereignty in the digital era

Technological sovereignty is at the heart of the EU's debate on open strategic autonomy. Those who control digital technologies are increasingly able to influence economic, societal and political outcomes. The EU's ability to defend and promote its interests, and its credibility as a strong foreign policy actor, will largely be a function of its technological command. In order to achieve the digital transformation and tackle the societal challenges according to its values and in respect of its socioeconomic model, Europe must master and shape digital technologies and their fast evolution. This requires significant investments in R & I in key digital technologies. In this context, 'digital sovereignty' refers to the EU's ability to act independently in the digital world, which will be conducive to fostering digital innovation ([196]). At the same time, reciprocal openness and a level playing field through strategic international R & I cooperation with like-minded countries may help to support the EU's technological competitiveness and open strategic autonomy.

The EU needs to strengthen its position in 'green' and 'digital' technologies to remain an economic power at global level. Six key enabling technologies were identified by the European Parliament in 2021 as essential to boosting EU growth and preserving EU leadership: advanced manufacturing and (nano)materials, life science technologies, microelectronics and nanoelectronics, photonics, AI, and security and connectivity technologies ([197]). Notably, these technologies are used in combination in specific domains (e.g. biosciences and computing), multiplying their respective impacts (e.g. the bio revolution).

The EU needs to control dependency on global value chains. Along with the actions started to reduce external dependencies in critical sectors, controlling this dependency is crucial to gain a better insight into the expected availability of materials and components, which is possible through a broader diffusion of reliable digital technologies across the value chains. The integration of technologies for simulation and forecasting, combined with the availability of reliable data and models and further development of very flexible manufacturing processes, will position EU industry as the leader in resiliency and efficiency, absorbing future value chain disruptions and improving the EU's competitiveness.

For the EU to ensure scientific excellence and remain a key scientific player on the global stage, there is a need to increase the effectiveness and performance of the EU's public research systems through stronger R & I investments and policy reforms. At the same time, it is crucial to continue reinforcing less developed national and regional research systems, aiming to narrow the current knowledge gap within and

([196]) European Commission, Joint Research Centre, Cagnin, C., Muench, S., Scapolo, F., Stoermer, E. and Vesnic-Alujevic, L. (2021), *Shaping and securing the EU's open strategic autonomy by 2040 and beyond*, Publications Office of the European Union, Luxembourg, doi:10.2760/414963.

([197]) European Parliament, European Parliamentary Research Service, Scientific Foresight Unit (2021), *Key Enabling Technologies for Europe's Technological Sovereignty*, European Parliament, Brussels.

between EU Member States ([198]). To make Europe the place where tech innovation flourishes, with breakthrough innovative solutions across the continent, the new European innovation agenda has been adopted. It positions Europe at the forefront of the new wave of deep tech innovation and start-ups, and it will help Europe to develop new technologies to address the most pressing societal challenges and to bring these technologies onto the market ([199]).

European industries can increase their global technological leadership though public and private investments in R & I. Private–public partnerships will be key for the future. While global corporate R & D continues to increase, many of the future R & I funding programmes for digital technologies will boost the green transformation and the EU's competitiveness. For instance, the transport sector will undergo a major digital transformation in the coming years and decades, with the introduction of connected and automated vehicles/vessels and infrastructures, and smart logistics and mobility services. Synergies between relevant EU programmes can also help the EU to achieve its technological sovereignty and spin-offs and spin-ins. Scaling up and transitioning from research to deployment (tech transfer) is key for the EU to benefit from long-term systematic investments.

The digital transformation of society and industry is bringing about new challenges, which require innovative responses to ensure that citizens and businesses benefit from trustworthy digital technologies. The EU should therefore be leading the efforts for secure digitalisation. Investment in cybersecurity R & I are required for European resilience, technological sovereignty and leadership, and to reinforce and further develop the operational capacity to prevent, deter and respond to threats.

Box 14. AI and SDGs

Within the context of digital technologies, AI has the potential to improve our ability to measure and identify weaknesses, priorities and areas of improvement related to the SDGs, while accelerating their achievement. The *Science, research and innovation performance of the EU 2022* report ([200]) highlighted the following examples of how AI has been or could be used for social good.

- **SDG 1: no poverty.** AI techniques have been used to automatically analyse satellite, mobile or digital transactions and real estate online advertisements to automatically infer poverty or socioeconomic levels in developing and developed countries.
- **SDG 2: zero hunger.** AI techniques have been used to predict the yields of crops from climate and agriculture data to automatically recognise invasive species and plagues, and to identify and recommend crops depending on the characteristics of the soil.
- **SDG 3: good health and well-being.** AI may be used to automate the discovery of new pharmacological compounds, automate protein folding, and assist in clinical decision-making related to, for example, the diagnosis of cancer, COVID-19 or tuberculosis in radiological tests. AI may also be used in other sectors with an effect on good health and well-being, for example use in transport safety to avoid vehicle–passenger collisions, and to optimise vehicle/passenger/freight traffic movements to minimise health-impeding emissions.
- **SDG 4: quality education.** AI methods can be used to enable more efficient academic management (e.g. automatically create schedules for teachers, support teachers in grading, provide 24/7 support through chatbots), to evaluate the quality of the education, and to personalise the learning experience.
- **SDG 5: gender equality.** AI methods can be used to automatically identify differences in gender representation, coverage and gender biases in newspaper coverage or commercial films using text, image, video and speech analysis. AI also has potential to reduce gender bias in recruitment.
- **SDG 6: clean water and sanitation.** Data-driven AI methods have been used to optimise and predict the efficacy of water desalination plants, to predict groundwater levels in coastal aquifers and/or predict their salinity, to model groundwater level changes in agricultural regions, and to detect and track major sources of water contamination, including networks for drinkable water.
- **SDG 7: affordable and clean energy.** Smart grids depend on AI methods to, for example, predict energy demand (including from electromobility), and optimise the maintenance and functioning of the grid to significantly increase its reliability and efficiency through the automatic detection of failures. Data-driven AI methods are also key enablers of the creation of efficient renewable energy, such as

([198]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 (SRIP)*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/38888.
([199]) European Commission (2022), A new European innovation agenda, COM(2022) 332 final.
([200]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

wind, solar, geothermal, hydro, ocean, bioenergy and hybrid energy, and of secure nuclear power plants. In addition to being used for energy supply, AI technologies are also key for optimised energy use on the demand side. This is particularly the case with energy-intensive sectors such as transport, where automated vehicles/planes/vessels may operate with AI-optimised traffic flows and energy use for reduced emissions.

- **SDG 8: decent work and economic growth.** AI is affecting the labour market, in terms of both the displacement of entire jobs and the automation of certain tasks within jobs. The percentage of jobs that are susceptible to being displaced by AI has an average value for Europe of between 45 % and 60 %. This transformation of the job market could lead to an increase in the polarisation of labour. At the same time, AI has the potential to improve job-matching outcomes in the labour market and to reduce skill mismatches that hinder overall productivity. It can do so through strengthening skills profiling and providing targeted career guidance.
- **SDG 9: industry, innovation and infrastructure.** Data-driven AI techniques are particularly valuable for monitoring, analysing and predicting failures in existing infrastructure. AI methods are also used to predict and better regulate transport flows, to assist in planning more efficient public transport routes and to deploy autonomous vehicles.
- **SDG 10: reduced inequalities.** AI has been said to contribute to inequality due to algorithmic bias and the 'winner-takes-all' phenomenon associated with technological development. However, data-driven AI methods can be used to reduce inequality. For example, AI algorithms can improve child welfare systems by automatically identifying when children might be in need of welfare, can foster financial inclusion by building alternative credit scores, and can ensure fair decision-making.
- **SDG 11: sustainable cities and communities.** Data-driven AI techniques have been used to improve urban planning by estimating urban density from aerial images, informing decisions related to roads and public transport, planning traffic, detecting traffic incidents, and predicting future traffic conditions or mobility needs.
- **SDG 12: responsible consumption and production.** AI enables smart production systems that, for example, minimise energy consumption, anticipate demand, detect manufacturing failures, automate tasks and perform systematic evaluations to detect areas of improvement. Furthermore, household waste can be minimised thanks to machine-learning methods applied to data captured by the internet of things.
- **SDG 13: climate action.** AI has proven to be a valuable ally in predicting extreme weather events and their impacts, such as heavy rain, hail, wildfires, floods and earthquakes, and in enabling a more efficient, prompt response to natural disasters. Autonomous drones have been used to monitor heat, prevent fires and search for survivors in floods and earthquakes. Furthermore, AI methods may be applied to industries or sectors that have a negative environmental impact to enable the reduction of GHG emissions.
- **SDG 14: life below water; and SDG 15: life on land.** AI methods have been used to estimate the volume of plastic debris in coastal areas, detect oil spills and estimate the CO_2 flux (which plays an important role in ocean acidification) in the oceans by analysing aerial images. Similarly, deforestation, forest quality, above-ground biomass and the risk of wildfires can be automatically estimated through deep neural networks applied on aerial images alone or in combination with other data sources.
- **SDG 16: peace, justice and strong institutions.** Institutional corruption can be detected automatically by data-driven machine-learning algorithms applied to financial transactions, public tender processes and government corruption. Machine-learning methods can be used to identify illegal drug trafficking and crime hotspots in cities; semantic and natural-language-processing techniques have been applied to social media content to detect extremist behaviours.

At the same time, AI raises a series of challenges and important risks. Data-driven AI systems make a significant contribution to the CO_2 footprint (which would need to be systematically measured and mitigated), present issues of privacy regarding the sensitive data used to train the algorithms, and may foster inequalities and biases if such data inherit biases from society. These challenges call for the deployment of a 'human-centric-AI' approach. Hence, research on AI with a 'human-centric-AI' approach should follow the high-level expert group's ethics guidelines for trustworthy AI ([201]), which list seven key requirements that AI systems should meet in order to be deemed trustworthy (including human agency and oversight).

([201]) European Commission, High-level expert group on artificial intelligence (2019), *Ethics Guidelines for Trustworthy AI*, European Commission, Brussels, https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=60419.

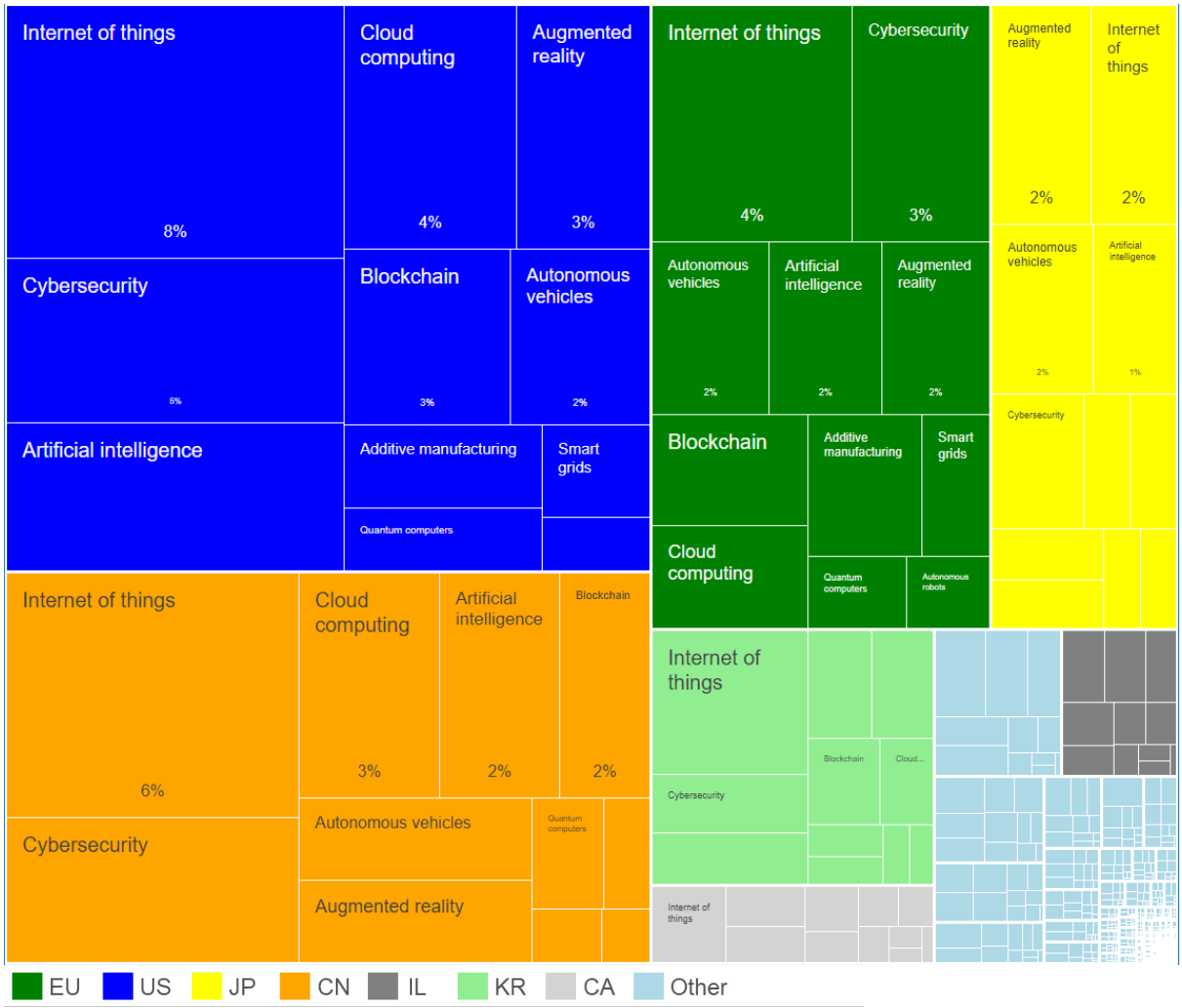
Further examples of potential AI applications are explored by the Oxford initiative on AI × SDGs ([202]), the AI for Sustainable Development Goals Think Tank ([203]) and the AI for good initiative ([204]).

Source: Based on European Commission, Directorate-General for Research and Innovation (2022), 'Chapter 11: Artificial intelligence for social good – The way forward', in *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

The clear leader in the digital space is the United States, with 38 % of digital patents coming from its inventors. China comes second with 22 %, closely followed by Europe (19 %) and then Japan (10 %). AI is an area where EU investments are particularly needed, with only 14 % of AI patents coming from Europe, as opposed to 38 % from the Unites States and 20 % from China. Europe, however, leads in additive manufacturing (37 %) and autonomous robots (26 %), and is on par with China and the United States when it comes to autonomous vehicles (Figure 44). Due to its transversal nature, the lag in AI is particularly important, potentially compromising the Europe's overall competitive position ([205]).

([202]) University of Oxford and Saïd Business School (n.d.), *Research Centres, Initiatives and Networks – Oxford initiative on AI × SDGs*, https://www.sbs.ox.ac.uk/research/centres-and-initiatives/oxford-initiative-aisdgs.
([203]) AI for Sustainable Development Goals Think Tank (n.d.), *AI for Sustainable Development Goals (AI4SDGs) Think Tank*, https://ai-for-sdgs.academy.
([204]) AI for Good Foundation (n.d.), *AI + Sustainable Development Goals*, https://ai4good.org.
([205]) Feijóo, C., Kwon, Y., Bauer, J. M., Bohlin, E., Howell, B., Jain, R., Potgieter, P., Vu, K., Whalley, J. and Xia, J. (2020), 'Harnessing artificial intelligence (AI) to increase wellbeing for all: The case for a new technology diplomacy', *Telecommunications Policy*, 44(6), 101988.

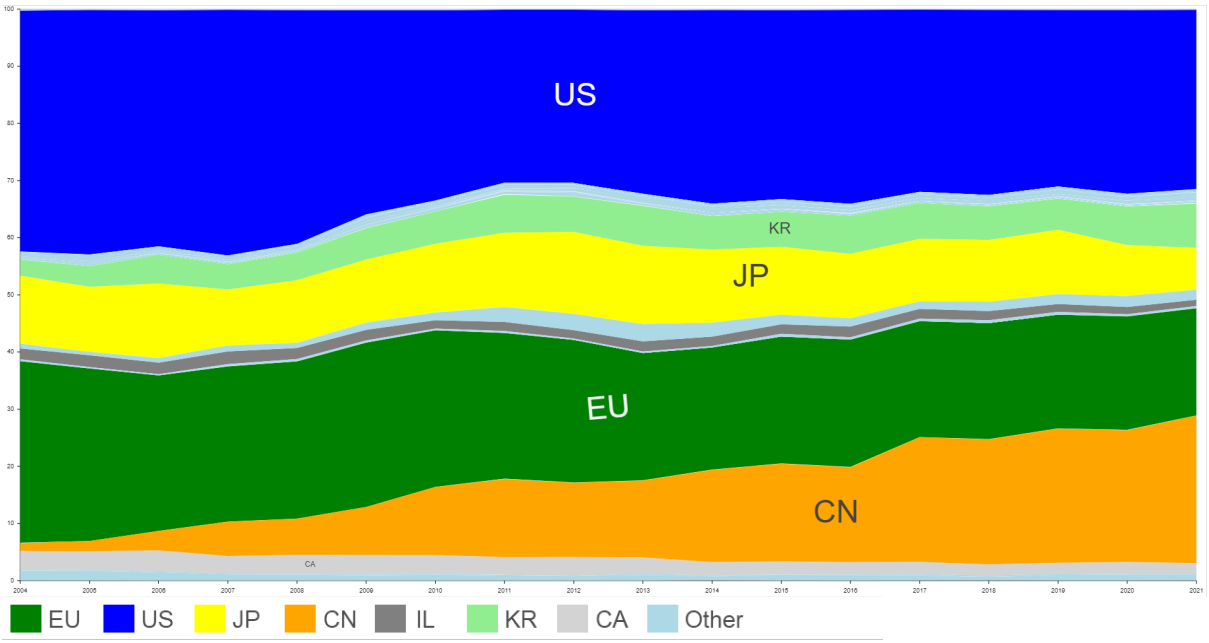
Figure 44. Percentage of digital patents across world regions, 2016–2021



Source: European Commission, ESIR (forthcoming), *Industry 5.0 and the Future of Work – Making Europe the centre of gravity for future good-quality jobs*, Publications Office of the European Union, Luxembourg.

If the current trend continues, China will be the top digital innovation producer in a few years. The United States and Europe were the leaders in the early 21st century, but the United States had a clear advantage. Since then, the relative performance of Europe has shrunk from 30 % to less than 20 %. The leaders of the digital transition now are clearly the United States and China. South Korea has been increasing its relative position over time, and Israel is still largely punching above its weight. Japan is showing signs of slowing down its production (Figure 45).

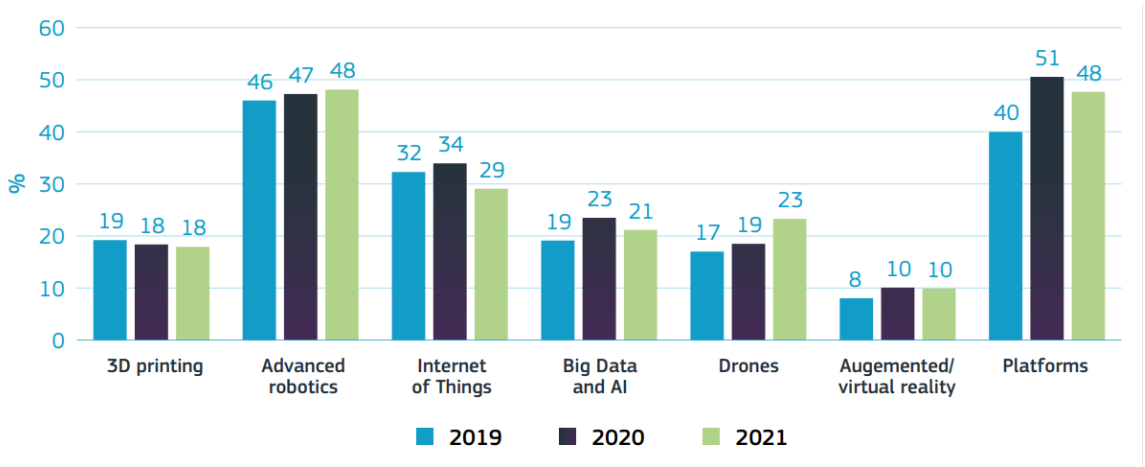
Figure 45. Dynamics of the digital transition – relative performance of regions (%), 2004–2021



Source: European Commission, ESIR (forthcoming), *Industry 5.0 and the Future of Work – Making Europe the centre of gravity for future good-quality jobs*, Publications Office of the European Union, Luxembourg.

The rapid development of ICT over the last few decades has set in motion an irreversible change in how business is carried out in the EU (Figure 46). How firms adopt and use ICT determines their ability to cope with the challenges of modern times. Further developing the ICT sector in the EU is critical to increase competitiveness by allowing European enterprises to take part in global digital supply chains. ICT plays a central role in promoting innovation and growth across EU Member States. The ICT sector is a key determinant of the competitive power of knowledge-based economies, as it is a magnet for investors and constitutes a natural environment for innovation. Notably, AI is transversal technology, being adopted across the world in all fields of science (Figure 47).

Figure 46. Share of EU firms adopting digital technologies, by technology type, 2019–2021



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

Figure 47. Intensity of publications on AI, by main research domain, 1960 to September 2022

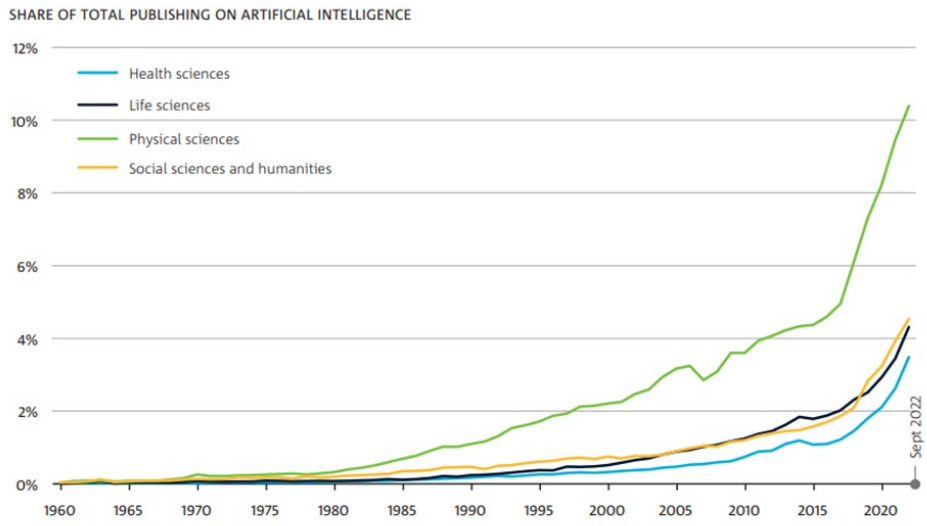


Figure 13. Artificial intelligence publishing intensity by main research domains.
Data source: The Lens [32]. Data sourced from January 1960 to September 2022.

Source: Hajkowicz, S., Naughtin, C., Sanderson, C., Schleiger, E., Karimi, S., Bratanova, A. and Bednarz, T. (2022), *Artificial Intelligence for Science – Adoption trends and future development pathways*, Commonwealth Scientific and Industrial Research Organisation, Brisbane.

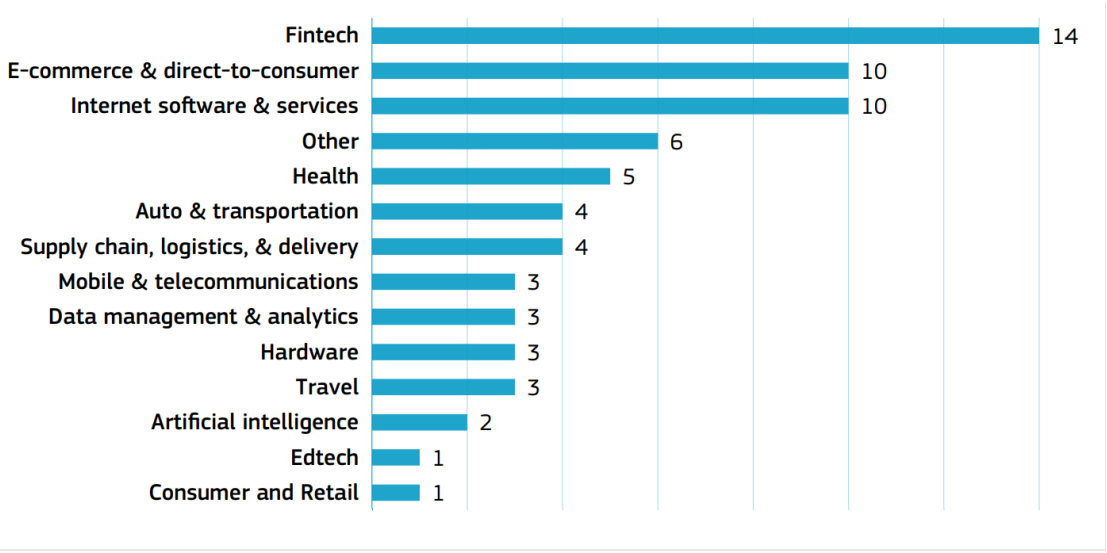
Technological leadership in digital technologies is crucial for EU security. Due to the increasing dependence of critical infrastructure on digital services and the development of new technologies (e.g. proliferation of the internet of things, the cloud, drones), cybersecurity has become a crucial strategic priority ([206]). This dependence on technologies, and thus the exposure to cyber threats, has been accentuated by the COVID-19 crisis. In addition, there has been a steep increase of threats that combine both physical and cyber aspects, also known as hybrid threats (e.g. hindering democratic decision-making, destabilising governments using disinformation). These threats require the EU and its Member States to identify and mitigate vulnerabilities in relation to their critical infrastructure from another angle. A number of key enabling technologies play a crucial role in the civil security market. Examples of solutions include AI tools developed for the purpose of facilitating digital investigation/forensics, and AI-based detection tools developed for border surveillance to allow more reliable and fully automated threat detection, replacing human screeners, and enabling real-time detection, monitoring and analysis of threats and hazards. In the future, if a country lags in its deployment of AI technology, its industry as a whole will likely face difficulties, potentially compromising the country's overall competitive position ([207]). Big data are also expected to become a very powerful tool in the security sector, as they contribute significantly to building intelligence about threats and incident management. Big data analytics can be used across all four civil security areas for data and information gathering, exploitation and exchange, surveillance and intelligence. In ICT, data analytics is used in video analytics, video surveillance systems and speech recognition, for instance.

Achieving technological leadership in digital technologies is also of high importance for the objective of the EU annual sustainable growth strategy, which places sustainability and social inclusion at the heart of the EU's economic policymaking. Digital technologies enable businesses to gain a competitive advantage, improve their services and products, and expand their markets, and these technologies have the potential to support the green transition ([208]). At the same time, the EU should pave the way towards a human-centric approach to digital technologies, promoting (as an example) AI that complements and uplifts human activities and values.

([206]) European Commission, Directorate-General for Migration and Home Affairs (2022), *EU Security Market Study – Final report*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2837/19472.
([207]) Feijóo, C., Kwon, Y., Bauer, J. M., Bohlin, E., Howell, B., Jain, R., Potgeiter, P., Vu, K., Whalley, J. and Xia, J. (2020), 'Harnessing artificial intelligence (AI) to increase wellbeing for all: The case for a new technology diplomacy', *Telecommunications Policy*, 44(6), 101988.
([208]) European Commission (2022), Annual sustainable growth survey 2023, COM(2022) 780 final https://commission.europa.eu/system/files/2022-11/COM_2022_780_1_EN.pdf.

Fast-growing innovative firms (such as start-ups and scale-ups) are essential to the EU's digital transition. Such companies typically swiftly adopt and are themselves carriers of cutting-edge technologies (Figure 48). The EU's performance in terms of start-ups, scale-ups and unicorn firms is improving, but efforts are still needed to improve the overall framework conditions for innovative companies to thrive. The number of European unicorn firms grew significantly in 2021. Nevertheless, many of the unicorn firms founded in Europe tend to move their headquarters elsewhere. In 2021, the United States reported almost seven times as many unicorn firms than Europe, while China outperformed the EU by a factor of more than two.

Figure 48. Sectoral distribution of EU unicorn firms, up to November 2021

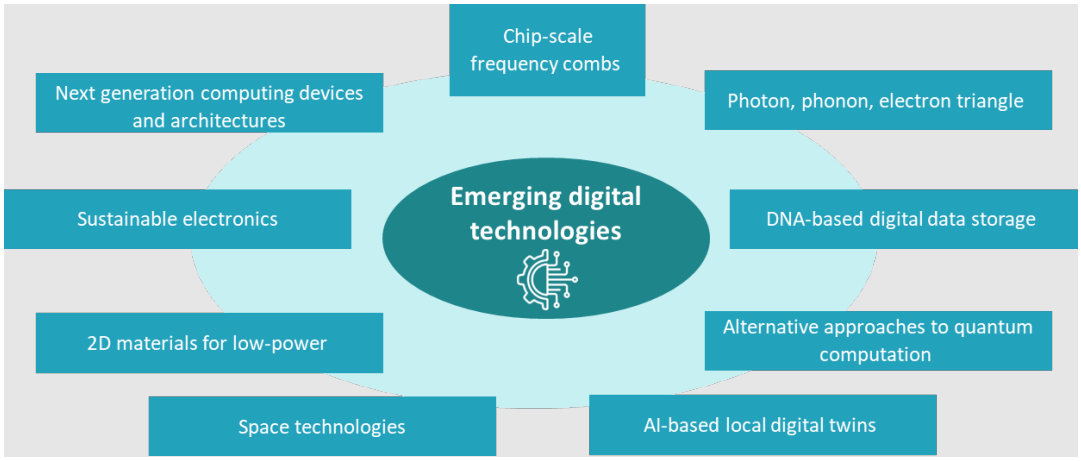


Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

The EIC has a big role to play in fostering the development of digital technologies in the EU. The EIC, launched in March 2021, focuses on identifying, developing and scaling up emerging technologies and breakthrough innovations in several domains. Figure 49 provides an overview of the type of critical emerging technologies identified as of interest for the EIC based on their potential for future technological, economic and social impacts. These include technologies in the fields of photonics, AI and electronics, and technologies aiming to increase the computing abilities of modern devices and data storage capabilities ([209]).

([209]) European Innovation Council (2022), *Identification of Emerging Technologies and Breakthrough Innovations*, EIC working paper 1/2022, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/7c1e9724-95ed-11ec-b4e4-01aa75ed71a1/language-en.

Figure 49. Emerging digital technologies



Source: EIC (2022), *Identification of Emerging Technologies and Breakthrough Innovations*, EIC working paper 1/2022, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/7c1e9724-95ed-11ec-b4e4-01aa75ed71a1/language-en.

3.4. Research and innovation needs for increasing EU resilience

According to the *Science, research and innovation performance of the EU 2022* report ([210]), **the COVID-19 pandemic and the Russian invasion of Ukraine highlighted the need** for Europe to improve its preparedness and **ensure that the R & I system is flexible enough to react to unexpected events rapidly and appropriately**. In 2021, as a response to the COVID-19 pandemic, the European Commission introduced a first step towards building resilience: NextGenerationEU ([211]). The Recovery and Resilience Facility, which represents 90 % of NextGenerationEU's total funds, is a clear step towards building a more sustainable and resilient EU.

However, the **EU still needs to understand its main needs, and subsequently target investments in research, development and innovation in both the short term and the long term to strengthen resilience and preparedness against future cross-border health threats and other crises**. R & I can support a holistic response, addressing all aspects and causes of future crises, therefore aiming to ensure resilience. **Overall, the EU's resilience and ability to tackle the challenges of tomorrow depends on the R & D, productivity and technological sovereignty** that we develop today. **If the EU underinvests in R & D today, the leaders of tomorrow will not have the tools to face the urgent priorities of the future.** In other words, Europe's preparedness and resilience to future crises rely on the ability to produce and apply, at scale, novel solutions in areas such as health, digital technologies, natural resources, energy, mobility, environment, food, the low-carbon economy and security. Therefore, it is of the greatest importance that the EU remains a strong player in terms of scientific production and technological output, which is essential for us to reinforce our competitiveness and resilience.

3.4.1. Civil security

Over the past decade, the EU has progressively tailored its R & I capacity to **EU security policy priorities**. This capacity plays a key role in addressing the current security challenges and is already helping us to find solutions to several of the most pressing issues. EU-funded security research is crucial to enable Member States' authorities and industries to develop and implement these solutions, particularly as it represents roughly 50 % of overall public funding invested in the EU and its Member States in this domain ([212]). Security research needs to involve citizens so as to be responsive to public concerns, to improve the quality of results

([210]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.
([211]) European Union (n.d.), *NextGenerationEU*, https://next-generation-eu.europa.eu/index_en.
([212]) This estimate factors in the funding available under national programmes, which differs considerably from one Member State to another. It does not factor in private investment in security research.

and to build public trust. The EU security union strategy ([213]), the counter-terrorism agenda for the EU ([214]) and the EU strategy to tackle organised crime (2021–2025) ([215]) recognise security research as a strategic enabler for the EU to keep up with evolving technological developments. R & I support the specific policy objectives set out in the EU security union strategy.

The war in Ukraine has brought to the fore the need for civilian protection and resilience supported by civil security research that is distinct from defence R & I activities. At EU level, the European Defence Fund ([216]) supports defence research with a budget of close to EUR 8 billion over 2021–2027, while Horizon Europe has an exclusive focus on civil applications. In its 2022 communication on the roadmap on critical technologies for security and defence ([217]), the Commission highlighted that these technologies increasingly originate in the civilian domain and use critical components with a dual-use nature. Against this backdrop, the Commission announced the preparation of an approach for encouraging dual-use R & I across EU programmes and instruments.

