



Study on strategic digital technologies for the EU Research and Innovation funding beyond 2027

Final Report
September 2026

technopolis
group

In collaboration with Fraunhofer ISI, Tecnalia, imec, OPIX, AIT, GlassAI and technology experts

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Executive Summary

The European Commission's Directorate-General for Communications Networks, Content and Technology (DG CNECT) has commissioned this study to inform priorities for the **research, development, and innovation of digital technologies in Europe**.

The objective is to identify those critical digital technologies in which the EU should invest to strengthen its R&I capacity under the next Multiannual Financial Framework (next MFF 2028–2034). The findings will support the **European Commission in shaping its future digital R&I investment strategy, particularly the digital components of the next Horizon Europe programme**.

This study complements a related European Commission study on the **“EU's critical digital capacities deployment beyond 2027”**, which focuses on the deployment phase of critical digital technologies in the context of a future EU deployment programme (successor of Digital Europe Programme). As the two studies were conducted in parallel and in a coordinated manner, including a common public consultation and data collection process, some overlap in the data analysis is inevitable. Nevertheless, the studies have distinct perspectives, with one focusing primarily on research and innovation and the other on technology deployment and market uptake.

The analysis presented in this report stems from extensive desk research, stakeholder and experts' consultation, foresight exercise including series of focus groups and workshops. The key findings of the study are presented below:

State of play of the EU's R&I positioning on digital technologies

The well-recognised challenge: Europe trails in critical digital technologies

In June 2026, the European Commission put forward the European Technological Sovereignty Package to strengthen Europe's capacity in semiconductors, AI, cloud computing and open-source technologies by investing in strategic digital capabilities. This reflects the recognition that Europe must address weaknesses across its entire digital ecosystem, as the evidence continues to paint a concerning picture of Europe's position in digital technologies.

Although Europe has perceived scientific strengths in digital technologies and it has a robust regulatory framework, the EU has been losing ground on research excellence internationally. Despite its leading position in the volume of scientific publications except for AI and Cybersecurity, the quality of EU scientific publications continues to lag behind that of the United States and China. The EU's performance in scientific excellence, gauged by its publications ranking in the top 1% or top 10% most highly cited globally, has been stagnant and falls behind China and the US across all digital technologies, which suggests the need to place greater emphasis on quality over quantity.

The EU trails the US, China, and Japan in patent applications across most digital fields except for Quantum and Photonics, indicating commercialisation challenges and a declining global position. Its gap is significant in the field of HPC, Advanced Connectivity but also in the field of Cloud-Edge-IoT. However, the central R&I challenge is not in misalignment between research agendas and industrial or societal needs. The comparative analysis of top EU patents and top scientific publications, together with qualitative expert assessments of key global opportunities, reveals a high degree of alignment with industrial priorities. The gaps lie in the EU's limited capacity to operate at the technological frontier, with research not consistently reaching the global top tier, and in its ability to commercialise research, where growth-stage funding remains insufficient.

The EU27 is also behind software code development as captured by the repositories created on GitHub and trails the US and China. Within the EU, Germany, France and the Netherlands are countries with the highest number of contributors to the code repositories. A striking feature is the relative absence of European actors. Apart from Arm (UK), Huggingface (that originates in France) and Red Hat (whose parent company is IBM,

an American firm), there are virtually no major European companies or universities among the leading contributors to globally visible open-source ecosystems. At the same time, the high share of self-employed developers understates the EU's overall participation, as many individual affiliations are not reflected in the available data.

The opportunities to seize: building technological sovereignty, scaling innovation, and unlocking synergies across digital technologies

Despite the challenges in digital research and innovation, several key drivers are expected to strengthen the EU's future position. In the EU, 60,411 EU tech companies develop critical digital technologies and drive private R&I, equivalent to ~4.75% of the EU ICT business population. Consisting mainly of AI and Cybersecurity companies, they foster innovations that underpin the economy and society and form the basis of the EU's next opportunities in critical digital technologies. These technology companies can be the basis and key partner in achieving European technology sovereignty as they provide the innovation and industrial capacity needed to translate research and innovation agendas into deployable technologies.

Moreover, the EU boasted 20,720 advanced digital tech startups in 2025, out of which 728 scaled up (3.5%) and are still operational, and 40 reached the unicorn status (0.2%). The EU digital startup landscape is performing well and digital tech startup creation has accelerated significantly in the EU as shown by various metrics. The cumulative number of start-ups, notably the total number of start-ups founded up to 2025 has been 3 times higher than in 2015. This rapid expansion of the EU's digital startup ecosystem provides a strong foundation for building globally competitive technology champions and accelerating innovation-driven growth.

The EU landscape of 12 key digital technology areas attracted a total of €82 bn in venture capital since 2015. Since 2015, investment in European start-ups has grown substantially, with early-stage funding more than doubling and growth-stage funding tripling. In line with global trends, investment into European digital technologies has expanded substantially over the past decade. Between 2015 and 2024, capital invested in the EU grew at a compound annual growth rate (CAGR) of ~20% overall, with seed funding rising by 21.6% per year, early VC by 21.8% per year, and growth VC by 19.1% per year.

The EU has strengths in several technologies and technology niches where R&I funding invested today can ensure future competitiveness. Evidence indicates that an interdisciplinary innovation ecosystem will play a critical role in translating research into impactful digital innovation. By connecting expertise across technologies and sectors, these ecosystems foster the co-development of solutions that are more responsive to societal challenges and better aligned with market opportunities.

Research into energy efficient digital technologies has emerged from this research as a key cross-cutting opportunity. Energy-efficient digital technologies are critical because they reduce energy consumption, lower operational costs, and minimise environmental impact while enabling the sustainable development and future use of all critical digital technologies.

Significant public and private investment in digital R&I but gaps still remain

Horizon Europe has made significant investments in digital technologies, with around €13 bn committed so far in the Horizon Europe Work Programmes 2021-2025 with a strong concentration of investments in Microelectronics, AI, Data and Connectivity. Despite the concentrated funding volumes, the programme still maintains a diversified support across a broader range of critical technologies. The highest volume of funding across most of the digital technologies was absorbed by private for-profit companies, except for high performance computing and quantum technologies (where research and education organisations and higher education attracted the most funding).

The Horizon Europe portfolio of digital technology projects shows an overall leverage factor of around 9.9% on EU contributions, with marked differences between technology areas. The analysis covers approximately €1.8 bn of leveraged funding in total.

A stable core of EU27 countries consistently lead scientific outputs, patent applications and startup concentration across digital technology areas. Germany, France, and the Netherlands emerge as the most relevant hotspots of digital technology R&I followed by Spain and Italy. Relative to their size, Sweden, Finland, Austria and Estonia also exhibit strengths.

Private investment levels in R&I range from €59.940 to €2 million annually per technology area. The highest average investment levels are observed in Photonics, Blockchain, and Cloud. The smallest average amounts are invested into the deployment of Data Analytics, NGI&XR and Cybersecurity.

International collaboration in digital R&I

The United States is by far the dominant non-European partner across all technology areas in terms of scientific co-publications in digital technologies. Between 19% and 36% of international co-publications are with US institutions, with particularly strong links in high-performance computing (36%) and robotics (31%). The United Kingdom consistently appears as the second most important partner country for the EU.

International collaboration in public R&I under Horizon Europe Cluster 4 is concentrated on EU associated countries. In terms of participation, the most prominent partners are Serbia, Turkey, Norway, Ukraine, and the United Kingdom. The US or China have a more limited participation and collaboration in digital R&I with European partner organisations.

In terms of collaboration among private companies in digital R&I, the largest markets for commercialising technologies are predominantly within the EU and/or the organisations' home country. Beyond these, the United States is consistently identified as a key market across technology areas. South Korea, Japan, Canada, Switzerland, Norway, and Taiwan also represent important markets for a substantial share of technology domains. In contrast, countries such as India, South Africa, and Singapore are primarily relevant only for selected technology areas.

EU R&I Strengths and Opportunities

Opportunities lie in technology cross-fertilisation

The EU has several strengths and opportunities in targeting R&I investments on research objectives that combine various technology areas:

- **AI stands out as a main technology cutting across all other digital technologies.** AI and robotics as embodied enable real-world learning, adaptation and ethical design via advances in perception, reasoning. In cybersecurity, AI-driven anomaly detection, automated response and threat intelligence require explainability, shared datasets, GPU resources. In **advanced computing for AI**, specialised AI accelerators are emerging to meet the computational demands of neural networks and large language models. **Edge AI and edge analytics involve deploying AI models directly on devices like sensors or IoT nodes for real-time data processing without cloud dependence.**
- **Semiconductor and photonics integration** enables photonic sensors, optical lasers and interconnects into chips for high-speed data transfer, AI-driven computing and advanced imaging. **Semiconductors underpin high performance computing, quantum and post-quantum applications:** cryo-ready materials for quantum processors and dedicated chips for quantum-resistant cryptography. **Hybrid quantum-classical computing** integrates quantum processors as co-processors within HPC workflows.

- **Cybersecurity is increasingly combined with other digital technologies:** for data, privacy-enhancing technologies (differential privacy, blind computation, homomorphic encryption, secure multiparty computation), synthetic data and federated analytics support confidential data sharing under GDPR, alongside digital identity (e.g., EU Digital Identity Wallet) and secure pipelines combining confidential computing with secure-boot and post-quantum cryptography for resilient distributed applications.
- **On advanced connectivity,** robust, high-speed, low-latency networks are vital across digital fields. For AI, networks handle massive data flows in real time between data centres, cloud, edge and devices without bottlenecks, ensuring security and flexibility. Robotics demands fast, semantic-aware protocols for coordinated actions, swarm control and remote operations.
- **Integration of XR with IoT and cloud-edge** enables real-time data exchange so virtual environments can adapt dynamically to the physical world, delivering context-aware, personalised experiences crucial for smart cities and industrial applications. IoT digital twins, real-time virtual models fed by sensor data, support monitoring, simulation and optimisation of devices, assets and processes, enhancing decision-making and operational efficiency across sectors.

Recommendations

This study came up with a list of 30 recommendations following the data analysis, stakeholder and expert consultations, extensive desk research and the final validation workshop that are summarised below:

Increase overall investments into digital R&I

Continue and expand EU support for research and innovation in critical digital technologies under the next R&I funding programme in 2028-2034: digital technologies will continue to evolve at pace, and those technological advances will transform the performance of the European economy as well as have an impact on its society.

Create a sharper R&I focus

Focus on European alternatives that address critical dependencies: the EU should proactively identify and close strategic gaps with critical digital dependencies on external actors. Most importantly, EU R&D funding should be used to build European alternatives in critical technologies such as for example replacing GPUs with distributed computational methods or investing in green supercomputing.

Adopt a cross-technology approach: challenges and opportunities in the digital domain are deeply interconnected across many critical digital technologies and this interdependence is only expected to grow. Rather than focusing on technology-specific grants, a cross-technology R&I pathway and approach would emphasise investment in coordinated system architectures, such as edge-AI, quantum computing & HPC, and digital-physical paradigms.

Focus on emerging disruptive R&I domains: an important objective is seen in investing in emerging technologies with disruptive potential and support early-stage research to develop Europe's next edge. The EU has strengths and opportunities to seize in a set of other technology subdomains that are expected to have high impact such as *Explainable and Trustworthy AI, Neuromorphic computing and new Microelectronics architecture, Edge AI, Cryptography, Decentralised identity, DNA-based data storage, Nanorobotics* just to name a few¹.

Become more strategic

¹ The detailed list of EU opportunities per digital technology area has been assessed and presented in the technology annexes.

Strike a balance between investment in emerging low-TRL technologies and support for more mature solutions with more concrete applications: gearing all funding towards specific technologies for strategic autonomy and industrial competitiveness risks prioritising incremental solutions for short-term needs at the expense of long-term competitiveness and resilience that needs to be taken into account.

Strengthen and prioritise R&I in energy-efficient digital technologies: energy efficiency emerges as a strategic, cross-cutting priority across all technology domains. Europe should actively invest in next-generation, low-power AI computing technologies, such as neuromorphic computing, photonic computing, in-memory architectures, and energy-efficient AI accelerators that enable high-performance computing while reducing energy consumption and overcoming the limitations of conventional chip designs.

Invest in human-centric digital R&I and in safe and trustworthy digital technologies that prioritise human needs, well-being, and societal values. The EU's comparative advantage is in safe and trustworthy technologies, hence human-centric R&I should focus on developing technologies that meet people's needs and create innovations that are usable, accessible, inclusive, and ethically responsible. It prioritises user experience, privacy, safety, and positive societal impact, thereby fostering trust, acceptance, and widespread adoption.

Further strengthen the link to industry and competitiveness

Invest in bridging the gap prevalent at Technology Readiness Level (TRL) 6: the future EU R&I programme should move even more towards prototype validation and system-level demonstration. Investments should target not only R&I but activities that reduce technical uncertainty, strengthen integration, and prepare the technology for scale. This includes funding for advanced prototyping, pilot projects, and field testing that mimic real operational environments. The future of R&I in critical digital technologies is shaped by the goal of integrating cutting-edge technologies with real-world challenges, ensuring innovation translates into impact and competitiveness.

Need for larger actions and significant co-financing by the private sector: to generate transformative innovation at scale, large-scale projects are seen as more effective. This will require increased co-investment from private actors alongside stronger co-funding from Member States, enabling projects at a scale that no single actor could support alone. In turn, this justifies giving private partners a meaningful role in the governance of major initiatives. At the same time, future actions should build on the capabilities, infrastructure and momentum already created through EU and national programmes, avoiding starting anew and duplicating the efforts.

Systematically anchor digital technology research and innovation within industrial environments to maximise impact, relevance, and adoption: European R&I programmes should prioritise application-driven research that directly addresses concrete industrial challenges including more market-pull actions. Coupling strategic investment in critical technologies with mechanisms that actively create and guarantee market demand will help create a bridge between R&I and deployment.

Foster robust framework conditions for digital R&I

Open-source development should be used more strategically across digital technologies: open-source initiatives across hardware, software, and networks are seen and recommended as powerful vehicles to reduce dependencies and accelerate uptake of EU-based solutions in line with the recent EU Open Source Strategy².

Strengthen protection of European research results: the next R&I programme should pay more attention to ensure continuity of EU control over critical IP and talent after the Horizon projects' funding period ends. It should have mechanisms to better control what

² <https://digital-strategy.ec.europa.eu/en/policies/open-source-strategy>

happens to the project results after the funding ends, making sure that afterwards technology commercialisation and profits stay in Europe.

Strengthen digital infrastructures that better adapt to changing framework conditions: Europe currently accounts for only a small fraction of global AI computing power and relies heavily on non-EU cloud providers. Dedicated AI chips, GPUs, and high-performance computing resources remain scarce and costly, leaving researchers and smaller organisations at a disadvantage. At the same time, the investments should take into account the evolving nature of digital technologies and put in place infrastructures that can adapt to reconfiguration, and responsiveness to changing economic conditions.

Foster better access to digital infrastructures: currently, it is an issue that EU infrastructures are often fragmented and underutilised by SMEs with uneven access and high costs as highlighted in expert consultations. While Europe has invested significantly in technology infrastructures, some are utilised less and unevenly accessed, especially by SMEs, non-digital industries, and interdisciplinary researchers.

R&I projects need to be accompanied by skills development and talent attraction initiatives: skills shortages in technology are pertinent across Europe and they cut across technology areas with specialists lacking in various technological domains. Talent attraction and retention are further constrained by global competition, salary differentials and the pace of technological change, which requires continuous upskilling.

Make implementation more agile and effective

Put in place governance and funding arrangements following a phase-sensitive approach: first, early-stage research funding should follow an open, bottom-up approach to ensure a broad diversity of exploratory pathways. Second, mid-phase collaborative R&D should actively foster the involvement of industry and society. Finally, the later phase should fast-track scaling, prioritising open calls, complemented by a diverse mix of financial instruments and targeted support for scale-ups. Governance arrangements and modes of private-sector engagement necessarily differ across these phases.

Fund R&I in cross-technology portfolios instead of technology specific calls: instead of funding digital technologies in separate calls and work programmes, there is a need to put more emphasis on interdependencies systematically across a coordinated portfolio. Because progress in one domain accelerates others, the future EU R&I programme should explicitly fund cross-technology portfolios such as quantum AI, edge AI, advanced data analytics and AI for virtual worlds to name some examples.

Expand fast-start mechanisms with shorter time-to-grant, challenge-driven calls, rolling cut-offs (applications assessed in cycles) for certain instruments: in the next R&I programme, the European Commission has explicitly indicated the introduction of simpler and faster approaches for the 2028–2034 programme³. As compute-centric innovation cycles move faster than traditional project timelines, there is a need for shorter time to grant approaches, while keeping excellence-driven funding intact.

Build feedback-loops in digital tech governance: the future R&I programme should support EU project funding pathways where the outcomes of R&I projects in one tech area are more systematically fed into another technology area. For example, AI acts as a general-purpose accelerator, improving quantum calibration, robotic perception and control, and XR content generation, while downstream deployment in robotics and immersive environments generates new data that feeds back into AI models.

Simplify and accelerate Horizon Europe's interactions with the private sector: this would help in broadening its attractiveness amongst deep-tech SMEs that are not primarily research and technology consultancies.

³ https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/horizon-europe-2028-2034-twice-bigger-simpler-faster-and-more-impactful-2025-07-16_en?

Increase flexibility in funding through bottom-up mechanisms: greater flexibility and risk tolerance would be reassuring for prospective private sector applicants, which could usefully expand the reach of the programme into new and emerging sectors. To ensure funding remains aligned with fast-moving technological developments, EU and national programmes should complement strategic top-down calls with more flexible bottom-up channels for low TRL research.

Improve the complementarity between upstream R&I-related ‘push’ measures and downstream measures from investment funding to regulatory and other financial instruments (‘pull’): ensure that digital Horizon R&I projects are directly connected to downstream instruments such as investment funds, blended finance facilities, procurement schemes, and scale-up financing, creating a continuous support pathway from research to market.

Strategic openness and international collaboration

Focus international collaboration on value-based partnerships: international collaboration should be strengthened in areas of mutual interest. While the EU is committed to strengthening its strategic autonomy, there is need to pursue international collaboration with key partners globally.

Adopt a targeted, risk-based openness framework that protects Europe’s strategic interests without undermining scientific excellence or international collaboration: rather than imposing broad or blanket restrictions on international research partnerships, the EU should implement clearly defined, proportionate safeguards focused on genuinely sensitive domains (dual-use technologies, critical infrastructure, frontier AI, advanced semiconductors), based on transparent risk assessments and strategic relevance. Blind reliance on trust should be avoided where it may not be warranted.

Selective protection with structured openness: enabling global collaboration in low-risk and fundamental research areas, while applying justified controls only where there is demonstrable risk to security, sovereignty, or strategic autonomy. Such a model preserves Europe’s attractiveness as a global research hub, sustains innovation and excellence, and avoids self-isolation, while still ensuring that public investment does not unintentionally weaken Europe’s long-term technological and geopolitical position.