Many of the research technologies developed by projects under previous research programmes (the seventh framework programme for 2007–2014, and Horizon 2020 for 2014–2020) are now mature enough that they can be used to produce and deploy new tools and solutions. This directly helps security practitioners implement security policy priorities.

State-of-the-art technologies are increasingly used for **criminal activities**. This is, for example, the case for cybercrime, violent extremism and radicalisation leading to terrorism, organised crime or child sexual abuse. To engage in such activities, criminals make full use of modern technology such as the dark web and encryption tools. **R & I supports the specific policy objectives set out in the EU security union strategy.** These include digital forensics, detection of explosives, and innovative techniques for gathering electronic evidence in criminal investigations (e.g. for the detection of child sexual abuse material online). Continued research is needed into how technological development and digitalisation (e.g. AI, immersive technologies, use of algorithmic amplification and manipulation tactics) bring new opportunities for criminals, violent extremists and terrorists, and new challenges and opportunities for law enforcement.

The **resilience of critical infrastructure**, for example against hybrid threats, has recently come to the fore. Security research can support the implementation of the recently adopted CER directive. The Council recommendation on an EU-wide coordinated approach to strengthen the resilience of critical infrastructure invites the Commission to promote the uptake of EU-funded research and innovation projects ([218]). Member States are encouraged to make best use of the results of relevant projects under research programmes, in particular for stress tests and for scenario planning.

A series of crises and challenges, such as irregular arrivals in the EU, have put the **Schengen area** (an area without border controls at internal borders) to the test. **The Schengen strategy** ([219]) **underlines the important role of R & I in making it possible to use modern technologies in the absence of internal border controls and as alternatives to temporary physical border checks.** At the **EU's external borders**, there remains potential for large-scale movements of people as a result of war, instrumentalisation of migration or social/environmental stress, with concomitant research needs to improve situational awareness and border management. As a cross-cutting component of **European integrated border management**, R & I develops capabilities supporting the thematic components of this management, such as being capable to carry out identity, health and security checks at borders ([220]). R & I also develops capabilities to provide border surveillance and situational awareness; combat identity and document fraud; support state-of-the-art solutions for the European Border and Coast Guard, interoperability, and performance of EU data

([213]) European Commission (2020), On the EU security union strategy, COM(2020) 605 final.
([214]) European Commission (2020), A counter-terrorism agenda for the EU: Anticipate, prevent, protect, respond, COM(2020) 795 final.
([215]) European Commission (2021), On the EU strategy to tackle organised crime 2021–2025, COM(2021) 170 final.
([216]) European Commission (n.d.), *European Defence Fund*, https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/european-defence-fund_en.
([217]) European Commission (2022), Roadmap on critical technologies for security and defence, COM(2022) 61 final.
([218]) Council of the European Union (2022), *EU Resilience: Council adopts a directive to strengthen the resilience of critical entities*, https://www.consilium.europa.eu/en/press/press-releases/2022/12/08/eu-resilience-council-adopts-a-directive-to-strengthen-the-resilience-of-critical-entities/.
([219]) European Commission, Directorate-General for Migration and Home Affairs (2021), *Towards a Stronger and More Resilient Schengen Area*, https://home-affairs.ec.europa.eu/news/towards-stronger-and-more-resilient-schengen-area-2021-05-28_en.
([220]) European Commission (2023), Establishing the multiannual strategic policy for European integrated border management, COM(2023) 146 final, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52023DC0146

exchange and analysis; improve risk detection, incident response and crime prevention; and improve European civilians' capabilities for maritime security, including search and rescue.

The EU has become increasingly exposed to extreme weather events and other natural hazards that threaten the security and safety of society. Flash floods, storm surges, droughts, wildfires and heatwaves are expected to continue to increase in frequency and magnitude, raising the level of risk for both human life and infrastructure. **R & I in the field of disaster resilience – which covers not only natural but also man-made hazards – still needs to develop prevention and response capabilities.**

The **COVID-19 pandemic** highlighted the role of security research as a tool to move from a reactive to a proactive approach in the field of security, based on foresight, prevention and anticipation. A number of tools used throughout the EU to contain the pandemic had stemmed from the output of security research ([221]).

EU-funded security research also helps the EU in strengthening its **open strategic autonomy**, for instance in sensitive areas such as biometrics and AI, and ensuring related **industrial competitiveness**. Technology helps the EU and national security authorities to develop state-of-the-art solutions in response to security problems. However, **the EU is currently importing crucial digital and physical security products from non-EU countries, limiting its ability to react swiftly and autonomously, where necessary, to complex security developments, and to resist economic and political pressure from other global powers**. Strategic dependence on non-EU countries for critical technologies might also represent a security risk (e.g. when relying on non-EU-country tools for space capabilities).

Appropriate public and private investments, diversification of supply chains, and support given to innovative and circular business models can help the EU to achieve open strategic autonomy, notably in R & I, and strengthen the EU's industrial capacity. In the action plan on synergies between civil, defence and space industries, the Commission promotes a capability-driven approach in the field of internal security and law enforcement. Security R & I could be a facilitator for this approach, which has proven useful in the space and defence sectors, and which could help expand the EU's security capabilities ([222]).

Taking into account that a specialised security industry is needed to develop state-of-the-art technologies ([223]), the Commission services commissioned a study to gain a comprehensive understanding of the functioning and the dynamics of the EU's security market, the main actors, past tendencies and future growth expectations ([224]).

3.4.2. Protect our health and well-being

R & I in the health sector has been instrumental in delivering solutions to the COVID-19 crisis. On the one hand, **COVID-19 has demonstrated that R & I is critical to protect the health and well-being of citizens, but it has also illustrated that efforts should be strengthened, and that transnational (and international) coordination should be improved** ([225]). As stated in Horizon Europe's 2021–2024 strategic plan, one important expected impact of health R & I is to ensure that 'health care systems provide equal access to innovative, sustainable and high-quality health care thanks to the development and uptake of safe, cost-effective and people-centred solutions, with a focus on population health, health systems resilience, as well as improved evidence-based health policies' ([226]). This entails addressing the long-standing and daily challenges of the health and care sector, and the sector's need for better crisis preparedness and

([221]) Example projects include the network of practitioners for emergency medical systems and critical care, and pandemic preparedness and response.

([222]) 'A [capability-driven approach] has two key features: first, users define what capability they need and, second, they express their intention to procure products that, once developed, will offer the desired capability. This approach has proven useful in the space and defence sectors as it allows for a clear policy steer, a forward-looking mentality, long-term planning, an inter-disciplinary approach encompassing all stakeholders and synchronisation of the various processes' (European Commission (2021), Action plan on synergies between civil, defence and space industries, COM(2021) 70 final, p. 4).

([223]) See point 1.8 of European Economic and Social Committee (2020), *EESC Opinion: The industrial dimension of the security union (own-initiative opinion)*, CCMI/173, European Economic and Social Committee, Brussels.

([224]) European Commission, Directorate-General for Migration and Home Affairs (2022), *EU Security Market Study – Final report*, Publications Office of the European Union, Luxembourg.

([225]) European Commission (2020), Building a European health union: Reinforcing the EU's resilience for cross-border health threats, COM(2020) 724 final.

(226) European Commission, Directorate-General for Research and Innovation (2021), *Horizon Europe – Strategic plan 2021–2024*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/083753.

management. It also requires citizens of all ages to be empowered to use and be able to trust innovative health and care solutions to manage their own health and navigate through health systems ([227]).

Europe is facing persistent and long-term challenges linked to the ageing population and related comorbidities, and to the increased burden of non-communicable diseases. According to the 2021 ageing report, due to the impact of ageing, 'public healthcare expenditure in the EU is projected to increase by 1.2 [percentage points] of GDP i.e. from 6.6 % to 7.7 % of GDP from 2019 to 2070' ([228]). **Non-communicable diseases, including cancer, account for 80 % of the disease burden in the EU and the majority of premature deaths in the EU** ([229])**.** Cancer is responsible for 1.3 million deaths in the EU each year – a figure that is set to increase by more than 24 % by 2035 if no decisive action is taken ([230]) – and about two thirds of all deaths in the European region result from diabetes, cardiovascular diseases, chronic respiratory diseases or mental disorders. Large inequalities in life expectancy exist between socioeconomic groups within EU Member States. Significant inequalities also exist between EU Member States, which relates to the much higher mortality rates of certain non-communicable diseases, in particular cardiovascular diseases, in some countries than in others ([231]).

Improving the resilience and digital transformation of health and care systems are of paramount importance to prepare for and respond to future health crises, and to assure access to high-quality health and care services during normal circumstances. R & I can also help develop/improve technologies (for instance for remote medical consultations or for self-administered health scans) to contribute to addressing the issues of medical deserts / the low density of medical practitioners in some regions (e.g. in rural areas). R & I can also help to lower the cost of healthcare, the affordability of which is an issue for a growing number of people. In addition, health and care systems are facing and will continue to face a significant burden linked to catching up on services that were postponed during the pandemic, while still struggling to cope with structural challenges such as scarce resources, unequal access to health and care services, demographic change, and workforce and skill deficits.

In parallel, health and care systems need to be part of the green transformation, so as not to fall behind as the European economy delivers on the European Green Deal. At the same time, the pandemic has introduced new challenges, such as the need to address post-COVID-19 health conditions in the future. Moreover, countries are waiting for biomedical research to discover potential therapeutic approaches ([232]). As indicated in the Commission communication on the follow-up to the Conference on the Future of Europe, the EU should help reinforce the healthcare systems and, in particular, the resilience and quality of our healthcare systems. To this end, R & I can play an essential role. For example, the Horizon Europe co-funded partnership on transforming health and care systems is part of the response to address these issues. Similarly, to deliver on the conference proposals, the Commission will consider **new areas of action, including R & I efforts to improve supply chain resilience and openness for critical medicines, medical products and ingredients**. Here, again, R & I can help strengthen the competitiveness and resilience of the EU's economy, single market and industry, and address strategic dependencies.

The EU should further invest in research on preparedness and serious cross-border health threats to develop knowledge and tools to provide rapid and effective responses in future emergencies, as was the case for the development of COVID-19 vaccines, for instance. The creation of HERA ([233]) aimed, inter alia, to promote R & I efforts in the field of pandemic preparedness, and in particular regarding medical countermeasures, including vaccines, therapeutics and diagnostics. To ensure that these medical countermeasures are eventually available on the market, continuity of the research efforts, spanning from early-stage research to more advanced research, is crucial. In all its activities, including R & I, HERA is focusing on three priority threat categories of life-threatening or otherwise seriously harmful hazards to health that have the potential to spread across Member States: (i) pathogens with high pandemic potential; (ii)

([227]) European Commission (n.d.), *eHealth*, https://digital-strategy.ec.europa.eu/en/policies/ehealth.
([228]) European Commission, Directorate-General for Economic and Financial Affairs (2021), *The 2021 Ageing Report – Economic and budgetary projections for the EU Member States (2019–2070)*, Publications Office of the European Union, Luxembourg, https://economy-finance.ec.europa.eu/system/files/2021-10/ip148_en.pdf.
([229]) European Commission, Directorate-General for Health and Food Safety (2022), *The EU 'Healthier Together' Non-communicable Diseases Initiative – Reducing the burden of non-communicable diseases*, European Commission, Brussels, https://health.ec.europa.eu/system/files/2022-07/ncd_initiative_factsheet.pdf.
([230]) European Commission (n.d.), *ECIS – European Cancer Information System*, https://ecis.jrc.ec.europa.eu/.
([231]) European Commission (2022), *Healthier Together EU Non-communicable Diseases Initiative*, Publications Office of the European Union, Luxembourg, https://health.ec.europa.eu/system/files/2022-06/eu-ncd-initiative_publication_en_0.pdf.
([232]) European Commission (2021), EU Strategy on COVID-19 therapeutics, COM(2021) 355 final.
([233]) European Commission (n.d.), *Health Emergency Preparedness and Response (HERA)*, https://health.ec.europa.eu/health-emergency-preparedness-and-response-hera_en.

chemical, biological, radiological and nuclear threats; and (iii) threats resulting from antimicrobial resistance ([234]). International cooperation will help to deliver solutions to all of these issues.

The European health union communication ([235]) thus stresses the critical role of the European level and European funds for R & I to establish transnational collaboration in the health sector. It also points out the need for increased prevention and health promotion; for new treatments, vaccines and antimicrobials; and to align clinical trials to patient and health systems ([236]); and for research data and data on health systems' capacity for diagnosis, prevention and treatment of specific communicable and non-communicable diseases, and patient safety.

Finally, adopting a **One Health perspective** is important for crafting strategies and countermeasures for tackling emerging health threats, in particular infections. New infectious agents with pandemic potential can arise out of interactions between humans, animals, and changing environmental conditions. These types of dynamics have been suggested to underlie outbreaks of Ebola-virus outbreaks and Covid-19 for example. It is also an important mechanism behind the spread of antimicrobial resistance (AMR) and continuing the fight of AMR with a special focus on the development of new antibiotics to tackle the market failure by the private sector is also critical.

3.4.3. Ensure social fairness and build resilience

The pandemic has put our economies and a number of professions under great pressure. Health and care professionals, frontline workers in retail, transport, social or sanitation services, and teachers and trainers have been hit hard by the crisis. Improving resilience through skills means reducing dependence on market conditions and increasing these workers' potential to navigate through life and professional transitions. Innovation in education, training and recognition of skills has a key role in this process. The COVID-19 pandemic has also shown the need to be resilient and digitally ready to continue educational and business activities, and to exploit the opportunities that digital solutions can offer in health and care. Moreover, some of the technologies rooted in the social economy, such as platform technologies and assistive technologies, have shown their potential during COVID-19. Decentralised platform technologies have also proven their potential to improve fair labour conditions and ensure the respect of social rights. Finally, the social economy is known to be a main driver for experimentation and innovation with green technologies and clean technologies.

Challenges to information technology infrastructure and e-systems have revealed the need to improve our human capacity for cybersecurity preparedness and response. The European skills agenda notably recommends implementing innovative learning, teaching and research through a challenge-based and transdisciplinary approach, to bring academia and industry together and boost university–business collaboration ([237]).

The innovation capacity of the EU is hampered by growing heterogeneity across communities with different routines, cultures and levels of trust. **Building resilience also calls for boosting social and place-based innovation, which has the potential to bring people from diverse backgrounds together with a common purpose through personal and collective commitment and joint actions.** Innovation can also offer new ways of producing sustainable goods, organising and delivering services, and new forms of civic participation, responding to concrete social needs or societal and ecological challenges. It can change social relations and potentially lead to systemic changes ([238]).

([234]) European Commission (2022), *Health Union: HERA delivers list of top-3 health threats to prepare against*, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_4474.

([235]) European Commission (2020), Building a European health union: Reinforcing the EU's resilience for cross-border health threats, COM(2020) 724 final.

([236]) *A European Health Union: A pharmaceutical strategy for Europe factsheet*. Factsheet - A European Health Union: A Pharmaceutical Strategy for Europe (europa.eu)

([237]) European Commission (2020), *European skills agenda for sustainable competitiveness, social fairness and resilience*, European Commission, Brussels, https://ec.europa.eu/migrant-integration/sites/default/files/2020-07/SkillsAgenda.pdf.

([238]) European Commission (2021), Building an economy that works for people: An action plan for the social economy, COM(2021) 778 final.

Any policy reforms aiming to enhance social fairness and build resilience should be underpinned by analysis of their distributional impact in line with the Commission communication on better assessing the distributional impact of Member States' policies[239].

3.4.4. Social, institutional and democratic dimensions

The quality of countries' institutions shapes their innovation and economic performance. Institutions are the 'rules of the game' in a society, or, more formally, the human-devised constraints that shape our interactions. A growing branch of the literature is studying the impact of institutions on economic growth and technological change. The main argument is that since institutions (such as property rights, the balance of political power, organisation of markets, democracy and choice of governance models) determine the incentives and constraints of economic actors, they will shape individual behaviour, and economic and 'sustainability' outcomes ([240]).

Good institutions are characterised by political stability, transparency and accountability, and show high degrees of rule of law, with low risk of expropriation and corruption. The economic gains of secure property rights stem from the fact that they lower the transaction costs of trade, and the costs of monitoring and enforcing contracts. A lack of property right enforcement will increase the likelihood that future profits from current investments may be lost, through either theft or outright government expropriation. Individuals and firms are unlikely to risk their own capital and resources if they are unsure about the returns. Countries with strong property rights protection tend to show better economic performance ([241]).

In addition, the political climate of the past few years has shown that liberal democracies are increasingly at risk. This trend has been reinforced by the COVID-19 pandemic and its subsequent waves of temporary (in most cases) restrictions of basic freedoms, by the invasion of Ukraine, and by the swarm of disinformation that both events have triggered. The rights and freedoms enshrined in the treaty on European Union (Article 2) and the Charter of Fundamental Rights of the European Union must also be preserved in times of crisis, and the rule of law and the EU values must be upheld across the EU at all times.

The importance of further research on the drivers and features of high-quality institutions and democratic processes has been highlighted by the recent geopolitical factors mentioned above. This may introduce new research gaps and opportunities, such as:

- the impact of the energy crisis, geopolitical tensions and rising authoritarianism in Europe on the health of European democracies;
- the emergence of metaverses, and the challenges and opportunities they bring for democracy and society;
- ways to preserve democratic rights and freedoms in times of crisis;
- demographic changes and the intergenerational pact;
- (unequal) access to social protection for diverse families;
- returns on social expenditures from a life-cycle perspective;
- new forms of inequalities in the light of the energy crisis, and the twin green and digital transition;
- preparedness to remedy new forms of inequalities beyond income inequality (e.g. health inequality (including mental health), environmental inequality, and inequality in all well-being dimensions);
- the social and economic impacts of the climate and biodiversity crisis, and related mitigation and adaptation policies;
- European trade, social and development policies in a changing geopolitical environment;
- the contribution of European and national cohesion, regional and urban development policies to the sustainable, fair, green and digital transition, taking into account demographic changes and ageing;
- the need for a citizens' toolbox from the behavioural sciences and implementation sciences for future socioeconomic transformations;

([239]) European Commission (2022), Better assessing the distributional impact of Member States' policies. COM(2022) 494 final

([240]) North, D. C. (1981), *Structure and Change in Economic History*, Norton, New York, NY; Acemoglu, D., Johnson, S. and Robinson, J. A. (2005), 'Institutions as a fundamental cause of long-run growth', in Aghion, P. and Durlauf, S. N. (eds.), *Handbook of Economic Growth – Volume 1A*, Elsevier, Amsterdam, pp. 385–472; Spolaore and Wacziarg (2013); Meuleman, L. (2019), *Metagovernance for Sustainability – A framework for implementing the sustainable development goals*, 1st edn, Routledge, Abingdon; Besley, T. and Persson, T. (2011), *Pillars of Prosperity – The political economics of development clusters*, Princeton University Press, Princeton, NJ.

([241]) Acemoglu, D., Johnson, S. and Robinson, J. A. (2001), 'The colonial origins of comparative development: An empirical investigation', *American Economic Review*, 91(5), pp. 1369–1401.

- technological development and its impact on governance styles (e.g. on citizen engagement, on setting market framework conditions).

Moreover, technological, societal and geopolitical factors and policy developments lead to the need for further research on the role and impact of creativity-driven innovation (through cultural and creative industries) on growth and new value chains in a circular economy, and also on human-centred economy and citizens' well-being. In particular, research measuring the impact of design would be needed in the context of its contribution to the competitiveness of enterprises, the twin green and digital transition, and the transformative changes of the economy and society. On the one hand, the cultural and creative industries were severely hit by the COVID-19 and energy crises. On the other hand, these industries demonstrated their value and (still unmeasured) potential for well-being and societal and economic impacts (e.g. a climate-neutral and green Europe, fit for the digital age, where the economy works for the people), and for providing growth and job creation in the European economy. They also play a key role in shaping culture, values and perceptions across the EU and beyond. At the same time, large parts of these industries lack the capacity to take the necessary measures to adapt to and thrive under the twin transition, let alone proactively contribute to societal and cultural resilience.

In addition to addressing needs for the European Collaborative Cloud for Cultural Heritage, together with the training needs for digital skills in the sector, a dedicated cultural and creative industry platform needs to be established, and targeted research on specific cultural and creative industries and on their business models must be undertaken. Furthermore, tangible and intangible heritage deserves further research in the context of cultural literacy, the intersection with technology, the role of the arts, the accessibility of culture and social inclusion. Various areas can benefit from research, including small cultural organisations, the role of volunteering and the role of young people in a new European identity.

4. POTENTIAL OF HORIZON EUROPE TO ADDRESS IMPORTANT ISSUES

Key messages from this chapter

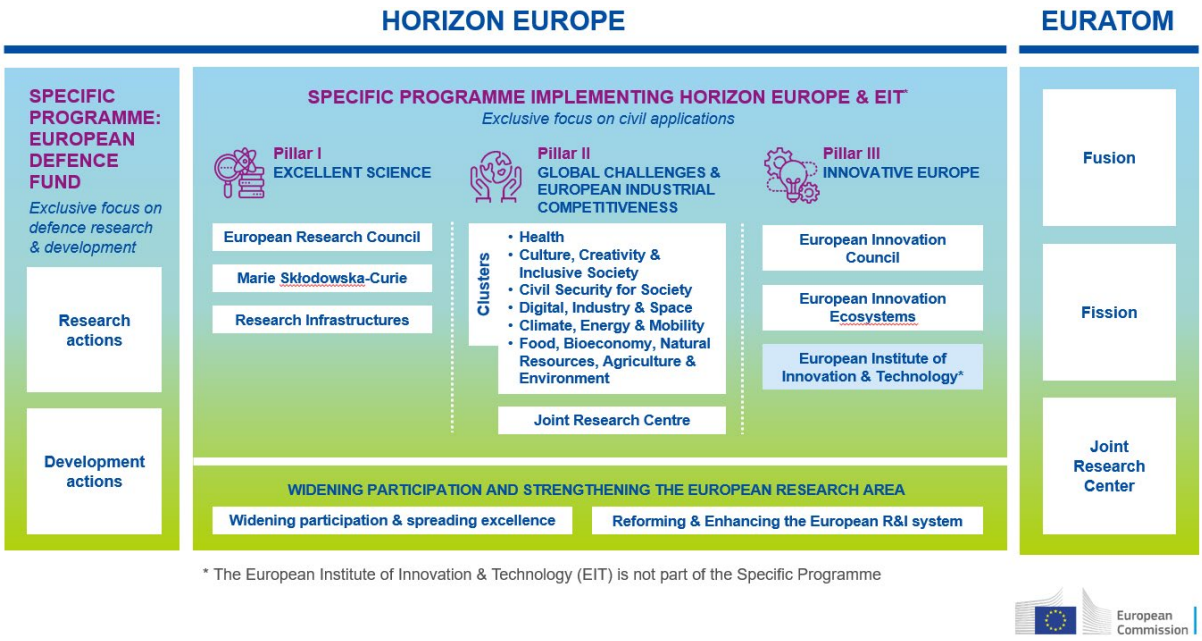
- With a budget of EUR 95.5 billion for 2021–2027, Horizon Europe represents the largest European R & I funding programme so far, and has the capacity to bring in large amounts of public and private investments. Horizon Europe aims to strengthen societal and economic impacts through funding excellent and impactful R & I, and the use of new and revitalised features such as the EU missions, a larger dedicated budget for innovators, insights of the social sciences and humanities, and a new approach to the European partnerships. Moreover, within Horizon Europe, citizen engagement has become even more prominent, and international cooperation in R & I remains a strategic priority for the EU, with Horizon Europe being one of the main tools used to achieve this.
- Horizon Europe brings forward a greater number of high-quality proposals and can potentially fund more projects than its predecessor, Horizon 2020. However, 71 % of the high-quality proposals are still not receiving funding because the budget is too small. To fund all high-quality proposals, an additional EUR 34 billion (approximately) would have been needed over 2021–2022. During this period, a total of 44 832 eligible proposals were submitted under the 236 calls launched, closed, and fully evaluated. Of these proposals, 53.9 % were of high quality. This is higher than the 46.1 % for Horizon 2020, and is a sign that the 'impact logic' of calls and topics indicating expected outcomes and asking for a 'pathway to impact' effectively guides applications. In addition, the success rate of proposals has been higher for Horizon Europe than it was for Horizon 2020: 15.9 % versus 11.9 %.
- Horizon Europe is almost on track in terms of climate mainstreaming and the commitment to spend at least 35% of Horizon Europe resources on climate action, with at the end of 2022, the preliminary figures indicating that Horizon Europe has contributed 34% on climate change from the budgets 2021 and 2022 combined of the operational budget.
- Ensuring synergies with other EU programmes is an important aspect of Horizon Europe. The legal framework of Horizon Europe explicitly calls for the creation and the strengthening of synergies with other EU funds to maximise the societal impact of R & I policies, and to leverage R & I investments in Europe from all sources. However, fostering strategic synergies is also very much a governance issue, calling for increased cooperation and continuous dialogue between EU bodies, national managing authorities and local authorities.
- A gap analysis has been performed for the six clusters of pillar 2 of Horizon Europe, with the goal of having an overview of their intervention areas (as defined in the specific programme), their coverage in the Strategic Plan 2021–2024 and work programmes 2021–2024, and current and potential gaps resulting from recent developments.

4.1. Horizon Europe at a glance

The EU framework programme for R & I is the major tool to foster R & I at EU level. With a budget of EUR 95.5 billion for 2021–2027, Horizon Europe represents the largest European research funding programme so far ([242]). It consists of three vertical pillars and one horizontal pillar (Figure 50), is open to the world, and funds excellent and impactful investments in R & I ([243]). The strategic plan of Horizon Europe defines the strategic orientations for R & I investments, and acts as a compass to help Horizon Europe stay on course with the political priorities of the Commission, with a focus on achieving a climate-neutral and green Europe fit for the digital age, where the economy works for the people. The strategic plan covering 2021–2024 was adopted at the beginning of 2021 ([244]).

The European R & I funding programmes, including Horizon 2020, were responsible for 7.2 % of public R & I funding in 2019 in Europe ([245])**.** Horizon 2020 (the EU framework programme for R & I over 2014–2020) alone contributed to 0.1 percentage points of the EU's (total) R & D intensity, which was estimated as 2.23 % in 2019 ([246]). Each euro invested in the programme mobilised an additional EUR 0.25 of public and private investments in R & I projects, equalling a total of EUR 16.9 billion ([247]). An estimated additional EUR 9.5 billion was also leveraged by the EU framework programme research teams (EUR 4.2 billion), and as private follow-up investments attracted by the EIC's accelerator portfolio companies (EUR 5.3 billion) ([248]). Furthermore, the EU's budget has substantially increased over the last few programming periods. Together with the European structural and investment funds, the EU framework programme for R & I is an important source of R & D funding in many Member States: it represents a high share of the total R & D expenditure in Member States such as Cyprus, Latvia and Lithuania.

Figure 50. Structure of Horizon Europe



NB: Euratom, European Atomic Energy Community.

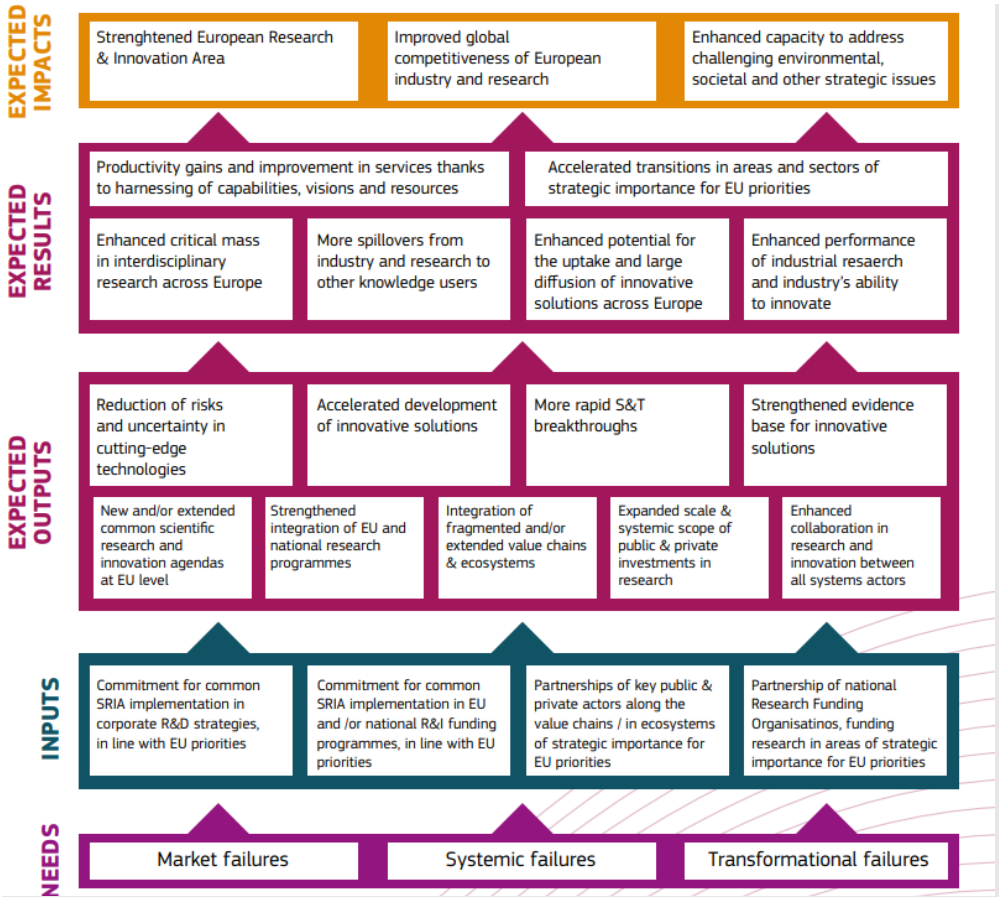
([242]) In addition to Horizon Europe, there are other EU programmes and initiatives that foster R & I within Europe, such as the cohesion policy, digital Europe and the EU health programme.
([243]) Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the framework programme for research and innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013 (OJ L 170, 12.5.2021, p. 1).
([244]) European Commission, Directorate-General for Research and Innovation (2021), *Horizon Europe – Strategic plan 2021–2024*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/083753.
([245]) European Commission, Directorate-General for Research and Innovation, Common R & I Strategy & Foresight Service, Chief Economist Unit, based on Eurostat (online data code: rd_e_gerdfund). It is important to note that there are sectoral variations. For example, EU-funded civil security research is estimated to represent roughly 50 % of publicly funded civil security research in the EU (European Commission (2021), Enhancing security through research and innovation, SWD(2021) 422 final).
([246]) Community Research and Development Information Service, Eurostat.
([247]) Horizon dashboard.
([248]) European Commission, EIC (n.d.), *EIC Fund and Investment Opportunities*, https://eic.ec.europa.eu/investment-opportunities_en.

Source: European Commission, Directorate-General for Research and Innovation.

Horizon Europe strengthens impact using new and revitalised features such as the EU missions, a larger dedicated budget for innovators, and a new, more coordinated, approach to European partnerships.

- Through greater directionality, the **EU R & I missions** tackle major societal challenges, based on trust in our ability to create a greener, more resilient, more inclusive and better society for future generations. These missions embrace a collaborative approach to catalysing ambitious R & I efforts for the long term, aiming to bring about real change on the ground. The five missions cover areas related to climate change, cancer, the ocean and waters, climate-neutral and smart cities, and healthy soils. They include clearly defined targets, timelines and procedures for tracking and evaluating the results obtained.
- Horizon Europe also builds on close partnerships between different public and private stakeholders, with the objective of steering public and private co-investment in a more focused, ambitious and efficient way to ensure the partnerships deliver on the Commission's political objectives. Under Horizon Europe, **European partnerships** have been set up to contribute to EU-wide transitions towards sustainability and push the digital transformation. EU partnerships are strategic instruments that enable long-term collaborations to be established and economies of scale to be achieved to tackle common challenges (Figure 51).

Figure 51. Intervention logic of the European partnership instrument



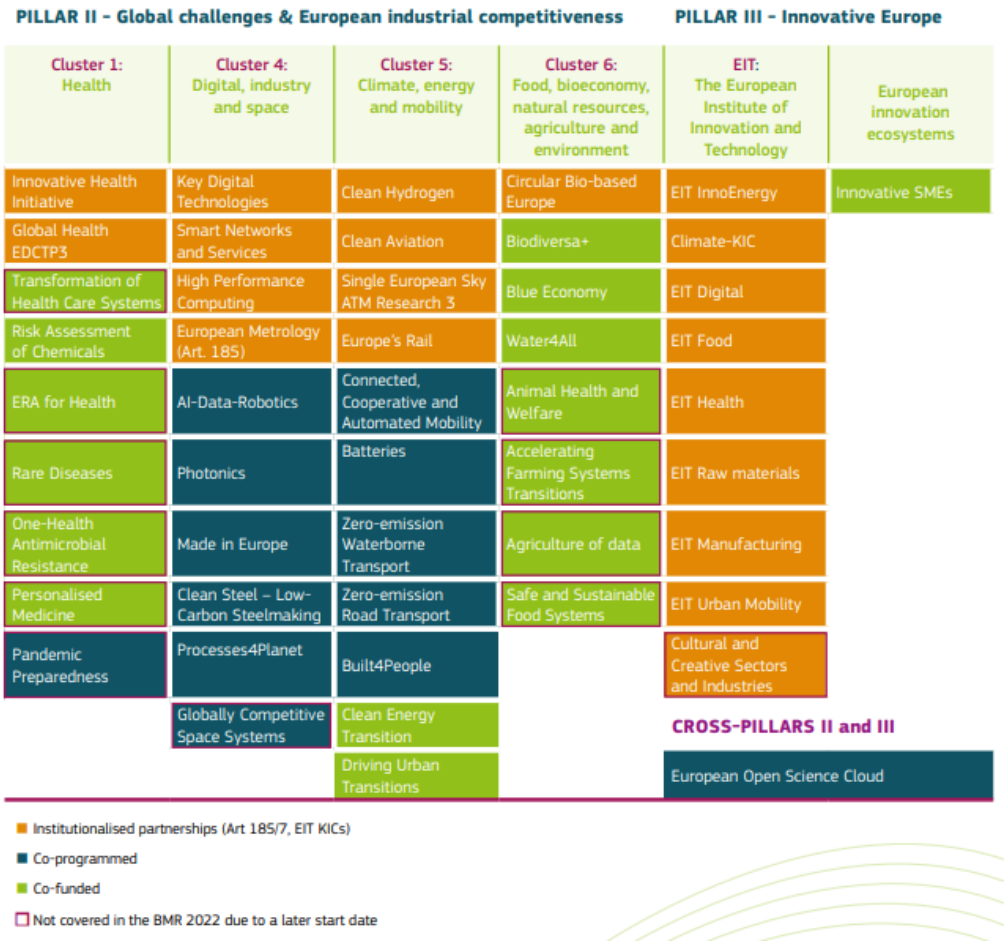
Source: Technopolis, published in European Commission, Directorate-General for Research and Innovation (2022), *Performance of European Partnerships – Biennial monitoring report 2022 on partnerships in Horizon Europe*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/web/eu-law-and-publications/publication-detail/-/publication/a6cbe152-d19e-11ec-a95f-01aa75ed71a1.