Résumé

La Direction Générale des réseaux de Communication, du Contenu et des Technologies (DG CNECT) de la Commission Européenne a commandé cette étude afin d’éclairer les priorités en matière de **recherche, de développement et d’innovation des technologies numériques en Europe**.

L’objectif est de recenser les technologies numériques critiques dans lesquelles l’UE devrait investir pour renforcer sa capacité de R&I sous le prochain cadre financier pluriannuel (prochain CFP 2028-2034). Les conclusions aideront la **Commission Européenne à façonner sa future stratégie d’investissement dans la R&I numérique, en particulier les composantes numériques du prochain programme Horizon Europe**.

La présente étude complète une étude connexe de la Commission Européenne sur le **«déploiement des capacités numériques critiques de l’UE au-delà de 2027»**, qui se concentre sur la phase de déploiement des technologies numériques critiques dans le contexte d’un futur programme de déploiement de l’UE (successeur du Programme pour une Europe numérique). Étant donné que les deux études ont été menées en parallèle et de manière coordonnée, y compris une consultation publique commune et un processus de collecte de données, un certain chevauchement dans l’analyse des données est inévitable. Néanmoins, les études présentent des perspectives distinctes, l’une se concentrant principalement sur la recherche et l’innovation et l’autre sur le déploiement de la technologie et l’adoption par le marché.

L'analyse présentée dans le présent rapport découle d'une vaste recherche documentaire, d'une consultation des parties prenantes et des experts, d'un exercice de prévision comprenant une série de groupes de discussion et d'ateliers. Les principales conclusions de l'étude sont présentées ci-dessous:

État d'avancement de la recherche, du développement et de l'innovation des technologies numériques dans l'UE

Un défi bien connu: L'Europe est à la pointe des technologies numériques critiques

En juin 2026, la Commission européenne a présenté le train de mesures sur la souveraineté technologique européenne visant à renforcer les capacités de l'Europe dans les domaines des semi-conducteurs, de l'IA, de l'informatique en nuage et des technologies open source en investissant dans des capacités numériques stratégiques. Cela reflète la reconnaissance du fait que l'Europe doit remédier aux faiblesses de l'ensemble de son écosystème numérique, étant donné que les éléments de preuve continuent de brosser un tableau préoccupant de la position de l'Europe dans les technologies numériques.

Bien que l'Europe dispose de forces scientifiques reconnues dans les technologies numériques **et dispose d'un cadre réglementaire solide, l'UE a perdu du terrain sur la scène internationale en matière d'excellence de la recherche.** Malgré sa position de leader dans le volume des publications scientifiques, à l'exception de l'IA et de la cybersécurité, la qualité des publications scientifiques de l'UE reste inférieure à celle des États-Unis et de la Chine. Les performances de l'UE en matière d'excellence scientifique, mesurées par ses publications classées dans le top 1 % ou le top 10 % des publications les plus citées à l'échelle mondiale, ont stagné et accusent un retard par rapport à la Chine et aux États-Unis dans toutes les technologies numériques, ce qui suggère la nécessité de mettre davantage l'accent sur la qualité plutôt que sur la quantité.

L'UE est à la traîne des États-Unis, de la Chine et du Japon en ce qui concerne les demandes de brevet dans la plupart des domaines numériques, à l'exception de la Quantique et de la Photonique, ce qui indique des défis en matière de commercialisation et une position mondiale en déclin. Son écart est significatif dans le domaine du HPC, de la connectivité avancée mais aussi dans le domaine du Cloud-Edge-IoT. Cependant, le défi central de la R&I n'est pas en décalage avec les programmes de recherche et les besoins industriels ou sociétaux. L'analyse comparative des principaux brevets de l'UE et des principales publications scientifiques, ainsi que les évaluations qualitatives par des experts des principales possibilités mondiales, révèlent un degré élevé d'alignement sur les priorités industrielles. Les lacunes résident dans la capacité limitée de l'UE à opérer à la frontière technologique, la recherche n'atteignant pas systématiquement le premier niveau mondial, et dans sa capacité à commercialiser la recherche, où le financement en phase de croissance reste insuffisant.

L'UE-27 est également à l'origine du développement de code logiciel tel que capturé par les référentiels créés sur GitHub et suit les États-Unis et la Chine. Au sein de l'UE, l'Allemagne, la France et les Pays-Bas sont les pays ayant le plus grand nombre de contributeurs aux référentiels de codes. Une caractéristique frappante est l'absence relative d'acteurs européens. Hormis Arm (Royaume-Uni), Huggingface (originaire de France) et Red Hat (dont la société mère est IBM, une entreprise américaine), on ne trouve pratiquement aucune grande entreprise ou université européenne parmi les principaux contributeurs aux écosystèmes open source mondialement visibles. Dans le même temps, la proportion élevée de développeurs indépendants sous-estime la participation globale de l'UE, étant donné que de nombreuses affiliations individuelles ne sont pas prises en compte dans les données disponibles.

Les opportunités à saisir sont: renforcer la souveraineté technologique, développer l'innovation et libérer des synergies entre les technologies numériques;

Malgré les défis en matière de recherche et d'innovation numériques, plusieurs facteurs clés devraient venir renforcer la position future de l'UE. Dans l'UE, 60 411

entreprises technologiques de l'UE développent des technologies numériques critiques et stimulent la R&I privée, ce qui équivaut à environ 4,75 % de la population d'entreprises du secteur des TIC de l'UE. Composées principalement d'entreprises d'IA et de cybersécurité, elles favorisent les innovations qui sous-tendent l'économie et la société et constituent la base des prochaines possibilités offertes par l'UE dans le domaine des technologies numériques critiques. Ces entreprises technologiques peuvent être la base et le partenaire clé pour atteindre la souveraineté technologique européenne, car elles fournissent l'innovation et la capacité industrielle nécessaires pour traduire les programmes de recherche et d'innovation en technologies déployables.

En outre, l'UE comptait 20 720 start-up de technologies numériques avancées en 2025, dont 728 ont pris de l'ampleur (3,5 %) et sont toujours opérationnelles, et 40 ont atteint le statut de licorne (0,2 %). Le paysage des start-up numériques de l'UE se porte bien et la création de start-up dans le domaine des technologies numériques s'est considérablement accélérée dans l'UE, comme le montrent divers indicateurs. Le nombre cumulé de jeunes pousses, notamment le nombre total de jeunes pousses créées jusqu'en 2025, a été trois fois plus élevé qu'en 2015. Cette expansion rapide de l'écosystème des startups numériques de l'UE fournit une base solide pour construire des champions technologiques compétitifs au niveau mondial et accélérer la croissance axée sur l'innovation.

Le paysage européen de 12 domaines clés des technologies numériques a attiré un total de 82 milliards d'euros de capital-risque depuis 2015. Depuis cette année-là, les investissements dans les jeunes entreprises européennes ont considérablement augmenté, les financements en phase de démarrage ayant plus que doublé et les financements en phase de croissance triplé. Conformément aux tendances mondiales, les investissements dans les technologies numériques européennes ont considérablement augmenté au cours de la dernière décennie. Entre 2015 et 2024, les capitaux investis dans l'UE ont augmenté à un taux de croissance annuel composé (TCAC) d'environ 20 % au total, le financement d'amorçage augmentant de 21,6 % par an, le capital de risque initial de 21,8 % par an et le capital de risque de croissance de 19,1 % par an.

L'UE possède des atouts dans plusieurs technologies et créneaux technologiques où le financement de la R&I investi aujourd'hui peut garantir la compétitivité de demain. Les données indiquent qu'un écosystème d'innovation interdisciplinaire jouera un rôle essentiel dans la traduction de la recherche en innovation numérique percutante. En reliant l'expertise entre les technologies et les secteurs, ces écosystèmes favorisent le co-développement de solutions plus réactives aux défis sociétaux et mieux alignées sur les opportunités du marché.

La recherche sur les technologies numériques économes en énergie apparaît comme une opportunité transversale essentielle. Les technologies numériques économes en énergie sont essentielles car elles réduisent la consommation d'énergie, réduisent les coûts d'exploitation et minimisent l'incidence sur l'environnement, tout en permettant le développement durable et l'utilisation future de toutes les technologies numériques critiques.

Investissements publics et privés importants dans la recherche numérique, mais des lacunes subsistent

Horizon Europe a réalisé des investissements importants dans les technologies numériques, avec environ 13 milliards d'euros engagés jusqu'à présent dans les programmes de travail d'Horizon Europe 2021-2025, avec une forte concentration d'investissements dans la microélectronique, l'IA, les données et la connectivité. Malgré la concentration des volumes de financement, le programme continue de bénéficier d'un soutien diversifié dans un éventail plus large de technologies critiques. Le volume de financement le plus élevé pour la plupart des technologies numériques a été absorbé par des entreprises privées à but lucratif, à l'exception du calcul à haute performance et des

technologies quantiques (où les organismes de recherche et d'enseignement et l'enseignement supérieur ont attiré le plus de financements).

Le portefeuille de projets dans le domaine des technologies numériques d'«Horizon Europe» présente un effet de levier global d'environ 9,9 % sur les contributions de l'UE, avec des différences marquées entre les domaines technologiques. L'analyse couvre au total environ 1,8 milliard d'euros de financement à effet de levier.

Un noyau stable de pays de l'UE-27 dirige en permanence les productions scientifiques, les demandes de brevets et la concentration des start-up dans les domaines des technologies numériques. L'Allemagne, la France et les Pays-Bas apparaissent comme les points chauds les plus pertinents de la R&I en matière de technologie numérique, suivis de l'Espagne et de l'Italie. Par rapport à leur taille, la Suède, la Finlande, l'Autriche et l'Estonie présentent également des points forts.

Les niveaux d'investissements privés dans la R&I varient de 59 940 à 2 millions d'euros par an et par domaine technologique. Les niveaux d'investissement moyens les plus élevés sont observés dans Photonics, Blockchain et Cloud. Les montants moyens les plus faibles sont investis dans le déploiement de Data Analytics, NGI&XR et Cybersecurity.

Collaboration internationale en recherche numérique:

Les États-Unis sont de loin le partenaire non-européen dominant dans tous les domaines technologiques en termes de co-publications scientifiques dans les technologies numériques. Entre 19% et 36% des co-publications internationales sont réalisées avec des institutions américaines, avec des liens particulièrement forts dans le calcul haute performance (36%) et la robotique (31%). Le Royaume-Uni apparaît systématiquement comme le deuxième pays partenaire le plus important de l'UE.

La collaboration internationale en matière de R&I publique dans le cadre du pôle 4 d'Horizon Europe se concentre principalement sur les pays associés à l'UE. En termes de participation, les partenaires les plus importants sont la Serbie, la Turquie, la Norvège, l'Ukraine et le Royaume-Uni. Les États-Unis ou la Chine ont une participation et une collaboration plus limitées dans la R&I numérique avec des organisations partenaires européennes.

En ce qui concerne la collaboration entre les entreprises privées dans le domaine de la R&I numérique, les plus grands marchés pour la commercialisation des technologies se situent principalement dans l'UE et/ou dans le pays d'origine des organisations. Au-delà de ceux-ci, les États-Unis sont constamment identifiés comme un marché clé dans tous les domaines technologiques. La Corée du Sud, le Japon, le Canada, la Suisse, la Norvège et Taiwan représentent également des marchés importants pour une part substantielle des domaines technologiques. En revanche, des pays tels que l'Inde, l'Afrique du Sud et Singapour sont principalement pertinents uniquement dans certains domaines technologiques.

R&I de l'UE: points forts et opportunités

Les opportunités résident dans la fertilisation croisée des technologies

L'UE dispose de plusieurs atouts et possibilités pour cibler les investissements dans la R&I sur des objectifs de recherche qui combinent différents domaines technologiques :

- **L'IA se distingue comme une technologie principale transposant toutes les autres technologies numériques.** L'IA et la robotique, telles qu'incarnées, permettent l'apprentissage, l'adaptation et la conception éthique dans le monde réel grâce à des avancées en matière de perception et de raisonnement. En cybersécurité, la détection d'anomalies, la réponse automatisée et les renseignements sur les menaces pilotés par l'IA nécessitent de l'explicabilité, des ensembles de données partagés et des ressources GPU. Dans le **domaine de l'informatique avancée pour l'IA**, des accélérateurs d'IA spécialisés émergent pour répondre aux exigences informatiques

des réseaux de neurones et des grands modèles de langage. **L'IA Edge et l'analyse Edge impliquent le déploiement de modèles d'IA directement sur des appareils tels que des capteurs ou des nœuds IoT pour le traitement des données en temps réel sans dépendance au cloud.**

- **L'intégration des semi-conducteurs et de la photonique** permet des capteurs photoniques, des lasers optiques et des interconnexions en puces pour le transfert de données à grande vitesse, l'informatique pilotée par l'IA et l'imagerie avancée. **Les semi-conducteurs sous-tendent le calcul à haute performance, les applications quantiques et post-quantiques:** matériaux cryo-prêts pour processeurs quantiques et puces dédiées à la cryptographie quantique résistante. **L'informatique quantique-classique hybride** intègre les processeurs quantiques en tant que coprocesseurs dans les flux de travail HPC.
- **La cybersécurité est de plus en plus associée à d'autres technologies numériques:** pour les données, les technologies renforçant la protection de la vie privée (vie privée différentielle, calcul à l'aveugle, cryptage homomorphe, calcul multipartite sécurisé), les données synthétiques et l'analyse fédérée prennent en charge le partage de données confidentielles au titre du RGPD, ainsi que l'identité numérique (par exemple, le portefeuille d'identité numérique de l'UE) et les pipelines sécurisés combinant l'informatique confidentielle avec la cryptographie à démarrage sécurisé et la cryptographie post-quantique pour des applications distribuées résilientes.
- **En ce qui concerne la connectivité avancée,** des réseaux robustes, à haut débit et à faible latence sont essentiels dans tous les domaines numériques. Pour l'IA, les réseaux gèrent des flux de données massifs en temps réel entre les centres de données, le cloud, les périphériques et les périphériques sans goulets d'étranglement, garantissant sécurité et flexibilité. La robotique exige des protocoles rapides et sémantiques pour les actions coordonnées, le contrôle des essaims et les opérations à distance.
- **L'intégration de XR avec l'IoT et le cloud-edge** permet l'échange de données en temps réel afin que les environnements virtuels puissent s'adapter dynamiquement au monde physique, offrant des expériences contextuelles et personnalisées cruciales pour les villes intelligentes et les applications industrielles. Les jumeaux numériques IoT, les modèles virtuels en temps réel alimentés par les données des capteurs, prennent en charge la surveillance, la simulation et l'optimisation des appareils, des actifs et des processus, améliorant ainsi la prise de décision et l'efficacité opérationnelle dans tous les secteurs.

Recommandations

Cette étude a permis d'établir une liste de 30 recommandations à la suite de l'analyse des données, des consultations des parties prenantes et des experts, des recherches documentaires approfondies et de l'atelier de validation final, qui sont résumées ci-dessous :

Accroître les investissements globaux dans la R&I numérique;

Poursuivre et étendre le soutien de l'UE à la recherche et à l'innovation dans le domaine des technologies numériques critiques dans le cadre du prochain programme de financement de la R&I en 2028-2034: les technologies numériques continueront d'évoluer à un rythme soutenu, et ces avancées technologiques transformeront les performances de l'économie européenne et auront une incidence sur sa société.

Créer une R&I focus plus nette

Mettre l'accent sur les solutions de remplacement européennes qui tiennent compte des dépendances critiques: l'UE devrait recenser et combler de manière proactive les lacunes stratégiques présentant des dépendances numériques critiques à l'égard d'acteurs extérieurs. Plus important encore, le financement de la R&D de l'UE devrait être utilisé pour construire des alternatives européennes dans les technologies critiques telles que, par exemple, le remplacement des GPU par des méthodes de calcul distribuées ou l'investissement dans le supercalcul vert.

Adopter une approche inter-technologique: les défis et les possibilités dans le domaine numérique sont profondément interconnectés entre de nombreuses technologies numériques critiques et cette interdépendance ne fera que croître. Plutôt que de se concentrer sur des subventions spécifiques à la technologie, une voie et une approche inter-technologies de R&I mettraient l'accent sur l'investissement dans des architectures de systèmes coordonnées, telles que l'IA de périphérie, l'informatique quantique & HPC et les paradigmes numériques-physiques.

Mettre l'accent sur les domaines émergents de la R&I perturbateurs: un objectif important est d'investir dans les technologies émergentes à potentiel de rupture et de soutenir la recherche en phase de démarrage afin de développer le prochain avantage de l'Europe. L'UE possède des atouts et a des opportunités à saisir dans un ensemble d'autres sous-domaines technologiques qui devraient avoir un impact important, tels que *l'IA explicable et digne de confiance, l'informatique neuromorphique et la nouvelle architecture microélectronique, l'IA Edge, la cryptographie, l'identité décentralisée, le stockage de données fondé sur l'ADN et la nanorobotique, pour n'en nommer que quelques-uns.*⁴

Devenir plus stratégique

Trouver un équilibre entre l'investissement dans les technologies émergentes à faible TRL et le soutien à des solutions plus matures avec des applications plus concrètes : orienter tous les financements vers des technologies spécifiques pour l'autonomie stratégique et la compétitivité industrielle risque de donner la priorité à des solutions incrémentales pour les besoins à court terme au détriment de la compétitivité et de la résilience à long terme qui doivent être prises en compte.

Renforcer et donner la priorité à la R&I dans le domaine des technologies numériques économes en énergie: l'efficacité énergétique apparaît comme une priorité stratégique et transversale dans tous les domaines technologiques. L'Europe devrait investir activement dans la prochaine génération de technologies informatiques d'IA à faible puissance, telles que l'informatique neuromorphique, l'informatique photonique, les architectures en mémoire et les accélérateurs d'IA économes en énergie qui permettent un calcul à haute performance tout en réduisant la consommation d'énergie et en surmontant les limites des conceptions conventionnelles de puces.

Investir dans la R&I numérique centrée sur l'humain et dans des technologies numériques sûres et fiables qui donnent la priorité aux besoins humains, au bien-être et aux valeurs sociétales. L'avantage comparatif de l'UE réside dans des technologies sûres et fiables, d'où une R&I centrée sur l'humain qui devrait se concentrer sur le développement de technologies qui répondent aux besoins des citoyens et créent des innovations utilisables, accessibles, inclusives et éthiquement responsables. Cela donne la priorité à l'expérience utilisateur, à la vie privée, à la sécurité et à l'impact sociétal positif, favorisant ainsi la confiance, l'acceptation et l'adoption généralisée.