- For the Strategic Plan 2021–2024, 49 partnerships were identified and selected (Figure 52). For these partnerships, an estimated total commitment of EUR 31.4 billion from partners other than the EU is expected ([249]). For the strategic plan 2025–2027, candidate partnerships have already been put forward.

([249]) European Commission, Directorate-General for Research and Innovation, *Performance of European Partnerships: Biennial Monitoring Report (BMR) 2022 on partnerships in Horizon Europe*, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2777/144363.

The selection of these candidate partnerships has a separate process and timeline, with the final selection included in the final Strategic Plan 2025–2027. This Strategic Plan Analysis nevertheless provides analytical support and evidence for the selection process of the second-wave partnerships to make sure the selection is based on the most up-to-date information and knowledge available on R & I.

Figure 52. Portfolio of the 49 European partnerships in the first Horizon Europe Strategic Plan (2021–2024)



NB: ATM, air traffic management; KIC, knowledge and innovation community.
Source: European Commission, Directorate-General for Research and Innovation (2022), *Performance of European Partnerships – Biennial monitoring report 2022 on partnerships in Horizon Europe*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/web/eu-law-and-publications/publication-detail/-/publication/a6cbe152-d19e-11ec-a95f-01aa75ed71a1.

- The set-up of the **EIC** provides dedicated support for innovations with potential for breakthroughs and with disruptive natures, which may be too risky for private investors. Within the EIC, the EIC accelerator represents one of the main funding instruments available to start-ups and SMEs within Horizon Europe.
- The **European Institute of Innovation and Technology (EIT)** is an integral part of Horizon Europe and an important instrument for the Horizon Europe objectives. The priority fields and strategy of the EIT for 2021–2027 are set up in the strategic innovation agenda (SIA) of the EIT ([250]). As depicted in Figure 52 the knowledge and innovation communities (KICs) of the EIT are also integral parts of the European partnerships, although their fields are defined through the EIT SIA. Currently, nine EIT KICs are up and running, of which the EIT KIC for cultural and creative sectors and industries was launched under Horizon Europe in 2022. Within the EIT SIA for 2021–2027, a second new KIC under Horizon Europe, in the field of water, marine and maritime sectors and ecosystems has been proposed, subject to a positive outcome

([250]) EIT (2022), *Strategic innovation agenda of the European Institute of Innovation and Technology (EIT) 2021–2027 (Decision (EU) 2021/820)*.

of an *ex ante* analysis to evaluate the relevance of this field. This analysis is currently ongoing and its results will feed into the 2025–2027 Strategic Plan ([251]).

- In Horizon Europe, **citizen engagement** has become even more prominent, and is applied through co-design (e.g. developing research agendas), co-creation (e.g. involving citizens and/or end users in developing new knowledge and innovations) and co-assessment (e.g. continual contribution to governance).
- Horizon Europe supports R & I activities that fully respect climate and environmental standards, which are priorities of the EU, and cause **no significant harm** to any of these areas. It also provides that 35 % of the expenditure for actions funded under the programme will have to contribute to climate objectives. Part of this is the programme's approach to midterm priority setting through **strategic planning**, formulating expected impacts, and a topic design expressing expected outcomes that contribute to those impacts; the formulation of activities and 'pathways to impact' is largely left to applicants
- Horizon Europe also includes a new **impact-oriented monitoring framework** strengthening evidence-informed R & I policymaking and providing deeper analytical insights for medium- and long-term impacts, in addition to dissemination and exploitation tools (Community Research and Development Information Service ([252]) and the Horizon results platform ([253]).
- **Excellent fundamental research and curiosity-driven research** are important parts of a thriving research and innovation ecosystem. Curiosity-driven research allows researchers to carry out frontier research that can open new avenues for tackling societal challenges or make radically new technology possible. Fundamental and curiosity-driven research are therefore necessities for the EU and its aspiration for scientific and technological leadership. In this regard, Pillar 1 (Excellent Science) of Horizon Europe, which includes the European Research Council, research infrastructures, and Marie Skłodowska-Curie actions, has an important role to play.
- **International cooperation in R & I** is a strategic priority for the EU, and Horizon Europe is one of the main tools for this. Association with Horizon Europe is the closest form of cooperation with non-EU countries, which allows entities of associated countries to participate in programme actions on equal terms with entities of EU Member States. The programme also includes targeted actions with non-associated key partners from non-EU countries, and almost all topics are open to the inclusion of international partners. In 2021, the European Commission adopted the communication on the global approach to research and innovation: Europe's strategy for international cooperation in a changing world ([254]). It set out that, in response to current global trends, the EU should lead by example, promoting rule-based multilateralism, pursuing reciprocal openness in R & I cooperation to facilitate global responses to global challenges, and exchanging best practices. Furthermore, it states that the EU should support its objectives of open strategic autonomy by, in parallel, modulating its bilateral cooperation with non-EU countries in certain areas. As an example of strengthened international cooperation on the horizon, 2023 will see the launch of the EU's new political focus on Latin America, with the Commission and Council presidents calling for a new paradigm and a strong political message in the EU's relations with the Latin America and the Caribbean region. The important R & I dimension of this rejuvenated partnership will be implemented through the Horizon Europe Work Programmes 2025 and 2026–27.
- Last but not least, several cross-cutting issues, among which are the mainstreaming of **social sciences and humanities, the gender dimension and gender equality, and open science practices** are instrumental to maximise the societal impacts of Horizon Europe. The combination of knowledge between the social sciences and the humanities and the 'natural' or 'life' sciences (also sometimes called science, technology, engineering and mathematics, or 'STEM') is fundamental in order to tackle societal and technological challenges that need to be integrated in a wider social, economic, cultural and political perspective ([255]). For this reason, the role of the social sciences and humanities has been increasingly taken into account in the framework programmes (Figure 53). The effective integration of the social sciences and humanities in all clusters, including all missions and partnerships, is a principle throughout

([251]) The EIT SIA mentions that other new KICs may be selected as well if budget allocations additional to those of the EIT become available, and these shall take into account the contribution of the governing board, the strategic planning of Horizon Europe and the criteria set for the selection of European partnerships, in particular openness, transparency, EU added value, contribution to the SDGs, coherence and synergies.

(252) European Commission (n.d.), *CORDIS*, https://cordis.europa.eu/.

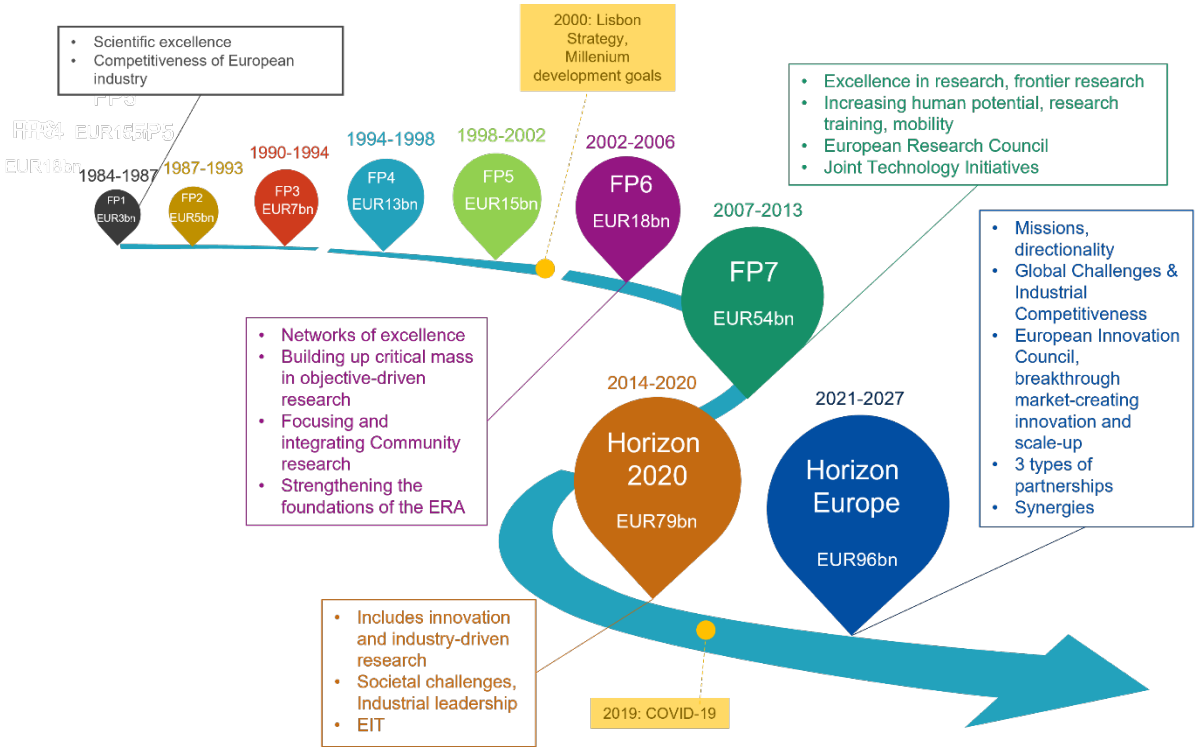
([253]) European Commission (n.d.), *Funding & Tender Opportunities – Horizon results platform*, https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/horizon-results-platform.

([254]) European Commission (2021), On the global approach to research and innovation, COM(2021) 252 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A252%3AFIN.

([255]) Keraudren, P. (2018), 'The contribution of social sciences and the humanities to research addressing societal challenges. Towards a policy for interdisciplinarity at European level?', in Tressaud, A., *Progress in Science, Progress in Society*, Springer International Publishing, Cham, pp. 43–57.

the programme cycle. Yet further steps may be taken to increase the proportion of evaluators with social science and humanities backgrounds for calls and missions related to societal challenges ([256]).

Figure 53. Evolution of the EU's R & I framework programme



Source: Steeman J-T., Peiffer-Smadja O., Ravet J. (2023). *Global benchmarking of the European framework programme for research and innovation: insights on public funding in major economies*. European Commission R&I paper series.

4.2. Current progress of Horizon Europe (2021–2022)

4.2.1. Key figures on the implementation of Horizon Europe

Since the beginning of Horizon Europe, in 2021 ([257])**, 236 calls have been launched, closed and fully evaluated**, with an average of 4.3 topics per call (higher than the Horizon 2020 average of 3.4) (Table 8). A total of 44 832 eligible proposals were submitted under those calls. **Overall, 54 % of the proposals were assessed by external experts as being of high quality (compared with 46 % for Horizon 2020).** Each proposal gathered 4.6 applicants on average (compared with 3.5 in Horizon 2020), and requested an average EU contribution of EUR 2.25 million (compared with EUR 1.7 million in Horizon 2020).

The success rate of proposals ([258]) **has been higher for Horizon Europe than it was for Horizon 2020** (15.9 % versus 11.9 %), meaning that, for now, Horizon Europe brings forward a higher share of high-quality proposals and could potentially fund more proposals than its predecessor. However, 71 % of these high-quality proposals ([259]) are still not receiving funding. **An additional EUR 34 billion (approximately) would**

([256]) European Alliance for Social Sciences and Humanities (2021), *SSH Integration in Horizon Europe and its Missions*, European Alliance for Social Sciences and Humanities, Paris.

([257]) Cut-off date for current data is 30 December 2022. The data covers Horizon Europe and Horizon 2020 (almost) in total, including the co-programmed/institutionalised joint undertakings. The parts not fully covered in the data for Horizon 2020 are the following: EIT KICs, neither proposals nor projects are covered; ERA-NET Cofund and European Joint Programme Cofund partnerships, only data on the first level of the grant are covered – data on the subgrants are not included; Article 185 partnerships, no data covered. The parts of Horizon Europe not covered in the data are the following: co-funded European partnerships, only data on the umbrella grant are visible; EIT KICs and Article 185, neither proposals nor projects are covered.

([258]) The success rate of proposals is the percentage of eligible proposals retained after evaluation out of the total number of eligible proposals submitted.

([259]) High-quality proposals are proposals with an evaluation score above the quality threshold.

have been needed to fund all high-quality proposals. The oversubscription rate expressed as a percentage of high-quality proposals not funded is slightly lower, but still relatively high, in Horizon Europe (71 %) than in Horizon 2020 (74 %).

In regard to the **climate mainstreaming objectives**. The Horizon Europe Regulation states that "actions under this Programme shall contribute at least 35% of the expenditure to climate objectives where appropriate". The commitment to spend at least 35% of resources on climate action applies to the entirety of Horizon Europe including the European Research Council (ERC), the European Innovation Council (EIC) and Institutionalised European Partnerships. R&I plays a central role in the green transition in accelerating and navigating the necessary transition by developing and demonstrating innovative approaches, supporting their deploying, and engaging citizens in innovation processes. At the end of 2022, the preliminary figures indicate that Horizon Europe has contributed 34% of funds from the operational budgets 2021 and 2022 combined on climate action (as of 30 March 2023). Table 7 shows the current estimated yearly expenditure for climate actions within the Horizon Europe programme, with also the estimates for the total of Horizon Europe. Base of future estimates are the 2023-2024 work programmes and a 35% contribution for 2025-2027, reflecting the minimum target as per the Horizon Europe legal basis. All figures are based on estimates for the whole duration of the Horizon Europe Programme and will be updated with actual figures based on ex-post assessment, as soon as these will become available. Corrective measures where necessary will then be proposed to ensure that the overall HE contribution to climate will reach 35%.

Based on the preliminary ex-post monitoring 7.3% of Horizon Europe spending have been allocated to address biodiversity for the period 2021-2022. Estimates show an increase to 8% for the work programme 23/24. The target of MFF and the ambition of Horizon Europe is to reach 10% spending on biodiversity by 2026-2027, which implies that more efforts will be needed in order to achieve this.

Table 8. Contribution of Horizon Europe to green budgeting priorities (million EUR)

	Implementation		Estimates					Estimates	
	2021	2022	2023	2024	2025	2026	2027	Total (2021-2027)	% of HE total (2021-2027)
Climate mainstreaming	4193.4	4486.9	4748.0	4604.0	4302.6	4392.5	4682.5	31 409.9	34.1%
Biodiversity mainstreaming	1050.8	1050.8	1284.5	862.4	884.0	902.0	920.0	6 954.4	7.5%
Clean air	1217.8	1217.8	689.1	638.3	-	-	-	3762.9	4.1%

Source: Programme Performance Statement (upcoming), based on ABAC, DGBUDG (April 2023)

In regard to the **digital objectives**, Horizon Europe investments in the digital transformation for 2021-2022 are up to EUR 9069.2 million which represents 33% of the Horizon Europe Budget, see Table 9. As the estimate of Horizon Europe refer to bi-annual work programmes 2021/2022, the figures indicated in the table correspond to the split of half the value to get a reference per year. Incoming monitoring data confirm these initial estimates. This figure includes contributions to developing digital solutions/applications in different economic sectors. The contribution to core digital (general-purpose) technologies amounts to EUR 4184.2 million for 2021-22.

Table 9. Contribution of Horizon Europe to digital budgeting priorities (million EUR)

	2021 implementation	2022 implementation	Total	% of the 2021-2022 envelope
Digital contribution	4534.6	4534.6	9069.2	33%

Source: Programme Performance Statement (upcoming), based on ABAC, DGBUDG (April 2023)

Table 10. Horizon Europe and Horizon 2020 – key figures on calls and proposals

Key figures	Horizon Europe	Horizon 2020 (total)
Calls launched and fully evaluated in 2021–2022 (for Horizon Europe)	236	1 076
Topics	1 007	3 706
Average number of topics per call	4.3	3.4
Eligible proposals submitted	44 832	285 568
Average number of applications in eligible proposals	4.6	3.5
Average EU contribution requested in eligible proposals (million EUR)	2.25	1.7
Proposals above threshold	24 161	131 528
Above-threshold rate (percentage of eligible proposals)	53.9	46.1
Retained proposals	7 108	34 125
Success rate of proposals (percentage of eligible proposals)	15.9	11.9
Oversubscription rate (percentage of high-quality proposals not funded)	70.6	74.1

Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

Following the evaluation of the proposals, **EUR 16.3 billion has already been awarded** through 5 509 signed grants (Table 11). However, many other grants are still under preparation, as 7 108 proposals had been selected for funding at the end of 2022 (see Table 10). **The average grant size under Horizon Europe is around EUR 3 million, significantly larger than in Horizon 2020** (EUR 1.9 million). However, average grant size varies greatly between programme parts, from EUR 0.6 million for Marie Skłodowska-Curie actions to EUR 8.4 million under the cluster of health. The average number of participants in signed grants is higher for Horizon Europe (7.1) than for Horizon 2020 (5.0).

Table 11. Horizon Europe and Horizon 2020 – key figures on signed grants

Key figures	Horizon Europe	Horizon 2020
Signed grants	5 509	35 426
Average number of participants in signed grants	7.1	5.0
Requested EU contribution in signed grants (billion EUR)	16.3	68.3
Average grant size (million EUR)	3.0	1.9 ([1])

NB: ([1]) Average grant size for Horizon 2020 was calculated including the 42 34 SME instrument phase 1 very small grants of EUR 50 000. When these are excluded the average grant size amounts to EUR 2.3 million.
Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

4.2.2. Proposals and requested EU contribution by pillar

Of the three vertical pillars, **pillar 2 'global challenges and European industrial competitiveness' manages to fund the highest percentage of proposals that are eligible for funding (success rate of 21.4 %)**, followed by pillar 1 'excellent science' (14.3 %) and pillar 3 'innovative Europe' (10.7 %) (Table 12). The (fourth) horizontal pillar 'widening participation and strengthening the European research area' has the highest percentage of high-quality proposals (73.2 %), but also received the lowest number of eligible proposals. The success rate is also quite high in the horizontal pillar (29.8 %). In total, the 7 108 retained proposals will be funded as follows: EUR 4.5 billion through the excellent science pillar, EUR 13.3 billion through the global challenges and European industrial competitiveness pillar, almost EUR 1.9 billion through the innovative Europe pillar, and close to EUR 800 million through the widening participation and strengthening the European research area pillar.

Table 12. Proposals and requested EU contribution by pillar

Pillar	Eligible proposals	High-quality proposals (above threshold)	Retained proposals	Above-threshold rate (percentage of eligible proposals)	Success rate (percentage of eligible proposals)	EU contribution requested in retained proposals (million EUR)	Additional funding needed to fund all high-quality proposals (million EUR)
Excellent science	31 625	15 734	4 535	49.8	14.3	4 511	6 745
Global challenges and European industrial competitiveness	9 089	6 016	1 946	66.2	21.4	13 345	22 906
Innovative Europe	3 138	1 694	335	54.0	10.7	1 899	3 712
Widening participation and strengthening the European research area	980	717	292	73.2	29.8	791	1 018
Total for Horizon Europe	**44 832**	**24 161**	**7 108**	**53.9**	**15.9**	**20 546**	**34 380**

Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

4.2.3. Proposals and requested EU contribution by programme part

The percentage of proposals above the quality threshold (i.e. high-quality proposals) is the highest for the EIT (100 %), followed by research infrastructures (82.7 %), Marie Skłodowska-Curie actions (74.9 %) and proposals submitted under the horizontal pillar (73.2 %) (Table 13). The European Research Council has the lowest share of proposals satisfying the minimum quality requirements (21.2 %), followed by European innovation ecosystems (49.4 %), the EIC (54.6 %) and by pillar 2, cluster 2 'culture, creativity and inclusive society' (58.1 %).

The EIT and research infrastructures also manage to fund the highest shares of eligible proposals by far – 85 % and 53.2 %, respectively – followed by reforming and enhancing the European R & I system (34.2 %) and widening participation and spreading excellence (29.0 %). The EIC is by some margin the programme part with the lowest share of eligible proposals funded, with a success rate of 8.8 %, followed by the ERC (11.9 %) and, again, pillar 2, cluster 2 'culture, creativity and inclusive society' (12.9 %).

In line with the political priorities of the European Commission, most funds are allocated through pillar 2, cluster 5 'climate, energy and mobility' (EUR 4.4 billion) and pillar 2, cluster 4 'digital, industry and space (EUR 3.6 billion), followed by the ERC (EUR 2.9 billion). The least funds are distributed through European innovation ecosystems (EUR 105 million), followed by reforming and enhancing the European R & I system (EUR 125 million) and pillar 2, cluster 3 'civil security for society' (EUR 229 million).

Table 13. Proposals, EU contribution and success rates, by programme part

Programme part	Eligible proposals	High-quality proposals (above threshold)	Retained proposals	Above-threshold rate (percentage of eligible proposals)	Success rate of proposals (percentage of eligible proposals)	EU contribution requested in retained proposals (million EUR)	Additional funding needed to fund all high-quality proposals (million EUR)
Pillar 1 – excellent science							
ERC	14 814	3 135	1 769	21.2	11.9	2 906	2 263
Marie Skłodowska-Curie actions	16 672	12 484	2 692	74.9	16.1	1 093	4 205
Research infrastructures	139	115	74	82.7	53.2	512	278
Pillar 2 – global challenges and EU industrial competitiveness							
Health	1 307	805	288	61.6	22.0	2 291	3 883
Culture, creativity and inclusive society	1 120	651	144	58.1	12.9	444	1 607
Civil security for society	313	189	51	60.4	16.3	229	649
Digital, industry and space	2 736	1 947	564	71.2	20.6	3 606	7 857
Climate, energy and mobility	2 121	1 384	511	65.3	24.1	4 434	5 027
Food, bioeconomy natural resources, agriculture and environment	1 492	1 040	388	69.7	26.0	2 341	3 883
Pillar 3 – innovative Europe							
EIC	2 549	1 393	225	54.6	8.8	691	3 618

European innovation ecosystems	569	281	93	49.4	16.3	105	77
EIT	20	20	17	100	85.0	1 103	16
Horizontal pillar – widening participation and strengthening the European research area							
Widening participation and spreading excellence	831	608	241	73.2	29.0	666	867
Reforming and enhancing the European R & I system	149	109	51	73.2	34.2	125	151
Total for Horizon Europe	**44 832**	**24 161**	**7 108**	**53.9**	**15.9**	**20 546**	**34 380**

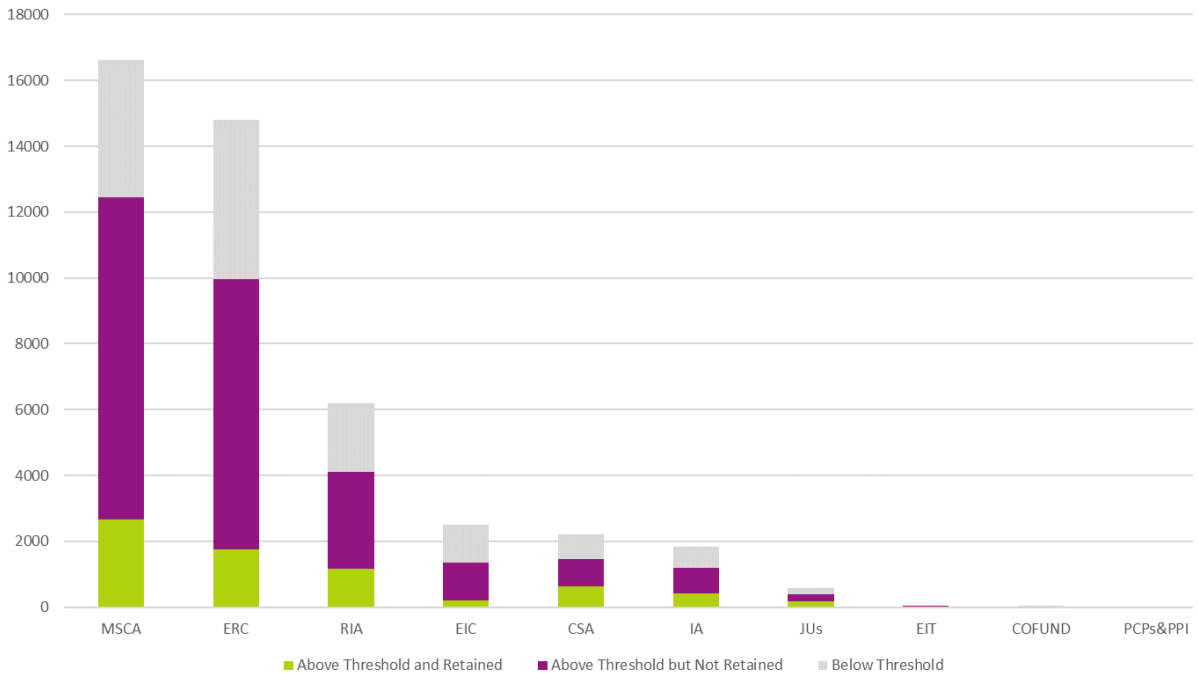
Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

4.2.4. Proposals and requested EU contribution by type of action

Most proposals are submitted for Marie Skłodowska-Curie actions. with 16 621 proposals, followed by the ERC (14 811) and research and innovation actions (6 197) (Figure 54). Horizon Europe funds several types of projects, also called type of actions ([260]).

([260]) The Horizon Europe programme guide provides an overview of the types of projects that can be funded: R & I actions, innovation actions (IA), coordination and support actions (CSA), programme co-fund actions (COFUND), public procurement of innovative solutions (PPI), pre-commercial procurement (PCP), Marie Skłodowska-Curie actions (MSCA), European Institute of Innovation and Technology (EIT), European Research Council (ERC), European Innovation Council (EIC), Joint Undertaking (JU) (European Commission (2022), *Horizon Europe (HORIZON) Programme Guide*, version 2.0, European Commission, Brussels, https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/programme-guide_horizon_en.pdf).

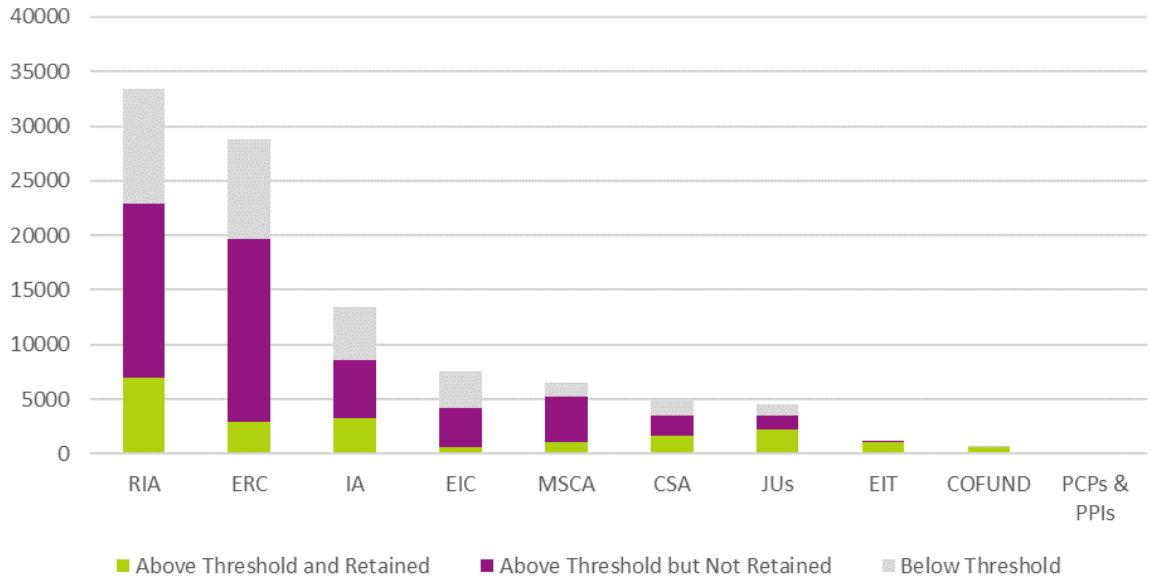
Figure 54. Eligible proposals submitted, by type of action and evaluation status



NB: Cofund, programme co-fund action; CSA, coordination and support action; IA, innovation actions; JU, joint undertaking; MSCA, Marie Skłodowska-Curie actions; PCP, pre-commercial procurement; PPI, public procurement of innovative solutions; RIA, research and innovation action.
Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

Most funding is requested for R & I actions, with over EUR 33 billion of EU contribution requested through the eligible proposals submitted, followed by ERC actions with EUR 28.8 billion, and innovation actions with EUR 13.4 billion (Figure 55). The most successful proposals (above threshold and retained) are the R & I actions as well, which will allocate EUR 7 billion (34.0 % of the total requested budget in all retained (selected) proposals) through signed grants, followed by innovation actions with EUR 3.3 billion (16.1 %) and ERC with EUR 2.9 billion (14.1 %).

Figure 55. EU funding (in million EUR) requested in eligible proposals submitted, by type of action and evaluation status



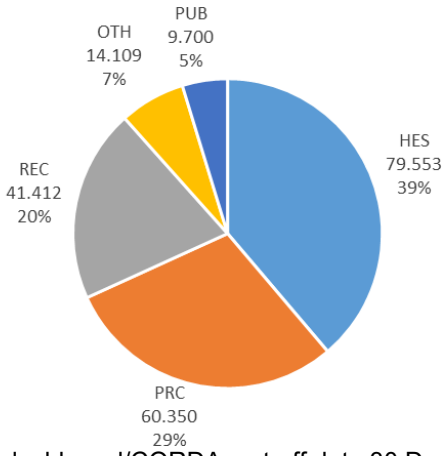
NB: Cofund, programme co-fund action; CSA, coordination and support action; IA, innovation actions; JU, joint undertaking; MSCA, Marie Skłodowska-Curie actions; PCP, pre-commercial procurement; PPI, public procurement of innovative solutions; RIA, research and innovation action.
Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

4.2.5. Applications and requested EU contribution by type of organisation

Five categories of legal entities are eligible for funding in Horizon Europe: higher education organisations (HES), private organisations (PRC), research organisations (REC), public organisations (PUB) and other bodies (OTH). An organisation can apply to several calls in different proposals. Over 205 000 applications were submitted through eligible proposals.

Higher education organisations submitted close to 40 % of the applications, with a total of 79 553 applications (Figure 56). They are followed by private for-profit organisations (60 350 applications) and research organisations (41 412 applications).

Figure 56. Applications by type of organisation



Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

The success rate of applications is the highest for public organisations (27.9 %), research organisations (24.6 %) and other bodies (25.0 %) (Table 14). It is the lowest for higher education organisations (18.5 %). The average success rate of applications ([261]) is 21.7 %, with one applicant out of every five participating in a retained proposal. **In total, higher education organisations will receive 34 % of the funding, with EUR 7 billion of EU contribution requested in the retained proposals**, followed by private for-profit entities (29.2 %, EUR 6 billion) and research organisations (25.6 %, EUR 5.3 billion).

Table 14. Proposals, success rate and EU contribution, by type of organisation

Type of organisation	Applications in eligible proposals	Applications in retained proposals	Success rate of applications (%)	EU contribution requested in retained proposals (million EUR)	Percentage of funding
Higher education organisations	79 553	14 698	18.5	6 976	34.0
Private for-profit entities	60 350	13 409	22.2	5 998	29.2
Research organisations	41 412	10 206	24.6	5 260	25.6

([261]) The success rate of applications is the percentage of applications in proposals retained for funding out of the total number of applications in all eligible proposals.

Public organisations	9 700	2 709	27.9	840	4.1
Other bodies	14 109	3 529	25.0	1 472	7.2
Total for Horizon Europe	**205 124**	**44 551**	**21.7**	**20 546**	**100**

Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

4.2.6. Applications, participation and requested EU contribution by country group

In regard to Horizon Europe progress by country group, **four out of every five applications come from EU Member States, with one out of every ten originating from Member States that have joined the EU since 2004** ([262]). Third countries represent 12.5 % of the applications, more than 50 % of which originate from United Kingdom-based organisations ([263]). Associated countries represent 5.7 % of all applications. Member States that joined before 2004 outperform the other Member States in terms of success rate of applications (22.2 % versus 20.5 %), as well as the associated countries (19.6 %) and third countries (21.2 %). In total, older Member States have already been allocated close to EUR 14 billion of Horizon Europe's funds through signed grants. Newer Member States and associated countries have received more than EUR 1 billion each. Third countries have been granted EUR 200 million.

([262]) Member States that joined before 2004: Belgium, Denmark, Germany, Ireland, Greece, Spain, France, Italy, Luxembourg, the Netherlands, Austria, Portugal, Finland and Sweden. Member States that have joined since 2004: Bulgaria, Czechia, Estonia, Croatia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Romania, Slovenia and Slovakia. For a list of associated countries and third countries, see European Commission (2023), *List of Participating Countries in Horizon Europe*, https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/common/guidance/list-3rd-country-participation_horizon-euratom_en.pdf.