Renforcer encore le lien avec l'industrie et la compétitivité

Investir pour combler l'écart qui prévaut au niveau de maturité technologique (TRL) 6: le futur programme R&I de l'UE devrait s'orienter encore davantage vers la validation des prototypes et la démonstration au niveau du système. Les investissements devraient cibler non seulement la R&I, mais aussi les activités qui réduisent l'incertitude technique,

⁴ La liste détaillée des possibilités offertes par l'UE dans chaque domaine des technologies numériques a été évaluée et présentée dans les annexes relatives aux technologies.

renforcent l'intégration et préparent la technologie à l'échelle. Cela comprend le financement de prototypages avancés, de projets pilotes et d'essais sur le terrain qui imitent des environnements opérationnels réels. L'avenir de la R&I dans les technologies numériques critiques est façonné par l'objectif d'intégrer des technologies de pointe aux défis du monde réel, en veillant à ce que l'innovation se traduise par un impact et une compétitivité.

Nécessité d'actions plus importantes et d'un cofinancement important par le secteur privé: pour générer une innovation transformatrice à grande échelle, les projets à grande échelle sont considérés comme plus efficaces. Cela nécessitera un co-investissement accru de la part d'acteurs privés ainsi qu'un cofinancement plus important de la part des États membres, ce qui permettra de réaliser des projets à une échelle qu'aucun acteur ne pourrait soutenir seul. À son tour, cela justifie de donner aux partenaires privés un rôle significatif dans la gouvernance des grandes initiatives. Dans le même temps, les actions futures devraient s'appuyer sur les capacités, les infrastructures et la dynamique déjà créées par les programmes nationaux et de l'UE, en évitant de recommencer et de reproduire les efforts.

Ancrer systématiquement la recherche et l'innovation dans le domaine des technologies numériques dans les environnements industriels afin d'en maximiser l'impact, la pertinence et l'adoption : Les programmes européens de R&I devraient donner la priorité à la recherche axée sur les applications qui abordent directement des défis industriels concrets, y compris davantage d'actions d'attraction du marché. Le couplage des investissements stratégiques dans les technologies critiques avec des mécanismes qui créent et garantissent activement la demande du marché aidera à créer un pont entre la R & I et le déploiement.

Favoriser des conditions-cadres solides pour la R&I numérique;

Le développement open source devrait être utilisé de manière plus stratégique dans l'ensemble des technologies numériques: les initiatives en matière de sources ouvertes concernant le matériel, les logiciels et les réseaux sont considérées et recommandées comme des vecteurs puissants pour réduire les dépendances et accélérer l'adoption de solutions basées dans l'UE, conformément à la récente stratégie de l'UE en matière de sources ouvertes.⁵

Renforcer la protection des résultats de la recherche européenne: le prochain programme R&I devrait accorder plus d'attention à la continuité du contrôle de l'UE sur la PI et les talents critiques après la fin de la période de financement des projets Horizon. Il devrait disposer de mécanismes permettant de mieux contrôler ce qui arrive aux résultats du projet après la fin du financement, en veillant à ce que la commercialisation des technologies et les bénéfices restent ensuite en Europe.

Renforcer les infrastructures numériques qui s'adaptent mieux à l'évolution des conditions-cadres : L'Europe ne représente actuellement qu'une petite fraction de la puissance de calcul mondiale de l'IA et dépend fortement de fournisseurs d'informatique en nuage de pays tiers. Les puces IA dédiées, les GPU et les ressources de calcul haute performance restent rares et coûteuses, ce qui désavantage les chercheurs et les petites organisations. Dans le même temps, les investissements devraient tenir compte de la nature évolutive des technologies numériques et mettre en place des infrastructures capables de s'adapter à la reconfiguration et à l'évolution des conditions économiques.

Favoriser un meilleur accès aux infrastructures numériques : à l'heure actuelle, il est problématique que les infrastructures de l'UE soient souvent fragmentées et sous-utilisées par des PME dont l'accès est inégal et les coûts élevés, comme souligné par les consultations d'experts. Si l'Europe a investi de manière significative dans les infrastructures technologiques, certaines sont moins utilisées et bénéficient d'un accès

⁵ <https://digital-strategy.ec.europa.eu/fr/policies/open-source-strategy>

inégal, en particulier pour les PME, les industries non numériques et les chercheurs interdisciplinaires.

Les projets de R&I doivent s'accompagner d'initiatives de développement des compétences et d'attraction de talents: les pénuries de compétences technologiques concernent toute l'Europe et touchent des domaines technologiques où les spécialistes font défaut dans divers domaines technologiques. L'attraction et la rétention des talents sont encore limitées par la concurrence mondiale, les écarts de salaire et le rythme des changements technologiques qui nécessitent un perfectionnement continu.

Rendre la mise en œuvre plus agile et efficace

Mettre en place des mécanismes de gouvernance et de financement selon une approche axée sur les phases: premièrement, le financement de la recherche à un stade précoce devrait suivre une approche ouverte et ascendante afin de garantir une grande diversité de parcours exploratoires. Deuxièmement, la R&D collaborative à mi-parcours devrait favoriser activement la participation de l'industrie et de la société. Enfin, la phase ultérieure devrait accélérer la mise à l'échelle, en donnant la priorité aux appels ouverts, complétés par une combinaison diversifiée d'instruments financiers et un soutien ciblé aux entreprises en expansion. Les modalités de gouvernance et les modes d'engagement du secteur privé diffèrent nécessairement d'une phase à l'autre.

Financer la R&I dans des portefeuilles inter-technologies plutôt que dans des appels spécifiques à la technologie: au lieu de financer les technologies numériques dans le cadre d'appels et de programmes de travail distincts, il est nécessaire de mettre davantage l'accent sur les interdépendances systématiques au sein d'un portefeuille coordonné. Étant donné que les progrès dans un domaine accélèrent d'autres, le futur programme R&I de l'UE devrait explicitement financer des portefeuilles trans-technologiques tels que l'IA quantique, l'IA de pointe, l'analyse avancée des données et l'IA pour les mondes virtuels, pour ne citer que quelques exemples.

Élargir les mécanismes de démarrage rapide grâce à des délais d'octroi plus courts, à des appels axés sur les défis et à des seuils glissants (applications évaluées par cycles) pour certains instruments: dans le prochain programme R&I, la Commission européenne a explicitement indiqué l'introduction d'approches plus simples et plus rapides pour le programme 2028-2034.⁶ Étant donné que les cycles d'innovation centrés sur le calcul évoluent plus rapidement que les calendriers traditionnels des projets, il est nécessaire de raccourcir le délai d'octroi des subventions, tout en maintenant intact le financement axé sur l'excellence.

Construire des boucles de rétroaction dans la gouvernance des technologies numériques: le futur programme R&I devrait soutenir les voies de financement de projets de l'UE dans lesquelles les résultats des projets de R&I dans un domaine technologique sont plus systématiquement intégrés dans un autre domaine technologique. Par exemple, l'IA agit comme un accélérateur à usage général, améliorant l'étalonnage quantique, la perception et le contrôle robotiques et la génération de contenu XR, tandis que le déploiement en aval dans des environnements robotiques et immersifs génère de nouvelles données qui alimentent les modèles d'IA.

Simplifier et accélérer les interactions d'Horizon Europe avec le secteur privé: cela contribuerait à accroître son attractivité auprès des PME de haute technologie qui ne sont pas principalement des sociétés de conseil en recherche et technologie.

Accroître la flexibilité du financement grâce à des mécanismes ascendants: une plus grande flexibilité et une plus grande tolérance au risque rassureraient les candidats potentiels du secteur privé, ce qui pourrait utilement étendre la portée du programme à des secteurs nouveaux et émergents. Afin de garantir que le financement reste aligné sur les évolutions technologiques rapides, les programmes nationaux et de l'UE devraient

⁶ https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/horizon-europe-2028-2034-twice-bigger-simpler-faster-and-more-impactful-2025-07-16_en?

compléter les appels stratégiques descendant par des canaux ascendants plus flexibles pour la recherche à faible TRL.

Améliorer la complémentarité entre les mesures «push» liées à la R&I en amont et les mesures en aval, du financement des investissements aux instruments réglementaires et autres instruments financiers («pull»): veiller à ce que les projets numériques Horizon R&I soient directement liés à des instruments en aval tels que les fonds d'investissement, les mécanismes de financement mixte, les systèmes de passation de marchés et le financement à grande échelle, en créant un parcours de soutien continu de la recherche au marché.

Ouverture stratégique et collaboration internationale

Mettre l'accent sur la collaboration internationale dans le cadre de partenariats fondés sur des valeurs: la collaboration internationale devrait être renforcée dans des domaines d'intérêt mutuel. Si l'UE est déterminée à renforcer son autonomie stratégique, il est nécessaire de poursuivre la collaboration internationale avec des partenaires clés à l'échelle mondiale.

Adopter un cadre d'ouverture ciblé et fondé sur les risques qui protège les intérêts stratégiques de l'Europe sans nuire à l'excellence scientifique ou à la collaboration internationale: plutôt que d'imposer des restrictions générales ou systématiques aux partenariats internationaux de recherche, l'UE devrait mettre en œuvre des garanties clairement définies et proportionnées axées sur des domaines véritablement sensibles (technologies à double usage, infrastructures critiques, IA aux frontières, semi-conducteurs avancés), sur la base d'évaluations transparentes des risques et d'une pertinence stratégique. Il faut éviter de se fier aveuglément à la confiance lorsqu'elle n'est pas justifiée.

Protection sélective avec ouverture structurée: permettre une collaboration mondiale dans des domaines de recherche fondamentale et à faible risque, tout en n'appliquant des contrôles justifiés que lorsqu'il existe un risque démontrable pour la sécurité, la souveraineté ou l'autonomie stratégique. Un tel modèle préserve l'attractivité de l'Europe en tant que pôle mondial de recherche, soutient l'innovation et l'excellence et évite l'auto-isollement, tout en veillant à ce que les investissements publics n'affaiblissent pas involontairement la position technologique et géopolitique à long terme de l'Europe.

Introduction

The EU faces a series of multi-dimensional challenges in effectively leveraging digital technologies to maintain competitiveness and resilience. **The global context of increased competition and risks of economic and technological dependencies on external players has heightened the EU's vulnerability, requiring strategic efforts to reduce reliance on critical imports.** Concurrently, the EU needs to address the pressing need for a sustainable, smart, and just digital transformation of industry and society. This requires a systemic approach that balances addressing known vulnerabilities with fostering innovation and maintaining the agility to identify and adapt to emerging technologies and needs.

Mario Draghi's report⁷ argued that Europe can no longer rely on its past growth drivers and needs a bold, R&I-focused approach to close the innovation gap with competitors like the US and China. Insufficient and fragmented R&I spending has undermined the EU's competitiveness, with many high-quality Horizon Europe projects going unfunded. Draghi calls for a doubling of the EU R&I budget, a tighter focus on disruptive innovation, the need for a more coordinated European R&I landscape, and more robust pathways for turning research into market-ready products, feeding into the European Commission's broader plan to boost sustainable prosperity and competitiveness.

In a similar line of thought, Heitor's 'Align, Act, Accelerate' Report⁸ offers a detailed roadmap to raise the impact of EU R&I programmes, highlighting four interlinked priorities: achieving scientific and technological excellence; boosting industrial competitiveness; pursuing societal transformations; and strengthening Europe's broader R&I ecosystem. It identifies fragmentation across Member States, insufficient translation of research into market-ready innovations, underinvestment in R&I (still below the 3% GDP target), and excessive bureaucracy as core obstacles.

One critical shift involves moving away from siloed technological advancements towards systemic integration of solutions across value chains and sectors. This requires cross-fertilisation between technologies, industries, and innovation pathways, ensuring smooth transitions from research and development to industry and societal uptake. To support this transition, ecosystem building and value-chain integration are essential. These efforts aim to strengthen societal and industrial capacities to absorb and use digital technologies effectively.

In addition, the ethical, societal, and environmental implications of digital transformation also need to be addressed comprehensively. These include **safeguarding human rights, promoting inclusiveness, and ensuring that technological progress aligns with broader sustainability goals.** Tackling these interlinked challenges is essential to enhance the EU's ability to drive systemic innovation, maintain its competitiveness, and secure its leadership in the global digital economy.

Study objectives

In this context, the European Commission Directorate-General for Communications Networks, Content and Technology (DG CNECT) has commissioned a study to provide considerations for the research, development and innovation of digital technologies for Europe, entitled "**Study on strategic digital technologies for the EU Research and Innovation funding beyond 2027**". The study focuses on the needs for investments in R&I of advanced digital technologies in Europe by 2036-2040. This time horizon has been chosen taking 2036 as the year when the final projects under FP10 are expected to start, and 2040, when the results of the last FP10's projects are expected to materialise. In order to recognise the uncertainty that is necessarily attached to such a long-term time horizon, this study adopts a foresight approach that is explicitly addressing different possible trajectories not only in the R&I itself but also in the wider context of research and innovation.

⁷ https://commission.europa.eu/topics/eu-competitiveness/draghi-report_en

⁸ <https://www.consilium.europa.eu/media/ny3j24sm/much-more-than-a-market-report-by-enrico-letta.pdf>

The **general objective** of the study is to support the European Commission in identifying the digital technologies in which the EU should invest to develop its R&I capacity under the next MFF (2028-2034), providing a robust analytical basis to inform the European Commission for the **shaping of the EU's future digital R&I investment strategy**.

This translates into the following **specific objectives**:

- provide a robust analytical basis upon which the European Commission can shape **the EU's future digital R&I investment strategy**
- provide an up-to-date mapping of the digital technology ecosystem across a selected set of major technology domains, assessing their maturity levels and identifying the trends expected to reach market readiness by 2036–2040,
- identify the relevant emerging digital technologies exploring future trends, foreseeable technology evolution, and investment needs during the next MFF (2028-2034), promoting European competitiveness and economic security by 2036-2040
- analyse the **strengths and weaknesses** of the EU in research, development and innovation of critical and key emerging digital technologies and the respective ecosystems
- assess the level of **coordination and synergy** with the R&I strategies and investment plans of the EU-27 Member States and industrial actors
- identify the **key global factors** that influence the Union's competitive position, assessing the degree of indispensability and dependency of such strengths to specific third countries
- provide practical **policy recommendations** and concrete suggestions for support mechanisms that can strengthen Europe's positioning both in currently critical technologies as well as emerging digital technologies, including the uptake of deep-tech into new application sectors.

Scope

As stipulated in Horizon Europe's Strategic Plan 2025-2027⁹, safeguarding Europe's open strategic autonomy and securing Europe's leading role in developing and deploying critical and emerging technologies is essential to achieve Europe's policy objectives, including competitiveness.

This covers **critical technologies** that play a pivotal role in ensuring resilience, sovereignty, and long-term competitiveness. The European Commission identifies critical technologies as those necessary to enable the EU to maintain leadership in strategic sectors, safeguard technological independence, and address geopolitical challenges. As such, the EU Roadmap on critical technologies for security and defence¹⁰ outlined a path to boost RD&I and reduce strategic dependencies in critical technologies and value chains for security and defence. It also laid the ground for the **EU Observatory of Critical Technologies** to identify, monitor and assess critical technologies for space, defence and related civil sectors¹¹.

In this context, the European Commission produced a set of "**Recommendation on critical technology areas for the EU's economic security**" in October 2023¹². This includes a list of 10 technology areas for the EU's economic security for further assessment with Member States, including advanced semiconductors technologies, artificial intelligence, quantum technologies, biotechnologies, all four considered as high-risk and subject to a targeted

⁹ <https://op.europa.eu/en/publication-detail/-/publication/6abcc8e7-e685-11ee-8b2b-01aa75ed71a1/language-en>

¹⁰ COM(2022) 61 final, Roadmap on critical technologies for security & defence, February 2022

¹¹ EU Monitor, Commission contribution to EU defence in the context of the strategic compass <https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vlqhmp8ptzd?ctx=vg9pjp5wsz1>

¹² C(2023)6689, Commission Recommendation on critical technology areas for the EU's economic security for further risk assessment with Member States, October 2023

assessment of risks by end 2023. The other six relate to advanced connectivity, navigation and digital, advanced sensing, space & propulsion technologies, energy technologies, robotics & autonomous systems and advanced materials, manufacturing & recycling technologies. These technologies are critical due to their transformative potential to drive performance and efficiency, their dual-use applications in both civil and military domains, and their susceptibility to misuse, including human rights violations and threats to peace and security. Four key risk categories are identified: supply chain resilience, including energy security; physical and cyber-security of critical infrastructure; technology security and leakage; and the weaponisation of economic dependencies and coercion.

In addition, the **Strategic Technologies for Europe Platform (STEP)**¹³ puts a specific emphasis on **digital technologies and deep-tech innovation**¹⁴ as target investment areas. To qualify as **critical** under the STEP framework, a technology must meet one of the two conditions stated below (not cumulative in the assessment of criticality)¹⁵:

Innovativeness: bring to the internal market an innovative, emerging, and cutting-edge element with significant economic potential.

- To qualify as critical under the STEP framework, a technology must meet one of the two conditions stated below (not cumulative in the assessment of criticality): Innovativeness: bring to the internal market an innovative, emerging, and cutting-edge element with significant economic potential. The technology should exhibit at least two of the following three characteristics: innovative, emerging, or cutting-edge.
- Additionally, the technology must demonstrate significant economic potential by having a substantial impact on development or manufacturing, addressing various Union markets, and generating positive spillover effects across Member States.

Strategic dependencies: contribute to reducing or preventing the strategic dependencies of the Union.

- The technology should meet several of the following factors: enhancing Union industrial and technological leadership, supporting critical infrastructures, increasing manufacturing capacity (only where a strategic dependency has been identified), strengthening security of supply, and promoting positive cross-border effects within the internal market.

Other international organisations such as the **OECD** use similar definitions of digital technologies when providing evidence-based analysis and global standard-setting for countries to navigate the impacts of digital transformation. These technologies include AI, data, connectivity, privacy, security, and other emerging technologies¹⁶.

On the basis of the above, the Table below presents the non-exhaustive list of technology areas and sub-areas which form the basis for the study's landscape analysis framework.

Table 1 Scoping of each technology area

¹³ C(2024)3148 final, Guidance Note concerning certain provision of Regulation (EU) 2024/795 establishing the Strategic Technologies for Europe Platform (STEP), May 2024

¹⁴ Understood as innovation with the potential to deliver transformative solutions, rooted in cutting-edge science, technology, and engineering, including innovation that combines advances in the physical, biological, and digital spheres. Deep tech sectors, sub-sectors, applications, and definitions may change as technologies and markets evolve over time.

¹⁵ "Authorities in charge of the programmes falling within the scope of the STEP Regulation should set specific criteria to meet the above conditions in their funding processes (e.g., calls for proposals) and accordingly must assess compliance with these conditions in the evaluation of the submitted projects."