([263]) Following Brexit, the United Kingdom is no longer a Member State and is considered a third country, as it is not yet associated with Horizon Europe. However, a transitional arrangement applies, as it is in the process of associating with Horizon Europe. The same applies to Morocco.

Table 15. Proposals, success rate, participation and EU contribution by country group

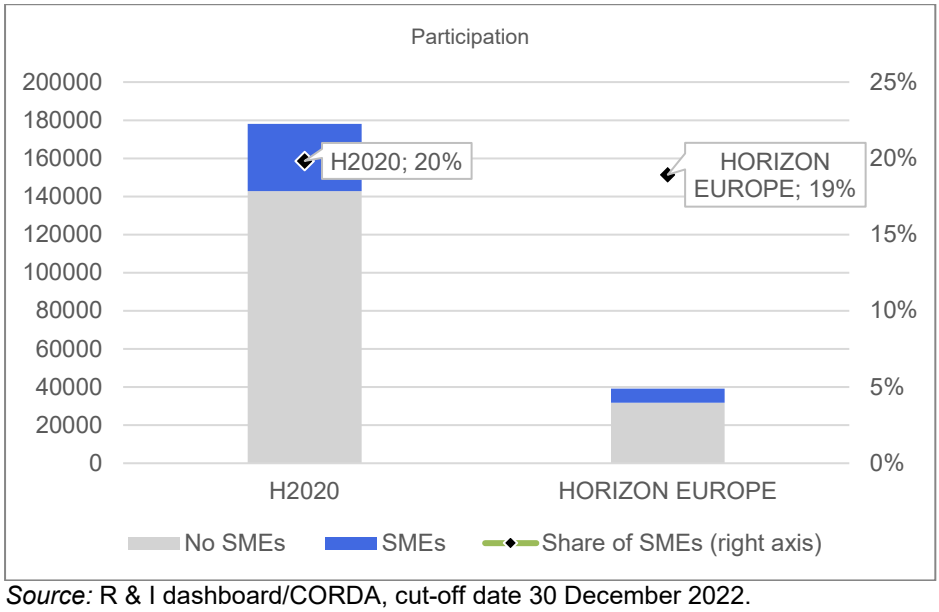
Country group	Applications in eligible proposals	Percentage of total number of applications	Success rate of applications (%)	Participation in signed grants	Percentage of all participation	EU contribution requested in signed grants (million EUR)	Percentage of total EU contribution requested in signed grants
Member States	167 859	81.8	21.9	32 954	84.3	14 989	92.1
Member States that joined before 2004	*145 604*	*71.0*	*22.2*	*28 972*	*74.1*	*13 835*	*85.0*
Member States that joined in 2004 or after	*22 255*	*10.8*	*20.5*	*3 982*	*10.2*	*1 154*	*7.1*
Associated countries	11 794	5.7	19.6	2 090	5.3	1 091	6.7
Third countries	25 471	12.5	21.2	4 035	10.3	200	1.2
United Kingdom	*14 037*	*6.8*	*19.8*	*1 850*	*4.7*	*34*	*0.2*
Total for Horizon Europe	**205 124**	**100**	**21.7**	**39 079**	**100**	**16 280**	**100**

Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

4.2.7. Small and medium-sized enterprises' project participation

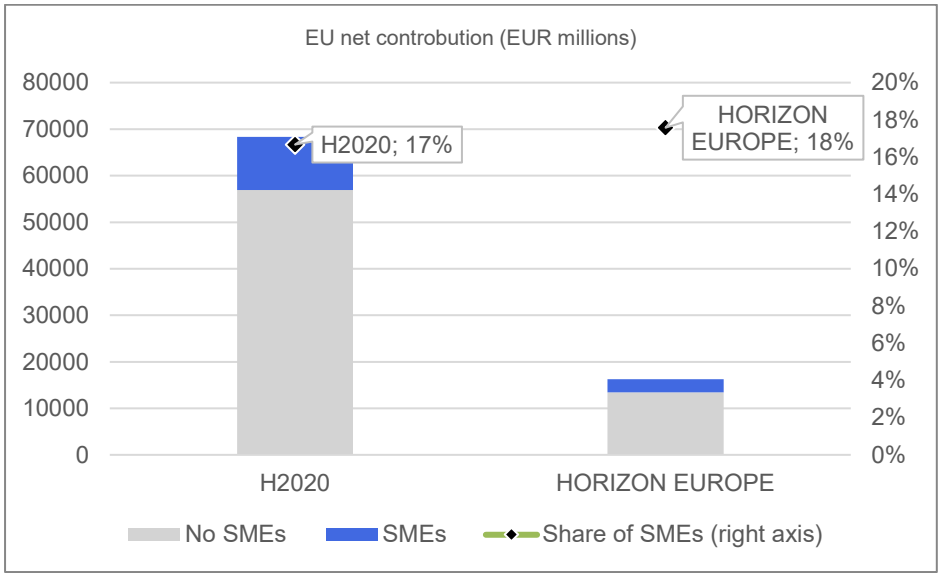
SMEs represent about one fifth of participation and of the EU's contribution in Horizon 2020 and Horizon Europe, with these shares remaining stable between the two programmes (Figure 57) ([264]). The share of SMEs in total participations was 20 % in Horizon 2020 (35 316 participations) and 19 % over the first 2 years of Horizon Europe (7 395 participations). In Horizon 2020, 17 % of the total EU net contribution was allocated to SMEs (Figure 56), which represents EUR 11.4 billion for Horizon 2020, while 18 % of total EU net contribution was allocated to SMEs for Horizon Europe so far (EUR 2.9 billion). Up to this point, the number of unique SME participants is 4 617 in Horizon Europe, with one SME participating approximately three times. For Horizon 2020, the total was 17 557 SME participants, with one SME participating approximately 2.5 times.

Figure 57. SMEs' participation in Horizon 2020 and Horizon Europe



Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

Figure 58. Net contribution from the EU to SMEs (million EUR) in Horizon 2020 and Horizon Europe

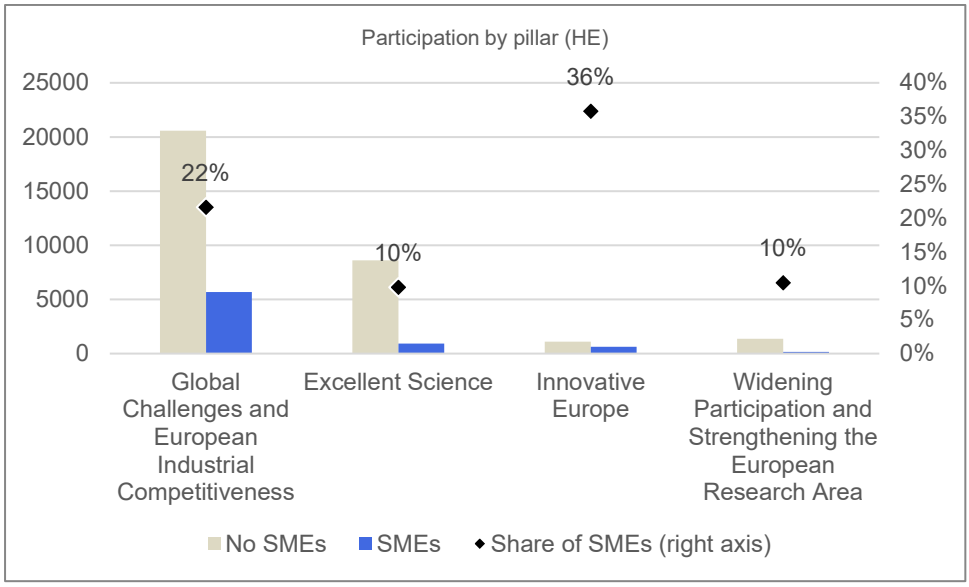


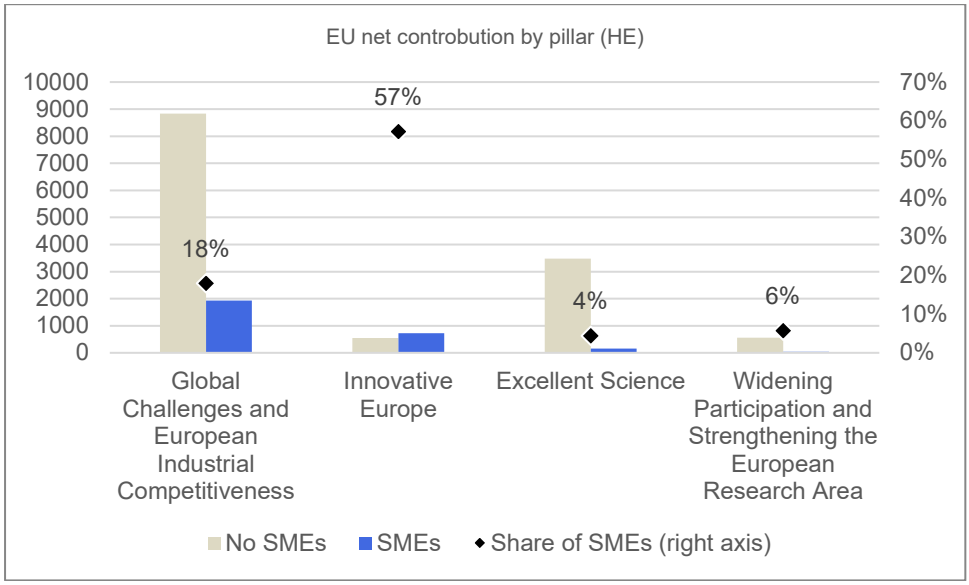
Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

([264]) The SME analysis section is based on self-declared data from participants.

In Horizon Europe, most SME participation is concentrated in the global challenges and European industrial competitiveness pillar, with 5 680 participations so far, and a total contribution of EUR 1.9 billion (Figure 59). SMEs represent 22 % of participation in this pillar, and 18 % of the EU's net contribution. The share of SMEs in the innovative Europe pillar is the highest, with 36 % participation (618 participations) and 57 % of the EU's net contribution (EUR 0.7 billion).

Figure 59. Horizon Europe participation by pillar (top) and EU net contribution by pillar (bottom)

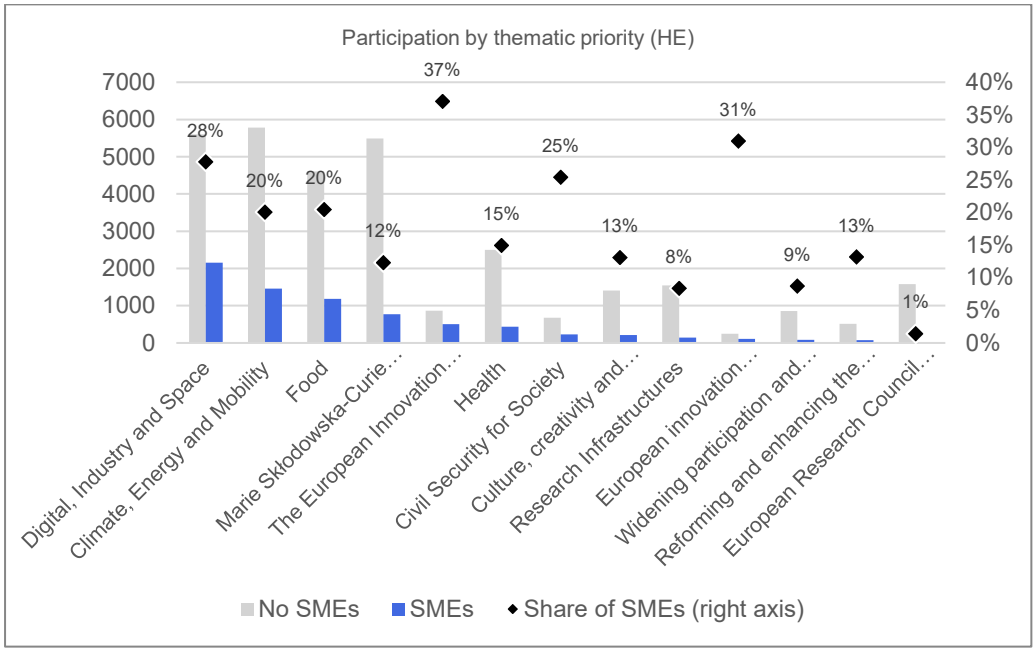


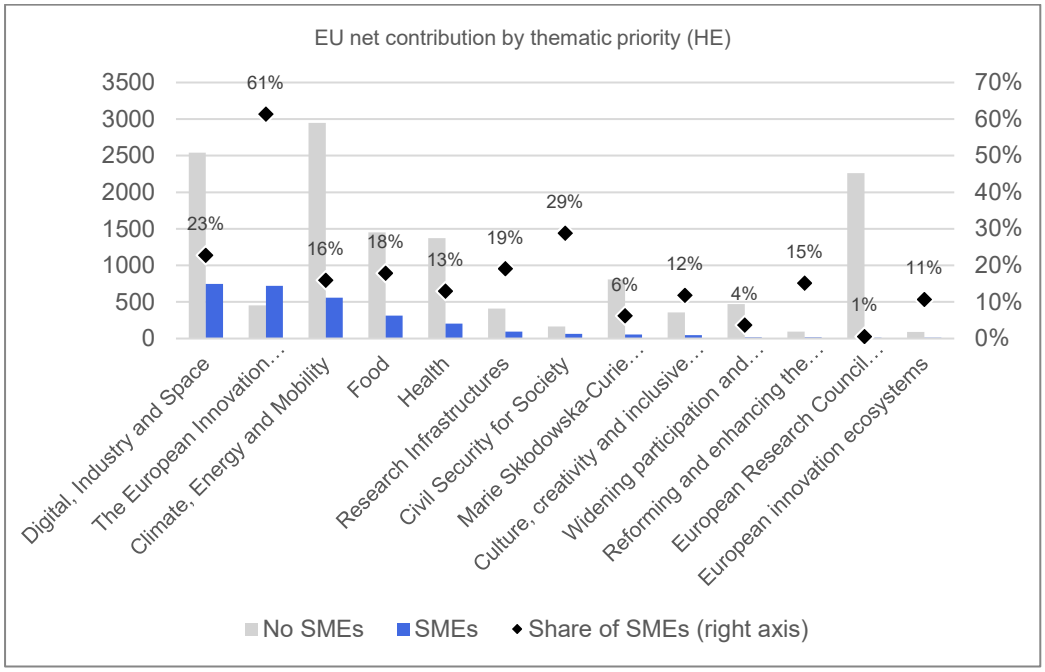


Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

In Horizon Europe, the share of SME participation is the highest in the EIC (37 %) and in the European innovation ecosystems (31 %) (Figure 60). SMEs also represent around a third of participation in the digital, industry and space cluster (28 %) and 25 % in the civil security for society cluster. A total of 61 % of the EU's contribution under the EIC goes to SMEs (EUR 718 million over 2021–2022). The share of the EU's net contribution to SMEs is also high in the civil security for society cluster (29 %), the digital, industry and space cluster (23 %), research infrastructure cluster (19 %) and the food, bioeconomy, natural resources, agriculture and environment cluster (18 %).

Figure 60. Horizon Europe SME participation by thematic priority (top) and the EU's net contribution to Horizon Europe by thematic priority (bottom)

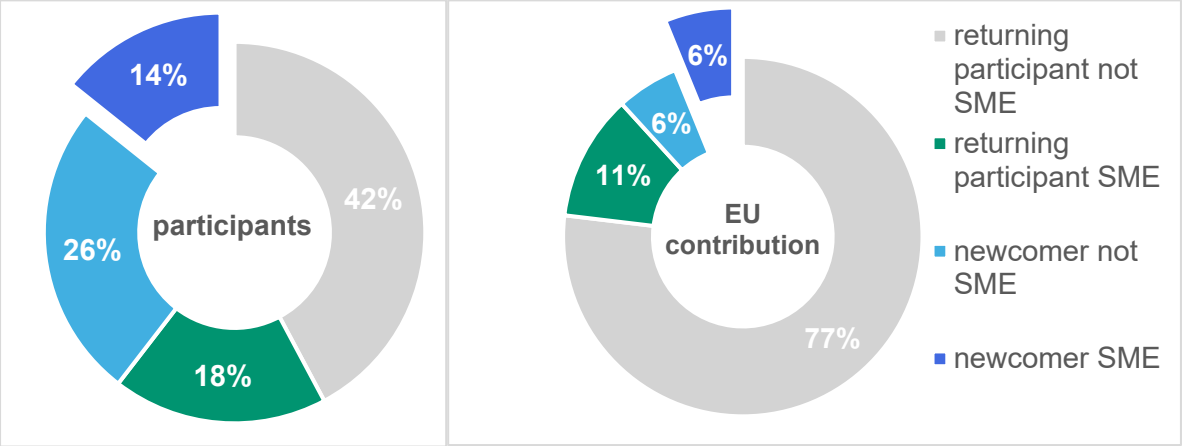




Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

Horizon Europe is attractive for newcomer SMEs. There are 2 026 unique participants (14.3 %) on the records that have been flagged as SMEs and did not have any successful application under Horizon 2020. These participants are 43.9 % of all SME participants. The 14.3 % of unique SME participants amounts to 6 % of the EU contribution received (Figure 61).

Figure 61. Share of newcomer SME participants in Horizon Europe, by number of unique participants (left) and EU contribution received (right)



Source: R & I dashboard/CORDA, cut-off date 30 December 2022.

4.3. Synergies between Horizon Europe and other EU funds

The creation of synergies refers to the interaction of two or more programmes aiming to enhance the effects that could be achieved by individual interventions ([265])**.** The challenges facing the EU are of increasing complexity and call for a more structured and strategic mix of policies at EU, national and regional level. In order to maximise the economic and societal impact of R & I policies, different EU funding programmes need to work on synergies and complement each other ([266]).

In 2007, in the communication on contribution to more growth and more and better jobs, the European Commission explicitly acknowledged the necessity to **create and strengthen synergies** between the framework programme for R & I and other funding instruments within the EU ([267]). Since then, **synergies have become increasingly important in the design of EU funding instruments, including the EU framework programme for R & I**. As an example, the 2014–2020 legal frameworks of Horizon 2020 and the European Structural and Investment Funds both explicitly require the implementing bodies to create synergies between the two programmes ([268]). Similarly, Horizon Europe also envisages the creation of synergies by design ([269]) (introducing a legal obligation to create synergies in Annex IV of Regulation (EU) 2021/695) through better harmonisation of funding rules for projects, higher flexibility of co-funding schemes, reduction of the overlaps in funding, closer alignment of complementing programmes' strategic priorities in support of a common vision, and dissemination and exploitation of results, monitoring, auditing and governance ([270]).

Synergies can take different forms, for example synergies within Horizon Europe, synergies across the multiannual financial framework, synergies across other EU policy interventions and synergies with the Member States' actions. In this section, attention is put on **synergies between Horizon Europe and other EU funding programmes**. When looking at synergies across the multiannual financial framework, it is important to distinguish between programmes in shared management and centrally managed programmes.

([265]) European Court of Auditors (2022), *Special Report: Synergies between Horizon 2020 and European structural and investment funds – Not yet used to full potential*, Publications Office of the European Union, Luxembourg, https://www.eca.europa.eu/Lists/ECADocuments/SR22_23/SR_H2020_and_ESI_Funds_EN.pdf.

([266]) Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the framework programme for research and innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013 (OJ L 170, 12.5.2021, p. 1), Annex IV.

([267]) European Commission (2007), Competitive European regions through research and innovation – A contribution to more growth and more and better jobs, COM(2007) 474 final.

([268]) European Court of Auditors (2022), *Special Report: Synergies between Horizon 2020 and European structural and investment funds – Not yet used to full potential*, Publications Office of the European Union, Luxembourg, https://www.eca.europa.eu/Lists/ECADocuments/SR22_23/SR_H2020_and_ESI_Funds_EN.pdf.

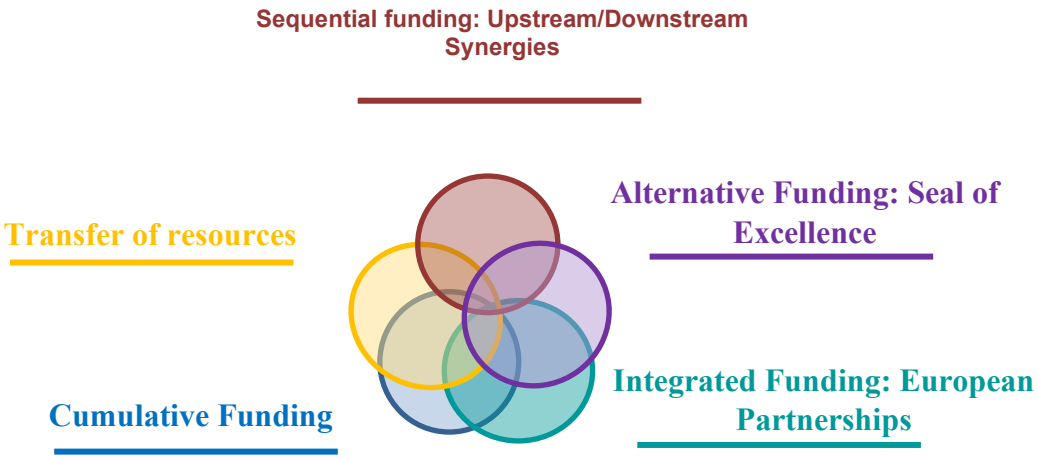
([269]) Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the framework programme for research and innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013 (OJ L 170, 12.5.2021, p. 1), recital 34.

([270]) European Commission, Directorate-General for Research and Innovation (2018), *A new horizon for Europe – Impact assessment of the 9th EU framework programme for research and innovation*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/194210.

As a case in point, increasing efforts have been put into strengthening synergies between the R & I framework programmes and the European Structural and Investment Funds. Nevertheless, despite both being intended to provide support to R & I activities within the EU, they differ in several respects (e.g. objectives, management, implementation), making the planning and implementation of synergies between these funds complex ([271]). A stronger focus on creating complementarities that could strengthen the impact of both funds is thus needed **to maximise the scientific, economic and societal impact of the EU's policies, and to leverage R & I investments in Europe from all sources**.

Figure 62 provides an overview of the types of synergies that can be created between Horizon Europe and other EU funds. **Upstream synergies** aim to support capacity-building activities for research to increase the chances of beneficiaries being successful in the framework programme's application process, while **downstream synergies** refer to the deployment of results from Horizon Europe's projects in other programmes or initiatives.

Figure 62. Types of synergies between Horizon Europe and other EU programmes



The Seal of Excellence ([272]) recognises the value of a proposal submitted under a competitive call that could not be funded due to budgetary constraints. Thus, it represents a quality label awarded by the European Commission to a specific project, intended to flag its quality and increase its chances to receive support from other EU or national sources of funding. Member States also have the possibility to **transfer resources** ([273]) allocated to them under shared managed programmes to the Horizon Europe programme, and use these for the benefit of the Member State or region ([274]). **Cumulative funding** ([275]) arises when the same action receives separate contributions from multiple EU funds, programmes or instruments (including both shared and centrally managed funds). Finally, synergies under **European partnerships** relate to initiatives jointly

([271]) European Court of Auditors (2022), *Special Report: Synergies between Horizon 2020 and European structural and investment funds – Not yet used to full potential*, Publications Office of the European Union, Luxembourg, https://www.eca.europa.eu/Lists/ECADocuments/SR22_23/SR_H2020_and_ESI_Funds_EN.pdf.

([272]) Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the framework programme for research and innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013 (OJ L 170, 12.5.2021, p. 1), Articles 2(23), 15(2), 24(4), and 48(7).

([273]) Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the framework programme for research and innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013 (OJ L 170, 12.5.2021, p. 1), Article 15(5) and (6).

([274]) European Commission (2022), Communication to the Commission – Approval of the content of a draft Commission notice on the synergies between ERDF programmes and Horizon Europe, C(2022) 4747 final.

([275]) Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the framework programme for research and innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013 (OJ L 170, 12.5.2021, p. 1), Article 15(5) and (6).

supported by the EU and private and/or public partners (such as industry, public bodies or foundations) for the development and implementation of R & I activities ([276]).

Box 15. Downstream synergies

Building on the experience of Horizon 2020, the potential for the roll-out and deployment of the results of the new framework programme through other EU programmes is still high. According to the evaluation study on 'the external coherence and synergies of Horizon 2020 within the European research and innovation support system', only a limited share of Horizon 2020 projects from various disciplines were linked (based on sharing at least one beneficiary and keywords) ([277]) to EU initiative projects beyond the Horizon 2020 framework. Similarly, the Court of Auditors also flagged the lack of more downstream synergies as a missed opportunity for translating R & I results into practice, thereby limiting the impact of EU funding ([278]).

A lack of information on and low awareness of the broad set of support schemes available through the different EU-funded programmes are some of the main challenges. Stakeholders typically struggle to understand the overall EU and national landscape of existing support mechanisms and the exact ways in which the traditional Horizon 2020 grants can be combined with other national and EU financial support (e.g. loans, equity, guarantees) ([279]).

The large number of available instruments creates a rather complex R & I support framework, aggravated by insufficient/non-centralised information for project opportunities and project results, which makes the navigability and understanding of their practical implementation challenging, especially for entities with no previous experience with Horizon 2020 or other support schemes ([280]).

Source: European Commission, Directorate-General for Research and Innovation.

Promoting an integrated approach and strengthening synergies between key EU policy instruments and funding programmes are crucial to reinforce the impact of the EU's policy actions and R & I results across different fields and areas. As an example, the Commission published the communication on the synergies between ERDF programmes and Horizon Europe in July 2022. The aim is to reinforce the impact of EU innovation and cohesion policies by providing national managing authorities with clear guidelines on how to create complementarities between the different programmes, thereby fostering excellence in R & I, while also mitigating and overcoming the persistent innovation divide. In addition, Annex IV of Regulation (EU) 2021/695 establishing Horizon Europe requires the creation of synergies with other EU funding programmes, providing details on how these synergies should apply, depending on the EU programme considered. These include, among others, synergies with the European Maritime, Fisheries and Aquamarine Fund to meet the R & I needs in the fields of marine and integrated maritime policy; with the European Social Fund Plus to ensure the scale-up of innovative curricula supported by the programme, and facilitate the reskilling of people to meet the new needs of the labour market; with the Connecting Europe Facility to support the roll-out of innovative new technologies in the fields of transport, energy and digital physical infrastructures; and with the Internal Security Fund and the Integrated Border Management Fund to support deployment of innovative new capabilities for law enforcement and for border management. Another example is represented by the Emissions Trading System's Innovation Fund ([281]), whose synergies with the

([276]) Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the framework programme for research and innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013 (OJ L 170, 12.5.2021, p. 1), Article 15(4).

([277]) The linking was carried out by, first, linking projects from Horizon 2020 with projects from other programmes if they shared at least one beneficiary. This provides initial insights into possible links between Horizon 2020 and other programmes, but it does not necessarily indicate any synergies or overlaps. Hence, to refine these links, projects that did not share any keywords were decoupled. Keyword linking was carried out, when possible, using European Science Vocabulary keywords, as the majority of Horizon 2020 projects have several of these keywords assigned to them.

([278]) European Court of Auditors (2022), *Special Report: Synergies between Horizon 2020 and European structural and investment funds – Not yet used to full potential*, Publications Office of the European Union, Luxembourg, https://www.eca.europa.eu/Lists/ECADocuments/SR22_23/SR_H2020_and_ESI_Funds_EN.pdf.

([279]) European Commission, Directorate-General for Research and Innovation (2023), *Evaluation study on the external coherence and synergies of Horizon 2020 within the European research and innovation support system – final report*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/90147.

([280]) European Commission, Directorate-General for Research and Innovation (2023), *Evaluation study on the external coherence and synergies of Horizon 2020 within the European research and innovation support system – final report*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/90147.

([281]) The Innovation Fund is one of the world's largest funding programmes for the demonstration of innovative low-carbon technologies. The fund will provide around EUR 38 billion of support from 2020 to 2030 (at EUR 75 per ton of CO_2),

R & I framework programme could facilitate the exploitation of R & I project results towards market uptake and commercialisation using an innovation pipeline approach.

There are still challenges to maximising the potential of synergies. Building on the experience with Horizon 2020, several factors have been identified as instrumental in creating and enhancing synergies between the framework programme and other EU funding instruments. These include, but are not limited to, improving cooperation between EU and national bodies involved in the management of the EU programmes by ensuring regular and structured dialogues and exchanges; ensuring a more systematic monitoring of the framework programme's implementation by exploiting data's potential to foster synergies; and improving the overall flow of information about high-quality projects between the European Commission and the Member States, which would allow the maximisation of the potential of initiatives such as the Seal of Excellence. ([282]). In addition, a better synchronisation of planning and implementation timelines of relevant EU programmes is needed to capitalise on the full potential of R & I investments in the EU ([283]).

4.4. Gap analysis by cluster of Horizon Europe

A gap analysis has been performed for the six clusters of pillar 2 of Horizon Europe, with the goal of having an overview of their intervention areas (as defined in the specific programme), their coverage in the Strategic Plan 2021–2024 and work programmes 2021–2024, and current and potential gaps resulting from recent developments. The gap analysis was carried out by the responsible Commission services, with input from across the Commission and from the programme committee configurations. The results from the gap analysis and the identified gaps are presented in detail in Tables 16–21.

depending on the carbon price (Agentschap Innoveren & Ondernemen (n.d.), *EU Funding Overview – Innovation Fund (ETS Innovation Fund)*, https://eufundingoverview.be/funding/innovation-fund#:~:text=The%20Innovation%20Fund%20is%20a%20key%20funding%20instruments,vision%20of%20a%20climate%20neutral%20Europe%20by%202050).

([282]) European Court of Auditors (2022), *Special Report: Synergies between Horizon 2020 and European structural and investment funds – Not yet used to full potential*, Publications Office of the European Union, Luxembourg, https://www.eca.europa.eu/Lists/ECADocuments/SR22_23/SR_H2020_and_ESI_Funds_EN.pdf.

([283]) Council of the European Union, General Secretariat of the Council (2023), *Draft Council conclusions on the European Court of Auditors' Special Report No 23/2022 entitled 'Synergies between Horizon 2020 and European structural and investment funds – Not yet used to full potential'*, Council of the European Union, Brussels, https://data.consilium.europa.eu/doc/document/ST-5227-2023-INIT/en/pdf.

Table 16. Gap analysis for cluster 1 – health

Intervention area	Coverage in Strategic Plan 2021–2024	Coverage in work programmes 2021–2024	Potential gaps
Health throughout the life course	This intervention area is covered by the strategic plan's expected impact 1 'staying healthy in a rapidly changing society' and expected impact 2 'living and working in a health-promoting environment'. It is also covered by expected impact 3 'tackling diseases and reducing disease burden', as this expected impact also covers prevention.	• Mental health • Healthy diets (including the ERA4Health partnership) • Non-communicable diseases (including Global Alliance on Chronic Diseases, ERA4Health partnership) • Healthy ageing • Children and adolescent health • Roadmap for personalised prevention • Healthy citizens (empowerment and health literacy)	• Prenatal, neonatal, maternal and paternal health are insufficiently covered. • R & I for planning, implementing and monitoring rehabilitation throughout the life course, especially in children are not addressed. • Mental health is well covered. However, it is a rapidly growing challenge exacerbated by climate change, digital stress, mental health aspects of the COVID-19 pandemic and Russia's invasion of Ukraine. Mental health was also highlighted as a main priority in the State of the Union address 2022.
Environmental and social health determinants	This intervention area is covered by the strategic plan's expected impact 2 'living and working in a health-promoting environment' and expected impact 1 'staying healthy in a rapidly changing society'. It is also covered by expected impact 6 'maintaining an innovative, sustainable and globally competitive health-related industry', as this expected impact addresses environmental pollution due to pharmaceuticals (manufacturing and use).	• Air quality and health • Electromagnetic fields and health • Climate change and health • Occupational health (mental and physical) • Pollution (including air quality, noise, light pollution and hazardous waste) • Chemical exposure (including EU co-funded partnership on risk assessment – the partnership for the assessment of risks from chemicals) • Environmental exposures throughout the life course: support for exposome research • Health impact of digitisation: health of children and adolescents • Promotion of healthy lifestyles and consumption behaviour: health of children and adolescents	• Environmental risk factors in occupational settings are insufficiently covered – exposure to hazardous substances (including nanomaterials) or biological agents in occupational environments and adverse health outcomes. • Health consequences of climate change and climate adaptation measures are insufficiently covered, as the topic is very broad and of growing importance. (This topic has also not been properly addressed across previous framework programmes.)