¹⁶ <https://www.oecd.org/en/topics/digital.html>

Technology areas	Sub technology areas	Scope
Advanced microelectronics and photonics	Microelectronics, High frequency chips and Semiconductor	Micro- and Nanoelectronics deal with semiconductor components and highly miniaturised electronic subsystems and their integration in larger products and systems. They include the fabrication, the design, the packaging and testing from nano-scale transistors to micro-scale systems integrating multiple functions on a chip. The scope of the area spans from emerging materials & substrate, front-end process innovation that goes beyond conventional CMOS technologies, novel architectures and devices structures & heterogenous integration and packaging to alternative computing paradigms, quantum electronics & post-quantum security, AI-driven hardware and software/hardware co-design as well as advanced sensing & bio-integrated electronics.
	Photonics (including high energy laser) technologies	Photonics is a multidisciplinary domain dealing with light, encompassing its generation, detection and management. Among other things it provides the technological basis for a variety of electronic components and equipment such as photodiodes, LEDs and lasers. The scope of the area spans from emerging materials & photonics materials research to advanced packaging and co-integration of photonics with microelectronics & other technologies (e.g. Quantum), integrated photonics & photonic integrated circuits (PIC). It also encompasses development for next-generation interconnect & communication, next generation of optical sensing and imaging as well as design, simulation & layout tools and metrology.
Advanced computing and quantum technologies	High Performance Computing	From a technology perspective the scope of the area spans from the hybridisation of new computing paradigm (AI, Quantum) with HPC, to hardware and system level integration with advanced integration & packaging, specialised accelerators & processors architectures, as well as hardware-software codesign and the development of an application software ecosystem. It also includes key HPC technical challenges such as secure and adaptive HPC architectures or sustainable computing.
	Quantum (computing, sensing, cryptography, communication)	The quantum technology area spans from quantum computing including for instance scalable quantum information processing & storage, fault tolerant QC & hybridisation of classical-quantum computing to Quantum as a service. It also includes quantum sensing technologies such as optical atomic clocks, quantum gravimeters and magnetometers and quantum communication technologies such as quantum networks and repeaters. Moreover, it focuses on key component technologies such as quantum control & readout.
AI, data and robotics	AI (Computer vision, language processing, object recognition)	The scope of the area encompasses AI systems across advanced computing paradigms, including Edge AI, high-performance computing and quantum-enhanced AI, as well as emerging non-silicon architectures. It spans the development of adaptive machine learning algorithms, such as self-supervised, federated, causal and transfer learning, and the integration of evolving AI paradigms including multimodal generative AI, causal and neurosymbolic approaches. It also covers the design of neural network architectures such as recurrent and convolutional networks, alongside critical aspects of AI ethics, including explainability, trustworthiness and environmental sustainability. Applications range from deep reasoning and autonomous AI agents to embedded and networked intelligence in domains such as AIoT, robotics and advanced control systems. Knowledge Graphs (and related semantic models) enhance and complement generative AI and LLMs by providing structured, contextual knowledge that improves reasoning, inference, and human-AI collaboration.

Technology areas	Sub technology areas	Scope
	Data analytics and data sharing technologies	Data analytics & data sharing technologies for big data encompasses hardware and software that integrate, organise, manage, analyse and present data. It is characterised by "four Vs": volume, velocity, variety and value. Big Data technologies are new generation of technologies and architectures, designed to economically extract value from very large volumes of a wide variety of data, by enabling high-velocity capture, discovery and/or analysis. The scope of the area covers the development of novel data architectures capable of handling diverse data types, including synthetic data, alongside advances in data storage such as DNA-based solutions and next-generation compression algorithms. It also includes real-time and prescriptive analytics designed to extract actionable insights from complex data environments. Particular emphasis is placed on secure and interoperable data sharing frameworks, including the implementation of trustworthy and EU-compliant data spaces, the emergence of data intermediaries, and the development of sustainable business models such as Data-as-a-Service (DaaS), which collectively underpin a more decentralised and sovereign data economy.
	Robotics, exoskeletons,	It addresses the advancement of robotics systems capable of operating in dynamic and unstructured environments, integrating novel mechanical architectures, adaptive materials, and next-generation sensors and actuators. It includes human-centric robotics such as exoskeletons, humanoids, care and soft robots, with a focus on intuitive human-robot interaction and socially-aware navigation. Developments in cognitive robotics aim at seamless AI integration through enhanced perception, knowledge representation and autonomous decision-making, including hybrid and joint action planning. Emerging energy solutions are also in focus, such as self-powered systems and structural integration of energy storage, while new robotic modalities, including nanobots, open pathways for applications in highly specialised and constrained contexts.
Cloud-edge-IoT and advanced digital security	Cybersecurity technologies incl. cyber-surveillance, security and intrusion systems, digital forensics	It covers advanced cryptographic techniques such as post-quantum (quantum-safe) cryptography, quantum cryptography ("beyond QKD"), lightweight cryptography for IoT, and crypto-agility for futureproofing digital infrastructures. It includes data security and privacy solutions like synthetic data generation, decentralised identity and digital wallets, alongside cloud and edge security approaches including confidential computing and fog/edge computing security. The domain also encompasses IoT and hardware security through secure IoT chips and embedded system security. AI-driven security and automation play a growing role, with developments in zero-trust orchestration platforms, automated contain-and-remediate orchestration, AI-augmented digital forensics, and the use of AI/ML for anomaly detection and behavioural analytics. It further addresses challenges linked to offensive AI, AI system security, explainable (XAI) security, digital twin security and continuous authentication. Network and infrastructure protection is reinforced through 5G/6G security advancements and measures against ransomware and extortion threats.

Technology areas	Sub technology areas	Scope
	Cloud to edge to IoT	It addresses the integration of devices, systems and components across the computing continuum, including intelligent IoT devices at the edge and the adoption of RISC-V hardware in cloud-edge infrastructures. It encompasses orchestration approaches such as operating systems for edge IoT systems, enabling traceability, safety and security, as well as stateful serverless computing across the cloud-edge. Ensuring trust and performance is central, with a focus on a seamless secure computing continuum and the use of confidential computing to address evolving security and privacy requirements. The convergence of Cloud-Edge-IoT with AI is also key, through developments in AI-native or cognitive cloud architectures that provide scalability and flexibility, and edge computing solutions that enable real-time insights and intelligent decision-making. Finally, green computing objectives are supported by energy-efficient edge computing systems and advancements in telco cloud-edge and connectivity .
	Blockchain, distributed ledger and digital identities	From a technology perspective, the scope of the area includes foundational developments in blockchain and distributed ledger technologies, such as scalability, consensus mechanisms, blockchain interoperability and their application in GovTech. It places strong emphasis on privacy and security through digital sovereignty, self-sovereign identity, verifiable credentials, regulatory-compliant private payments and zero knowledge technology. The area further explores innovative infrastructures including decentralised marketplaces, decentralised physical infrastructure networks, and the integration of AI and ML with blockchain. It also covers emerging use cases and enablers such as green blockchain, open and next generation hardware for the future internet, AI-generated content (AIGC) including generative AR, and frameworks supporting data ownership and sovereignty.
Advanced connectivity and next generation internet	Advanced digital communications and connectivity (incl. 6G)	The scope of the area covers advanced digital communication and connectivity systems, including AI-driven network management , networks for AI, low-power wide area networks, and time-sensitive networking with deterministic routing. It encompasses next-generation network infrastructures such as multi-access edge computing, reconfigurable and adaptive wireless technologies, and ultra-dense networks. The area also includes developments in network softwarisation and virtualisation , including cloud-native networking, next generations of network function virtualisation, network programmability via network APIs and SDKs, and 6G digital twin modelling. Optical and radio technologies , next generation WiFi, and open radio access networks contribute to a more programmable and flexible connectivity landscape. In addition, it includes quantum technology for communication as well as satellite technologies , particularly advanced non-terrestrial communication systems, expand coverage and resilience, while surveillance and protection technologies ensure secure and robust network operation.
	Next generation internet and XR	The scope of the area covers technologies for the next level of immersion , including multisensorial XR systems, human digital twins, digital humans, and digital twins of objects active in the virtual worlds, supported by next generation communication technologies, AI-driven smart glasses and holographic systems to enable responsive and embodied virtual experiences. It also includes decentralised and secure Web3 , encompassing secure decentralised finance (DeFi) 3.0, next generation peer-to-peer systems, and advanced encryption and privacy tools that foster trust and autonomy in decentralised digital environments. Finally, it addresses sovereign Web 4.0 infrastructure through enabling technologies such as the spatial web, scalable IoT ecosystems, and the decentralisation and diversification of XR development platforms, supporting an open, resilient and sovereign digital infrastructure for future applications.

Source: Technopolis Group 2025

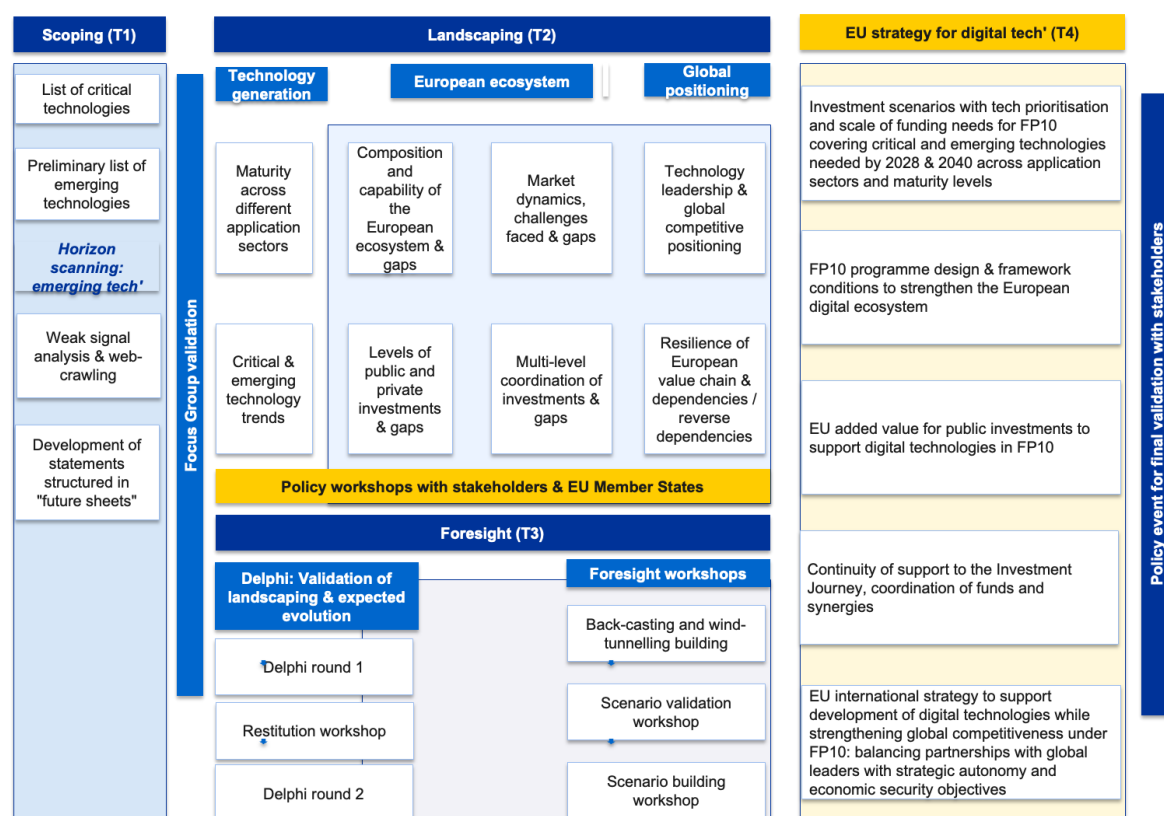
Methodology and analytical framework

To address the objectives of this study, the data collection and analysis was divided into two main phases as described below.

The first phase of the study, following inception, consisted mainly in the scoping and landscaping analysis. The scoping phase, combined with the horizon scanning exercise, enabled the listing of critical and emerging digital technologies relevant for investment in the next EU R&I programme (next Horizon Europe), which constitute the scope of the study. This list has been validated through both focus group discussions with technology experts and stakeholders, and through the delphi process (round 1). The list of critical and emerging technologies had been enriched during the landscaping exercise, which provided a wide range of additional insights on the technology generation trends, the structure and dynamics of the European ecosystem, as well as the positioning and competitiveness of the EU in the global landscape. The results from the scoping and landscaping phases were discussed and enriched through two workshops which took place in Aalborg (3rd July 2025) and in Brussels (10th July 2025).

The second phase of the study covered the foresight and considerations for the EU strategy for digital technologies. The foresight phase sought to validate the findings from the scoping, horizon scanning and landscaping analysis, and develop future scenarios covering each of the critical and emerging technologies. The final considerations also cover reflections about the programme design to support the development of digital technologies, as well as the EU added value of those investments, the need for continuity of support throughout the investment journey, and ultimately the EU internationalisation strategy tailored to each specific digital technology field as concluded via the stakeholder consultations. The draft recommendations were validated in a workshop organised on the 5th February 2026 in Brussels.

Figure 1 Analytical framework for the study



Source: Technopolis Group (2025)

Report structure

This report is structured as follows:

- **State of play and EU's R&I positioning:** provides an overview of the EU digital R&I landscape and analysis of patent, publication, startups and firm investment data, review of the EU policy and regulatory frameworks and public investment at EU level with examples from the national level.
- **EU strengths, challenges and opportunities:** identifies the main R&I trends and the related EU strengths and challenges for each digital technology area in the EU, covering critical and emerging technological trends, research and technology infrastructure needs, skills, ecosystem development, and international positioning.
- **Roadmap of future R&I investments:** provides considerations on the EU added value and objectives, forward-looking roadmap and contextual factors and strategic considerations for programme design.
- **Recommendations:** provides a summary of the main findings and outlines a list of recommendations for the future EU R&I programme supporting digital tech
- **Annex 1-12:** present the detailed technology specific trends per 12 technology
- **Annex 13:** presents an **international benchmarking** exercise with 6 EU countries
- **Annex 14:** contains the synopsis report of the stakeholder consultation.

1. State of play and EU's research and innovation positioning in digital technologies

1.1 Policy and regulatory context for digital technology R&I in the EU

The EU's research agenda in digital technologies is centered around technological sovereignty, competitiveness, and resilience in a rapidly evolving global landscape while at the same time ensuring inclusive, trustworthy and sustainable transformation aligned with European core values. The political guidelines for the next European Commission emphasise boosting Europe's competitiveness and leadership in the transition to a clean and digital economy, fostering a *"new age of invention and ingenuity."*¹⁷

Research and innovation are no longer viewed solely as drivers of economic growth but also as instruments of economic security, industrial strategy, and geopolitical preparedness. The EU's global positioning, articulated through the Economic Security Strategy¹⁸, seeks to minimise risks stemming from geopolitical tensions and rapid technological change while preserving openness and economic dynamism. This approach was reinforced in 2025 through revised measures encouraging Member States to review outbound investments in critical technologies such as semiconductors, AI, and quantum technologies, alongside strengthened coordination of export controls on dual-use items¹⁹. The proposal for the next Horizon Europe programme²⁰ further reflects this shift by incorporating dual-use and defence-related research, aligning research funding more closely with competitiveness and strategic autonomy objectives. Echoing these developments, the Niinistö's report²¹ emphasised the need to close the substantial defence

¹⁷ Ursula von der Leyen, Europe's choice: political guidelines for the next European Commission 2024–2029

¹⁸ High Representative of the Union for Foreign Affairs and Security Policy, Joint Communication to the European Parliament, the European Council and the Council on "European Economic Security Strategy", Brussels, 20.6.2023, JOIN(2023) 20 final.

¹⁹ European economic security. Available online at: <https://www.consilium.europa.eu/en/policies/european-economic-security/>

²⁰ <https://www.consilium.europa.eu/en/press/press-releases/2026/06/26/mff-2028-2034-council-agrees-its-position-on-horizon-europe-the-new-and-ambitious-framework-programme-for-research-and-innovation/>

²¹ Sauli Niinistö (2024), Safer Together Strengthening Europe's Civilian & Military Preparedness and Readiness

innovation investment gap between Europe and the United States and to strengthen civil–military coordination as part of a broader preparedness agenda.

The stronger focus on a more integrated European innovation ecosystem is another policy development. Enrico Letta’s proposal for a “fifth freedom” (the free movement of research, innovation, knowledge, and education) frames existing fragmentation in knowledge flows as a structural obstacle to competitiveness²². Although initiatives such as the European Research Area have advanced integration, persistent national barriers continue to impede the circulation of researchers, data, and access to research infrastructures. The Strategic Technologies for Europe Platform (STEP)²³, designed to support industrial investment in critical technologies, exemplifies efforts to operationalise this vision by linking industrial competitiveness with deeper market integration.

The pursuit of technological sovereignty has become particularly visible in critical technologies. The *2025 State of the Union*²⁴ identified digital and clean technologies as essential pillars of Europe’s autonomy, with President Ursula von der Leyen emphasising the need for Europe to exercise greater control over the technologies underpinning its economy and security. The address highlighted large-scale investments in European AI Gigafactories, alongside initiatives such as the Cloud and AI Development Act²⁵, the Quantum Sandbox, and a proposed multi-billion-euro Scaleup Europe Fund²⁶ intended to help high-growth companies in AI, cloud computing, and quantum technologies remain and expand within Europe. As a further step in 2026, the European Commission adopted a **technology sovereignty package**²⁷ to strengthen the EU’s digital autonomy and technological competitiveness. The package combines new legislation and strategic initiatives, including also the proposed *Chips Act 2.0* to reinforce Europe’s semiconductor ecosystem, the already mentioned *Cloud and AI Development Act* to expand sovereign digital infrastructure and AI capacity, the *EU Open Source Strategy* to promote secure and innovative open-source technologies, and a *Strategic Roadmap for Digitalisation and AI in Energy* to accelerate the digital transformation of the energy sector. The underlying message is that Europe’s digital strategy must become “*faster, smarter, and more European*”²⁸ which captures the broader ambition to establish European technological capabilities without abandoning principles of openness and ethical governance. Technology sovereignty is also reflected in the *EU’s International Digital Strategy*²⁹, which aims at strengthening Europe’s capabilities in strategic digital sectors such as AI, semiconductors, quantum technologies, cybersecurity, and next-generation connectivity. While promoting cooperation with trusted international partners and an open, rules-based digital order, the strategy seeks to reduce critical dependencies, increase resilience, and ensure that Europe can shape global standards and digital governance according to its own values and interests. The strategy aims at directing investment and collaboration towards developing European expertise, infrastructure, and innovation ecosystems that underpin research and innovation agendas in digital technologies.

The ambition of technological sovereignty is complemented by efforts to remove structural barriers to scaling up innovation across the EU. In November 2025, the European Commission proposed a new Digital Package aimed at simplifying EU digital rules, reducing regulatory complexity and administrative burdens, and making the Single Market more supportive of innovation and technological deployment. The package includes a Digital Omnibus³⁰, streamlining rules on AI, cybersecurity, and data; complemented by a new Data Union Strategy to foster high-quality data for AI. European Business Wallets are

²² Enrico Letta (2024) - Much more than a market. Available online at:

<https://www.consilium.europa.eu/media/ny3j24sm/much-more-than-a-market-report-by-enrico-letta.pdf>

²³ https://strategic-technologies.europa.eu/index_en

²⁴ 2025 State of the Union Address by President von der Leyen. Available online at:

https://ec.europa.eu/commission/presscorner/detail/ov/SPEECH_25_2053

²⁵ <https://digital-strategy.ec.europa.eu/en/policies/cloud-and-ai-development-act>

²⁶ https://eic.ec.europa.eu/eic-fund/scaleup-europe-fund_en

²⁷ <https://digital-strategy.ec.europa.eu/en/policies/eu-tech-sovereignty>

²⁸ https://ec.europa.eu/commission/presscorner/detail/ov/SPEECH_25_2053

²⁹ <https://digital-strategy.ec.europa.eu/en/policies/international-digital-strategy>

³⁰ <https://digital-strategy.ec.europa.eu/en/library/digital-omnibus-regulation-proposal>

also included in the package, offering EU companies a digital identity to simplify their paperwork and facilitate business activities across EU Member States.³¹ To address another key structural barrier, the Commission also launched the new **EU Start-up and Scale-up Strategy**³², which aims to address obstacles preventing new companies from emerging and scaling up. The strategy supports inter alia innovation friendly regulations, improves access to finance (e.g. reinforcing the European Innovation Council (EIC) and the related EIC fund, framework for IP valuation); fosters market uptake and expansion to accelerate the commercialisation of research results (e.g. revision of EU public procurement directives) and supports skills development and access to technology infrastructures.

The strengthening of Europe's research and technology infrastructures constitutes another pillar of this strategy. The new European Strategy on Research and Technology Infrastructures³³, adopted in September 2025, outlines the EU's approach to ensuring that its R&I ecosystem is supported by world-class infrastructures, including advanced laboratories, large-scale scientific instruments, data centres, pilot lines, and testbeds. The strategy emphasises improving accessibility for researchers, industry, and start-ups across Member States, enhancing governance and coordination of infrastructures investments, and attracting and developing highly skilled talent. It also promotes digitalisation of infrastructures and fosters international collaboration. These actions aim to reinforce Europe's scientific excellence, innovation capacity, and global competitiveness.

At the level of specific technology domains, the Commission has launched targeted initiatives designed to secure leadership in strategically important fields. The European AI in Science Strategy (2025) aims to accelerate scientific discovery through the integration of advanced AI tools across disciplines. Central to this effort is RAISE (Resource for AI Science in Europe), a virtual pan-European infrastructure providing shared access to high-performance computing resources, datasets, funding mechanisms, and training opportunities. These initiatives align with broader frameworks such as the AI Continent Action Plan and the Apply AI Strategy, reflecting the EU's commitment to ethical, transparent, and human-centric AI deployment while strengthening interdisciplinary collaboration and talent development.

The Commission's proposal for a new Multiannual Financial Framework, amounting to nearly €2 trillion between 2028 and 2034, demonstrates the intention to match strategic ambitions with financial resources. These developments illustrate a profound transformation in European digital R&I policy: research, industrial strategy, economic security, and technological sovereignty are increasingly conceived as mutually reinforcing dimensions of a single long-term project aimed at securing Europe's position in an increasingly contested global technological landscape.

Regulatory & legal context for digital technology development in the EU

Europe has progressively consolidated a robust regulatory framework that positions R&I as a strategic driver of technological competitiveness, resilience, and strategic autonomy. Rather than merely correcting market failures, this evolving governance model seeks to build the industrial, technological, and resource capabilities underpinning Europe's long-term prosperity and security. **Regulation is increasingly deployed as an instrument of capability-building, shaping the conditions for innovation, strengthening critical value chains, and fostering the ecosystems required for emerging technologies** to be developed and scaled within Europe. Recent years have seen the emergence of a comprehensive regulatory agenda aimed at positioning the EU at the forefront of advanced digital and strategic technologies, including the AI Act (2024), the Chips Act (2023), the Data Act (2024), the Net-Zero Industry Act, or the Critical Raw Materials Act, and as further summarised in the Table below by technology area. The **Competitiveness Compass**³⁴ has

³¹ European Commission, Simpler EU digital rules and new digital wallets to save billions for businesses and boost innovation (2025), Available online at: https://ec.europa.eu/commission/presscorner/detail/en/ip_25_2718

³³ The European Strategy on Research and Technology Infrastructures, [Online](#)

³⁴ https://commission.europa.eu/topics/competitiveness/competitiveness-compass_en

repositioned these initiatives within a broader strategy. Rather than treating them as standalone regulatory interventions, the Compass presented them as complementary instruments for building the infrastructures, capabilities, and ecosystems required to translate scientific excellence into EU industrial leadership.

In this regard, the Competitiveness Compass puts a specific emphasis on the imperative to close the innovation gap of the EU with other major economies (i.e. US & China). Besides ensuring the condition for advanced technologies to thrive, and investing in new growth engines, the Compass identifies several other conditions to ensure the EU restarts a virtuous innovation cycle.

In the Table below, the key policy and regulatory initiatives are summarised that either directly or indirectly foster research and innovation linked to the specific technology area. These various acts reflect a policy approach in which regulation supports capability-building and which seeks to channel resources into cutting-edge R&I, strengthen critical value chains, reinforce Europe's industrial base, and accelerate the development and deployment of these critical digital technologies.

Table 2 EU strategic policy initiatives

EU strategic policy and regulatory initiatives
EU main policy initiatives conducive for R&I: • Advanced Connectivity: Gigabit Infrastructure Act (2024), Digital Network Act (strengthens the environment in which R&I takes place) (Q4 2025), Smart Networks and Services Joint Undertaking SRIA • AI: White Paper on AI (2020), AI Package, incl. proposed AI Act, Communication on fostering an EU approach to AI, revised coordinated Action Plan on AI (2021), Proposal for an AI liability directive (proposal, 2022); AI on demand platform; AI Act (2024), EU AI Office (2024); InvestAI initiative (2025), AI Continent Action Plan (2025) Apply AI Strategy, AI Factory Initiatives & AI in Science (Q1 2025), ADRA SRIA, Digital Omnibus on AI³⁵ • Blockchain & Distributed ledger technologies: European Blockchain Partnership (2018), European Blockchain and web3 strategy, European Regulatory Sandbox for Blockchain (2023) • Cloud-edge-IoT: Cloud and AI Development Act • Cybersecurity: Cyber Resilience Act (2023), NIS2 Directive (2023), European cybersecurity strategy, ECCC regulation, Cybersecurity Act (2019), Cyber Solidarity Act (2023) • Data: European Strategy for Data (2020), Open Data Directive (2019), Data Governance Act (2022), Data Act (2024), Data Union Strategy (2025) • Supercomputing and quantum computing: EuroHPC Regulation (and revisions introducing AI Factories, 2024), EuroHPC SRIA, European declaration on quantum technologies, Quantum Europe Strategy (2025) • Semiconductor: Chips Act (2022), Chips JU SRIA, Critical Raw Materials Act, EIT Raw Materials SRIA • Quantum: Quantum Strategy, Quantum Flagship, EuroQCI, European Quantum Act • Next Generation Internet & XR: Virtual Worlds SRIA, Media & Audiovisual Action Plan, EU strategy on Web 4.0 and virtual worlds (2023) • Other sectoral initiatives: Digital identity (draft Architecture and Reference Framework for the European Digital Identity wallet), Health (Promotion of electronic health records based on a common European exchange format, eHealth Network guidelines, European health data space), Defence: Action plan on synergies between civil, defence & space industries (2021), European Defence Industrial Strategy (2024) EU preparedness strategy (2025), Space: Space Act (2025) • The Union's Secure Connectivity Programme integrates digital technologies to ensure resilient, autonomous, and secure satellite communication across Europe. Combining advancements in quantum encryption, AI-driven network management, and cloud-edge integration, the programme strengthens the EU's capacity to protect critical infrastructure and enable trusted connectivity.

Source: Technopolis Group 2025, Own compilation

³⁵ [https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI\(2026\)782651](https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2026)782651)

1.2 Performance of the European R&I digital ecosystem

Cutting-edge research in digital technologies has never been more crucial. In uncertain and challenging times as today, committing resources to research, development and innovation of digital technologies will lay the foundation for future discoveries and sustained economic progress. Digital technologies increasingly underpin economic productivity, industrial competitiveness, security, and societal resilience. In this section, the state of play of EU R&I landscape is investigated based on traditional methodologies such as scientific publications, patent statistics, start-ups data and novel techniques such as capturing software development trends through data from GitHub, webscraping and textmining of company websites.

1.2.1 EU's scientific performance

The EU demonstrates strong scientific capabilities in digital technologies, underpinned by world-class research institutions and collaborative innovation networks. However, despite its recognised strengths and leading position in the volume of scientific publications, the quality of EU scientific publications continues to lag behind that of the United States and China, which suggests the need to place greater emphasis on quality over quantity.

In terms of the number of scientific publications, in 2024 the EU ranked first in almost all digital technologies in scope of this study except for AI and Cybersecurity where it occupies the second position after China. However, Europe is lagging behind in producing high impact publications captured as the top 10% or top 1% highly cited publications across most digital technologies.

Table 3 International position of the EU in terms of the absolute number of scientific publications in digital technologies in 2024

	Advanced Connectivity	AI	Blockchain	Cloud-Edge-IoT	Cyber security	Data analytics	HPC	Micro electronics	NGI XR	Photonics
EU27	#1st	#2nd	#1st	#1st	#2nd	#1st	#1st	#1st	#1st	#1st
China	2	1	2	2	1	3	3	3	3	2
USA	3	3	3	3	3	2	2	2	2	3

Source: OPIX (2025) based on OpenAIRE

The top 10% highly cited publications show that the EU27 falls behind in various technology fields, notably it follows China and the US. As other research also shows, the EU's performance in scientific excellence, gauged by the percentage of its publications ranking in the top 1% or top 10% most highly cited globally, has been stagnant over the last decade. China's scientific output, which has been growing exponentially, has seen such rapid improvement in quality that it now performs above the world average at a higher rate than the EU. China surpassed the EU in the share of publications in the top 10% most highly cited in 2015 and subsequently lost its slight advantage on the very top of excellence, overtaking the EU in the top 1% most highly cited in 2016³⁶.

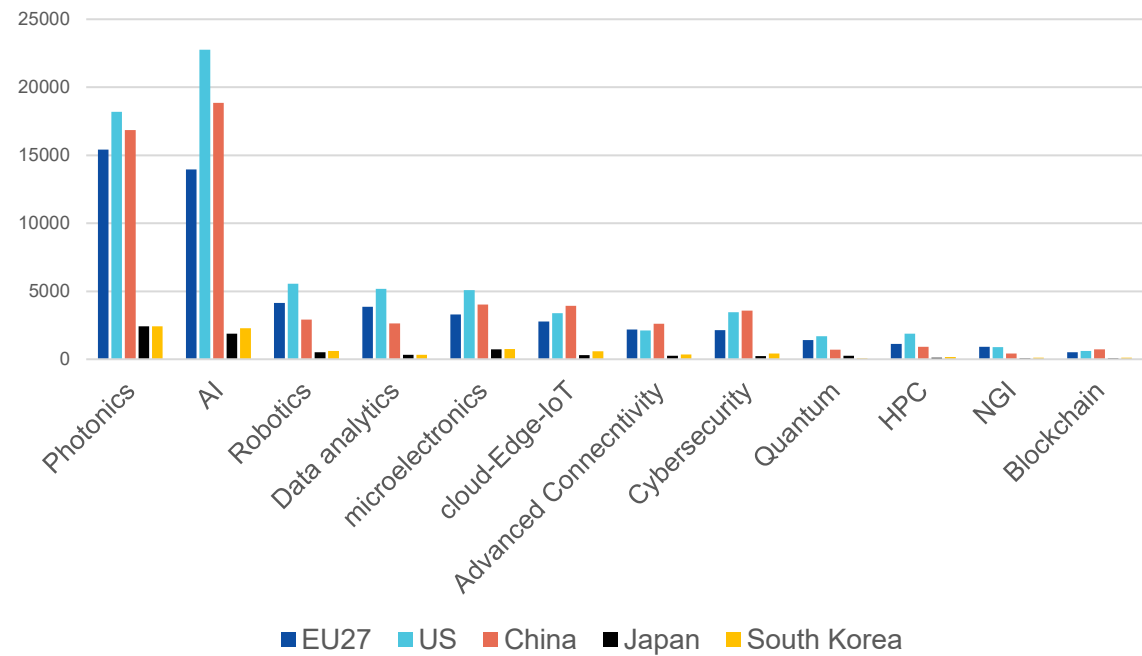
The reasons behind these trends are manifold: Europe is comparatively stronger in economics, social sciences, arts, and humanities, while China dominates applied sciences, engineering, chemistry, and enabling technologies, and the US remains particularly strong in health sciences. Since many highly cited papers increasingly come from these

³⁶ JRC (2021). China overtakes the EU in high-impact publications, European Commission: Science, research and innovation performance of the EU, 2024 – A competitive Europe for a sustainable future, Publications Office of the European Union, 2024, <https://data.europa.eu/doi/10.2777/965670>,

technological and scientific frontiers, Europe's specialisation puts it at a disadvantage³⁷. Another reason is the pipeline of STEM graduates in the EU that account for 11–35% of graduates across EU countries, whereas countries such as India and South Korea exceed 30%. Fewer STEM-trained researchers reduce the capacity to generate cutting-edge work in fields that attract the most citations.

Nonetheless, the idea that European research is better and the EU is only lagging in commercial exploitation has been challenged for several years with numerous journal articles claiming that Europe leads in terms of quantity but not quality of research³⁸. Dosi, Llerena and Sylos Labini³⁹ argued already in 2006 that the underlying premise of a pure science-industry linkage failure is largely a myth, and that Europe's real weaknesses lie instead in frontier research capacity and in the innovative capabilities of European corporate actors themselves. Their conclusion is that policy should place “*much less emphasis on various types of networking, and much more on policy measures aimed at strengthening both frontier research and European corporate actors*”.

Figure 2 Number of scientific publications in the top 10% journals by top R&I investors for each sub-technology area



Source: OPIX (2025) based on OpenAIRE

Technology trends since 2021, in terms of publication counts across key digital fields, show both dynamic growth phases and more recent shifts in such momentum. The high volume of publications in **AI, Data analytics, Photonics and Microelectronics** and

³⁷ European Commission: Science, research and innovation performance of the EU, 2024 – A competitive Europe for a sustainable future, Publications Office of the European Union, 2024, <https://data.europa.eu/doi/10.2777/965670>.
³⁸ See for example: Rodríguez-Navarro, A., & Narin, F. (2018). European paradox or delusion—Are European science and economy outdated? Science and Public Policy, 45(1), 14–23. <https://doi.org/10.1093/scipol/scx021>;
³⁹ Dosi, G., Llerena, P., & Sylos Labini, M. (2006). The relationships between science, technologies and their industrial exploitation: An illustration through the myths and realities of the so-called “European Paradox”. Research Policy, 35(10), 1450–1464. <https://doi.org/10.1016/j.respol.2006.09.012>

semiconductors reflect the EU's strong scientific focus in these fields (see Figure below).

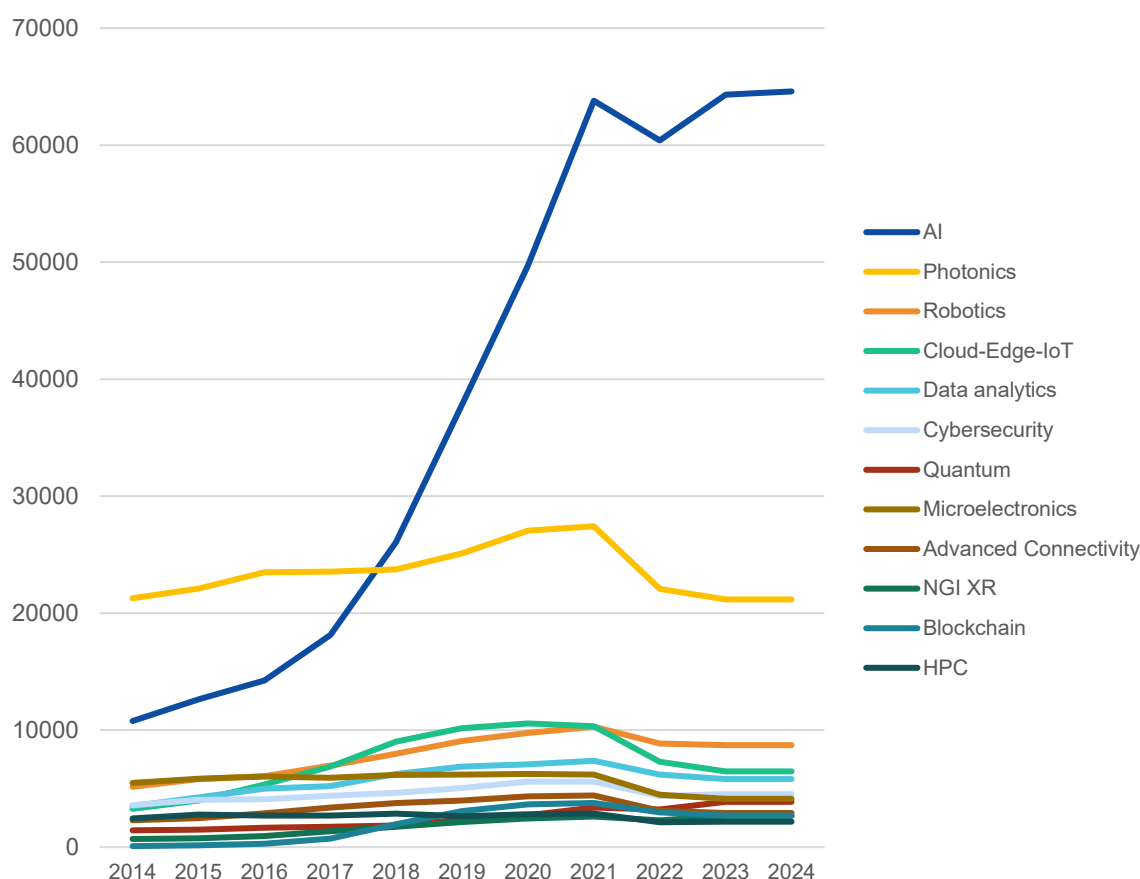
- **AI has emerged as the fastest-growing scientific domain within the EU27**, in alignment with findings from recent bibliometric studies⁴⁰⁴¹. Between 2021 and 2025, AI-related publication output expanded at an average annual growth rate exceeding 20%, ultimately rising to over 50,000 publications in 2024 in the EU27 and further increasing in 2025.
- **Publications on Data analytics and data-sharing technologies** rank second following AI, showing a clear upward trend and peaking at 25,000 in 2021.
- **Photonics and Microelectronics & Semiconductors exhibit more stable yet robust growth trajectories** among the top-performing domains, with both fields recording an average annual growth rate of approximately 3% from 2014 to 2021.
- From a small base, **Quantum technologies show strong growth** in both periods, particularly recently, indicating their transition from theoretical exploration to practical applications. This marks a strategic frontier in digital science.