Non-communicable and rare diseases	This intervention area is mainly covered by the strategic plan's expected impact 3 'tackling diseases and reducing disease burden'. It is also partly covered by expected impact 1 'staying healthy in a rapidly changing society' (as it covers understanding health and mechanisms of diseases, and prevention and screening programmes) and expected impact 5 'unlocking the full potential of new tools, technologies and digital solutions for a healthy society' (as it covers treatments, cures or other therapeutic interventions).	• Palliative, supportive and end-of-life care • Understanding of the mechanisms of non-communicable diseases • Understanding of health and disease parameters • Treatments, cures or other therapeutic interventions • Health promotion, disease prevention and screening • Diagnostic tools and techniques • Comparative effectiveness research • Implementation research on risk reduction for non-communicable diseases • Rare diseases (including the rare diseases partnership) • Support for structuring brain health research in Europe through a coordination and support action topic in the cluster 1 part of the 2023–2024 work programme • Fostering of the European research area (the ERA4Health partnership) • Support for the EU Mission on Cancer and Europe's beating cancer plan	• Understanding and management of multimorbidities are insufficiently covered. • Rehabilitation is not covered – effective approaches for acute or chronic health conditions. • A potential future brain health research partnership is to be considered for the 2025–2027 strategic plan.
Infectious diseases, including poverty-related and neglected diseases	This intervention area is mainly covered by the strategic plan's expected impact 3 'tackling diseases and reducing disease burden'. It is also partly covered by expected impact 5 'unlocking the full potential of new tools, technologies and digital solutions for a healthy society' (as it covers *in*	• Understanding of infection-related mechanisms • Prevention, detection and treatment of infectious diseases • Pandemic preparedness (including support for an EU partnership on pandemic preparedness) • Public health emergencies (COVID-19 clinical trials and cohorts)	• There is a potential gap on the impact of the evolution of ecosystems on the dynamics of infectious diseases. • Pandemic preparedness and response will need further investments, including those to ensure the development of appropriate medical countermeasures for serious cross-border health threats. • There is need to address low vaccine uptake, understand vaccine hesitancy and build vaccine confidence.

	vitro diagnostic devices to tackle cross-border health threats).	• Antimicrobial resistance (the one health antimicrobial resistance partnership)	• There is a potential gap on transborder aspects of infectious diseases – relation to migratory flows and increased human mobility in general.
Tools, technologies and digital solutions for health and care, including personalised medicine	This intervention area is covered by the strategic plan's expected impact 5 'unlocking the full potential of new tools, technologies and digital solutions for a healthy society' and expected impact 6 'maintaining an innovative, sustainable and globally competitive health-related industry'.	• Health tools and technologies • Integrated tools, technologies, devices, biotechnology, nanomedicine and advanced therapies • Innovative processes for the development and manufacturing • Safety, efficacy, interoperability and quality of tools and technologies • Regulatory science and standards for health tools and technologies • Information tools and technologies, and health data	• Cross-sectoral cooperation of key stakeholders could be strengthened. • Integrated tools and hybrid health technologies are to be further explored, as the field is broad and very dynamic. • Deployment and procurements need to be revisited.
Healthcare systems	This intervention area is covered by the strategic plan's expected impact 4 'ensuring access to innovative, sustainable and high-quality healthcare' and expected impact 6 'maintaining an innovative, sustainable and globally competitive health-related industry'.	• Quality of care and patient safety • Decision support tools (cancer) • Resilience of health and care systems (procurement for resilience, access to regular care in emergency situations) • Financing of health and care services and products (including health technology assessment and pricing models) • Health and care workforce • People in vulnerable situations and access to care • Environmentally sustainable health and care systems • Support for innovation procurement • Support for the transformation of health and care systems (the transforming health and care systems partnership)	Possible gaps will depend on content of calls and activities launched under the partnership on transforming health and care systems. The partnership will focus on key challenges for the resilience of health and care systems. Priority areas will be integrated care, person-centred care, workforce skills, financing and governance, digitalisation, quality of care and patient safety.

		• Personalised medicine (including the partnership on personalised medicine) • Health information and use or reuse of health data – electronic health record exchange format (EEHRxF)	

Table 17. Gap analysis for cluster 2 – culture, creativity and inclusive society

Intervention area	Coverage in Strategic Plan 2021–2024	Coverage in work programmes 2021–2024	Potential gaps
Democracy and governance	This is covered by expected impact 7 'democratic governance is reinvigorated by improving the accountability, transparency, effectiveness and trustworthiness of rule-of-law-based institutions and policies, and through the expansion of active and inclusive citizenship empowered by the safeguarding of fundamental rights'.	The first two work programmes covered all the elements included in the strategic plan. This includes topics linked with the following broad areas: • evolution of democracies (four topics) • education (one topic) • role of social capital and access to culture (one topic) • democratic governance (two topics) • populism, racism, extremism and radicalisation (four topics) • media and journalistic standards (two topics) • inclusion and intercultural dynamics, and identities (three topics) • technology and AI (two topics) • deliberative, participatory and direct democracy (four topics) • inequalities (three topics) • disinformation (two topics)	Recent geopolitical factors may lead to new research gaps in areas such as: • the impact of the energy crisis, geopolitical tensions and rising authoritarianism in Europe on the health of European democracies • the emergence of metaverses and the challenges and opportunities they bring for democracy and the intergenerational pact • the theory and practice of scientific diplomacy • judicial independence • academic freedom and freedom of expression, strengthening an open and enlightened public discourse, moving away from misinformation and combating self-censorship • local democracy and citizen empowerment • the impact of wars and post-war reconstruction on governance • political parties and their transformation

		• multilateral governance (four topics) • justice systems (one topic) • gender (mainstreamed and the focus of two topics) • intergenerational (one topic)	
Culture, cultural heritage and creativity	This is covered by expected impact 8 ‘the full potential of cultural heritage, arts and cultural and creative sectors as a driver of sustainable innovation and a European sense of belonging is realised through a continuous engagement with society, citizens and economic sectors as well as through better protection, restoration and promotion of cultural heritage’.	Most of the elements of the strategic plan have been covered in 32 topics of the first two work programmes in the following areas: • 28 topics on research and innovation on cultural heritage and cultural and creative industries • 2 topics on engagement with stakeholders • 2 topics on a European Collaborative Cloud for Cultural Heritage	Developments in science, technology, AI, culture, international economic relations, geopolitics and policy, and the post pandemic reality that has emerged have lead to new research gaps, including gaps on: • the European Collaborative Cloud for Cultural Heritage • the need for digital skills in the sector • a dedicated cultural and creative industry platform, and targeted research on specific cultural and creative industries and on their business models • tangible and intangible (including digital and digital-born) heritage in the context of cultural literacy, the role of the arts, the accessibility of culture, European integration and cohesion, and social inclusion • cultural heritage in the context of climate change and sustainability • small cultural organisations • the role of volunteering and the role of young people in a new European identity • silver age tourism and dissonant heritage (referring to visiting places that have been associated with genocide, ethnic cleansing, war or disaster), including the cultural heritage of colonialism • provenance research
Social and economic transformations	This is covered by expected impact 9 ‘social and economic resilience and sustainability are strengthened through a better understanding of the	The first two work programmes thoroughly covered all the elements included in the strategic plan. This	Recent economic and geopolitical factors may lead to new research gaps, such as gaps on:

	social, ethical, political and economic impacts of drivers of change (such as technology, globalisation, demographics, mobility and migration) and their interplay'. This is covered by expected impact 10 'inclusive growth is boosted and vulnerabilities are reduced effectively through evidence-based policies for protecting and enhancing employment, education, social fairness and inequalities, including in response to the socioeconomic challenges due to the COVID-19 pandemic'.	includes topics linked with the following areas: • education (six topics) • skills, growth, fairness and resilience (five topics) • beyond GDP indicators and sustainability (two topics) • migration (seven topics) • inequalities (three topics) Moreover, horizontal elements such as the role of drivers of changes, COVID-19 and gender were integrated in most (for COVID-19) or all (for gender) topics. They were also at the centre of three standalone topics.	• new forms of inequalities in the light of the energy crisis, and the twin green and digital transition • social aspects of mental health issues • preparedness actions, including culture- and arts-based ones, to remedy new forms of inequalities such as mental health, with special focuses on youth, displaced people and the ageing population • social and economic impacts of climate change and related mitigation policies • migration governance, in particular labour immigration, including in the context of climate change • tax and benefit systems and their fairness, European trade, and social and development policies in a changing geopolitical environment affecting global value chains • the contribution of European and national cohesion, regional and urban development policies to the sustainable, fair, green and digital transition, and taking into account demographic changes and ageing • the contribution of behavioural sciences and implementation sciences to future socioeconomic transformations • modernisation of public authorities' governance and management systems to engage with citizens and meet their expectations regarding service provision, transparency, accessibility, openness, accountability and users' centricity

Table 18. Gap analysis for cluster 3 – civil security for society

Intervention area	Coverage in Strategic Plan 2021–2024	Coverage in work programmes 2021–2024	Potential gaps
Disaster-resilient societies	This is covered by expected impact 11 'losses from natural, accidental and man-made disasters are reduced through enhanced disaster risk reduction based on preventive actions, better societal preparedness, and resilience and improved disaster risk management in a systemic way'.	Expected impact 11 is covered by annual calls under destination 'a disaster-resilient society for Europe', and by topics under destination 'strengthened security research and innovation'. The work programme actions cover the following areas: • increased risk awareness and preparedness of citizens • improved disaster risk management and governance • strengthened capacities of first and second responders • improved harmonisation and/or standardisation for crisis management, and chemical, biological, radiological and nuclear substances and explosives	• Transport disasters • Post-disaster recovery • Economics of disasters • Nature-based solutions for prevention The following topics could not be taken up in the work programme 2023–2024 due to budget prioritisation, and thus remain research gaps: • cooperation across disciplines and administrative levels related to disaster and crisis management • augmented reality solutions for improved situational awareness in emergency situations • integration of citizen volunteers • disaster risk reduction cooperation among global organisations, and local first and second responders Recent geopolitical and societal changes may lead to new research gaps, such as: • ways of dealing with climate-related disaster events, which are becoming potentially more frequent and more serious • the increased tendency for cascading and compound events • civilian protection and the resilience of citizens
Protection and security	This is covered by two expected impacts: expected impact 12 'legitimate passengers and shipments travel more easily into the EU, while illicit trades, trafficking, piracy, terrorist and other criminal acts are prevented, thanks to improved air,	Expected impact 12 is covered by annual calls under destination 'effective management of EU external borders', and by topics under destination 'strengthened security research and innovation'.	• Interoperability between civil protection and military forces • Tackling terrorist ideas and beliefs, and crimes based on sexual orientation or racial discrimination • Counterfeit products

	land and sea border management and maritime security including better knowledge of social factors'; and expected impact 13 'crime and terrorism are more effectively tackled, while respecting fundamental rights, and resilience and autonomy of physical and digital infrastructures are enhanced and vital societal functions are ensured, thanks to more powerful prevention, preparedness and response, a better understanding of related human, societal and technological aspects, and the development of cutting-edge capabilities for police authorities and infrastructure operators, including measures against cybercrime'.	As well as open topics, the work programme actions cover the following areas: • efficient border surveillance and maritime security • secured and facilitated crossing of external borders • better customs and supply chain security Expected impact 13 is covered by annual calls under destination 'better protect the EU and its citizens against crime and terrorism' and destination 'resilient infrastructure', and by topics under the destination 'strengthened security research and innovation'. Work programme actions cover the following areas: • modern information analysis for fighting crime and terrorism • improved forensics and lawful evidence collection • enhanced prevention, detection and deterrence of societal issues related to various forms of crime • increased security of citizens against terrorism, including in public spaces • organised crime prevented and combated • citizens protected against cybercrime • improved preparedness and response for large-scale disruptions of European infrastructures • resilient and secure (urban areas and) smart cities	• Dangerous chemicals (chemical, biological, radiological and nuclear) The following topics could not be taken up in the 2023–2024 work programme due to budget prioritisation, and thus remain research gaps: • increased security for air cargo • prevention and mitigation of piracy, hijacking, attacks or kidnapping of ships' crew • 3D printing of weapons, including of energetic materials • risk of non-state actors' development and deployment of a bioterrorist weapon • organised property crime • lawful interception: facing upcoming challenges • environmental impact of production of illicit drugs • counterfeiting of pharmaceutical products • climate proofing of critical entities and impact of climate change on critical infrastructure • pathways to standardisation and certification schemes for security • safety and security of security practitioners operating in hazardous environments • data repository for security R & I Recent geopolitical and societal changes may lead to new research gaps, such as: • tackling of the potential increase in organised crime such as human trafficking, cybercrime and firearms trafficking • protection and resilience of critical entities, including implementing the CER directive • situational awareness and border management for potential large-scale movements of people • increased social instability creating potential for misinformation with security implications and for violent radicalisation

			• continued technological development and digitalisation (e.g. AI, immersive technologies, use of algorithmic amplification and manipulation tactics) creating new opportunities for criminals, violent extremists and terrorists, and new challenges and opportunities for law enforcement
Cybersecurity	This is covered by expected impact 14 ‘increased cybersecurity and a more secure online environment by developing and using effectively EU and Member States’ capabilities in digital technologies supporting protection of data and networks aspiring to technological sovereignty in this field, while respecting privacy and other fundamental rights; this should contribute to secure services, processes and products, as well as to robust digital infrastructures capable to resist and counter cyberattacks and hybrid threats’.	Expected impact 14 is covered by annual calls under destination ‘increased cybersecurity’. Work programme actions cover the following areas: • secure and resilient digital infrastructures and interconnected systems • hardware, software and supply chain security • cybersecurity and disruptive technologies • smart and quantifiable security assurance and certification shared across Europe • human-centric security, privacy and ethics • system security and security lifetime management, secure platforms and digital infrastructures • privacy-preserving and identity technologies • secured disruptive technologies • cryptography	• Secure and resilient hardware and software systems, particularly for critical infrastructure protection and in support of the Cyber Resilience Act, including in relation to new and emerging threats • The need to increase the security of widely-used technologies • The need to strengthen post-quantum R & I and crypto-agility

Table 19. Gap analysis for cluster 4 – digital, industry and space

Intervention area	Coverage in Strategic Plan 2021–2024	Coverage in work programmes 2021–2024	Potential gaps
Manufacturing technologies	This is covered primarily by the strategic plan's expected impact 15 'global leadership in clean and climate-neutral industrial value chains, circular economy and climate-neutral digital systems and infrastructures (networks, data centres), through innovative production and manufacturing processes and their digitisation, new business models, sustainable-by-design advanced materials and technologies enabling the switch to decarbonisation in all major emitting industrial sectors, including green digital technologies'; and expected impact 20 'a human-centred and ethical development of digital and industrial technologies through a two-way engagement in the development of technologies, empowering end users and workers, and supporting social innovation'. This is also linked to expected impact 16 'industrial leadership and increased autonomy in key strategic value chains with security of supply in raw materials achieved through breakthrough technologies in areas of industrial alliances, dynamic industrial innovation ecosystems and advanced solutions for substitution, resource and energy efficiency, effective reuse and recycling and clean primary	In 2021–2022, the investments in manufacturing centred on particular technologies, mostly factory level, addressing the made in Europe SRIA. In 2023–2024, the investments in manufacturing were shifted towards more systemic approaches, integrating technologies and addressing supply chains, the circular economy, and manufacturing as a service; the human side was integrated through skills development, and biointelligent manufacturing was addressed for the first time.	• The development of human-centred technology (industry 5.0), including social science and humanities perspectives • Breakthrough manufacturing technologies including biotechnological production, and services to accelerate sustainable and digital technological transformation • The ever-increasing need for resilience and supply chain management, including diversification of supplies and distribution of scarce resources – there are major new challenges for supply chain management following the disruptions caused by the new geopolitical situation and the COVID-19 pandemic, but also due to new business models needed to implement the Green Deal and the circular economy, and new employment patterns • The availability of better data / digital spaces to predict the availability of components and plan production, and more flexibility • A renewed emphasis on energy efficiency • A greater emphasis on systemic circularity – collecting, reusing and recycling materials and components – and improving tracing and sorting • Integrating material development and production, with attention paid to the concept 'safe and sustainable by design'

	production of raw materials, including critical raw materials and leadership in circular economy'; expected impact 17 'globally attractive, secure and dynamic data-agile economy by developing and enabling the uptake of the next-generation computing and data technologies and infrastructures (including space infrastructure and data), enabling the European single market for data with the corresponding data spaces and a trustworthy artificial intelligence ecosystem'; and expected impact 18 'open strategic autonomy in digital technologies and in future emerging enabling technologies by strengthening European capacities in key parts of digital and future supply chains, allowing agile responses to urgent needs, and by investing in early discovery and industrial uptake of new technologies'.		
Digital technologies, including quantum technologies and photonics	This is covered by the strategic plan's expected impact 15 'global leadership in clean and climate-neutral industrial value chains, circular economy and climate-neutral digital systems and infrastructures (networks, data centres), through innovative production and manufacturing processes and their digitisation, new business models, sustainable-by-design advanced materials and technologies enabling the switch to decarbonisation in all major emitting industrial sectors, including green digital technologies'; expected impact 16 'industrial leadership and increased autonomy in key strategic	The 2021–2024 work programmes addressed this intervention area under destination 4 ('digital and emerging technologies for competitiveness and fit for the Green Deal'). They covered the following areas. • **Quantum.** Activities covered the maturation of the quantum computing and simulation platforms; support for basic research that will lead to the next generation of quantum-sensing technologies and devices; transition of laboratory demonstrators to industrial applications for market uptake; first steps in building a quantum	• Low-TRL research on Quantum technologies. • Quantum computing and simulation (development of the higher layers of the software stack, and new quantum algorithms) • Identification of highly scalable, mass-manufacturable quantum computing components and architectures • Quantum sensing (miniaturisation and integration of quantum sensors for widespread uptake) • Quantum communications (improvement of industrialisation by realising manufacturable technology) • Experimentation, testing and production facilities (transition towards standard industrial design and manufacturing processes

	value chains with security of supply in raw materials, achieved through breakthrough technologies in areas of industrial alliances, dynamic industrial innovation ecosystems and advanced solutions for substitution, resource and energy efficiency, effective reuse and recycling and clean primary production of raw materials, including critical raw materials and leadership in circular economy'; and expected impact 18 'open strategic autonomy in digital technologies and in future emerging enabling technologies by strengthening European capacities in key parts of digital and future supply chains, allowing agile responses to urgent needs, and by investing in early discovery and industrial uptake of new technologies'.	internet; support for the development of critical components and technologies needed to build a space quantum key distribution system; basic quantum research; and pilot lines and testing facilities for quantum. • **Photonics.** Activities covered fostering of the progressive integration of light-based functionalities into miniaturised systems and eventually integrated circuits; and the extension of sensing capabilities to new wavelengths of light, which opens up new applications. Other topics revolved around two technology groups: sensing/imaging systems and light sources/modulators. • **Communication networks.** Activities in this area were conducted by the smart network and services joint undertaking, except for two actions with low technology readiness levels (intervention area 'emerging technologies'). • **Microelectronics.** Activities in this area were mostly conducted by the key digital technologies joint undertaking, except actions with lower technology readiness levels (intervention area 'emerging technologies').	established by the microelectronics and photonics industry) • Digital/smart photonics for advanced manufacturing and an industrial internet managing data spaces and digital twins (integration of software and hardware, including augmented, virtual and extended reality; and integration of photonic and optoelectronic devices) • Sensing and imaging (networks) enabling and using AI for mobility, safety and security, smart manufacturing and farming • Biophotonics and medical photonics (diagnostics of infectious diseases and neurodegenerative diseases; smart and/or AI-empowered compact sensors for wearables and point-of-care diagnostics; bio-interfaces) • Next-generation resilient and secure communication networks (automation in communication networks, flexible and programmable ready-to-use devices enabling a lower carbon footprint; and quantum-grade components) • Photonics and optoelectronics integration at relevant wavelengths (sensing, communication) and up to photonic integrated circuits • Photonics for new computing paradigms beyond von Neumann architecture, including neuromorphic and quantum computing
Emerging enabling technologies (graphene / advanced materials at	This is covered by the strategic plan's expected impact 16 'industrial leadership and increased autonomy in key strategic value chains with security of supply in raw materials,	The 2021–2024 work programmes addressed this intervention area under destination 4 ('digital and emerging technologies for competitiveness and fit	Gaps related to graphene and other 2D materials include the following. • There is a need to address industrial-scale manufacturing of structures incorporating 2D materials.

large, photonics and electronics)	achieved through breakthrough technologies in areas of industrial alliances, dynamic industrial innovation ecosystems and advanced solutions for substitution, resource and energy efficiency, effective reuse and recycling and clean primary production of raw materials, including critical raw materials and leadership in circular economy'; and expected impact 18 'open strategic autonomy in digital technologies and in future emerging enabling technologies by strengthening European capacities in key parts of digital and future supply chains, allowing agile responses to urgent needs, and by investing in early discovery and industrial uptake of new technologies'.	for the green deal'). They covered the following areas. • **Graphene.** Activities covered the new generation of advanced electronic and photonic devices and sensors based on 2D materials; devices and systems based on 2D materials, for energy storage and harvesting, and for biomedical applications; advancement of the integration of 2D materials with current silicon technologies; fostering of the societal acceptance of the 2D material technologies; and further studying and development of the emerging 2D materials and heterostructures. • **Electronics.** Activities covered the ultra-low-power, secure processors for edge computing; open source hardware for ultra-low-power, secure processors; functional electronics for green and circular purposes in order to develop flexible and printed electronics solutions; research (with a low technology readiness level) addressing innovative semiconductor and microelectronic and nanoelectronic system design concepts. • **Communication networks.** Activities covered research (with a low technology readiness level) on disaggregated architectures with radio access networks beyond 5G/6G, RAN disaggregated architectures and on ultra-low-energy and secure networks.	• For electronics and related technologies, pilot lines and the upscaling of production are crucial, as is securing the supply chain for chips based on 2D materials. • Further investments are needed to bridge the gap between demonstration at laboratory scale and industrial adoption. • A made-in-Europe approach, integrating the complete value chain, is needed. • Risk assessment for operators and end users and regulations are far behind regarding their introduction into the market. • Further work is needed on biomedical applications of 2DM. • The investigation of safe and sustainable-by-design advanced materials and related process technologies is a crucial push in order to profit from the potential of these novel advanced materials and the systems they will provide. • Low-cost sensors based on 2D materials are needed to monitor the quality of water, food and air. • Further work is needed on 2D materials for various technologies (e.g. automotive, energy efficient ICT, aerospace, health). Gaps related to electronics include the need to sustain the fast-paced evolution of device performance, customisation, miniaturisation and cost, while reducing environmental footprint. Materials, integration (3D, electron/photon/phonon/spin interaction) and packaging. Gaps related to communication networks include gaps on: • The full value chain approach including components, integration and packaging and microelectronics for industry-grade connectivity and the Chips act.

			• Micro-electronic and photonic components for future 6G platforms.
Advanced materials	This is covered by the strategic plan's expected impact 15 'global leadership in clean and climate-neutral industrial value chains, circular economy and climate-neutral digital systems and infrastructures (networks, data centres), through innovative production and manufacturing processes and their digitisation, new business models, sustainable-by-design advanced materials and technologies enabling the switch to decarbonisation in all major emitting industrial sectors, including green digital technologies'; and expected impact 16 'industrial leadership and increased autonomy in key strategic value chains with security of supply in raw materials, achieved through breakthrough technologies in areas of industrial alliances, dynamic industrial innovation ecosystems and advanced solutions for substitution, resource and energy efficiency, effective reuse and recycling and clean primary production of raw materials, including critical raw materials and leadership in circular economy'.	The 2021–2024 work programmes addressed this intervention area under destination 2 'increased autonomy in key strategic value chains for resilient industry', in both the 2021–2022 work programme and the 2023–2024 work programme. In the 2021–2022 work programme, the focus was on the safe-and-sustainable-by-design advanced materials that are needed to meet the challenges of climate neutrality, transition to a circular economy and a zero-pollution Europe, and bring broader benefits in many different applications. In the 2023–2024 work programme, two main lines were followed: (i) strategic innovation markets driven by advanced materials for the twin green and digital transition and (ii) safe and sustainable by design.	• Strategic cross-cluster approach to advanced materials, including the concepts of bioinspiration, biologisation and bioprinting. • Emphasise circularity, sustainability and SSbD aspects of advanced materials/chemicals • Learning from nature and applying the here found concepts to proposed technical systems by using bioinspired, biohybrid and living materials. • There is a need to focus on the static as well on the dynamic properties of complex materials and on materials under extreme conditions. • Advanced materials and strategies as well as processes for sustainable value chains able to reduce the dependency on CRMs. • Integrating development and production of bio-based advanced materials/chemicals. • Emphasise data-driven research methodologies based on machine learning that can address all aspects of the materials workflow. • Digital spaces and tools for advance materials/chemicals design and information sharing along the value chain. • Tools for the safe and Sustainable by Design (SSbD framework as well as training of workforce (especially for SMEs) and students to use these. • Strengthened European capacity to produce and use chemicals and materials in a sustainable and energy efficient way. • Advanced materials for construction e.g. better energy recovery • Engaging SMEs in the design and upscaling of innovation of advanced materials.

			• Responsible sourcing and tracing and recycling of materials. • An EU innovation ecosystem of technology infrastructures, -OITBs.
Artificial intelligence and robotics	This is covered by the strategic plan's expected impact 15 'global leadership in clean and climate-neutral industrial value chains, circular economy and climate-neutral digital systems and infrastructures (networks, data centres), through innovative production and manufacturing processes and their digitisation, new business models, sustainable-by-design advanced materials and technologies enabling the switch to decarbonisation in all major emitting industrial sectors, including green digital technologies'; expected impact 17 'globally attractive, secure and dynamic data-agile economy by developing and enabling the uptake of the next-generation computing and data technologies and infrastructures (including space infrastructure and data), enabling the European single market for data with the corresponding data spaces and a trustworthy artificial intelligence ecosystem'; expected impact 18 'open strategic autonomy in digital technologies and in future emerging enabling technologies by strengthening European capacities in key parts of digital and future supply chains, allowing agile responses to	The 2021–2024 work programmes addressed this intervention area under destination 3 ('world-leading data and computing technologies'), destination 4 ('digital and emerging technologies for competitiveness and fit for the Green Deal') and destination 6 ('a human-centred and ethical development of digital and industrial technologies'). • In the area of robotics, investments were made on foundational concepts and application areas. • In the area of AI, R & I efforts were on progressing a set of technological areas related to the emerging paradigms (efficient methods of machine learning from multiple angles, scalability, explainability, robustness, reliability, language understanding and interaction) that can be harnessed for use in contemporary and upcoming challenges.	• Europe's research landscape is fragmented and there is a growing disconnect between industrial and academic AI research, due to the data-needs and high computational demands for modern AI. • New data and AI legislation will require compliance tools, experimentation sandboxes and validation/certification environments for systems. • The deployment (from 2023 onwards) of the first generation of Common European Data Spaces (funded under DEP) needs to be supported by new methods and tools for interoperability, data verification/validation, tracking/logging, including to ensure availability of large data sets while being compliant with applicable privacy regulation. • Algorithmic foundations of AI, machine learning (frugal, incremental), explainability, reliable and affordable generative and foundational models beyond text only, mixing data-driven and symbolic approaches or new paradigms. • Data and AI solutions for energy systems to ensure seamless and robust operation of energy grids with increasing share of renewable energy sources and fluctuating demand. • Dedicated instruments that allow start-ups and smaller companies to benefit from AI, data and robotics and to be an active part in developing the next generation smart technologies.

	urgent needs, and by investing in early discovery and industrial uptake of new technologies'; and expected impact 20 'a human-centred and ethical development of digital and industrial technologies, through a two-way engagement in the development of technologies, empowering end users and workers, and supporting social innovation'.		• Societal Trust and acceptance in AI, Data and Robotics • A coherent approach to skills development is needed across Europe from school to university to the job market (including academia-industry interaction and on-the-job training). • There is significant materials research across Europe and there is a strong need to connect this to the development of future robotic systems. Focus is needed to set European standards. • Core research in robotics (and smart objects) still needs to address remaining gaps at the cutting edges of autonomy, self-learning, interaction, perception and for new functionalities and form-factors, like ultra-small ones, or for use on land, air and water. • More disruptive approaches are needed in manufacturing (e.g. bio-intelligent manufacturing, circular manufacturing). Use of foundational models in industry settings is largely unexplored (embedding prior knowledge, robotic control, model compression/distillation). • Study and monitor the application of AI, data and Robotics in R&I and in particular in Science and Engineering, which is key for the productivity of science and for the strategic autonomy of the EU.

Next-generation internet	This is covered by the strategic plan's expected impact 18 'open strategic autonomy in digital technologies and in future emerging enabling technologies by strengthening European capacities in key parts of digital and future supply chains, allowing agile responses to urgent needs, and by investing in early discovery and industrial uptake of new technologies'; and expected impact 20 'a human-centred and ethical development of digital and industrial technologies, through a two-way engagement in the development of technologies, empowering end users and workers, and supporting social innovation'.	The 2021–2024 work programmes addressed this intervention area under destination 6 ('a human-centred and ethical development of digital and industrial technologies'). • In the area of next-generation internet, the initiative started building a large and growing community of innovators that is developing bottom-up technology solutions in priority areas such as trust and privacy, digital identities, internet architectures, blockchain and internet searches. • In the area of extended reality, research efforts targeted actions in interaction modelling and augmented/virtual reality technologies, and innovation actions in selected areas (collaborative telepresence, media, learning and haptics for all).	• The virtual worlds and metaverses (open, compliant, empowering users, businesses and industry) are some of the pressing challenges ahead of us. XR and NGI technologies are at the core of this challenge. • NGI: support to new open source solutions across their whole life-cycle; digital commons; focus NGI on bigger impact (security; sustainability; user empowerment; decentralisation) and political priorities (digital identity, product security, solutions for the "virtual worlds". • Authoring tools, including AI-assisted ones, to create virtual worlds, metaverses, digital twins and multi-modal user experiences (Extended Realities, Cyber-Physical Systems). • Extended reality: innovative display and immersion technologies and architectures, multimodal human-computer interaction; open-source real-time engines (e.g., spatial computing, rendering, multi-point interaction) based on established open standards such as OpenXR and WebXR; XR applied to digital twin technology. Ensure interoperability and create technical standards.
Advanced computing and big data	This is covered by the strategic plan's expected impact 17 'globally attractive, secure and dynamic data-agile economy by developing and enabling the uptake of the next-generation computing and data technologies and infrastructures (including space infrastructure and data), enabling the European single market for data with the corresponding data spaces and a trustworthy artificial intelligence ecosystem'; and expected impact 18 'open strategic autonomy in digital	The 2021–2024 work programmes addressed this intervention area under destination 3 ('world-leading data and computing technologies') and destination 4 ('digital and emerging technologies for competitiveness and fit for the green deal'). • In the area of data, R & I efforts in the work programmes aimed to mature and push the limits of data analytic capabilities, and provide methods and technologies for complying with emerging data legislation, standards, and the	• **Data technologies.** New legislation will require progressive development, piloting and deployment of data infrastructures and compliance methods/tools creating trusted environments for data-collection, curation, protection, exchange and trusted data-science operations. New threats will require robust, practical and flexible support for resilient energy, healthcare, mobility, food applications, some of those from real-time data streams. The provision of data spaces and data-driven tools, including AI and multi-paradigm collaborative solutions, will need to respond to these emerging needs.

	technologies and in future emerging enabling technologies by strengthening European capacities in key parts of digital and future supply chains, allowing agile responses to urgent needs, and by investing in early discovery and industrial uptake of new technologies'.	principles for the findability, accessibility, interoperability and reuse of digital assets. • R & I investments focused on establishing a baseline technology and emerging system concepts based on the cloud edge computing paradigms by building on relevant elements of computing, connectivity, the internet of things, AI and cybersecurity. • On the open source side (software/hardware), actions pursued openness at levels from the kernel to the processor, developing the ability to deploy high-performance computing / cloud / edge systems with computing devices based on open hardware architectures. • As regards advanced computing technologies (high-performance computing), these activities are conducted by the European high-performance computing joint undertaking.	• **Cloud edge and internet of things.** New pathways for networked, agile and green IoT-edge computing; extended decentralisation at the Cloud to Edge continuum for virtual reality/metaverse; automated, highly-contextualized (close to the data, up-to-date and robust), AI-driven decision making approach to local device/cloud governance to provide Quality of Service. • **Software engineering and open source.** Regarding AI for Software Engineering, "software co-engineering", the following aspects of the software development lifecycle are not covered yet: code search using natural language processing techniques, using AI to analyse the code quality, perform automatic bug fixing, or the application of AI-based failure prediction algorithms for the software at operation time, have, at this stage not been fully incorporated; low-code approaches will increase software quality and productivity, wider take-up, and ease of deployment, also from close-to-the-user configuration and personalisation.
Advanced circular industries	This is covered by the strategic plan's expected impact 15 'global leadership in clean and climate-neutral industrial value chains, circular economy and climate-neutral digital systems and infrastructures (networks, data centres), through innovative production and manufacturing processes and their digitisation, new business models, sustainable-by-design advanced materials and technologies enabling the switch to decarbonisation in all major emitting industrial sectors, including green	The 2021–2024 work programmes addressed this intervention area under destination 1 ('climate neutral, circular and digitised production'), in section 'circularity and zero pollution in process industries'; and destination 2 ('increased autonomy in key strategic value chains for resilient industry'), in section 'raw materials for EU open strategic autonomy and successful transition to a climate-neutral and circular economy'.	• There are potential gaps regarding the engagement of citizens. • The value of resources, materials and products, including in industrial waste, should be maintained for much longer with research on new strategies to achieve more durability/longer product lifetime. • New measurement reporting methods for circular industries, as well as policies to avoid greenwashing. • There are potential gaps regarding sustainable sourcing, usage and production of primary and secondary raw materials.

	digital technologies'; and expected impact 16 'industrial leadership and increased autonomy in key strategic value chains with security of supply in raw materials, achieved through breakthrough technologies in areas of industrial alliances, dynamic industrial innovation ecosystems and advanced solutions for substitution, resource and energy efficiency, effective reuse and recycling and clean primary production of raw materials, including critical raw materials and leadership in circular economy'.		• Ensuring safe and sustainable materials cycles including eco-design. • Ensuring a quality assured information flow in supply chains for resources, materials and products to enable safety and sustainability. • New pathways for industrial waste Cradle-to-Cradle approaches. • There are potential gaps regarding the deployment of research on the emergence of local circular value chains operated and managed by industry. • Industrial symbiosis should be used as a systemic approach to circularity, with resource flows efficiently distributed between plants across sectors and urban communities for an effective circular industry, maximising the potential and safety of secondary materials and minimising pollution. There is a need to ensure the valorisation and life cycle assessment of materials, and product streams' traceability for the consumption of resource and energy across goods and their manufacturing/logistics. • Available resources should be equally accessible, to avoid conflicts between industry and citizens. The security of supply using local resources should apply wherever possible. • Circularity needs to be more emphasised where reusing materials make sense, including for advanced digital manufacturing methods, notably of additive manufacturing materials. Need for tools to visualize, plan, implement, standardise and quantify circularity approaches in industry. • More disruptive approaches are needed in manufacturing and process industries. Regulation needs to keep up with these approaches. • There are potential gaps regarding tools for data-driven, automatised, digitised certification/qualification processes.