As for the remaining technology areas, most show positive publication trends over time within the EU, albeit with varying degrees of growth:

- **Advanced digital communications and connectivity:** this mature and foundational area shows steady long-term growth, maintaining a stable annual growth rate over the period of 2014-2024. Its consistent expansion reflects ongoing evolution in communication standards and infrastructure rather than disruptive innovation.
- **Blockchain:** Starting from a very small base, blockchain experienced explosive growth over the full period, with strong momentum in 2024. This pattern typifies an emerging technology still in rapid diffusion, attracting diverse academic and applied interest.
- **Cloud-edge-IoT:** Initially moderate in size, this field shows robust early and sustained growth, underlining the expanding role of distributed computing. Recent acceleration since 2023 highlights its importance as a backbone for AI and real-time data ecosystems.
- **Cybersecurity:** Cybersecurity maintains solid, consistent growth since 2014, indicating steady research attention driven by ongoing global digitalisation and persistent security challenges. Its balanced trend reflects both maturity and continuing innovation.
- **High performance computing:** Despite its strategic importance, growth remains modest, reflecting a mature, infrastructure-intensive domain. The years 2023-2024 show stability rather than expansion, as computational capacity increasingly underpins rather than drives innovation.
- **Next generation internet and extended reality:** This area has expanded rapidly since 2022, reflecting convergence between networking, immersive environments, and user experience technologies. The momentum suggests growing academic integration of human–digital interface studies.
- **Robotics:** Robotics demonstrates consistent, moderate growth from a sizable foundation, balancing applied engineering with new AI-driven directions. Its trajectory signals continued expansion in interdisciplinary and automation-focused research.

⁴⁰ European Commission (2023). Trends in the use of AI in science – A bibliometric analysis, Publications Office of the European Union, 2023, <https://data.europa.eu/doi/10.2777/418191>

⁴¹ Dibiaggio, L., Nesta, L., & Vannuccini, S. (2024). European sovereignty in artificial intelligence: A competence-based perspective (Working Paper No. 20/2024). Luiss Institute for European Analysis and Policy. <https://leap.luiss.it/wp-content/uploads/2024/12/WP20.24-European-Sovereignty-in-Artificial-Intelligence.pdf>

Figure 3 Number of publications per technology area within the EU27

Source: OPIX (2025) based on OpenAIRE

A general publication peak across most digital technology areas is observed in 2021. Subsequently, a decline in annual publication volumes is visible in 2022 and 2023 across all technology domains. This downtrend is likely multifactorial. One contributing factor is the post-pandemic normalisation of research activity. During the COVID-19 lockdown period (2020–2021), many digital fields benefited from increased research leading to a temporary surge in scientific output⁴². As academic institutions resumed normal operations, publication activity appears to have stabilised or even declined in relative terms. In parallel, another key factor is the inherent time lag in academic publishing. Recent studies have shown that many publications from 2022 and 2023 may still be under peer review or awaiting indexing⁴³, meaning that the apparent decline could be partially attributed to delayed visibility rather than a true drop in research intensity⁴⁴.

However, as the data suggest Europe's strong scientific output does not consistently translate into technological leadership or commercial success.

While the topic analysis conducted in this study shows that the **EU's top 1% most highly cited publications are closely aligned with industrial needs and emerging opportunities identified by experts, their strong commercial potential is not matched**

⁴² See for example Volpe, Massimo & Ralli, Massimo & Isidori, Andrea. (2024). "The impact of the COVID-19 pandemic on research activities: A survey of the largest Italian academic community".

⁴³ Aczel, B., Barwich, A. S., Diekmann, A. B., Fishbach, A., Goldstone, R. L., Gomez, P., Gundersen, O. E., von Hippel, P. T., Holcombe, A. O., Lewandowsky, S., Nozari, N., Pestilli, F., & Ioannidis, J. P. A. (2025). The present and future of peer review: Ideas, interventions, and evidence. 122(5), e2401232121. <https://doi.org/10.1073/pnas.2401232121>

⁴⁴ There are important specificities and caveats to consider because apparent changes in publication trends may partly reflect terminological or classification shifts, rather than true shifts in research activity. In some cases, the evolution of professional jargon may cause publications to shift from one topic classification to another, as many areas are interconnected. Moreover, technologies that were once considered more generic may have become embedded within more specialized or emerging domains. The example of microelectronics and semiconductors illustrates this point: recent research in semiconductors may increasingly fall under categories such as quantum technologies or next generation internet and extended reality.

by comparable efforts to translate these scientific advances into products, services, and scalable businesses. This reflects persistent challenges in technology transfer, access to scale-up financing, and the integration of research excellence into broader innovation ecosystems. Structural barriers such as fragmented innovation governance⁴⁵, disconnected or unevenly developed ecosystems, limited coordination across countries and institutions, weak links between research and industry, and persistent talent shortages prevent scientific excellence from fully turning into market-ready technologies and competitive companies.

1.2.2 EU technological innovations in digital

Between 2015 and 2022, EU patenting was led by Microelectronics and semiconductors, Photonics, and Robotics, with Artificial Intelligence showing the fastest growth and a strong focus on practical, domain-specific applications, highlighting Europe's emphasis on embedding trustworthy, real-world AI into industry and society.

The use of patent data provides a complementary perspective to the bibliometric analysis by capturing innovation efforts and more commercially oriented knowledge creation. While bibliometrics primarily measure scientific output and collaboration, patent data offers insights into the practical application and commercialisation of research. Measured by the number of patent applications filed by EU27 applicants between 2012 and 2022, Figure 3 below shows the intent to protect and commercialise research outputs in the 12 technology areas in scope of the study.

In the EU, the top four patenting technology areas were Microelectronics and Semiconductors, Artificial Intelligence, Photonics, and Robotics in the period from 2015 to 2022. Following other lines of research⁴⁶, patent activity in AI has particularly experienced a strong acceleration in recent years, growing significantly from just under 100 in 2015 to over 1,400 in 2022, closely tracking the steep increase observed in publication volumes.

Both Microelectronics and semiconductors and Photonics maintain the highest volume of patent filings, though with a more stable trend line and less pronounced growth in the most recent available years⁴⁷. Robotics, while smaller in scale, exhibits a steady upward trajectory.

Certain technology areas show clear upward trends, albeit from smaller starting bases such as Next Generation Internet (NGI) and Extended Reality (XR) technologies, that rose from just 83 patents in 2012 to 210 by 2022. Quantum technologies also exhibit notable growth, increasing from fewer than 10 annual filings before 2015 to 162 in 2022. In contrast, areas such as Blockchain, Cybersecurity, and Cloud-Edge-IoT experienced shorter-term peaks followed by slight contraction trends, possibly indicating initial exploratory patenting phases that have since stabilised. For example, Blockchain patents peaked in 2018 and 2021, in alignment with the surges observed within scientific publications.

The top ten applicants that filed for the highest number of patents in the field of the 12 digital technologies in the scope of this study have been Siemens (DE), Robert Bosch (DE), LM Ericsson (SE), Philips Electronics (NL), CEA – Commissariat à l'Énergie Atomique (FR), Nokia Technologies (FI), Signify Holding (NL), Thales (FR), Volkswagen (DE), and ASML (NL). Analysing the composition of these patent applicants shows that Europe's

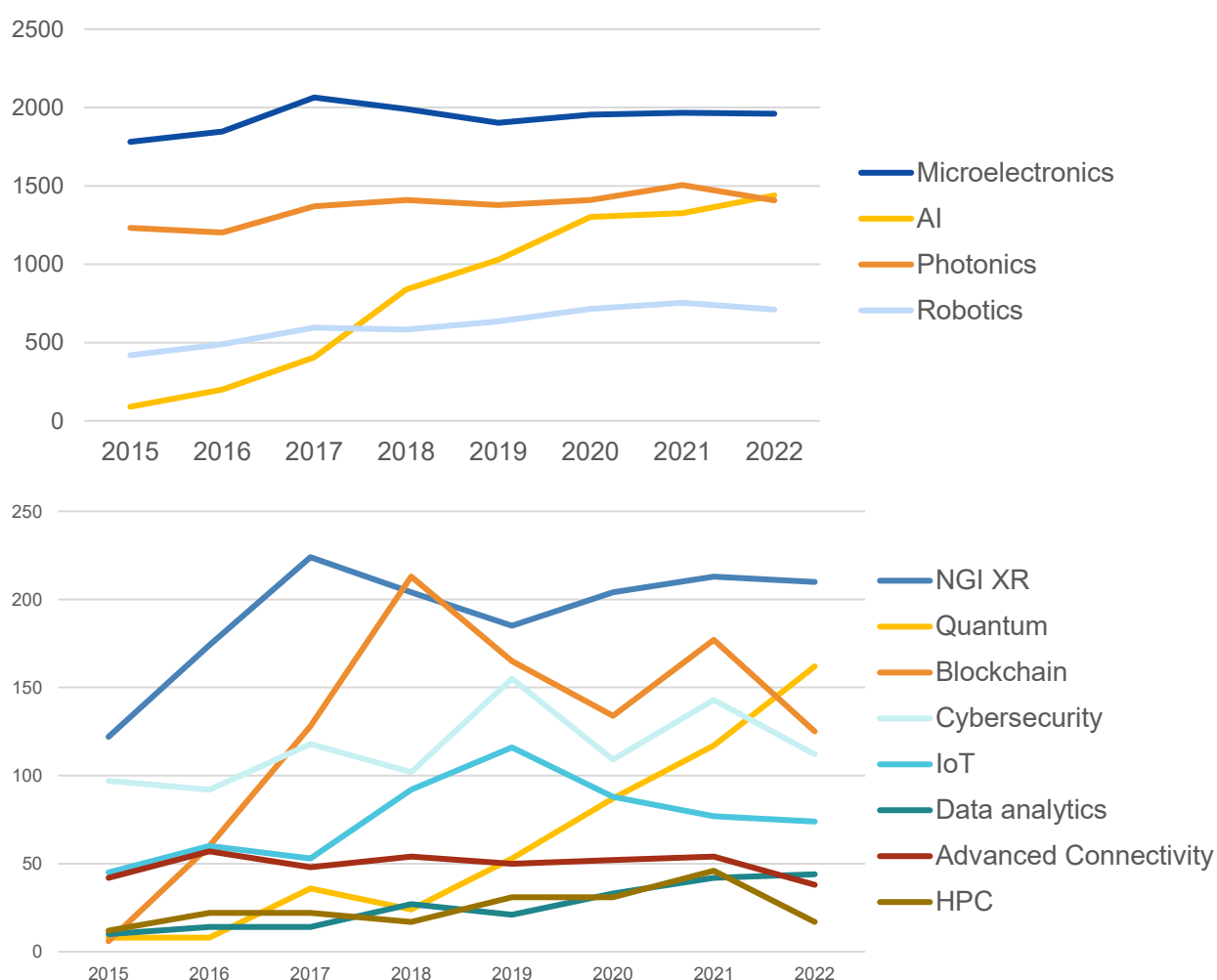
⁴⁵ See in Pierre-Alexandre BALLAND & Valentina DI GIROLAMO & Florence BENOIT & Julien RAVET & Alexandr HOBZA, 2025. "[Divided We Fall Behind: Why a fragmented EU cannot compete in complex technologies](#)," [EU research and innovation paper series](#) KI-01-25-083-EN-N, Directorate General for Research and Innovation (DG RTD) of the European Commission.

⁴⁶ Dibiaggio, L., Nesta, L., & Vannuccini, S. (2024). European sovereignty in artificial intelligence: A competence-based perspective (Working Paper No. 20/2024). Luiss Institute for European Analysis and Policy. <https://leap.luiss.it/wp-content/uploads/2024/12/WP20.24-European-Sovereignty-in-Artificial-Intelligence.pdf>

⁴⁷ The drawback of patent data is the consequent time lag, which can be up to three years: <https://www.epo.org/en/searching-for-patents/helpful-resources/patent-knowledge-news/analysing-unitary-patent-data-patstat>

digital innovation is primarily driven by large, established industrial firms with strong engineering capabilities and sustained R&D investment. Patenting activity is concentrated in sectors of traditional EU industrial strength such as manufacturing and advanced hardware and is largely application-driven, focusing on integrating digital technologies into real-world industrial systems. As also analysed by related research, Bosch emphasises AI innovation in Europe through applications in automotive engineering, autonomous driving⁴⁸, humanoid robotics and advanced manufacturing, and Philips and Siemens concentrate their AI efforts on healthcare and industrial applications⁴⁹. The US pattern of patenting activity in digital technologies and in particular in AI is broader and more software/vertical-driven, often aimed at consumer applications and specifically targeting autonomous systems, finance, health, or security⁵⁰.

Figure 4 Total number of patent applications per technology area in EU27 countries, 2012–2022



Source: Fraunhofer ISI (2025) based on PATSTAT

The further analysis of the individual patent applications and the subdomains within each technology area provides additional insights into the most important technological trends that the EU is focusing on and has most potential.

⁴⁸ <https://www.springerprofessional.de/en/automotive-industry/companies---institutions/bosch-is-focusing-on-robotics-and-ai/52651568>

⁴⁹ <https://www.philips.com/a-w/about/news/archive/blogs/innovation-matters/2026/ai-is-working-in-healthcare-now-lets-scale-it.html>

⁵⁰ <https://insights.greyb.com/global-artificial-intelligence-patent-landscape/>

In AI, the analysis of the patents' topics indicates that European patent applications most often centre on making AI systems intelligent, trustworthy, and capable of operating in real-world environments, particularly at the edge, where they must function in real time under constraints such as limited data, power, and connectivity. European AI patents mainly focus on AI systems that aim at adaptive, secure, explainable, and autonomous decision-making across physical systems. Industrial applications are at the core including healthcare, manufacturing, and critical infrastructure, turning AI into embedded, resilient intelligence.

Figure 5 Most important subdomains within AI where EU patent filings have risen over the past 3 years

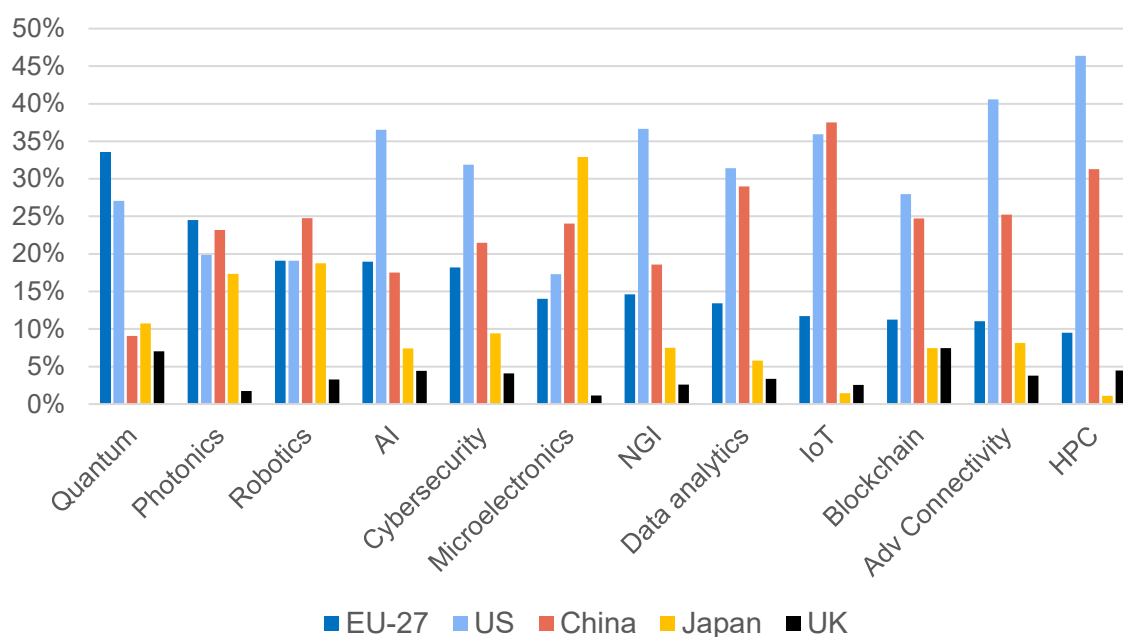
Subarea	Typical technical focuses	Example patent claim language
Applied AI in specialised industrial domains	Edge-optimised deep learning models, explainable AI (XAI), AI-assisted robotics control, multimodal industrial AI	- A method for implementing a deep learning model on an edge device, including quantisation and optimisation for limited resources. - A system providing transparent decision-making in an AI model with explanation modules. - A control system for autonomous robotics leveraging AI to fuse sensor data and make real-time decisions.
Machine learning for automation and decision support	Online/incremental learning, domain adaptation, few-shot/zero-shot learning	- A method for online or incremental learning in a changing environment with concept drift. - A transfer learning/domain adaptation approach with limited data. - A few-shot/zero-shot learning architecture for specialised industries, including data setup.
Computer vision, pattern recognition, and image processing	3D vision, SLAM, medical imaging, industrial QA	- AI-assisted 3D vision/SLAM method with odometry and map updating. - Medical imaging analytics with AI support, including segmentation. - Object and scene understanding for quality control in manufacturing.
Speech and dialog systems (NLP)	Edge NLP, offline speech recognition, domain-specific assistants	- Local speech recognition on devices without network connectivity. - Domain-specific AI assistants (e.g., legal/technical advisory). - Controlled language generation with safety and style governance.
Edge computing and hybrid-cloud architectures	Model compression, secure edge execution, distributed inference	- Model compression techniques (quantisation, pruning) to reduce compute load. - Secure execution of AI on devices (trusted execution environments). - Distributed AI inference across industrial networks (edge-to-cloud).
Cybersecurity and privacy in the digital ecosystem	AI threat detection, privacy-preserving AI, secure firmware	- AI-enabled detection of threats and anomalies in networks. - Privacy-preserving AI (federated learning, differential privacy). - Secure firmware updates, secure boot, and AI security architectures.
Sensing, IoT, and distributed systems	AI fusion in sensor networks, intelligent edge gateways, real-time decisions	- Energy-efficient sensor networks with AI-driven data fusion. - Intelligent edge gateway solutions for industrial use. - Sensor fusion for automotive/smart mobility with real-time decision-making.

Subarea	Typical technical focuses	Example patent claim language
Biometric identification and verification	Facial/iris/fingerprint, behavioural biometrics	- Biometric identification in controlled environments with improved matching performance. - Behavioural biometrics and continuous authentication.
Data and knowledge management	Semantic technologies, ontologies, knowledge graphs	- Building semantic models, ontologies, and knowledge graphs for Industry 4.0. - AI-assisted data preparation, data governance, and quality control.
Robotics and autonomous systems	Cobots, AI-enabled SLAM, learning-based control	- Collaborative robot (cobot) architectures with human-robot coexistence and safety features. - AI-assisted planning and SLAM, learning-based control in complex environments.
HealthTech and digital medicine	Diagnostic AI, telemedicine support	- AI-assisted diagnostics and triage systems. - Telemedicine AI support and treatment-planning assistance.
Computational science and simulation	AI in simulations, materials science	- AI-assisted simulations of complex systems and optimisation in material science. - AI-driven data analysis and visualization in scientific research.

Source: Fraunhofer ISI based on PATSTAT and

Despite the dynamic landscape, the patent analysis also shows that the EU is lagging behind the main international competitors across all digital technologies except for Quantum and Photonics. The gap is particularly significant in the field of HPC, Advanced Connectivity and Cloud-Edge-IoT. The EU's position continues to be challenged by the US, China, and Japan, amid a growing market concentration.

Figure 6 World share of patent applications of the EU and its international competitors in (2022 as latest available year)

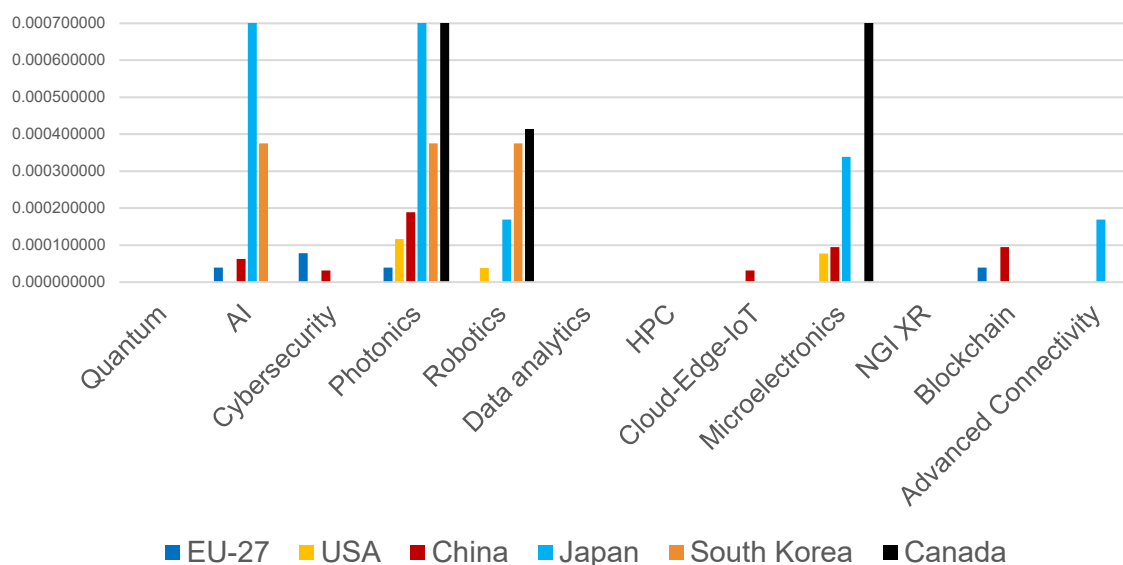


Source: Fraunhofer ISI (2025) based on PATSTAT

Europe is underperforming also in terms of patent applications normalised per billion GDP, standing out only in Cybersecurity. Japan and South Korea perform well in several technologies

compared to their size, for example in AI, Photonics or Robotics. Canada shows substantial relative strength in the tech domains of Photonics, Microelectronics and Robotics.

Figure 7 Patent applications per billion GDP in the EU and its international competitors (2022 as latest available year)



Source: Fraunhofer ISI (2025) based on PATSTAT

Standard Essential Patents (SEPs) provide an additional perspective for patent analysis. SEPs protect technologies that are indispensable for implementing a technical standard, such as 4G, 5G, Wi-Fi, or USB. When a patent is declared essential to a standard, any company wishing to develop products that comply with that standard must use the patented technology, typically through licensing. In other words, SEPs are patents referenced in technical standards that define product specifications in global technology markets.

The inclusion of a patented invention in a technical standard signals its technological significance. While not all breakthrough innovations become SEPs, standard-essential patents are more likely than other patents to represent foundational innovations with broad technological and commercial relevance, whereas incremental innovations are less likely to be incorporated into widely adopted standards.

More broadly, the inclusion of patents in standards reflects the ability of firms to establish their technological solutions as industry-wide reference points. Companies that succeed in embedding their innovations in technical standards are often able to shape the direction of technological development, influence future market evolution, and secure significant commercial advantages. Consequently, the number of SEPs originating from a given country or region provides an indirect indicator of the relevance of its innovation output for global markets and of its firms' capacity to shape emerging technological ecosystems.

This study analyses patents referenced in standards developed by the European Telecommunications Standards Institute (ETSI). ETSI standards are widely recognised internationally and are frequently adopted by global companies seeking to comply with robust and internationally accepted technical specifications. Their global influence also reflects the so-called "Brussels Effect", whereby European regulatory and standard-setting frameworks often become de facto global benchmarks.⁵¹). Likewise, these standards are naturally most immediately relevant for shaping the European digital market. At the same time, there is necessarily a certain European bias towards company representation in the related standardisation committees and thus also, to a degree, the patents that these might

⁵¹ Bradford, A. (2020). *The Brussels Effect: How the European Union rules the world*. Oxford University Press. <https://doi.org/10.1093/oso/9780190088583.001.0001>

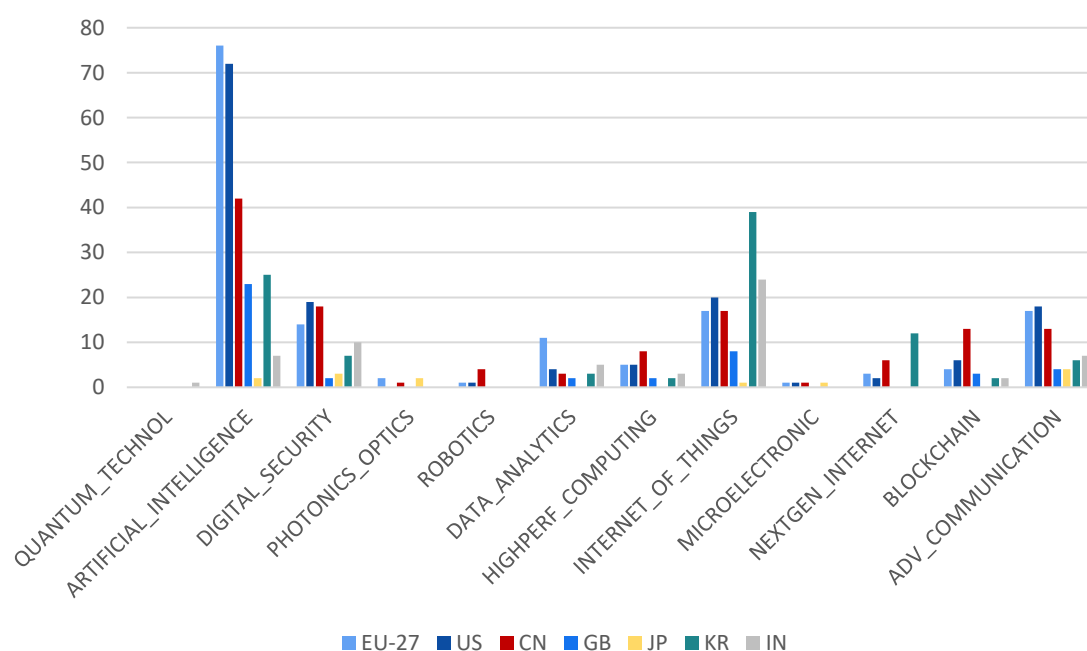
feel motivated to reference in the standards they agree on. Against this background, the analysis paints a two-sided picture.

On the one hand, European inventions still constitute a remarkable basis of reference for European standards. Generally speaking, about one third of all technological references made via patents refer to inventions made in Europe.

On the other hand, the relevance of inventions made in the US surpasses those of European origin in many of the specific domains, and China, known for its firms' proactive standardisation activities, is catching up fast. Even in standards issued by European-based organisations, the majority of technological references are thus no longer to European inventions.

Overall, this analysis is therefore in line with many others in this report, underlining that **European firms no longer hold a position of strategic control in the digital domain. At the same time, their technological output remains relevant as a reference in many subdomains of the digital sector, leaving some leverage** to future entrepreneurs and policy makers. The most important policy conclusion of the analysis of standard essential patents is that European firms must be put in a better position to operate in a regulatory framework conducive to breakthrough innovation and get the necessary access to funding to scale novel ideas that can shape future markets. Without that perspective, many commercial actors will turn away from pursuing those innovation projects that would subsequently become reflected in standard essential patents.

Figure 8 World share of standard essential patent applications of the EU and its international competitors in 2022



Source: Fraunhofer ISI (2025) based on PATSTAT

1.2.3 Open-source software development for digital technologies

Online platforms for managing code collaboration have become ubiquitous for digital technology development and software code development is a signal of innovation. GitHub data shows rapid global growth in open software development in the EU and globally, with over 1.3 million repositories created in the world between 2014 and 2024 and AI emerging

as the fastest-growing field. Overall, the EU lags behind the US and China in code contributions.

While innovation in digital technologies can be tracked using traditional indicators such as academic research and patenting trends, they miss an important dimension: the software code through which digital technologies are developed. This is particularly important as software is only patented if it has a clear technical and implemented contribution. In the rapidly evolving fields of digital technologies, GitHub captures innovation more effectively than patent records because **it reflects ongoing open-source development in real time, whereas patents are subject to substantial delays between invention and formal registration**⁵². Open-source platforms allow capturing the developer ecosystem such as experimenting with and building on AI models.

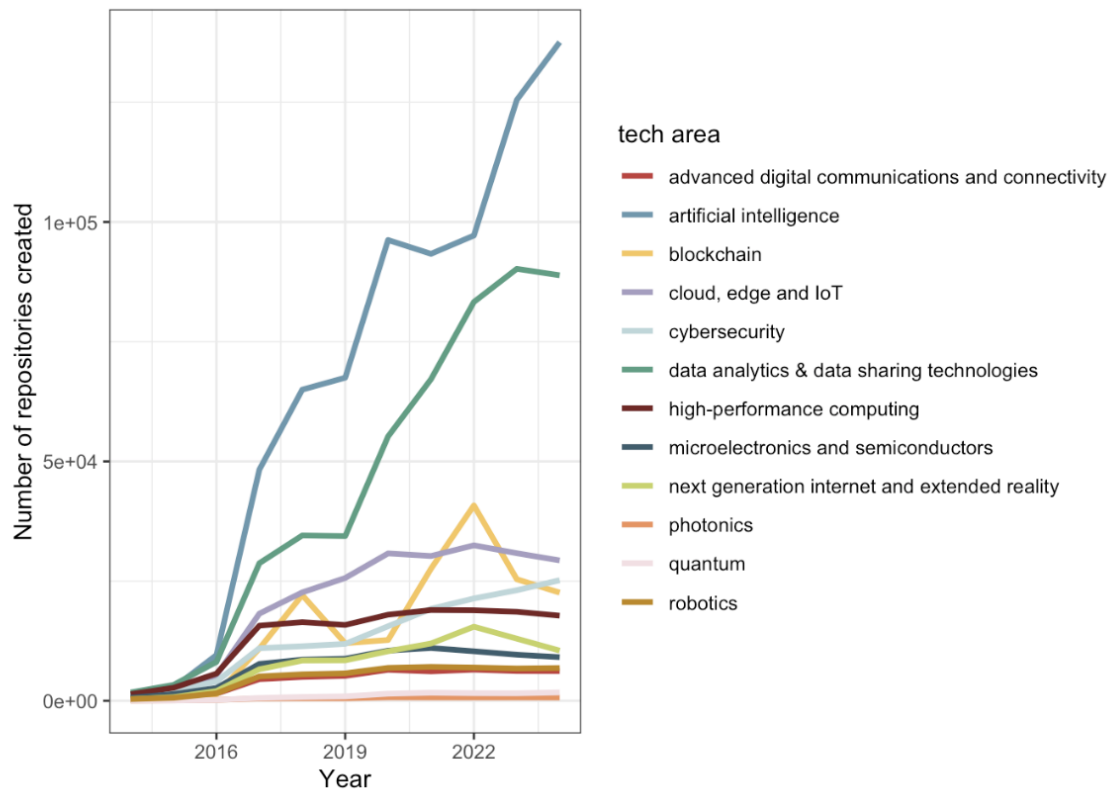
GitHub, as well as Gitlab and Bitbucket, builds on the git version control technology to create online platforms to develop software. These platforms have enabled huge growth in open-source software which underpins innovation in critical digital technologies such as AI, robotics or cloud computing. GitHub is the biggest collaborative coding platform in the world, with over 500 million projects hosted and 5 billion contributions to projects in 2024. For instance, many of the most impactful technologies in AI (from Meta's ollama to deepseek's R1) are developed in GitHub, which makes understanding and analysing the patterns of development, collaboration and innovation in this space crucial to capturing digital innovation.

The results of the analysis of GitHub conducted in the framework of this project show that between January 2014 and December 2024, there were 1,341,457 software code repositories created across the 12 technology areas, which gathered 70,400,087 developers globally.

- The number of software code repositories **has increased exponentially** both in the EU and globally in particular in the field of **Artificial Intelligence followed by Data analytics** (the latter stalling in 2024).
- **Cybersecurity related code development** shows a steady upward trajectory.
- In Blockchain technologies code development started to decrease in 2022 after a previous sharp increase.
- **Code development has also slowed down in the field of Next Generation Internet and XR.**
- Development in the field of Cloud-Edge-IoT has been stabilising and slightly decreasing since 2022 as well.
- Code development is the least common for the fields of Robotics, Photonics and Quantum.

Figure 9 Number of repositories created in GitHub related to digital technologies reflecting software development and innovation trends

⁵² See also in: Choi, J., Lee, S., & Lee, H. (2026). Navigating the AI technology landscape from GitHub data. Technology in Society, 84, Article 103090. <https://doi.org/10.1016/j.techsoc.2025.103090>



Source: Technopolis Group based on GitHub (2025)

The top repositories linked to each digital technology provide further insights into emerging trends and collaboration patterns on specific thematic that are expected to have an impact on the directions of innovation in the future. Besides the technology-specific trends, it is also evident that there are several cross-technology developments:

- First, **AI is not only appearing in the repositories related to AI but across all other technologies** as an enabling capability.
- **Innovation is moving toward edge, distributed, and sovereign computing**, with intelligence and data processing increasingly deployed closer to users and devices through self-hosted, decentralised, and cloud-edge architectures. From the development trends, it is clear that this combines various technologies and appears not just as part of data analytics or cloud-edge-IoT, but also in microelectronics, for example edge AI inference on microcontrollers, or distributed networks as part of advanced connectivity etc.
- The **rise of autonomous systems and intelligent automation** spans also robotics, software agents, and self-managing infrastructures capable of sensing, reasoning, and acting with minimal human intervention.
- Finally, the growing **convergence of the physical and digital worlds**, through spatial computing, advanced sensing, digital twins, and cyber-physical systems is creating intelligent environments in which digital technologies interact seamlessly with real-world processes.

Table 4 Most popular repositories (in terms of stargazer count) by technology area in GitHub

Most relevant repositories per technology	Innovation trends that the top 50 repositories reveal
Advanced Connectivity: Tabby, Stats, WindTerm	Open-source projects reveal three main trends: the growth of edge computing and IoT , enabling more intelligence to run locally on connected devices; increasing emphasis on secure and flexible network management across distributed systems; and stronger capabilities in wireless communication and cybersecurity , supporting resilient, privacy-preserving, and interoperable digital infrastructures.
Artificial Intelligence: Tensorflow, AutoGPT, Transformers, Stable Diffusion web UI	AI development is moving from standalone models toward agentic systems and autonomous workflows , with tools that enable AI agents to reason, plan, and execute tasks independently. There is growing emphasis on open and interoperable foundation models . Innovation is increasingly focused on democratising AI , through no-code platforms, user-friendly interfaces, and lightweight deployment tools that make advanced capabilities accessible beyond specialist communities. Projects centred on RAG ⁵³ , vector databases and data integration indicate a strong trend toward data-centric AI , where models are connected to enterprise knowledge and real-world information sources. Finally, advances in efficient inference, fine-tuning, GPU acceleration, and edge deployment reflect efforts to make AI faster, cheaper, and more deployable across diverse computing environments , reducing barriers to adoption and supporting technological sovereignty.
Blockchain: unionlabs/union, FuelLabs/fuel-core Rust full node, OpenBB-finance/OpenBB	There is a shift toward scalable and interoperable blockchain infrastructures , including cross-chain protocols, modular architectures, and high-performance runtimes. Projects centred on zero-knowledge proofs, homomorphic encryption, and privacy-preserving cryptography indicate growing demand for secure and censorship-resistant digital systems. Projects increasingly support decentralised finance (DeFi), algorithmic trading, and digital asset management , expanding blockchain applications beyond cryptocurrencies. The rise of decentralised social media, autonomous agents, and self-hosted platforms reflects a broader movement toward user ownership, data sovereignty, and reduced reliance on centralised intermediaries.
Cloud-Edge-IoT: kubernetes, localstack, traefik	Shift toward cloud-native and sovereign digital infrastructures , characterised by container orchestration, infrastructure-as-code, serverless computing, distributed databases, and self-hosted platforms. At the same time, the growing importance of vector databases, AI gateways, and portable runtimes points to the convergence of AI and cloud technologies , enabling intelligent applications to operate seamlessly across cloud and edge environments.
Cybersecurity: Fatedier/frp, macrozheng/mall, sherlock-project/sherlock	Shift toward secure-by-default, self-hosted infrastructure , characterised by reverse proxies, NAT traversal tools, zero-config HTTPS, VPN/tunneling systems, and multi-protocol networking stacks that make local services globally accessible without traditional infrastructure overhead. Strong emphasis on continuous security automation , reflected in vulnerability scanners, secret detection, OSINT tooling, reverse engineering frameworks, and cloud/container security platforms that embed security directly into development workflows. Growing adoption of developer productivity and full-stack boilerplate ecosystems , including opinionated backend systems, RBAC-heavy admin platforms, and rapid enterprise application scaffolding. Parallel emergence of AI-native and data-centric infrastructure , particularly modular RAG frameworks, vector-store-agnostic pipelines, and LLM integration layers that abstract intelligence into application backends. Finally, increasing focus on unified observability and data abstraction layers , where cloud storage, local filesystems, and system telemetry are converged into queryable, portable, and cross-platform interfaces.