			Development of new business models is key for the deployment of circular technologies and value chains. • AI tools coupled with digital twins are needed. • The spreading of lighthouse demonstrators is necessary. • Strategies for reducing dependence on critical raw with a need to better take into account the climate/environmental subjects. • Recycling technologies (including instrumentation, chemistry, materials and new processes for recovery and recycling CRMs). • It is important to tackle all critical raw materials (there are 30 on the 2020 list) and the 83 materials analysed in the critical raw material assessment. • There are potential gaps regarding the development of technologies for mining waste and tailing reuse and recycling. • There is a need for substitution possibilities for critical raw materials in key strategic sectors. • Enabling and deployment of circularity schemes related to the urban/industrial water cycle. • There are potential gaps regarding the sustainable supply and substitution of raw materials.
Low-carbon and clean industries	This is covered by the strategic plan's expected impact 15 'global leadership in clean and climate-neutral industrial value chains, circular economy and climate-neutral digital systems and infrastructures (networks, data centres), through innovative production and manufacturing processes and their digitisation, new business models, sustainable-by-design advanced materials and technologies enabling the switch to	The 2021–2024 work programmes addressed this intervention area under destination 1 ('climate neutral, circular and digitalised production') and destination 2 ('increased autonomy in key strategic value chains for resilient industry'), in the section 'raw materials for EU strategic autonomy and successful transition to a climate-neutral and circular economy'.	• There is a need for further development of low carbon and long term climate neutral production technologies e.g. DRI; Object of the Research is the use of Hydrogen, accompanied by other technologies like CCU and recycling • There is a need to reduce Europe's energy dependency while increasing the use of local resources by means of renewable energy integration, energy efficiency and circularity. • Securing raw materials supply, including by: Development of novel, holistic mineral system models for economic deposits of critical raw

	decarbonisation in all major emitting industrial sectors, including green digital technologies'; and expected impact 16 'industrial leadership and increased autonomy in key strategic value chains with security of supply in raw materials, achieved through breakthrough technologies in areas of industrial alliances, dynamic industrial innovation ecosystems and advanced solutions for substitution, resource and energy efficiency, effective reuse and recycling and clean primary production of raw materials, including critical raw materials and leadership in circular economy'.	In the 2021–2022 work programme, the focus was on decreasing GHG~T~ and pollutant emissions, optimising the use of resources and reducing the overall environmental impact. The 2023–2024 work programme served the combined objective of maximising energy efficiency, reducing Europe's energy dependency and achieving the climate neutrality of energy-intensive industries.	materials; advanced new exploration techniques; Data science techniques in research and exploration for raw materials. • Innovative low-cost technologies for the recovery and abatement of pollutants Support research and technical development of Carbon-Capturing technologies. • There is a need for industrial products with low- or zero-carbon-emission production processes through the life cycle, including carbon capture and utilisation abatement technologies. • There are potential gaps regarding the integration of renewable energy in the energy-intensive process industries through electrification and hydrogen use. • Emphasis on energy/raw material efficiency via, more efficient processes ; demonstration of clean technologies in the industrial environment e.g., heat pumps; and optimisation of energy- and raw material use including exchanges between industrial plants. • Tools and technologies needed to support data collection and data driven processes optimisation and boost replicability. • Further R & I is needed on data generation, collection and use as part of the necessary systemic transition. • There is a need to organise a more effective and faster transfer to market (i.e. a first-of-its-kind climate-neutral demonstrator for results of applied research, development and innovation with technology readiness levels of 5–8. • There is a need to emphasise the human dimension through the industry 5.0 concept. • There are potential gaps regarding improving the energy efficiency of extractive and processing activities and reducing environmental impact, including mining waste,

			water consumption, CO_2 footprint, dirt and noise.
Space, including Earth observation	This intervention area consists of the following subinterventions: fostering of the EU's space sector competitiveness; reinforcement of the EU's independent capacity to access space; continued evolution of the Galileo and European Geostationary Navigation Overlay Service (EGNOS) infrastructures and services; continued evolution of the Copernicus services; development and adoption of applications for Galileo, EGNOS and Copernicus; development of innovative space capabilities: SSA; development of innovative space capabilities: quantum; development of innovative space capabilities; European Union Governmental Satellite Communications (Govsatcom); support for the development of space entrepreneurship and skills; technological non-dependence; space science; and in-orbit demonstration and validation (IOD/IOV).	In each subintervention area, the first 4 years of Horizon Europe focused on the following areas and activities. • Foster the EU's space sector competitiveness: Areas identified in the SRIA aiming to increase the competitiveness of end-to-end systems and associated services were addressed. Activities addressed key technologies for satellite system and application development, including specific actions on electric propulsion, industrial processes and production tools. • Reinforce EU's independent capacity to access space: Areas identified in the SRIA aiming to increase competitiveness and expand commercial space transportation offer and services were addressed. Activities addressed the technological gaps in key innovations, such as reusability; low-cost, high-thrust propulsion; and new space transportation solutions. Topics were linked to recovering space transportation vehicles, in-orbit servicing, and improving the flexibility and openness of European test and launch facilities. • Continue to evolve the Galileo and EGNOS infrastructures and services: Activities included the	• Foster the EU's space sector competitiveness: Horizon Europe should focus on the areas not yet addressed in order to achieve the abovementioned vision and objectives, with activities complementing and building on the outcomes of the previous ones. Technologies evolve continuously: therefore Horizon Europe should continue to address lower TRL activities, in parallel with the completion of demonstrators. • Reinforce EU's independent capacity to access space: Horizon Europe should focus on the areas not yet addressed in order to achieve the abovementioned vision and objectives, in particular those on further reducing costs and greening the propulsion of existing launchers, on fostering reusability and on supporting the development and validation of news ones. New orbital and suborbital spaceports and new test facilities should also be considered. Continue to evolve the Galileo and EGNOS infrastructures and services: Activities for infrastructure engineering and technology evolution need to be strengthened, including efforts on making test user receivers available to test the future Galileo second generation signals and to support engineering verification activities for Galileo second generation and EGNOS version 3. Promising concepts like LEO-PNT and optical inter-satellite-links should be further supported. Further activity for critical technologies (e.g. atomic clocks) are needed to further mature multiple supply sources and technology diversity. Research on new services, such as EGNOS for non-aviation

		launch of early proof-of-concept studies for assessing the feasibility and viability of a European mission for low-Earth-orbit positioning, navigation and timing, complementing the existing European global navigation satellite system missions. Activities on ground segment improvements and on space segment capabilities were continued from Horizon 2020's previous activity. Research on new technologies for ground and space segments were initiated, with the aim of future integration in early batches of Galileo second generation's satellites. • Continue to evolve the Copernicus services: Activities focused on innovative data assimilation techniques for atmospheric composition satellite observations and coupled systems, predictability and multi-model product generation, multi-hazard systems to identify compound and cascading events, integrated soil–vegetation–atmosphere interface modelling, improvements of emission estimates from co-emitted species and auxiliary observations to separate anthropogenic and natural contributions, new models for biogeochemistry and marine ecosystems, land cover and land cover status change assessments and land surface models, progress on Arctic monitoring and forecasting systems and the	users, is also needed. In order to stay competitive we must focus on reducing the time to first fix for services such as HAS and OS-NMA. Novel technologies are needed, such as rad-hard spintronics. Further activities for PRS augmentation in LEO PNT are also needed. • Continue to evolve the Copernicus services: The gaps to be filled are identified by the Copernicus Services monitoring the environment (marine, atmosphere, land, climate); as part of their roadmaps for R&D for security and possibly emergency management applications, a SRIA is being prepared in cooperation with Member States, national space programmes and the entrusted entities. • Development and adoption of applications for Galileo, EGNOS, Copernicus and GOVSATCOM: Further research is needed to support the development of applications relying on the combined use of Galileo and Copernicus, and of the upcoming secure connectivity constellation of the infrastructure for resilience, interconnectivity and security by satellite. The same applies as above for applications supporting resilience against cyber threats and in general security. Activities to further advance the protection of GNSS receivers against jamming and spoofing are also needed. More efforts are needed to make Copernicus applications a business case with public authorities. • Development of innovative space capabilities: SSA: HE should support the needs and trends that will have emerged from the 21-24 activities, such as in the domains of SST radar upgrades to catalogue small space objects in LEO, high performance telescopes in MEO and GEO, automated collision avoidance, support to space debris mitigation and remediation, platform for commercial data and services, low-cost nanosat space-based surveillance system,

		monitoring of the SDGs with Copernicus reference data. • Development and adoption of applications for Galileo, EGNOS, Copernicus and GOVSATCOM: Addressed in particular the synergetic use of global navigation satellite systems and Copernicus in support of the Green Deal's objectives and policies, increasing the EU's climate ambition for 2030 and 2050, was addressed. In addition, the uptake of European global navigation satellite systems in the long-lead transport markets (such as aviation, maritime, rail and road) was fostered, together with the development and adoption of applications of the satellite system and Copernicus in the public sector. • Development of innovative space capabilities: SSA: The generic topics coordinated by the EU space surveillance and tracking (SST) partnership, established in 2022, that were addressed were (i) new and improved EU SST missions and services; (ii) SST and space traffic management system architecture and evolutions; (iii) space-based SST (mission, system and sensors network); (iv) SST sensors and processing; and (v) SST networking, security and data sharing. These topics will have contributed to ensuring the full and optimal capacity of the EU SST partnership by the end of 2024.	etc. All elements of SSA need to be addressed: SST, STM, SW and NEO. • Development of innovative space capabilities: Quantum: R&I will be needed to launch the Quantum Space Gravimetry Pathfinder Mission before the end of the decade and to demonstrate in space the various components necessary for a Quantum Space Gravimetry Mission payload and to develop other quantum-based technologies for space missions, e.g. quantum radars. • Development of innovative space capabilities: GOVSATCOM: HE should address the need for Govsatcom and secure connectivity for true interoperability at terminal level. This could be achieved with different means (e.g. achieving 'true roaming', supporting the miniaturisation and reduction in cost of terminals (possibly including handheld terminals), contributing to the 5G non-terrestrial network standardisation processes and tools, and investigating the related security features). Interoperability and standardisation in the space and ground segment need to be addressed. • Support to the development of space entrepreneurship and skills: These efforts need to be pursued, with a focus on giving experiments more opportunities to access aggregation and launch services for IOD/IOV. • Technological non-dependence: A new consolidated assessment of the most urgent technology areas to address is being produced by a COM (DEFIS)-ESA-EDA joint task force between the Commission's Directorate-General for Defence Industry and Space, the European Space Agency and the European Defence Agency. This will take into consideration the impact of the Russian aggression on the space sector. Horizon Europe topics should address

		• Development of innovative space capabilities: Quantum: A Quantum Space Gravimetry Pathfinder Mission and associated technology were developed, demonstrating the various components necessary for a quantum space gravimetry payload through a call in the 2025 work programme. • Development of innovative space capabilities: GOVSATCOM: Activities focused on field-programmable gate array components for space communication, security features, AI for optimal resource allocation, regenerative processors and other actions towards the development of upstream building blocks. In addition, actions focused on initial developments towards a multi-orbit user terminal. Concerning downstream actions, the activities were related to demonstration of different Govsatcom use cases. • Support to the development of space entrepreneurship and skills: A new initiative, competitive space start-ups for innovation, was established, with matchmaking, a business accelerator, hackathons, mentoring and prizes, and the promotion of innovative procurement solutions related to the EU space programme. Cooperation with the EIC was also established, under which the accelerator component of the EIC could be used to offer blended finance (grant and equity) to	high-priority actions stemming from that new assessment. • Space science: Scientific instrumentation and other technologies for robotic space exploration remain important R & I strands for further support. • IOD/IOV: Horizon Europe should continue to support IOD/IOV services for promising technologies that need flight heritage, including ready-to-fly IOD/IOV satellites.

		space-related SMEs, including start-ups. • Technological non-dependence: Space-related work programmes have addressed critical space technologies covering non-dependence issues in the area of electrical, electronic and electro-mechanical components; radiation facilities; packages; printed circuit boards; electrical thrusters; critical materials (lead-free transition); and others. • Space science: Actions supported the areas of space science with modest budgets. • IOD/IOV: Actions supported IOD/IOV services for European actors, including SMEs and start-ups.	

Table 20. Gap analysis for cluster 5 – climate, energy and mobility

Intervention area	Coverage in Strategic Plan 2021–2024	Coverage in work programmes 2021–2024	Potential gaps
Climate science and solutions	The main key strategic orientation (KSO) is KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy'. This is covered by expected impact 21 'transition to a climate-neutral and resilient society and economy enabled through advanced climate science, pathways and responses to climate change	This intervention area is addressed under destination 1 ('climate sciences and responses for the transformation towards climate neutrality'); aspects related to climate adaptation have also been dealt with by the EU Mission on Adaptation to Climate Change. The cluster 5 work programme covers a total of 37 topics, with a total budget of EUR 494.5 million. The main areas covered are:	• Challenges identified in the sixth assessment report of the IPCC • The need for greater emphasis on the social dimension of climate action – better knowledge of socioeconomic benefits of climate action, including equity considerations and improving those consideration in the modelled mitigation pathways • The need for better understanding and monitoring of terrestrial carbon fluxes, and improvements of the methods for their monitoring on different spatial and temporal scales

	(mitigation and adaptation) and behavioural transformations'. The impact area is 'climate change mitigation and adaptation'.	• Earth system science, pathways to climate neutrality, climate change adaptation (including climate services), social science for climate action and a better understanding of climate–ecosystem interactions • contributions to key international assessments (e.g. IPCC report, the state of the environment report) • strengthening of the European research area on climate change • increase of the transparency, robustness, trustworthiness and practical usability of the knowledge base on climate change for use by policymakers, practitioners, other stakeholders and citizens	• The expansion of the scientific knowledge base to enable improved implementation of the Montreal Protocol – including research on hydrofluorocarbon phase-down pathways, and on interactions between climate- and ozone-depleting substances • The need for better understanding, prediction and attribution of extreme climate events – with a focus on the development of effective climate services and early warning systems • Knowledge supporting holistic policy solutions combining climate and other policy goals, and promoting the more active involvement of citizens • The call from leading climate scientists to do more research on faster climate change scenarios ('the climate endgame', a cross-cutting issue over all clusters)
Energy supply	The main KSO is KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy'. This is covered by expected impact 23 'more efficient, clean, sustainable, secure and competitive energy supply through new solutions for smart grids and energy systems based on more performant renewable energy solutions'. The impact area is 'affordable and clean energy'.	This intervention area is addressed under destination 3 ('sustainable, secure and competitive energy supply'). In total, this covers 94 topics, with a total budget of EUR 1 398.5 million. The main areas covered are the following. • **Renewable energy.** Europe's global leadership in affordable, secure and sustainable renewable energy technologies and services can be boosted by improving its competitiveness in global value chains and its position in growth markets, notably through the diversification of the renewable services and technology portfolio (including photovoltaics, wind energy, renewable fuels,	• The need to focus on heat pumps, photovoltaics and wind due to accelerated deployment needs and objectives (REPowerEU plan) and challenges to system integration • Strengthening of the European solar photovoltaic industrial value chain, in line with the new European Solar Photovoltaic Industrial Alliance and the EU solar energy strategy • Innovative technologies for biomethane production in synergy with the biomethane industrial partnership (in line with REPowerEU's biomethane action plan) • Use of R & I to improve and upscale technologies using advanced biofuels and synthetic renewable fuels for made-in-Europe industrial manufacturing to avoid creating a new dependency on outside supply • Long-term R & I for eventually achieving the energy autonomy of the EU (as a complement to the short-term-oriented REPowerEU energy priorities)

		bioenergy, geothermal, hydropower, ocean energy and solar thermal, and cross-technology activities). This covers 88 topics, with a total budget of EUR 1 308.5 million. • **Carbon capture, utilisation and storage.** Accelerating the development of carbon capture, utilisation and storage is a CO_2 emission mitigation option in electricity generation and industry applications. • **Co-funded partnership on the clean energy transition.** This leverages national funding (the EU's contribution for 2021–2024 was EUR 138 million).	• Integration of biodiversity considerations across energy R & I activities • The need to address socioeconomic aspects in R & I (e.g. gender equality, skills and training, labour markets, energy access and energy poverty) • Emerging needs and policy in international R & I collaboration • Replacement of critical raw materials in key technologies generating renewable energy
Energy systems and grids	The main KSO is KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy'. This is covered by expected impact 23 'more efficient, clean, sustainable, secure and competitive energy supply through new solutions for smart grids and energy systems based on more performant renewable energy solutions'. The impact area is 'affordable and clean energy'.	This intervention area is addressed under destination 3 ('sustainable, secure and competitive energy supply'). In total, this covers 38 topics, with a total budget of EUR 613.6 million. The main areas covered are: • energy systems, grids and storage – specifically the cost-effective, uninterrupted, resilient and affordable supply of energy to households and industries in a scenario of high penetration of variable renewables and other new low-carbon energy supplies • the co-funded partnership on the clean energy transition	• The new requirements on the energy grids due to accelerated, variable deployment of renewable energy sources • Reinforcing a flexible yet robust energy grid • Greater cooperation between transmission system operators and distribution system operators • R & I for better grid control, operation and resilience • The rapid digitalisation of the grid

Buildings and industrial facilities in the energy transition	The main KSO is KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy'. This is covered by expected impact 24 'efficient and sustainable use of energy, accessible for all is ensured through a clean energy system and a just transition'. The impact areas are 'affordable clean energy' and 'circular and clean economy'.	This intervention area is addressed under destination 4 ('efficient, sustainable and inclusive energy use'). In total, this covers 38 topics, with a total budge of EUR 452.60 million. Main areas covered are the following. • **Buildings.** The budget was EUR 368 million for 31 topics, of which EUR 218 million contributes directly to the co-programmed European Partnership on 'People-centric sustainable built environment', Built4People. More energy efficient building stocks; higher buildings' performance with lower environmental impacts; combination of energy efficiency, renewable energy sources and digital and smart technologies; higher quality, more affordable built environment • **Industry.** The budget was EUR 84 million for 6 topics. These focused on increasing energy efficiency and reducing industry's GHG and air pollutant emissions.	Potential gaps regarding buildings are the need to: • foster easy-to-replicate innovative building renovation solutions to speed up building renovation (with an additional focus on demonstrations) • accelerate the decarbonisation of the built environment, through zero-emission buildings (and carbon-positive buildings) • increase digitalisation, and to integrate the smart readiness of buildings into building renovation • alleviate consumer poverty and boost consumer empowerment through a people-centric approach • create holistic solutions and approaches to building renovation in alignment with the New European Bauhaus • cover more temperature ranges and industrial applications, in particular for heat upgrading (heat pumps and other techniques), integration of renewable thermal energy sources and heat storage Potential gaps regarding industrial facilities are the need for: • integration of renewables and electrification of industrial processes • a focus on heat upgrades (heat pumps) and heat storage
Communities and cities	The main KSO is KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy'. This is covered by expected impact 22 'clean and sustainable transition of the energy and transport sectors towards	This intervention area is mainly addressed through the EU Mission on Climate-Neutral and Smart Cities (implemented through the dedicated mission work programme annex), which had a total budget of EUR 439 million during 2021–2023 (of which EUR 267 million was from cluster 5).	Potential gaps are to be discussed in the context of the EU Mission on Climate-Neutral and Smart Cities.

	climate neutrality facilitated by innovative crosscutting solutions'. The mission area is climate-neutral and smart cities.	The cluster 5 work programme included two actions, with a total budget of EUR 79 million, of which one was the co-funded European partnership on driving urban transitions, which has a total EU contribution of EUR 74 million so far.	
Industrial competitiveness in transport Clean, safe and accessible transport and mobility Smart mobility	The main KSO is KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy'. These are covered by expected impact 25 'towards climate-neutral and environmentally friendly mobility through clean solutions across all transport modes while increasing global competitiveness of the EU transport sector'; and expected impact 26 'safe, seamless, smart, inclusive, resilient, climate neutral and sustainable mobility services for people and goods thanks to user-centric technologies and services including digital technologies and advanced satellite navigation services'. The impact area is 'smart and sustainable transport'.	These intervention areas addressed under destination 5 ('clean and competitive solutions for all transport modes') and destination 6 ('safe, resilient transport and smart mobility services for passengers and goods'). The total budget was EUR 1 541 million for 121 topic. The main areas addressed are the following. • **Road transport.** This covers 20 topics, with a budget of EUR 333.5 million. It focuses on transforming road transport to zero-emission mobility through a world-class European R & I and industrial system, ensuring that Europe remains a world leader in innovation, production and services in relation to road transport (contributing to the co-programmed European partnership 'towards zero emission road transport'). • **Aviation.** This covers 13 topics, with a budget of EUR 210 million. It focuses on accelerating the reduction of all aviation impacts and emissions (CO_2 and non-CO_2, including manufacturing, end of	Under road, aviation and waterborne transport, actions needed to accelerate the development and deployment of zero-emission vehicles/planes/vessels and the associated infrastructure, including storage, are the following. • **Road transport.** There is a need for vehicle-to-grid (V2G) solutions. • **Aviation.** There is a need for electric propulsion for large aircrafts, and engines using renewable hydrogen or hydrogen-based renewable fuels of non-biological origin. • **Waterborne.** There is a need for low- and zero-carbon shipping propulsion; efficient vessel retrofitting; an increase of the (re)construction capacity of the European shipyard (to allow for transport of hydrogen and hydrogen-based fuels); refuelling infrastructure; and on-board carbon capture, including on-board fuel production potential. Under transport-related health and environment, actions should address: • developing solutions for reducing noise and pollutants • assessing and addressing the cumulative effects of different sources of pollution from transport on the environment • improving the monitoring and modelling of air quality in the light of the upcoming revision of the air quality legislation

		life, and noise), developing aircraft technologies for deep reduction of GHG emissions, and maintaining the European aerospace industry's global leadership position. • **Waterborne transport.** This covers 28 topics, with a budget of EUR 343.6 million. It focuses on accelerating the development and preparing the deployment of climate-neutral and clean solutions in the inland and marine shipping sector, reducing its environmental impact (on biodiversity, noise, pollution and waste management), improving its system efficiency, leveraging digital and EU satellite navigation solutions and contributing to the competitiveness of the European waterborne sector (with the majority of topics contributing to the co-programmed European partnership 'zero emission waterborne transport'). • Transport-related health and environment. This covers five topics, with a budget of EUR 39 million. It focuses on devising more effective ways for reducing emissions and their impacts through improved scientific knowledge about the health impacts of air pollution and noise due to transport. • **Connected, cooperative and automated mobility (CCAM).** This covers 21 topics, with a budge of EUR 264 million. It focuses on accelerating the implementation of innovative CCAM technologies and systems for passengers and goods	• creating innovative solutions to reduce fragmentation of habitats by roads (or other transport modes) and to ensure connectivity Under CCAM, actions should include ones to test seamless, affordable, inclusive and user-oriented CCAM-based mobility solutions in large-scale demonstrations, with a particular focus on shared, smart and zero-emission mobility for passenger and goods transportation with high public buy-in of these solutions. Attention will need to be placed on understanding the possible business opportunities for the different use cases. Under multimodal transport, infrastructure and logistics, actions should aim towards green and smart infrastructures, advanced AI-supported multimodal network/traffic management, and green and smart logistics (e.g. physical internet). Under safety and resilience, actions should address: • reducing road deaths on rural and regional roads • further work on passive and tertiary safety (human body models, post-crash safety and rescue operations, thermal propagation due to new power trains, etc.) • safer road infrastructure • AI and big data in support of road safety

		(all topics contributing to the co-programmed European partnership 'connected, cooperative and automated mobility'). • **Multimodal transport, infrastructure and logistics.** This covers 18 topics, with a budget of EUR 223 million. It focuses on further developing a multimodal transport system through sustainable and smart long-haul and urban freight transport and logistics, and upgraded and resilient physical and digital infrastructures for smarter vehicles and operations, for optimised system-wide network efficiency. • **Safety and resilience.** This covers 13 topics, with a budget of EUR 122.5 million. It focuses on drastically decreasing the number of transport accidents, incidents and fatalities towards the EU's long-term goal of moving close to zero fatalities and serious injuries by 2050, even in road transportation (vision zero), and increasing the resilience of transport systems.	
Energy storage	The main KSO is KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy'. This is covered by expected impact 22 'clean and sustainable transition of the energy and transport sectors towards climate neutrality facilitated by innovative crosscutting solutions';	This intervention area is addressed under destination 2 (as regards batteries), and also destination 3 (as regards liquid and gaseous renewable fuels, and energy storage for the energy system – see intervention area 2) and destination 5 (use of batteries and transport fuels for road	Potential gaps are reducing external raw material dependency for batteries, and improving collection and recycled content of batteries.

	and expected impact 23 ‘more efficient, clean, secure and competitive energy supply through new solutions for smart grids and energy systems based on more performant renewable energy solutions’. The impact areas are ‘affordable clean energy’, ‘circular and clean economy’ and ‘smart and sustainable transport’.	transport, aviation and waterborne transport – see intervention areas 6–8). The main area covered is as follows. • **Batteries.** This covers 32 topics, with a total budget of EUR 513 million. It focuses on nurturing a world-class European R & I ecosystem on batteries along the value chain based on sustainable pathways. It includes improvement of technological performance to increase application user attractiveness (particularly in terms of safety, cost, user convenience, fast charging and environmental footprint), while in parallel supporting the creation of a competitive, circular and sustainable European battery-manufacturing value chain (all topics contribute to co-programmed European partnership ‘towards a competitive European industrial battery value chain for stationary applications and e-mobility’).	

Table 21. Gap analysis for cluster 6 – food, bioeconomy, natural resources, agriculture and environment

Intervention area	Coverage in Strategic Plan 2021–2024	Coverage in work programmes 2021–2024	Potential gaps

Environmental observation	The main KSOs are KSO B 'restoring Europe's ecosystems and biodiversity, and managing sustainably natural resources' and KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy'.
	
	This is mainly covered by expected impact 32 'innovative governance models enabling sustainability and resilience are established and monitored through enhanced and shared use of new knowledge, tools, foresight, and environmental observations as well as digital, modelling and forecasting capabilities'.
	
	The impact areas are all those in cluster 6.
		This intervention area is addressed mainly under destination 7.
		
		The cluster 6 work programme covered 15 topics in total, with a budget of EUR 156 million (total budget of EUR 174 million, as it also funded several other actions).
		
		The main areas covered are:
		• deploying and adding value to environmental observations, which involves:
		  ○ supporting the uptake, accessibility and exploitability of Earth observation (EO) at EU and global levels
		  ○ supporting the European Green Deal's priorities and the one health approach challenges, through the creation of a common Earth-observing system data gateway data space, and support of Europe's part of the group on EO initiative, building on meteorological satellite data
		  ○ addressing climate change (e.g. development of new technologies to acquire *in situ* observation datasets, dissemination and exploitation of climate observation by the World Meteorological
			• EO in the polar regions
			• Ocean observation
			• Improvement of EU governance on EO, international coordination, development of standards and good practices, and harmonisation of data management and data technologies
			• Support for Europe's part of the group on EO initiative, and other initiatives of the group, with focuses on Africa and South America
			• EO to understand and predict the climate, and support climate mitigation and adaptation, including loss and damage
			• Monitoring and assessment of biodiversity
			• Integration of biodiversity data across domains and methods
			• Zero pollution, covering pollution in oceans and water (including groundwater, underwater noise), air and soil pollution, microplastics and nanoplastics, nutrients and pollutants of emerging concern
			• Improvement of the monitoring of air quality
			• Agricultural monitoring
			• EO services to support food security
			• EO for resilient, climate-neutral and healthy cities and communities

		Organization, customisation/pre-operationalisation of prototypes for end user services in the areas of adaptation and mitigation, use of environmental observation and EO in the context of the new EU–China climate change and biodiversity flagship initiative) ○ fostering citizens' observations, engagement and empowerment in urban contexts to support environmental compliance • innovating with governance models and supporting policies, including the 'agriculture of data' partnership	
Biodiversity and natural resources	The main KSO is KSO B 'restoring Europe's ecosystems and biodiversity and managing sustainably natural resources'. This is covered by expected impact 28 'biodiversity is back on a path to recovery, and ecosystems and their services are preserved and sustainably restored on land, inland water and at sea through improved knowledge and innovation'. The impact area is 'enhancing ecosystems and biodiversity on land and in waters'.	This intervention area is addressed under destination 'biodiversity and ecosystem services'. The cluster 6 work programme covered 44 topics in total, with a budget of EUR 503 million. The main areas covered are: • biodiversity loss, including: ○ genomics ○ endangered wildlife ○ chemical pollution ○ light and noise pollution ○ changes in ecosystems, building on observation programmes ○ invasive alien species ○ digital for nature • biodiversity protection and restoration, including: ○ the trans-European nature network	Potential gaps regarding the need for improved understanding and mitigation of drivers of biodiversity loss, including knowledge about biodiversity status and trends, are: • the impact of climate change • issues of emerging concern • cumulative impacts • monitoring of key geographic and taxonomic gaps, ecosystem functions, species interactions, key drivers and pressures and socioeconomic aspects • addressing of the decline of insects population and of key species • valorisation of past observations and existing datasets • addressing of the impacts of war on biodiversity Potential gaps regarding the need for improved methods for and knowledge of biodiversity protection and restoration include knowledge and

		○ networking with history museums to build taxonomic research capacity ○ the maintenance and restoration of pollinators in agriculture ○ support for the implementation of protection of species and habitats – nature directives ○ the by-catch of protected species • mainstreaming biodiversity in society and the economy, transformative change, including: ○ the economics of nature-based solutions (NBS) ○ NBS and the insurance sector ○ ecosystems for policymaking and decision-making ○ the impact of biomass trade on biodiversity ○ a multi-factorial approach for transformative change ○ policy and governance for transformative action ○ digital transformation and biodiversity ○ an NBS multi-stakeholder platform ○ natural capital accounting ○ behaviour and transformative change ○ NBS in higher education ○ biodiversity, economics and finance, and macro-financial risk ○ a nature-positive economy ○ biodiversity in urban and peri-urban areas ○ the interconnection between biodiversity and climate	methods for: • the protection and restoration of all targeted ecosystems, habitats and species, as laid down in the proposal for the Nature Restoration Law • the protection of species • the identification of the most suitable areas for restoration • the identification and testing of suitable indicators • support for the preparation and implementation of national restoration plans • support for revision of lists of protected habitats and species • the identification of funding, governance and managing opportunities for both biodiversity and climate • the improvement of modelling and protection of data on nature Potential gaps regarding transformative change in which biodiversity is mainstreamed in society and the economy include: • innovative tools and methods to ensure citizen engagement in biodiversity conservation • quantification of economic benefits of nature protection and restoration, and costs of non-action • development of sustainable economic models ensuring biodiversity protection, including methods to quantify and incentivise sustainability co-benefits of carbon removal activities on biodiversity and ecosystems • a nature-positive economy Potential gaps regarding biodiversity and health include: • remaining gaps on interlinkages between health and biodiversity

		policies (support to IPBES and IPCC) ○ the dependence of society and the economy on pollinators ○ governance and digitalisation addressing biodiversity loss ○ NBS to reduce impacts of extreme droughts ○ NBS and NEB ○ educational innovation with NBS ○ the sociopolitics of NBS • biodiversity and health, including: ○ the connection between ecosystems and pandemics ○ nature-based therapy for health and well-being ○ degraded ecosystems and the emergence of zoonotic diseases • connecting science and policy, including: ○ the European partnership Biodiversa+ ○ the science service ○ support to IPBES and IPCC ○ business and biodiversity ○ cooperation with the Convention on Biological Diversity	• links between nature and mental health There is a potential gap regarding the connection between science and policy, at European and global levels, including support as needed according to the post-2020 global biodiversity framework (IPBES and the Convention on Biological Diversity).
Agriculture, forestry and rural areas	The main KSOs are KSO B 'restoring Europe's ecosystems and biodiversity and managing sustainably natural resources' and KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy'.	This intervention area is addressed under destinations 1, 2, 3, 4, 5, 6 and 7. The cluster 6 work programme covered 133 topics in total, with a budget of EUR 1 300 million. The main areas covered are: • climate neutrality and adaptation to climate change (climate-smart	• **Climate change.** There is need to increase knowledge and tools to mitigate and adapt to climate change and its impacts, especially on the sustainability of permanent grassland and peatland; foster the resilience of crops; and address trade-offs of farming and related biodiversity adaption versus mitigation. • **Agroecology.** There is need to increase knowledge and develop tools to foster

	This is covered by expected impact 27 ‘climate neutrality is achieved by reducing GHG emissions, maintaining natural carbon sinks, and enhancing the sequestration and storage of carbon in ecosystems, including by unfolding the potential of nature based solutions, production systems on land and at sea as well as rural and coastal areas, where adaptations to climate change are also being fostered for enhancing resilience’; expected impact 28 ‘biodiversity is back on a path to recovery, and ecosystems and their services are preserved and sustainably restored on land, inland water and at sea through improved knowledge and innovation’; expected impact 29 ‘sustainable and circular management and use of natural resources as well as prevention and removal of pollution are mainstreamed, unlocking the potential of the bioeconomy, ensuring competitiveness and guaranteeing healthy soil, air, fresh and marine water for all, through better understanding of planetary boundaries and deployment of innovative technologies and other solutions, notably in primary production, forestry and bio-based systems’; expected impact 30 ‘food and nutrition security for all within planetary boundaries is ensured through knowledge, innovation and digitalisation in agriculture, fisheries, aquaculture and food systems, which are sustainable, resilient, inclusive,	farming, paludiculture, resilience and adaptation of agriculture and forestry, agroecological approaches, forestry, livestock systems, and renewable energy at farm level) • the preservation and restoration of biodiversity and ecosystems (crop breeding, forest ecosystems, conservation and use of crop wild relatives, valorisation of legumes, promotion of minor crops and pollinator-friendly farming systems, agroecological practices for biodiversity such as intercropping, monitoring and effective measures for agrobiodiversity, and resilient beekeeping) • the sustainable and circular management of natural resources (agricultural residues and waste, bio-based solutions, NBSs, optimisation of the nutrient budget in agriculture, business models in the bioeconomy, forest services and value chains, sustainable production of wood and non-wood products, water availability and manure quality) • food and nutrition security for all from sustainable food systems (agroecological approaches, animal health and welfare, protein crop systems and value chains, plant health, prevention of food adulteration, boosting of organic farming and organic aquaculture, blockchain technologies in the agrifood sector, plant protection products, use of digital technologies for small- and	agroecology; improve knowledge of the benefits and trade-offs of fostering systemic and circular agroecological approaches and biodiversity, including socioeconomic aspects and input cost reduction (depending on coverage under the agroecology living labs partnership); and bolster livestock organic production though breeding for resilience. • **Breeding and genetic resources.** There is need to improve breeding and genetic resources for conservation (for crops and forest trees) and to reduce (agrochemical) inputs in agriculture. • **Pollution and biodiversity.** There is a need to address challenges for soil, water, nutrient and biodiversity through methods such as integrated nutrient management plans, soil decontamination and carbon removal, research on the sublethal effects of pesticides on pollinators, water pollutants and their impact on environmental health and air pollution. • **Plant health.** There is need to bolster plant health, manage pests and diseases, and support farmers meeting potential regulation requirements on the sustainable use of pesticides. • **Animal health and welfare.** There is need for knowledge and tools to foster animal (positive) health and welfare (and synergies); the development of disease countermeasures (e.g. vaccines), including against parasitism; emerging risks; one health alternatives to antimicrobials and data systems (depending on coverage of partnership on animal health and welfare). • **Sustainable livestock systems.** Knowledge and tools are needed to foster sustainable livestock systems in areas such as emission mitigation, circular approaches for livestock

	safe and healthy from farm to fork'; expected impact 31 'rural, coastal and urban areas are developed in a sustainable, balanced and inclusive manner thanks to a better understanding of the environmental, socioeconomic, behavioural and demographic drivers of change as well as deployment of digital, social and community-led innovations'; and expected impact 32 'innovative governance models enabling sustainability and resilience are established and monitored through enhanced and shared use of new knowledge, tools, foresight, and environmental observations as well as digital, modelling and forecasting capabilities'. The impact areas are 'enhancing ecosystems and biodiversity on land and in waters'; 'clean and healthy air, water and soil'; 'sustainable food systems from farm to fork on land and sea'; and 'circular and clean economy'.	medium-sized farms and farm structures, sustainability aspects of agricultural and food systems, climate-neutral and biodiversity-friendly farming systems, the EU–African union cooperation on food security, sustainable agriculture and agroforestry management, fostering of opportunities for organic agrifood systems, co-funded partnerships on agroecology and living labs and research infrastructures, and co-funded partnerships on animal health and welfare) • balanced development of rural, coastal and urban areas (social aspects and labour conditions, health and safety, boosting of women-led innovation, rural innovation, the ecological and digital transition of rural communities, digitalisation and smart solutions, urban farming's impacts, territorial governance and rural–urban synergies, geographical indications, new business models for farmers and rural communities, and the impact of COVID-19) • innovative governance models enabling sustainability and environmental observation (assessment of the impacts of digital technologies in agriculture, broadening of the agricultural European innovation partnership's operational group's outcomes, compilation and sharing of knowledge ready for practice, the data economy, deepening of the	management, and the diversification of livestock systems for adaptation to climate change. • **Protein crops.** There is a need to leverage the potential of protein crops through provision of advisory services, implementation of circular methods to valorise by-products, and assessment of the EU and global dynamics of pulse/protein crops for livestock feed and human diets. • **Rural areas.** There is a need to stimulate rural social dynamics in areas such as improvement of community services, contribution to the energy transition, newcomers' contributions, rural–urban synergies and innovation ecosystems. • **Urban agriculture.** There is need to identify gaps and opportunities regarding innovative urban agriculture, and develop solutions to foster the sustainability transition. • **Sustainable bio-based solutions in rural areas.** There is need for the development of sustainable bio-based products, including the production of renewable energy; introduction of nature-positive business models; and improvement of the position of farmers in bioeconomy value chains. • **Forestry.** There is a need to foster multifunctional forests for future generations through sustainable management approaches, technologies, innovative wood and non-wood products, prevention and management of forest disturbances, urban forestry, management of genetic resources, deployment of inclusive and fair value chains, and improved governance. • **Digital and data technologies.** There is need for enabling digital and data technologies (objectives of the long-term vision of rural areas) through the public administration's

		functioning of innovation support., development of EU advisory networks, development of the markets and use of digital technologies and infrastructure, improvement of national agricultural knowledge and innovation system (AKIS) organisation, improvement of the preparation of multi-actor projects, innovative tools and methods to evaluate the design and support, monitoring and implementation of effective common agricultural policy strategic plans, modelling of land aspects in the context of climate change, the potential of drone technologies, support for knowledge exchange between all AKIS actors in the Member States, thematic networks to compile and share knowledge ready for practice, upscale of sensor data for monitoring of production and agri-environmental conditions, advancement of analytical capacity and tools to support EU agrifood policies post-2027, digital and data technologies for livestock tracking and plant health, digitalisation in agriculture and forestry, and co-funded partnership agriculture of data (shared with intervention area 1)	implementation of legal frameworks on cyber and data technologies, and digital services; and increasing sustainability performance. • **AKIS.** There is need for the development of AKIS of the future through understanding of the connection among multi-actor tools, research on skills, training and education for farmers, further AKIS thematic networks, generational renewal of farmers' further support for AKIS development, and extension of the lifetime of demo farms. • **Value chains.** Knowledge and innovation are needed to further support innovative policies, business models and value chains enabling sustainable food systems and agriculture, including tools for business education for farmers. • **International cooperation.** There is need to foster international R & I cooperation, which is important for the geopolitical dimension in cross-cutting areas such as food production, water management, organic production, soil health, biodiversity, urban farming, forestry, rural areas and development of digital skills.
Seas, oceans and inland waters	The main KSOs are KSO B 'restoring Europe's ecosystems and biodiversity, and managing sustainably natural resources', KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy'	This intervention area is addressed under all destinations. The cluster 6 work programme covered 37 topics in total, with a budget of EUR 430 million. The main areas covered are:	There are potential gaps on the need to increase multidisciplinary R & I for healthy and productive ocean and seas, in particular: • observing, valuing, restoring and protecting coastal and marine biodiversity and ecosystems services

	and KSO D ‘creating a more resilient, inclusive and democratic European society’. This is covered by expected impact 28 ‘biodiversity is back on a path to recovery, and ecosystems and their services are preserved and sustainably restored on land, inland water and at sea through improved knowledge and innovation’; expected impact 29 ‘sustainable and circular management and use of natural resources as well as prevention and removal of pollution are mainstreamed, unlocking the potential of the bioeconomy, ensuring competitiveness and guaranteeing healthy soil, air, fresh and marine water for all, through better understanding of planetary boundaries and deployment of innovative technologies and other solutions, notably in primary production, forestry and bio-based systems’; expected impact 31 ‘rural, coastal and urban areas are developed in a sustainable, balanced and inclusive manner thanks to a better understanding of the environmental, socioeconomic, behavioural and demographic drivers of change as well as deployment of digital, social and community-led innovations’; and expected impact 32 ‘innovative governance models enabling sustainability and resilience are established and monitored through enhanced and shared use of new knowledge, tools, foresight, and	• the value of marine and coastal biodiversity • stressors on marine and coastal biodiversity • mapping of coastal and marine biodiversity • demonstration for marine and coastal ecosystem restoration • maritime spatial planning for marine protected areas • restoration of deep-sea habitats • marine and coastal infrastructure NBS • biodiversity and ecosystem services • sustainable fisheries and aquaculture • innovation for blue bioeconomy and biotechnology sector value chains • clean environment and zero pollution • the ocean for climate action	• monitoring and capacity methods for indicator-based assessments of the state of the marine environment and marine protected areas • freshwater and inland waters, particularly restoration methods for European lakes and freshwater ecosystems and reservoirs in a closely linkage with climate change and invasive species, and improving regulating ecosystem services • sustainable fisheries and aquaculture, particularly producing R & I for organic aquaculture and for offshore aquaculture; reducing the impact of fisheries on the marine environment and on the seabed; and creating disruptive technological advances to modernise fisheries data collection, fisheries monitoring and control, and for efficiently fighting food fraud and illegal, unreported and unregulated fishing R & I; supporting the development of research on socioeconomic impacts of the adoption of new technologies and innovation in fisheries and aquaculture; and producing R & I on new environmentally friendly technologies in the fisheries and aquaculture sectors • clean aquatic environment and zero pollution, particularly monitoring, assessing and mitigating the cumulative effects of different sources of pollution in ocean and waters, and producing accurate mapping and improving global governance of plastic pollution in a one health approach • improved understanding of the ocean–climate–biodiversity nexus and of the polar regions in climate change mitigation and adaptation • blue bioeconomy and biotechnology, particularly support for bioprospecting of marine natural products and omics advances for remediation of marine ecosystems

	environmental observations as well as digital, modelling and forecasting capabilities'. The impact area is 'enhancing ecosystems and biodiversity on land and in waters'.		• resilient, inclusive, healthy and green coastal communities, supporting nature connectedness applied to aquatic environments • innovative governance, particularly support for the international cooperation commitments • technologies for the digital ocean, particularly integrated modelling (physics, biogeochemical, ecosystems) of the land–sea interface (coastal zones, rivers and estuaries), technologies for socioecological data and models, and technologies for user and impact-driven digital twin applications
Food systems	The main KSO is KSO B 'restoring Europe's ecosystems and biodiversity, and managing sustainably natural resources'. This is covered by expected impact 30 'food and nutrition security for all within planetary boundaries is ensured through knowledge, innovation and digitalisation in agriculture, fisheries, aquaculture and food systems, which are sustainable, resilient, inclusive, safe and healthy from farm to fork'. The impact area is 'sustainable food systems from farm to fork on land and sea'.	This intervention area is addressed under destinations 2, 6 and 7. The cluster 6 work programme covered 47 topics in total, with a budget of EUR 457 million. The main areas covered (in line with the food 2030 pathways) are: • food and data • alternative proteins and dietary shifts • food waste and resource efficiency • food systems Africa • microbiome • food safety and traceability • personalised nutrition • governance	Along the food 2030 pathways, further R & I investments are required to foster the implementation of systemic approaches to deliver co-benefits and foster the deployment of solutions. Potential gaps regarding environmental sustainability, circularity and resource efficiency of food systems, are related to: • transitioning towards low-energy and low-carbon-footprint food systems, with a focus after primary production, considering the land–water–energy–food nexus • reducing fossil fuel dependence across supply chains • developing low-carbon-footprint food system solutions (e.g. precision fermentation) that are performant from a system perspective Potential gaps regarding building food systems' resilience are by better anticipating, preventing and reacting to crises, in particular climate change, at all levels, from local to global. Potential gaps regarding contributing to biodiversity restoration are:

			• tackling biodiversity from the angle of regenerative food systems (e.g. product-marketing strategies • enhancing community engagement (at different scales) and the consumption of nutritious, environmentally sustainable foods from biodiversity-rich areas • demonstrating food production business cases that are regenerative A potential gap regarding food waste is improving the implementation of strategies to monitor, manage and valorise food waste. A potential gap regarding pollution from food processing industries is addressing pollution from the food-and beverage-processing industries, and other downstream actors. A potential gap regarding the traceability of food products is the development of effective digital systems and tools (e.g. fresh and processed fisheries and aquaculture products).
Bio-based innovation systems in the EU bioeconomy	The main KSOs are KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy' and KSO B 'restoring Europe's ecosystems and biodiversity, and managing sustainably natural resources'. The main expected impacts are expected impact 29 'sustainable and circular management and use of natural resources as well as prevention and removal of pollution are mainstreamed, unlocking the potential of the bioeconomy, ensuring competitiveness and guaranteeing	This intervention area is addressed under destinations 3, 4 and 7. The cluster 6 work programme covered 41 topics in total, with a budget of EUR 273 million. The main areas covered are: • innovating sustainable circular bio-based systems and the bioeconomy (e.g. non-plant biomass feedstock; microbiomes for bio-based innovation; bio-based plastics, specifically end-of-life options; life science convergence with digital technologies; enzymes and	Potential gaps regarding bio-based innovations (innovating sustainable bio-based systems and the bioeconomy, and increasing the environmental performance and sustainability of processes and products) are related to: • the circularity of bio-based systems (focus on biowaste/recycling, waste management and valorisation), evaluation of the life cycle of bio-based products and bio-based technologies to improve recirculation in bio-based processes, and pollutant prevention, mitigation and control • the safe-and-sustainable-by-design approach to bio-based value chains, and a better understanding of the carbon removal potential of bio-based economies

	healthy soil, air, fresh and marine water for all, through better understanding of planetary boundaries and deployment of innovative technologies and other solutions, notably in primary production, forestry and bio-based systems'; expected impact 27 'climate neutrality is achieved by reducing GHG emissions, maintaining natural carbon sinks, and enhancing the sequestration and storage of carbon in ecosystems, including by unfolding the potential of nature based solutions, production systems on land and at sea as well as rural and coastal areas, where adaptations to climate change are also being fostered for enhancing resilience'; expected impact 31 'rural, coastal and urban areas are developed in a sustainable, balanced and inclusive manner thanks to a better understanding of the environmental, socioeconomic, behavioural and demographic drivers of change as well as deployment of digital, social and community-led innovations'; and expected impact 32 'innovative governance models enabling sustainability and resilience are established and monitored through enhanced and shared use of new knowledge, tools, foresight, and environmental observations as well as digital, modelling and forecasting capabilities'. The impact area is 'circular and clean economy'.	microbial hosts for industrial biotechnology; symbiosis in bio-based industrial ecosystems; low-toxicity construction bio-based materials; cascading valorisation of biomass; labelling options for bio-based products; and circular bioeconomy start-up villages) • increasing the environmental performance and sustainability of bio-based processes and products (e.g. environmental sustainability criteria for biological feedstock, environmental performance of bio-based industrial sectors, new genomics techniques for bio-based innovation, bioremediation, bio-sensors and zero-waste biorefineries) • being innovative with governance models, and supporting bioeconomy and bio-based systems policies (e.g. regional governance models in the bioeconomy, education on bioeconomy, revitalisation of communities with bio-based models, and integrated assessment of land use and biomass demands)	• biodiversity protection, restoration and enhancement, and zero pollution in the bio-based sector, including through NBS • the role of (sustainable, circular and climate-/biodiversity-friendly) primary resources in bio-based value chains enabled by biotechnology and other advanced approaches • the environmental, social, economic and cultural dimensions of the sustainability of bio-based systems • the lack of standards and criteria for the supply of sustainable biomass, including cultivation of industrial crops on marginal lands and biomass with low risk of indirect land use change • the short lifetimes of bio-based products (upcycling and the role of consumers' choices) • the digitalisation of bio-based technologies • biotechnology approaches (with a clearer focus on environmental accidents / pollution detection and remediation), healthy bio-based foods, alternative proteins and the microbiome • demonstration of regenerative, blue, bio-based business cases tailored to the EU's regional seas Potential gaps regarding the bioeconomy (being innovative with governance models and supporting policies, and innovating sustainable bio-based systems and the bioeconomy) are related to: • fostering of the bioeconomy in Member States / regions that are lagging behind • development of innovative production and business models offering economic opportunities for primary producers and rural areas, and contribution to a fair distribution of benefits in fair value chains • R & I, development and bioeconomy education in countries covered by the central-eastern European initiative for knowledge-based

			agriculture, aquaculture and forestry in the bioeconomy • bioeconomy model regions • bioeconomy solutions with the highest potential for climate mitigation, biodiversity restoration, water management, etc. • regional innovation valleys for the bioeconomy and food systems • sustainable and circular management of land and biomass demands that promotes more sustainable consumption patterns for environmental integrity, and youth participation and leadership • societal acceptance of new bio-based solutions • trust building in the bioeconomy/bio-based sectors underpinned by the social sciences and humanities
Circular systems	The main KSOs are KSO C 'making Europe the first digitally enabled circular, climate-neutral and sustainable economy' and KSO B 'restoring Europe's ecosystems and biodiversity, and managing sustainably natural resources'. These are mainly covered by expected impact 27 'climate neutrality is achieved by reducing GHG emissions, maintaining natural carbon sinks, and enhancing the sequestration and storage of carbon in ecosystems, including by unfolding the potential of nature based solutions, production systems on land and at sea as well as rural and coastal areas, where adaptations to climate change are also being fostered for enhancing resilience';	This intervention area is addressed under destinations 1, 3, 4, 5 and 7. The cluster 6 work programme covered 44 topics in total, with a budget of EUR 522 million. The main areas covered are: • sectoral circular economy, in particular over-packaging, single-use plastic and related microplastic pollution; buildings and the construction sector; textile value chains; plastic value chains; electronic value chains; households; tourism; and furniture • the territorial circular economy, in particular: ○ support for the implementation and demonstration of circular systemic solutions at local and regional scales	Potential gaps regarding the sectoral circular economy are: • coherence between material and energy efficiency • documentation of environmental impacts • sharable datasets to inform future prioritisation Potential gaps regarding the territorial circular economy are: • involvement of local and regional authorities in R & I projects • further supporting and promoting innovative business cases, social norms, governance, and financing models in cities and regions • mobilising further financial expertise for supporting cities and regions in translating project ideas into credible, robust and mature investment concepts

	expected impact 28 ‘biodiversity is back on the road to recovery, and ecosystems and their services are preserved and sustainably restored on land, inland water and at sea through improved knowledge and innovation’; expected impact 29 sustainable and circular management of natural resources as well as prevention and removal of pollution are mainstreamed, unlocking the potential of the bioeconomy, ensuring competitiveness and guaranteeing healthy soil, air, fresh and marine water for all, through better understanding of planetary boundaries and deployment of innovative technologies and other solutions, notably in primary production, forestry and bio-based systems’; and expected impact 32 ‘innovative governance models enabling sustainability and resilience are established and monitored through enhanced and shared use of new knowledge, tools, foresight, and environmental observations as well as digital, modelling and forecasting capabilities’. The impact area is ‘circular and clean economy’.	○ project development assistance to help project promoters develop bankable investment projects ○ enhancement of collaboration between organisations providing technical assistance to cities and regions • water, in particular: ○ consolidation of knowledge about freshwater ecosystem restoration ○ market uptake of successful circular economy water-related projects, and decentralised approaches for water and wastewater management ○ prevention and management of diffuse pollution in urban areas, prevention of groundwater contamination in the context of climate change, improved monitoring and treatment for securing drinking water, and an integrated and harmonised approach to monitoring water quality in urban areas ○ improved monitoring of water availability, climate-sensitive water allocation systems and economic instruments, sustainability of alternative water supply resources, and integrated multilevel water governance approaches ○ water security for the planet (the Water4All partnership)	• facilitating replication and further deployment of local and regional circular systemic solutions Potential gaps regarding water are: • large-scale implementation of circular systems for water / water sludge reuse, and recovery of key nutrients • resilience of water resource systems in the context of climate change and emerging energy and food crises • alternative water supply solutions in the context of increasing water stress • harnessing digital technologies / AI / machine learning in the water sector • drought impacts on freshwater biodiversity and ecosystems under climate change scenarios • knowledge and innovation on micropollutants in water systems, strategies and technologies to reduce biocides in water systems, and detection tools for the identification and characterisation of microplastics and nanoplastics in the environment

5. CONSIDERATIONS REGARDING POTENTIALS AND LIMITATIONS FOR TAKE-UP OF RESULTS

Key messages from this chapter

- The take-up of R & I results remains a challenge in the EU. Although still one of the key global manufacturers of medium- and hi-tech products, the EU is behind other major economies in terms of exports and job creation in knowledge-intensive services.
- Improving the EU's ability to translate scientific discoveries into market and non-commercial solutions is a priority. Overall, the EU shows a strong scientific system and remains ahead of its competitors in applying open science. Nevertheless, more efforts are needed to bridge the gap between scientific research, innovation, and the market, as well as to strengthen the development of transformative going beyond traditional commercial use. Despite its large and qualified scientific base, the quality of the EU's scientific production is still proportionally lower than that of China and the United States. The latter also remains in the lead in terms of patent applications.
- Promoting a culture of knowledge valorisation in the EU's R & I system remains key to boosting the EU's competitiveness. The focus of R & I policies needs to go beyond simple knowledge transfer activities, moving towards knowledge valorisation and value creation by fostering multi-actor approaches that could complement more traditional industry–academia collaborations, thereby facilitating the involvement of all relevant actors, and helping to match the supply and demand for innovation.
- Improved knowledge transfer and knowledge valorisation call for better framework conditions for the EU's innovation landscape, from creating a more agile, transparent and innovation-friendly regulatory framework, reducing the EU's skills shortage and promoting standardisation, to enhancing the funding opportunities available to the EU's innovative enterprises.
- Horizon Europe has a big role to play in supporting the development of the EU's R & I ecosystems through its missions and European partnerships, the EIC, the European innovation ecosystems, the EIT with its KICs, and Horizon Europe's research infrastructures promoting open science, together with the Marie Skłodowska-Curie Actions and the European Research Area.

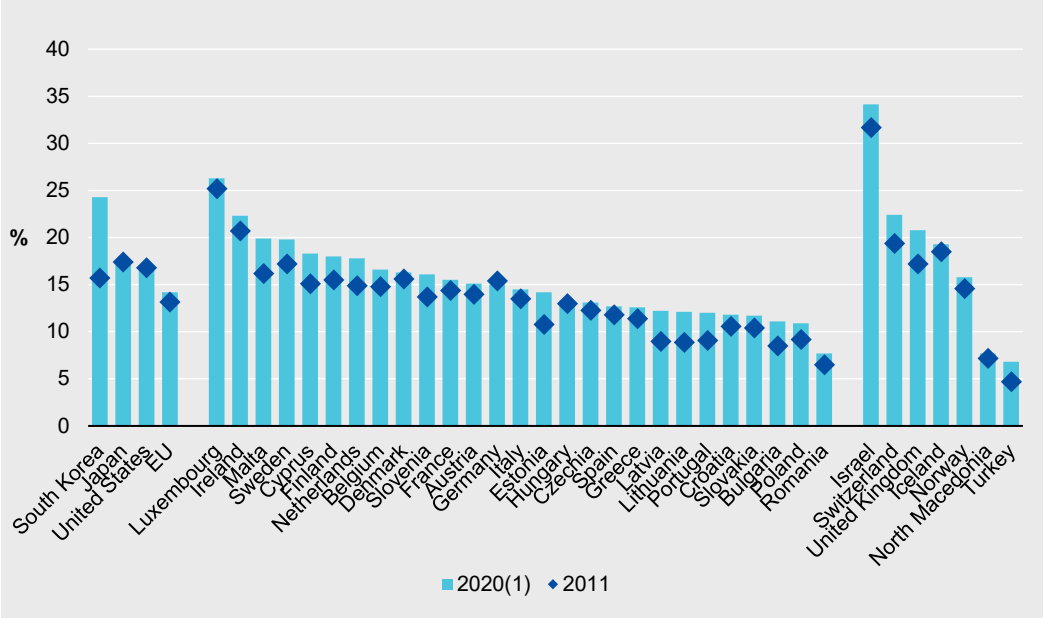
5.1. Economic impact of research and innovation in the EU

Innovation is a key driver of economic growth, being able to foster productivity and overall competitiveness. Investigating the economic impact of innovation activities in the EU provides important insights into the ability of the EU's economy to efficiently use its resources, and be able to produce and take on new and more advanced technologies, thereby increasing its overall competitiveness in the global market.

The EU remains one of the key global manufacturers of medium- and hi-tech products ([284])**.** The EU is third among its global competitors in the exports of medium- and hi-tech products (with a share of 62 % of its total exports), after Japan and South Korea (both leading with 73.4 % thanks to their strong ICT and automotive sectors), but ahead of China ([285]). **The EU performs comparatively less well in exports of knowledge-intensive services** ([286]) (67 % in 2020), being unable to catch up with Japan, South Korea and the United States, although still outperforming China.

The creation of jobs in knowledge-intensive activities remains a challenge for the EU. In 2020, employment in knowledge-intensive activities in business industries as a percentage of total employment was less than 15 % in the EU, well below South Korea, Japan and the United States, despite the small average increase experienced since 2011 (Figure 63). Israel is the global leader, with a share of 34 %. Among EU Member States, the top performers are Luxembourg (26.3 %) and Ireland (22.3 %) ([287]).

Figure 63. Employment in knowledge-intensive activities in business industries as a percentage of total employment, 2011 and 2020



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

In the onset of the COVID-19 crisis, R & I played a key role, exerting a strong influence on the development of the pandemic and its economic and social consequences. As a case in point, the pandemic demonstrated the importance of data and digital technologies as support for policy actions to address the health risks. Measures to contain the pandemic have generated an important change in how firms operate, acting as a **catalyst for the digital transition**. At the same time, **R & D investment in the EU declined during the crisis**, with significant

([284]) The indicator on the exports of medium- and hi-tech products measures these products as a percentage of total product exports. It measures the technological competitiveness of a country, but also reflects the ability to commercialise the results of research and innovation products.

([285]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg.

([286]) The indicator on exports of knowledge-intensive services aims to capture the competitiveness of the services sector by reflecting the ability of an economy to export services with high levels of value added and successfully take part in knowledge-intensive global value chains.

([287]) It is worth mentioning that this indicator is significantly sensitive to a country's economic structure, and that countries with strong financial and/or ICT service sectors tend to perform better than others.

differences between sectors. R & I activities increased in health and ICT, while the automotive sector, for example, recorded a drop in activities ([288]).

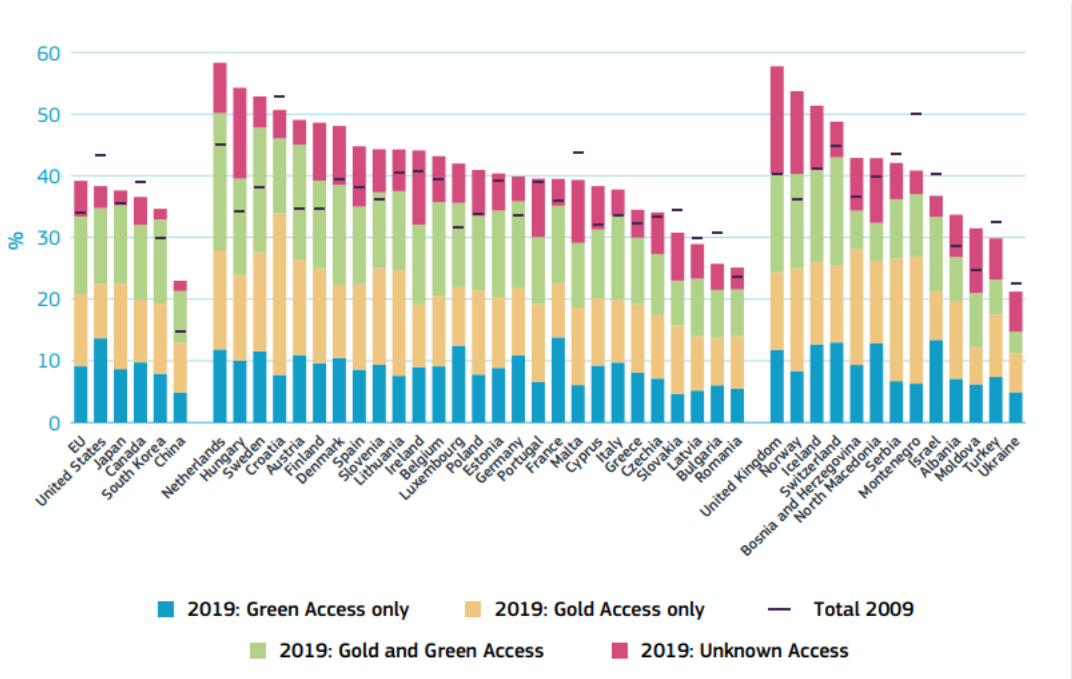
Efforts directed at easing access to and adoption of productivity-enhancing technologies are essential to increase competitiveness while reducing inequalities. Improving the EU's business environment and innovation capacity requires addressing long-standing issues, such as shortcomings in access to finance, innovation-averse regulatory frameworks, the persistent divide between strongly performing firms and laggards, and difficulties attracting and retaining talent, with renewed vigour. These aspects are at the core of the New European Innovation Agenda ([289]).

5.2. Bridging the gap between research, innovation and marketable solutions

5.2.1. Translating scientific discoveries into marketable solutions

Europe, which hosts strong higher education institutions and scientists, has a well-performing science system overall (see Section 3 for more information) **and is ahead of its global competitors in applying open access approaches**. Open access means making scientific publications freely available to anyone, thereby promoting the free exchange of knowledge. Over 39 % of total EU publications are freely available under at least one open access publishing pathway ([290]). The United States, Japan, Canada and South Korea are close behind, with shares ranging from 38 % to 35 %. By contrast, China's share is much lower and accounts for 23 % of the total scientific production of the country (Figure 64).

Figure 64. Open access scientific publications with digital object identifiers as a percentage of total scientific publications with digital object identifiers, 2009 and 2019



NB: Full count used for publications.
Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

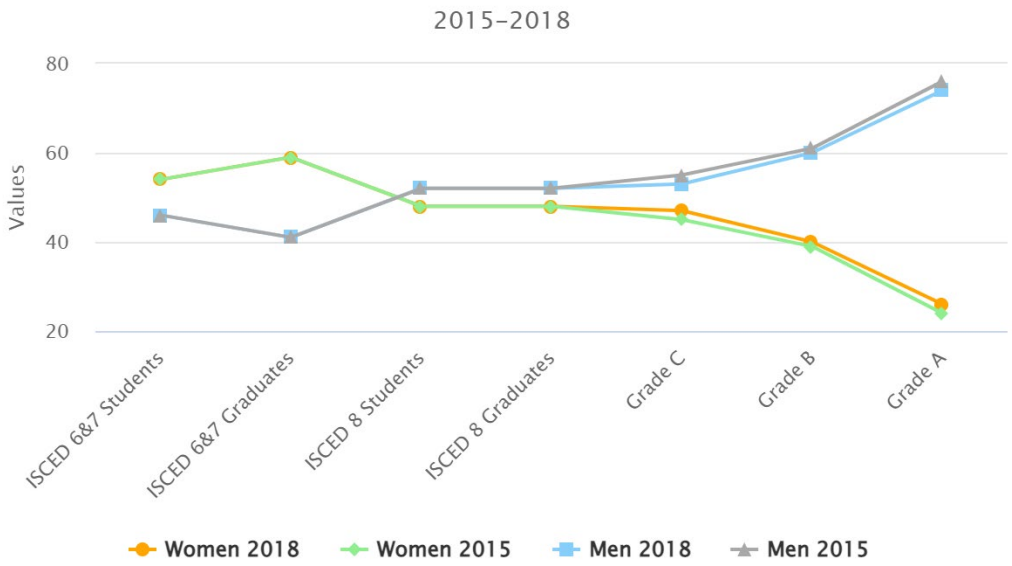
Open access to scientific knowledge remains a key priority, as it makes R & I systems more efficient and creative, reinforcing scientific excellence and society's trust in science. For these reasons, it is key to increase the policy efforts to lift existing barriers to, create the conditions for and adopt the necessary policies for making the

([288]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/52f8a759-1c42-11ed-8fa0-01aa75ed71a1/language-en.
([289]) European Commission (2022), A new European innovation agenda, COM(2022) 332 final.
([290]) There are various types of open access publishing but the two most common are 'gold' and 'green'. Gold open access means immediate access to an article in an online journal. Green open access involves publishing in a traditional subscription journal as usual, then self-archiving in a publicly and freely accessible repository after an embargo period set by the publisher.

European scientific system more open regarding knowledge sharing and collaborations, while safeguarding the EU's interests and open strategic autonomy.

The underrepresentation of women in leadership positions remains a significant issue in the higher education sector in the EU, despite progress towards improving their representation. In 2018, women accounted for over 40% of academic staff on average, but only 26.2% of grade A positions. In 2019, women held less than 25% of head positions and made up only 31.1% of board members and 24.5% of board leaders at the European level. Research has shown that gender diversity in leadership positions is positively associated with better organizational performance, increased innovation, and improved decision-making. Thus, increasing the representation of women in leadership positions can lead to better outcomes for both individuals and organizations, as well as contribute to the broader goal of promoting gender equality in society.

Figure 65. Proportion (%) of men and women in a typical academic career, students and academic staff, EU27



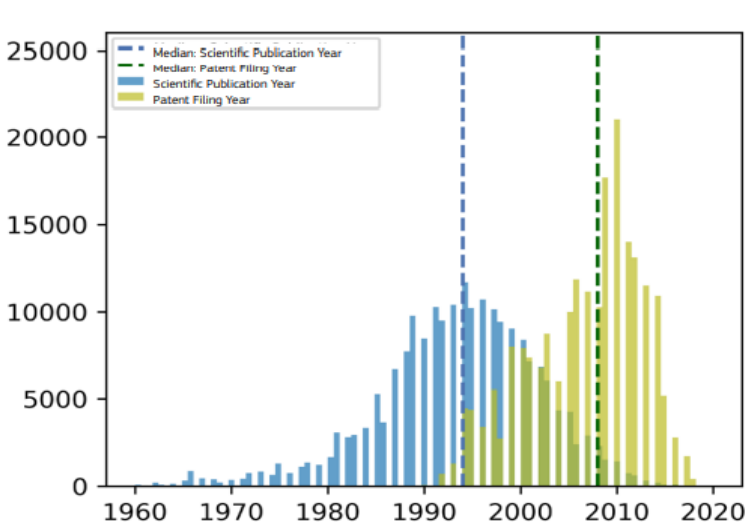
Source: European Commission, Directorate-General for Research and Innovation, She figures 2021: gender in research and innovation: statistics and indicators, Publications Office, 2021, https://data.europa.eu/doi/10.2777/06090. ([291])

Efforts are also needed to accelerate the translation of scientific results into market viable solutions. The value of Europe's science base partly materialises once science reaches the market, a *sine qua non* condition for generating welfare improvements and economic benefits. Turning science into innovation is not an easy task, and providing an adequate environment that maximises the appropriation of science is particularly challenging. Improving our understanding of how science translates into actual products is essential to steer policy action accordingly, and devise the appropriate policy tools and incentive schemes.

On average, it takes about 20–25 years for scientific findings to reach the market. Figure 66 depicts the distribution of the publication years of scientific papers behind today's products, and the distribution of the filing years of the patents protecting these products. For the most part, the science that led to today's products was published during the 1990s, with the median being the mid-1990s. The science base also has a long-lasting effect, with some papers published in the 1980s and earlier still contributing to today's technological progress. On the technology side, **products on the market today appear to use technology developed more than 10 years ago**, with little heterogeneity across technology fields. These long lags exceed the typical policy time frame and, consequently, pose an immediate challenge to policy evaluation and planning.

([291]) Bachelor's and Master's or equivalent level (ISCED levels 6 & 7) followed by Doctoral level or equivalent (ISCED level 8). ISCED 6 – Bachelor's or equivalent level. ISCED 7 – Master's or equivalent level. ISCED 8 – Doctoral or equivalent level. Grade C: The first grade/post into which a newly qualified PhD (ISCED 8) graduate would normally be recruited within the institutional or corporate system. Grade B: All researchers working in positions that are not as senior as the top position (A) but definitely more senior than the newly qualified PhD holders (C) (i.e. below A and above C). Grade A: The single highest grade / post at which research is normally conducted within the institutional or corporate system.

Figure 66. Distribution of the publication years of science and technology contained in today's products



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

UK and Scandinavian universities contribute the most to the development of the hi-tech sector in Europe. The Anglo-Saxon model's dominance concerning technology transfer is partially due to its strong economic ties and cultural proximity to the United States. The Scandinavian university research landscape also displays quite a strong performance, with four universities in the top 50 of the world's academic entities contributing to the development of hi-tech goods, for a population of about 21 million inhabitants among Denmark, Norway and Sweden ([292]). Furthermore, **European universities exhibit very heterogeneous profiles regarding the fields of science that are being translated**. Whereas some universities are very strong in one field, others have a more balanced profile, suggesting that there is no dominant discipline when it comes to research impact.

More efforts are needed to bridge the gap between basic research, innovation and marketable solutions. Even though the EU has a large, qualified scientific base, the United States and China outperform it in terms of patent applications (see Section 3). In addition, despite the enormous scientific production of the EU, especially in comparison with the United States, its quality is proportionally lower than that of China and the United States (Figure 27). The 'from-lab-to-fab' approach and the capacity to deploy technological solutions in industry are determinants in maximising the impact of R & I on key global value chains and the EU's industrial competitiveness. In order to catch up with other major economies and become more competitive internationally, the EU needs to further promote a culture of knowledge valorisation (see Figure 67) in its R & I system by ensuring that knowledge-based institutions manage their intellectual capital effectively, monitoring the real-world success of recent EU legislation on business restructuring and insolvency (particularly with a view to supporting risk-taking enterprises such as start-ups that bring innovations to the market), and by improving the links between academia, industry, citizens and policymakers. An important initiative in this regard is the network of KICs created through the EIT. The EIT KICs focus on developing innovative products, services and training, and facilitating interactions among members of their EIT communities ([293]). Co-creation-based exploratory approaches can complement more traditional industry–academia collaboration, and help match the supply and demand for innovation ([294]). The European partnerships under Horizon Europe are also intended to work in this direction, providing an additional instrument to maximise the valorisation, exploitation and dissemination of knowledge results ([295]) (see Chapter 4).

Fostering multi-actor approaches in innovation projects is, thus, key to ensuring and facilitating the involvement of all relevant actors. A successful example in this regard is the European innovation partnership for agricultural productivity and sustainability funded by the common agricultural policy, which brings together innovation

([292]) European Commission, Directorate-General for Research and Innovation (2023), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times: Executive summary*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/497405.

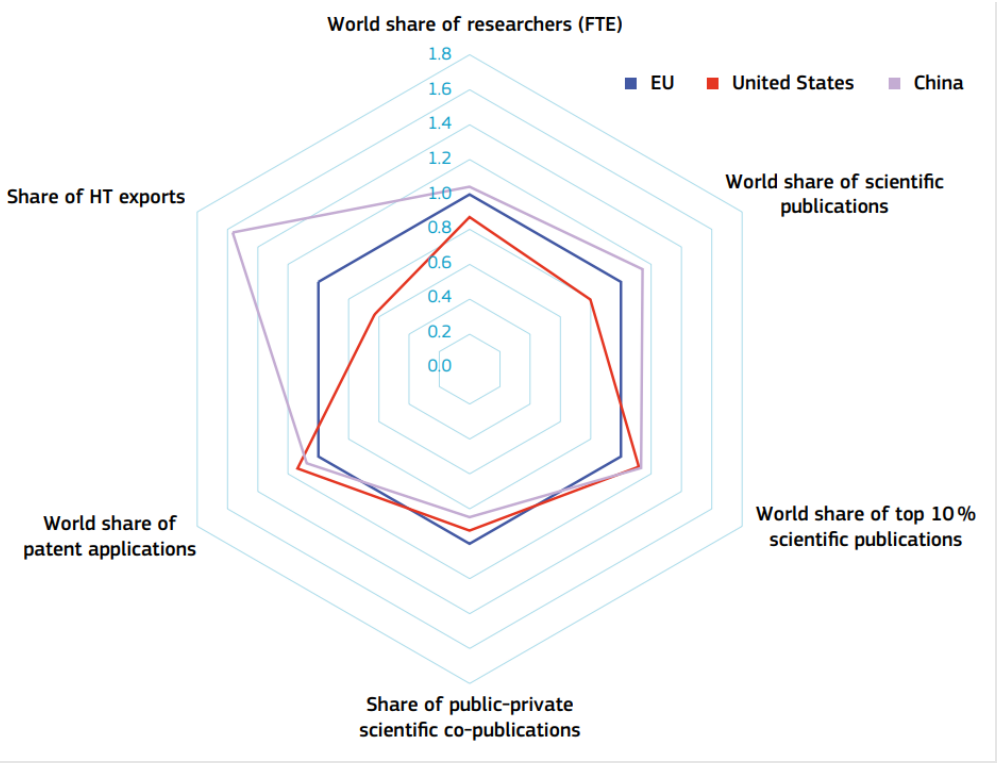
([293]) For more information on the EIT communities, see EIR (n.d.), *EIT Innovation Hubs*, https://eit.europa.eu/our-communities/eit-innovation-communities/innovation-hubs.

([294]) European Commission, Directorate-General for Research and Innovation (2021), *Testing the feasibility of a new industry–academia knowledge exchange concept focusing on companies' needs – Final report*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/530089.

([295]) European Commission, Directorate-General for Research and Innovation (2022), *Performance of European Partnerships – Biennial Monitoring Report 2022 on partnerships in Horizon Europe*, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2777/144363.

actors (farmers, foresters, advisers, researchers, businesses, non-governmental organisations and others) to develop innovative solutions focusing on farmers' and foresters' needs through Operational groups ([296]). These type of cooperation aims to create added value by better linking research and farming practices ([297]). The Multi-actor approach applied in R&I projects was developed already in Horizon 2020 and it has been implemented in multitude of calls in Horizon Europe Pillar II especially in Cluster 6. This approach ensures the genuine and sufficient involvement of relevant actors and makes the R&I process more demand driven. Synergies between EIP-AGRI and Horizon Europe were promoted to make the best use of R&I results by end-users. Another example is the European innovation partnership on active and healthy ageing ([298]), which brings innovators, researchers, citizens, and regional and national stakeholders together to promote the uptake of innovative solutions to promote better and more person-centred health and care for Europe's ageing population ([299]).

Figure 67. Knowledge valorisation



Source: European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

A modern R & I policy requires a change of focus from managing intellectual property in knowledge transfer activities, to knowledge valorisation ([300]) **and value creation** ([301]). This entails broadening the scope from intellectual property management to intellectual asset management in order to cover more results or products

([296]) Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013 (OJ L 435 06.12.2021, p. 1, ELI: http://data.europa.eu/eli/reg/2021/2115/oj).

([297]) EU Cap Network (n.d.). *Innovation & knowledge exchange.* https://eu-cap-network.ec.europa.eu/support/innovation-knowledge-exchange-eip-agri_en

([298]) European Commission (n.d.), *Shaping Europe's Digital Duture – The European innovation partnership on active and healthy ageing (EIP on AHA)*, https://digital-strategy.ec.europa.eu/en/policies/eip-aha.

([299]) European Commission (n.d.), *Active and Healthy Living in the Digital World*, https://futurium.ec.europa.eu/en/active-and-healthy-living-digital-world.

([300]) Knowledge valorisation looks at the creation of societal value from knowledge by translating research findings into innovative products, services, processes and/or business activities (, L. HM, Van de Burgwal, A. Dias, and E. Claassen (2019), 'Incentives for knowledge valorisation: a European benchmark', The Journal of Technology Transfer 44.1, pp. 1-20.). Knowledge valorisation is the process of creating social and economic value from knowledge by linking different areas and sectors, and transforming data and research results into sustainable products and solutions that benefit society in terms of economic prosperity, environmental benefits, progress and better policymaking (European Commission (2022), Proposal for a Council recommendation on the guiding principles for knowledge valorisation, COM(2022) 391 final).

([301]) European Commission (2022), Council recommendation on the guiding principles for knowledge valorization, COM(2022) 391 final.

generated by R & I, while maintaining the balance with openness in science ([302]). The policy should encourage universities to focus more on value creation and utilisation of research results rather than value capture when managing their intellectual property ([303]). Furthermore, it needs to address all ecosystem actors involved in R & I activities, including local communities and citizens. Some examples of available best practices of knowledge exchange are present in the EU, such as the agricultural knowledge and innovation systems ([304]). Finally, it must develop an entrepreneurial mind set with its practices, processes and skills.

In addition, **cultural and creative aspects of the human experience also need to be embedded in R & I policies and efforts**. The R & I agenda is becoming more human-centric, and EU innovation policy must be based on a definition of innovation that acknowledges and values all forms of new knowledge – technological, but also business models, financing, governance, regulatory and social forms – that help generate jobs and value for the economy and society and drive systemic transformation.

5.2.2. Improving the take-up of non-commercial solutions to societal challenges

New technologies and market-based solutions alone may not be sufficient to address major challenges such as climate change, biodiversity loss or growing inequalities ([305]). **Emerging technologies, nature-based solutions, social innovations and broader shifts in cultural repertoires are essential parts of transformative change towards sustainable futures** ([306])**.** As an example, social innovation has appeared as a successful approach for a deep transformation of our systems and practices, as it has the potential to offer novel approaches to contemporary crises that differ from traditional technology-based solution, and would then be complementary to these in achieving the SDGs ([307]).

Stakeholders' engagement, citizen participation, citizen empowerment and cross-sectoral collaborations are key aspects of social innovation. Social economy enterprises, partnerships, cooperatives, public-owned enterprises, and associations have proven to be innovative in dealing with socio-economic and environmental problems, while contributing to economic development. In 2018, there were more than 1.9 million active partnerships, cooperatives, and associations across the EU, employing more than 34.8 million persons, about 10.5% of the total workforce. They are particularly active in education, health care and social work activities and employ 28% of the persons working in those sectors ([308]).

Furthermore, **arts and cultural organisations can boost knowledge valorisation processes through their distinctive skills and competencies** ([309]) and **help to reach beyond functionality**. A more holistic approach to knowledge valorisation can help to better foster well-being, inclusion and sustainability, thereby likely increasing the uptake of R & I developments. The roles of culture, cultural diversity, and the cultural and creative sectors and industries are key in this regard, as proven by the New European Bauhaus initiative ([310]), and the upcoming EIT KIC on culture and creativity, which will start operating in 2023 ([311]).

([302]) European Commission, Directorate-General for Research and Innovation (2022), *Open science and intellectual property rights – How can they better interact? State of the art and reflections – Executive summary*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/347305.

([303]) European Commission, Directorate-General for Research and Innovation, Holgerson, M. (2022), *The management and commercialisation of intellectual property in European universities, Publications Office of the European Union*, Luxembourg,https://data.europa.eu/doi/10.2777/969317.

([304]) Advancing research, knowledge-sharing and innovation will be essential for securing a smart and sustainable agricultural sector. The reformed common agricultural policy will benefit from this increased investment, incorporating stronger agricultural knowledge and innovation systems to boost the development of innovation projects, disseminate their results and encourage their use as widely as possible. Farm advisory services will be a key tool in sharing new knowledge and ideas.

([305]) European Environmental Agency (2021), *Nature-based solutions in Europe – Policy, knowledge and practice for climate change adaptation and disaster risk reduction*, Publications Office of the European Union, Luxembourg.

([306]) Folke, C., Polasky, S., Rockström, J., Galaz, V., Westley, F., Lamont, M., Scheffer, M., Österblom, H., Carpenter, S. R., Chapin III, F. S., Seto, K. C., Weber, E. U., Crona, B. I., Gretchen, C. D., Dasgupta, P., Gaffney, O., Gordon, L. J., Hoff, H., Levin, S. A. Lubchenco, J., Steffen, W. and Walker, B. H. (2021), 'Our future in the Anthropocene biosphere', *Ambio*, 50, pp. 834–869.

([307]) European Commission, Directorate-General for Research and Innovation (2023), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times: Executive summary*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/497405.

([308]) European Commission, Directorate-General for Research and Innovation (2023), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times: Executive summary*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/497405.

([309]) European Commission, Directorate-General for Research and Innovation (2022), *Fostering knowledge valorisation through the arts and cultural institutions*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/377987.

([310]) European Union (n.d.), *New European Bauhaus – Beautiful | sustainable | together*, https://new-european-bauhaus.europa.eu/index_en.

([311]) EIT (n.d.), *EIT Culture & Creativity – Transforming Europe's cultural and creative sectors and industries*, https://eit.europa.eu/eit-community/eit-culture-creativity.

5.2.3. Better framework conditions for research and innovation

Fostering knowledge transfer and knowledge valorisation calls for an improvement of the framework conditions of the EU innovation landscape. Setting the correct framework conditions to allow innovation and knowledge to flourish is an important prerequisite for success in R & I in Europe, as the conditions set business incentives and shape the innovation capacity of economies. Good framework conditions positively affect business investment decisions, ease access to markets for new and innovative companies, and contribute to reallocating resources towards more productive and innovative activities. Political stability, transparency, accountability and a high degree of rule of law are essential to create an environment in which firms are incentivised to innovate and to take calculated risks for innovation.

Improving the conditions and long-term sustainability of innovation funding is also crucial to unlock the growth potential of knowledge-based economies and sectors. Intangible-intensive sectors have strong productivity potential, but typically face more financial constraints than the rest of the economy. Less financial frictions would improve firms' ability to fund their innovation activities, thereby improving their productivity performance. External funding plays a critical role in enhancing investment opportunities, but its use remains limited to the biggest product innovators; internal funding continues to be the primary source of innovation for all European businesses. Enhancing access to equity capital, especially for small innovative firms, is thus key to creating growth opportunities.

The number of EU scale-ups has increased in recent years, but the gap between the EU and the United States remains. On average, there are three times as many tech scale-ups in the United States than in Europe ([312]). Despite the contraction experienced with the outbreak of the coronavirus, European fast-growing companies showed a good degree of resilience to the COVID-19 shock. **European scale-ups** ([313]) **are strongly concentrated in a few countries**, notably the United Kingdom and France, which account for about 50 % of total scale-ups in Europe. In 2021, the United Kingdom remained the leading country in terms of scale-up performance, counting for around 33 % of the European scale-up force. London maintained its record as Europe's scale-up capital, with 145 scale-up companies. Paris followed, with 50 fast-growing firms, accounting for 17 % of total scale-ups in France. Berlin ranked third, with 25 scale-ups ([314]).

The European scale-up landscape is dominated by companies operating in the digital and tech industries. Around 57 % of European scale-ups are active in the computer software industry (57.1 %). The banking, insurance and financial services sector ranks second with 12 %, while 7.5 % of European scale-ups firms operate in the field of biotechnology and life-sciences ([315]).

Availability of staff is one of the main barriers identified by innovative start-ups. Difficulty in hiring staff with the appropriate skills is reported as one of the main constraints to start-ups' growth ([316]). This is particularly relevant for high-growth start-ups, which appear to experience significant difficulties in recruiting staff with appropriate technical skills, and finding personnel with the right qualifications or experience ([317]).

Labour shortages are particularly relevant in sectors linked to the green and digital transitions. Labour shortages in sectors linked to the transition to a climate-neutral economy have been reported by several Member States ([318]), while the percentage of enterprises with hard-to-fill vacancies for ICT specialists has been steadily increasing in the last decade: the share of enterprises that tried to recruit ICT specialists rose from 40 % in 2012 to 55 % in 2020 ([319]). Furthermore, a serious shortage of AI skills is reported in the EU when compared with China and the United States ([320]). A potential reason is that the EU produces fewer master's degree and PhD graduates in computer science and AI, or that it does not adequately present itself as an attractive place for foreign professionals to consider relocating to for a career in these areas. **Addressing the EU's skill shortage is, thus, of pivotal**

([312]) Mind the Bridge (2019), Tech Scale ups EU

([313]) Here defined as young fast-growing companies (10 years old or younger) that have received at least EUR 1 million within the past 10 years (January 2011 to December 2020) (Erasmus Centre for Entrepreneurship (2021), *European ScaleUp Monitor 2021*, https://ece.nl/research/european-scaleup-monitor/).

([314]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

([315]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

([316]) EIB (2020), From starting to scaling: How to foster startup growth in Europe, https://www.eib.org/en/publications/from-starting-to-scaling.

([317]) EIB (2020), From starting to scaling: How to foster startup growth in Europe, https://www.eib.org/en/publications/from-starting-to-scaling.

([318]) Eurofund, 2021.

([319]) c.f. Eurostat's survey on ICT use in enterprises, variable code ISOC_SKE_ITRCRN2.

([320]) J., Anderson, P., Viry, and G. B., Wolff (2020), 'Europe has an artificial-intelligence skills shortage', Bruegel-Blogs.

importance to improve both knowledge transfer and knowledge valorisation, thereby increasing the economic and societal impact of Horizon Europe.

In this regard, **efforts should also be oriented towards strengthening the integration of research and researchers from social sciences and humanities** disciplines in research projects across the programme, including in the R & I missions, aiming to address pressing societal challenges. The increasing complexity of emerging phenomena cannot be fully understood or addressed from within knowledge silos, calling for interdisciplinary approaches to stimulate the kind of radical innovations that are necessary to address modern societal challenges, thereby keeping a human-centric approach to R & I.

5.2.4. Enabling innovation through an improved regulatory framework

To ensure well-functioning markets that incentivise competition and innovation (thereby maximising the impact of the EU's R & I investments), **Europe needs a fit-for-purpose, forward-looking and overall innovation-friendly regulatory framework**. Regulations can be powerful instruments through which to foster innovation in the EU.

Several factors prevent regulations in the EU from fully acting as drivers of innovation. The EU is faced with challenges common to other regulatory systems, for example how to ensure that regulations are agile enough to adapt rather than react to the pace of innovation, and when and how to regulate disruptive innovation when only limited evidence is available.

However, EU-specific challenges may also come into play. These include the length of the legislative process, risks of market fragmentation if the same innovation is treated differently across Member States, and problems in national implementation of EU regulations (inadequate transposition or implementation, gold-plating burdens or obstacles in the delivery phase of the legislation). These factors can also discourage investments and limit innovation. At the same time, regulations alone may not be sufficient. Innovation requires public buy-in and trust, with the societal uptake of innovation also being a demand-side indicator of emerging regulatory gaps or deficiencies.

Regulations need to be made future-proof and fit for purpose to continue to be effective while meeting the desired policy goals in a fast-moving and increasingly complex environment. The emergence of new practices, technologies and business models and the acceleration of innovation call for more flexible and experimental approaches to regulations, such as the implementation of the innovation principle, regulatory sandboxes and innovation clauses.

Experimental approaches aim to test new solutions or alternative business models in a controlled real-world environment before admitting them to the market. Current regulatory sandboxes in the EU context cover genuine innovations that are expected to deliver consumer and/or wide societal benefits. They allow the regulator some flexibility while maintaining regulatory standards, and they facilitate learning, keeping up with developments in the sector and strengthening ties between regulators from different policy fields.

Closely connected to sandboxes are experimentation clauses, which can serve as the legal basis for sandboxes or simply allow for flexibility under certain circumstances. They enable authorities tasked with implementing and enforcing legislation to exercise a degree of flexibility in relation to innovative technologies, products or approaches, even if they do not conform to all existing legal requirements.

Furthermore, the digital and green transition and a well-functioning and resilient single market rely on a standardisation system that adequately reflects EU policy priorities. As emphasised in the European Green Deal and in the new industrial strategy for Europe, developing new standards, coupled with the EU's increased participation in international standardisation bodies, is essential to boosting the competitiveness and resilience of European industry and to building a sustainable future. Standards will help to valorise and channel scientific discoveries and inventions towards the green and digital transition and the EU's open strategic autonomy ([321]).

European standardisation must respond to an increasingly rapid pace of innovation and needs to deliver standards fast, while preserving high-quality outputs. Standards and standardisation allow the codification of knowledge and for it to be made available to a wide range of stakeholders ([322]). Thus, they help to bridge the gap between research and the market, and increase the probabilities of market uptake of technological innovations. Developing and diffusing standard methods to assess the potential and impact of technologies over their entire life

([321]) European Commission, Directorate-General for Research and Innovation (2022), *ERA industrial technology roadmaps for low-carbon technologies and for circular industrial technologies*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/92567.

([322]) European Commission, Directorate-General for Research and Innovation (2022), *ERA industrial technology roadmap for low-carbon technologies in energy-intensive industries*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/92567.

cycle help develop and diffuse technologies in different industries, thereby representing an important instrument to promote innovation, for both policymakers and businesses ([323]).

Standardisation has an important role in R & I investment agendas as it helps pave the way for large-scale deployment of new and strategic technologies. The EU standardisation strategy ([324]) stresses the untapped potential of EU-funded pre-normative research in supporting future trends in standardisation by allowing new technologies to create opportunities for our industries. The role of Horizon Europe is underlined, as it entails a strong anticipation of standardisation needs, and strong linkages between strategic priorities and pre-normative research, which should, however, account for innovative-context specifics (e.g. site specifics of farming practices), for which one-size-fits-all standards may not be efficient. **Horizon Europe's European partnerships with industry have a big role to play in this regard.** By their very nature, Horizon Europe's partnerships cannot act in isolation but must seek complementarities with other relevant initiatives or programmes to accelerate the development and diffusion of innovation. Thus, they enable systematic engagement with a variety of stakeholders and end users, including standardisation bodies and international partners, to ensure that these solutions are taken up and can ultimately deliver on the ambitious goals ([325]).

Engaging the R & I community early on in standard development also provides an opportunity to build expertise and skills in standardisation. Today, researchers, spin-offs and start-ups often do not consider standardisation a priority: they are not always aware of the benefits of standardisation, they do not have the necessary resources, or they consider time spent on standardisation activities to be not sufficiently rewarded. A consistent approach to facilitate standardisation activities and raise strategic awareness among researchers and innovators thus needs to be promoted by a dedicated European code of practice on standardisation for researchers.

Opening up the European R & I system to the participation and collective intelligence of society is another key ingredient for the success of the EU's innovation policy. Encouraging and developing the engagement of society, embedding high integrity and ethics standards, raising interest in science and supporting Europe's brightest minds to engage in scientific careers are all essential components of R & I policy programmes. Europe cannot thrive without ensuring the best possible match between the immense potential achievements science has to offer and the needs, values and aspirations of citizens ([326]).

5.3. Horizon Europe's role in supporting the take-up of innovation results: fostering innovation activities

Thanks to its pan-European approach, the scale of its support and its strong networks with all R & I players, the EU framework programme for R & I plays a unique role in supporting the development of the EU R & I system. Horizon Europe has an important role to play in addressing each of the challenges mentioned in the previous section. For instance, the EIC was designed to bridge two critical funding gaps that innovative companies face in their growth journey, namely the transition phase from the laboratory to the market, and the scale-up phase for high-risk innovations. In being able to support cutting-edge innovative projects in different strategic fields (such as green, digital and health), the EIC proved to be crucial in the fight against COVID-19, and is set to become the key EU investor in early-stage highly innovative start-ups, helping them gain additional support to scale up through the combination of public grants and patient equity investment. The European innovation ecosystems facilitate the creation and strengthening of more connected, inclusive and efficient innovation ecosystems that support the scaling of companies and spur innovation to address societal challenges in a responsible way, as laid out in the New European Innovation Agenda ([327]). R & I results enable industry to master the green and digital transition and to become more resilient. The updated industrial strategy ([328]) emphasises the central role that the European partnerships under Horizon Europe and complementing industrial alliances play in this regard. A stronger and accelerated transfer of R & I results to EU industrial ecosystems is encouraged in the strategy by means of the European research area industrial technology roadmaps, which feed priorities for R & I into European transition pathways for key industrial ecosystems.

([323]) European Commission, Directorate-General for Research and Innovation (2022), *ERA industrial technology roadmap for low-carbon technologies in energy-intensive industries*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/92567.

([324]) European Commission (2022), An EU strategy on standardisation – Setting global standards in support of a resilient, green and digital EU single market, COM(2022) 31 final.

([325]) European Commission, Directorate-General for Research and Innovation (2022), *Performance of European Partnerships – Biennial monitoring report 2022 on partnerships in Horizon Europe*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/144363.

([326]) European Commission, Horizon Europe (2021), *Open Science – Early knowledge and data sharing, and open collaboration*, Publications Office of the European Union, Luxembourg.

([327]) European Commission (2022), A new European innovation agenda, COM(2022) 332 final.

([328]) European Commission (2021), Updating the 2020 new industrial strategy: Building a stronger market for Europe's recover, COM(2021) 350 final.

The EIT and its KICs drive innovation by bringing together organisations from the business, higher education and research sectors to find solutions to pressing global challenges. The EIT has created Europe's largest innovation ecosystem, with over 3 000 partners, with a particular focus on supporting entrepreneurial education, developing innovative projects and business creation and acceleration, and creating new innovative solutions to address global challenges in areas of climate change, digitisation, sustainable energy, raw materials, manufacturing, food production, healthy living, urban mobility, and culture and creativity.

Horizon Europe is also well-placed to valorise R & I results through standardisation. The Commission is assessing how to better support researchers and innovators participating in EU-funded research, development and innovation projects to take part in standardisation activities. It launched the standardisation booster ([329]), a platform to help beneficiaries – whose Horizon 2020 and Horizon Europe research results are likely to lead to the revision or creation of a standard – test the relevance of their results for standardisation.

Citizen science is a powerful tool for public engagement and empowerment in policymaking, and for raising awareness ([330])**.** Under the seventh framework programme for R & I (2007–2013), the Commission funded several projects involving citizen science, including Socientize, an initiative to promote and support citizen science. Under the eighth framework programme (2014–2020), the Horizon 2020 science with and for society subprogramme aimed to build effective cooperation between science and society, foster the recruitment of new talent for science, and couple scientific excellence with social awareness and responsibility. A budget of EUR 462 million was allocated to this subprogramme. Since its start, 150 projects have been funded, with a total budget of EUR 319 million ([331]).

In Horizon Europe, citizen engagement has become even more prominent than in Horizon 2020. It has been envisaged as taking place in terms of co-design (e.g. developing research agendas), co-creation (e.g. involving citizens, social partners and/or end users in developing new knowledge and innovations), and co-assessment (e.g. continual contribution to governance), taking the concept of responsible R & I further. The previous strategic plan for Horizon Europe was co-designed, in particular through a web-based consultation and views expressed by participants in the European research and innovation days. In total, the views of more than 10 000 respondents across 64 countries – from universities, research organisations, industry and civil society, and covering all Member States – were integrated into the strategic planning ([332]).

Open science through the sharing of knowledge, data and tools in the R & I process is also a key element of Horizon Europe. Horizon Europe features research infrastructures, which aim to support the development and consolidation of the European Open Science Cloud ([333]). Marie Skłodowska-Curie actions are also intended to promote the diffusion of open science practices and to support the development of appropriate skills among researchers. As an example, the Marie Skłodowska-Curie actions Green Charter promotes the sustainable implementation of research activities, providing a code of good practice for any individuals and institutions benefitting from funding.

The European missions of Horizon Europe will also play a key role in fostering innovation throughout the EU ([334])**.** The five missions, launched in September 2021, will connect all relevant actors through new forms of partnerships for co-design and co-creation, and involve multiple sectors and actors. Horizon Europe will also support European partnerships with EU Member States, the private sector, foundations, and other stakeholders. The aim is to deliver actions on global challenges and industrial modernisation through co-creation and concerted R & I efforts.

Furthermore, **the widening participation and strengthening the European Research Area part of Horizon Europe will support the further development of the open science policy and adoption of open science practices (**[335]**)**. The European Research Area will increase coordination, exchange of good practices and tools, development of guidance and training, implementation of institutional changes and consolidation of evidence on

([329]) European Commission, IP Helpdesk (2022), *European Standardisation Booster: New five open calls for Horizon Europe and H2020 projects*, https://intellectual-property-helpdesk.ec.europa.eu/news-events/news/european-standardisation-booster-new-five-open-calls-horizon-europe-and-h2020-projects-2022-07-18_en#:~:text=European%20Standardisation%20Booster%20is%20a%2024-month%20European%20Commission,urgencies%20identified%20in%20the%20EU%20Strategy%20on%20Standardisation.

([330]) European Commission, Directorate-General for Research and Innovation (2020), *Citizen Science – Elevating research an innovation through societal engagement*, Publications Office of the European Union, Luxembourg.

([331]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

([332]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

([333]) European Commission, Horizon Europe (2021), *Open Science – Early knowledge and data sharing, and open collaboration*, Publications Office of the European Union, Luxembourg.

([334]) European Commission (2022), Annual report on research and technological development activities of the European Union and monitoring of Horizon Europe and Horizon 2020 in 2021, COM(2022) 389 final.

([335]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

impacts. In 2021, there was major progress in the renewed European Research Area with the introduction of the Council recommendation for a pact for research and innovation and the European research area policy agenda[336]. It sets out 20 measures for 2022–2024, including future R & D investments and structural reforms, and sharing of open knowledge and promotion of attractive scientific careers ([337]).

The open research Europe publishing platform is also providing Horizon 2020 and Horizon Europe beneficiaries (including the European Atomic Energy Community and European cooperation in science and technology) with the possibility of using a high-quality, open access, peer-reviewed publishing venue, at no cost to them, during and after their grant period. This not only helps beneficiaries to meet their open access obligations, but also further incentivises open peer review.

In addition, **the EIC aims to support the development and take-up of breakthrough innovations in several domains**. It was designed to bridge two critical funding gaps that innovative companies face in their growth journey, namely the transition phase from the laboratory to the market, and the scale-up phase for high-risk innovations. Thus, the EIC supports the most talented and visionary European researchers and entrepreneurs, adopting a primarily bottom-up model that allows the submission of breakthrough ideas from various science and technology fields that could affect a range of sectors and applications ([338]).

([336]) European Commission (2021), Proposal for a COUNCIL RECOMMENDATION on a Pact for Research and Innovation in Europe, COM(2021) 407 final.

([337]) European Commission (2022), Annual report on research and technological development activities of the European Union and monitoring of Horizon Europe and Horizon 2020 in 2021, COM(2022) 389 final.

([338]) EIC (2022), *Identification of Emerging Technologies and Breakthrough Innovations*, EIC working paper 1/2022, Publications Office of the European Union, Luxembourg, https://op.europa.eu/en/publication-detail/-/publication/7c1e9724-95ed-11ec-b4e4-01aa75ed71a1/language-en.

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The Horizon Europe Strategic Plan 2025–2027 Analysis underpins the development of the Horizon Europe Strategic Plan 2025–2027 by providing a solid base of evidence, as set out in the legal basis of Horizon Europe. The analysis explores whether the changes in the context of EU policy, in the world, in society, economy and policy, in science, technology and innovation, and in our appreciation of future challenges and opportunities since the first strategic plan require a change of strategy regarding the plan's orientations, directions and activities. Using tailor-made foresight and state-of-the-art analysis such as that in the Science, research and innovation performance of the EU 2022 report, this analysis gives an overview of key political, socioeconomic and environmental drivers that are relevant for the EU and Member States' policy priorities, and challenges and opportunities we are facing as a European society, together with examples of the role research and innovation (R & I) plays in addressing them. Focusing overall on the key themes of resilience and the just green and digital transition, this analysis provides orientations on society's demands for R & I, based on, among other sources, input gathered at a dedicated citizen engagement event and during an online public consultation. Finally, the analysis provides an overview of current R & I activities and identifies gaps in the existing efforts by using analytics and data on the implementation of Horizon Europe.

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