⁵³ "Retrieval augmented generation, or RAG, is an architecture for optimising the performance of an artificial intelligence (AI) model by connecting it with external knowledge bases. RAG helps large language models (LLMs) deliver more relevant responses at a higher quality." Source: <https://www.ibm.com/think/topics/retrieval-augmented-generation>

Most relevant repositories per technology	Innovation trends that the top 50 repositories reveal
Data analytics and data sharing: supabase, mall, strapi	Shift toward developer-first full-stack platforms that combine databases, APIs, CMS, and admin tools into unified backends (often Postgres-centric). At the same time, rapid growth in open-source SaaS replacements reflects a move toward self-hosted analytics, customer relationship management, project management, and deployment infrastructure . A parallel trend is the rise of modern data engineering stacks, built around distributed databases, streaming pipelines, and real-time analytics systems . Increasingly, these are converging with AI-native infrastructure, where RAG pipelines, LLM-ready data tools, and agent frameworks are embedded directly into backend systems.
HPC: vercel/next.js, tauri-apps, pytorch	Shift toward full-stack development frameworks that unify frontend and backend (React, FastAPI, Node/TypeScript) into production-ready systems. Strong growth in AI-native infrastructure , including LLM inference engines, distributed training, and GPU-accelerated libraries for scalable model deployment. Parallel expansion of cloud-native microservices ecosystems , built around API gateways, orchestration tools, and configuration platforms for distributed systems. At the same time, systems-level performance tooling in Rust, Go, and similar languages is enabling faster, safer infrastructure from VMs to developer tools.
Microelectronics: exelban/stats, arendst/Tasmota, Tencent/ncnn	The most popular repositories reflect the growing convergence of open hardware ecosystems, edge AI, and embedded systems . High-performance AI inference frameworks optimised for mobile devices, microcontrollers, GPUs, and specialised accelerators reflect a strong shift toward deploying intelligence directly on edge hardware rather than in the cloud. Open-source embedded operating systems, real-time kernels, and developer frameworks are enabling more secure, scalable, and interoperable connected devices. Another major trend is the rise of specialised, low-power, high-performance chips and integrated systems that enable immersive, natural, and privacy-preserving human-machine interaction directly at the edge. At the same time, advances in hardware monitoring, energy optimisation, and resource management highlight increasing attention to efficiency, sustainability, and performance across heterogeneous computing architectures.
NGI and XR	Innovation trends evident from the top repositories include a decentralised, immersive, and AI-native digital ecosystem . Decentralised social networks, peer-to-peer protocols, blockchain infrastructure, and privacy-preserving technologies are reshaping how online communities, data sharing, and digital services are organized. At the same time, advances in computer vision and generative AI , including object detection, pose estimation, and neural graphics (e.g., NeRFs), are enabling richer interactive experiences. The rapid growth of XR technologies, WebXR, WebGPU, and real-time 3D engines is accelerating the development of immersive virtual and augmented environments, while AI training frameworks increasingly leverage game engines and simulations.

Most relevant repositories per technology	Innovation trends that the top 50 repositories reveal
Photonics: flipperzero-firmware, cadquery, f3d	The key innovation trends are driven by the convergence of advanced sensing, digital fabrication, and autonomous systems . LiDAR technologies dominate, with strong innovation in SLAM, odometry, sensor fusion, 3D localisation, and point-cloud perception technologies ⁵⁴ for robotics, drones, and autonomous vehicles. Multi-modal AI approaches that combine cameras, LiDAR, radar, and inertial sensors are becoming standard, enabling richer environmental understanding and more robust autonomy. At the same time, open-source tools for digital manufacturing and maker technologies, including CAD scripting, CNC machining, laser cutting, remote-control firmware, and embedded systems are democratising hardware development. Another important trend is the integration of 3D machine learning, photogrammetry, and computer vision into industrial, agricultural, and urban applications , while lightweight, computationally efficient algorithms increasingly target deployment on resource-constrained edge devices.
Quantum: qiskit, deepchem, Cirq	The key innovation trends highlight the rapid maturation of quantum computing as an open, software-driven ecosystem. Development is increasingly centred on interoperable frameworks such as Qiskit, PennyLane, Q#, and ProjectQ, enabling researchers and developers to design, simulate, and deploy quantum algorithms across different hardware platforms. A major trend is the convergence of quantum computing with AI and machine learning, particularly for applications in drug discovery, materials science, chemistry, and physics . Hybrid quantum-classical workflows and high-performance simulators are becoming essential to bridge current hardware limitations, while advances in tensor networks and quantum chemistry software expand practical use cases. The trends evident by the many repositories related to post-quantum cryptography reflects preparations for future cybersecurity challenges posed by quantum technologies.
Robotics: openpilot, EasySpider, ItChat	The key innovation trends visible from open source development centre on the rapid convergence of robotics, AI, and automation into integrated, end-to-end platforms . A major focus is on autonomous systems (especially self-driving and embodied AI), supported by advanced simulation environments for safe training and testing . Reinforcement learning and robot learning frameworks are expanding quickly, enabling scalable decision-making and control across physical and virtual agents. At the same time, perception technologies such as computer vision, LiDAR processing, and SLAM remain foundational for spatial intelligence. Another clear trend is the growth of robotic process automation and web-based automation tools, increasingly enhanced with large language models for natural language control.

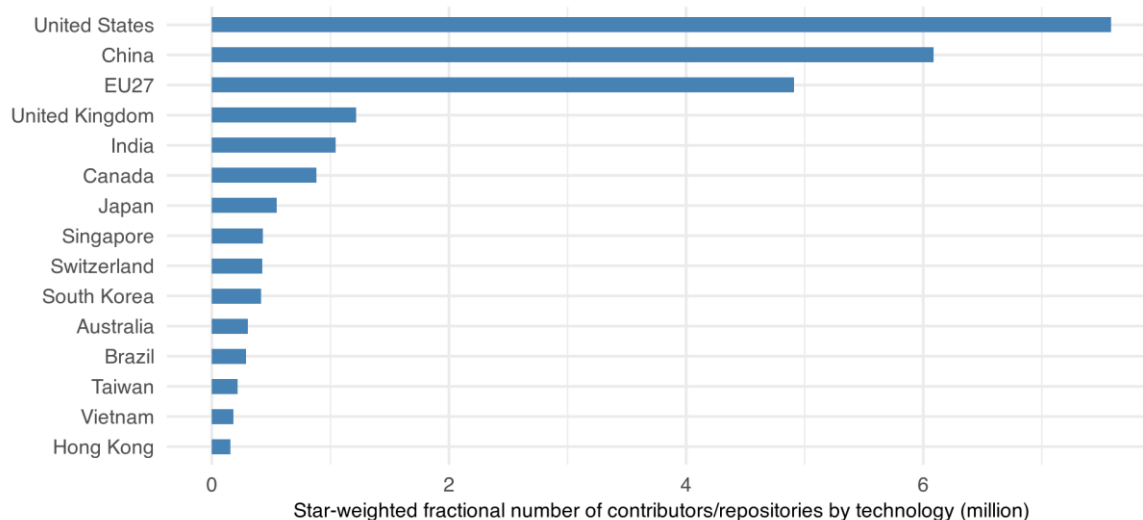
Source: Technopolis Group based on GitHub (2025) Note: Popularity is measured by the number of stars as users typically use them to bookmark repositories, they find interesting or useful.

When it comes to trends across geographies, the EU27 lags behind the US and China in the development of open software code, as recorded in the repositories created on GitHub. **Within the EU, Germany, France and the Netherlands are the countries with the highest number of contributors** to code repositories. Similarly, the 2026 Stanford AI Index report⁵⁵ noted that US-based AI projects still attract the most engagement, but the growth of open-source AI is broadening global participation. **Contributions from regions outside Europe are now increasing faster than in Europe and are approaching US activity levels on GitHub**, fostering a richer ecosystem of multilingual models and evaluation benchmarks. In this context, engagement in open-source communities is emerging as an important measure of whether countries are shaping the future of AI as producers and innovators, rather than primarily adopting technologies developed elsewhere.

⁵⁴ Technologies that enable autonomous systems to determine their position, build maps, and integrate data

⁵⁵ <https://hai.stanford.edu/ai-index/2026-ai-index-report>

Figure 10 Top 15 countries by number of contributors/repositories for artificial intelligence with EU countries aggregated



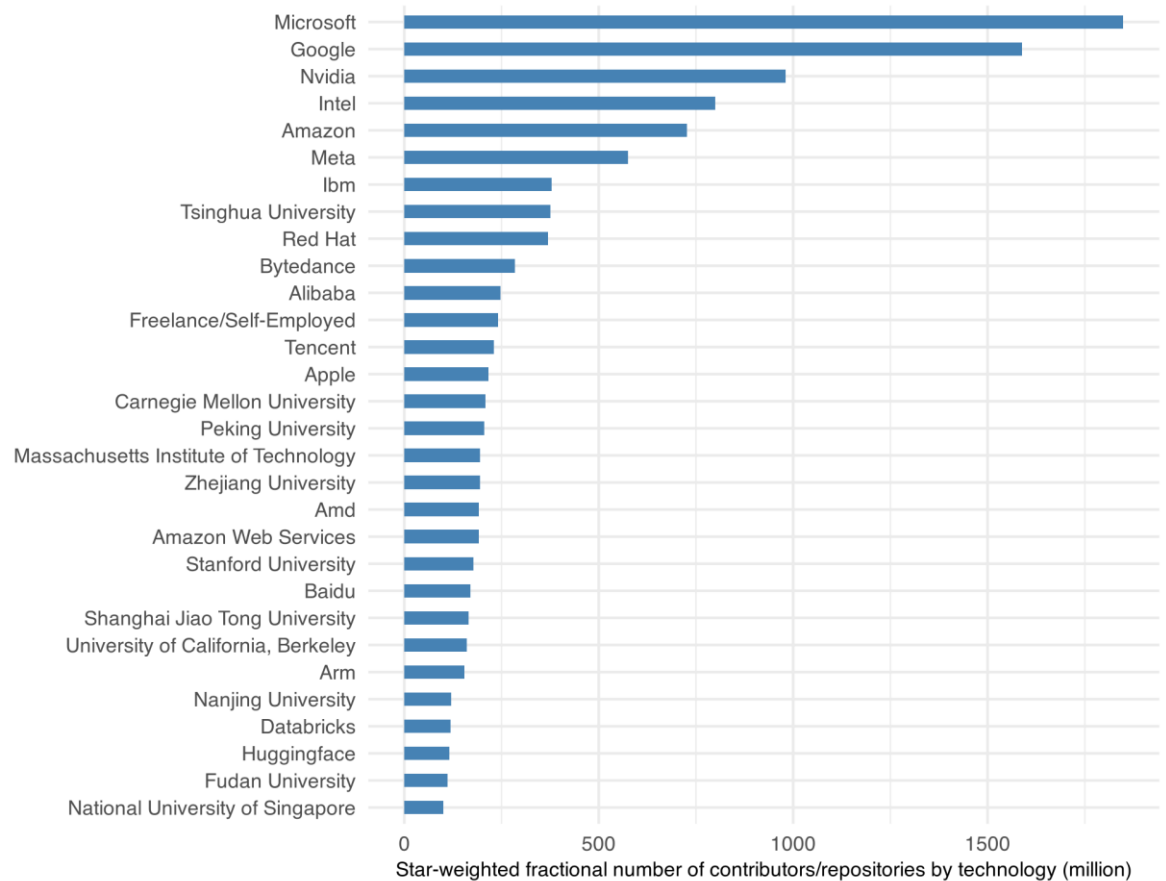
Source: Technopolis Group based on GitHub (2025)

As an example, the list of 30 most important companies contributing to the repository in AI has mainly actors from the US and some from China and Singapore (see Figure below). Large US technology firms dominate the landscape, with Microsoft leading by a substantial margin, followed by Google, Nvidia, Intel, Amazon, and Meta. This underscores the pivotal role of hyperscalers and semiconductor companies in shaping global innovation through open-source development. The distribution also reveals the growing importance of Chinese technology companies and universities, including ByteDance, Alibaba, Tencent, Baidu, Tsinghua University, Peking University, Zhejiang University, and Shanghai Jiao Tong University, demonstrating China's increasing influence in frontier digital technologies and research-driven software ecosystems. At the same time, leading academic institutions such as MIT, Stanford, Carnegie Mellon, UC Berkeley, and the National University of Singapore remain key contributors, illustrating the **close interaction between scientific research and industrial innovation**.

A striking feature is the relative absence of European actors. Apart from Arm (UK), Huggingface (that originates in France) and Red Hat (whose parent company is IBM, an American firm), **there are virtually no major European companies or universities among the leading contributors to globally visible open-source ecosystems. These companies are specialised technology firms**, whose open-source activities help drive advances in cloud infrastructure, AI, semiconductors, and developer tools.

There is also a large share of **freelance and self-employed contributors**, which hides further European contributors and highlights the importance of distributed and community-led innovation alongside corporate actors.

Figure 11 Top 30 companies by number of contributors/repositories for AI



Source: Technopolis Group based on GitHub (2025)

1.2.4 National divide in technology development

The EU's research and innovation ecosystem is marked by a persistent innovation divide with leaders predominantly located in Northern and Western Europe and moderate/emerging innovators in Southern and Eastern Europe, a pattern observed between 2000 and 2022 as highlighted by the Science, Research and Innovation performance of the EU 2024 report⁵⁶. In terms of geographical coverage, the Figures below illustrate the evolution of the total number of publications and the total patent applications per technology area in the EU-27 between 2014 and 2022.

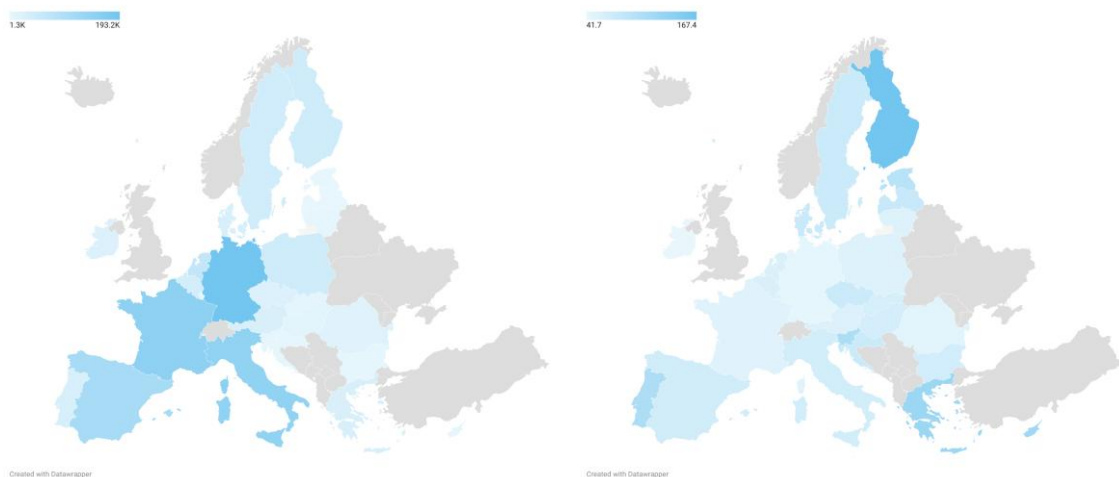
The analysis of national-level publication patterns reveals a **stable core of EU27 countries consistently leading absolute scientific output across digital technology areas.**

⁵⁶ https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/science-research-and-innovation-performance-eu-2024-report_en

Germany, France, the Netherlands, Spain, and Italy emerge as the top five contributors throughout the period 2014–2023 (see map below).

- Among these, Germany holds the leading position in terms of total digital publication volume and demonstrates strong presence across the areas of Photonics, Microelectronics, and Cybersecurity.
- Notably, Italy distinguishes itself as the leading EU27 contributor in terms of publication output in Artificial Intelligence, Robotics, Cloud-Edge-IoT, and Blockchain.

Figure 12 Number of scientific publications in all digital technologies – concentration within the EU in absolute numbers (left) and normalised by the size of the country (right)



Source: OPIX based on OPENAIRE

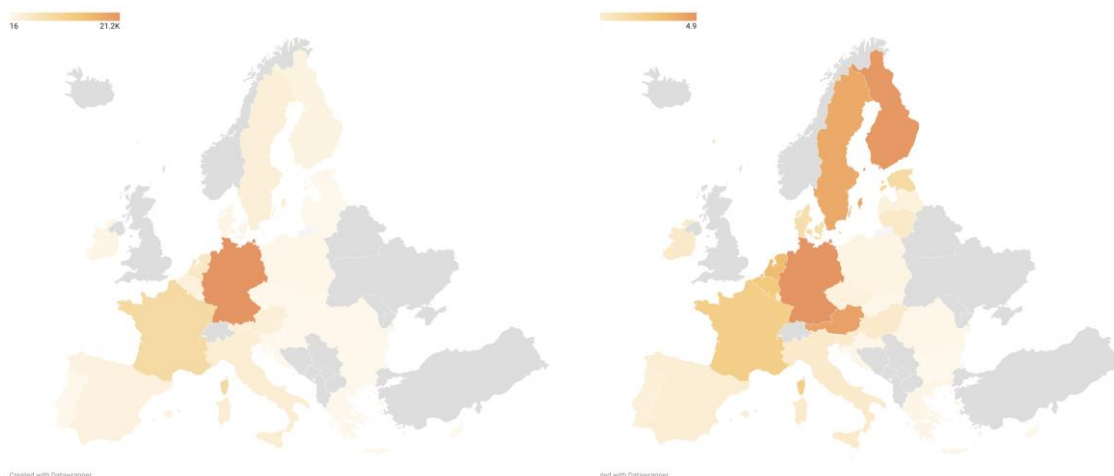
In general, the patent trends are aligned with the size and innovation performance of the different EU countries, with **Germany leading all digital technology fields, followed by France in terms of absolute number of patenting** (see map below).

The countries in third to fifth positions however differ in the various technology fields, with some specialisation patterns that can be identified. Some remarkable findings include:

- Finland emerges as the main EU quantum specialisation hotspot in relative terms, combining a relatively high volume of quantum patents with a strong concentration of quantum activity within its overall patent portfolio.
- The Netherlands, by contrast, records high absolute quantum patenting but a lower degree of specialisation, reflecting its broad-based innovation profile across multiple digital technologies such as microelectronics, photonics and AI.
- Sweden stands out in Robotics and Artificial Intelligence, with a strong concentration of patent activity in these fields. This is complemented by substantial patenting in Cybersecurity.
- Estonia shows a marked specialisation in Cybersecurity, with cybersecurity-related patents accounting for a significant share of its overall digital patent portfolio despite lower absolute volumes.
- Spain's patenting activity is strong in the areas of Robotics and High-performance computing, with a particularly high concentration of HPC patents compared to its overall digital patenting activity.
- Ireland displays a notable specialisation in Blockchain technologies, standing out among Member States for the relative importance of blockchain patents in its digital innovation profile.
- Denmark shows a strong relative positioning in Robotics, with robotics-related patents representing a significant share of its overall digital patenting.
- Belgium and Austria exhibit diversified but above-average activity in enabling digital technologies, including microelectronics, HPC and data analytics.
- In microelectronics and photonics, patenting activity remains highly concentrated, with Germany and France clearly dominating in absolute terms.

The patent distribution also reflects the European digital and innovation divide and should be complemented with reflections on the adoption rates of digital technologies. This is less the case in very niche areas where the EU market is very concentrated (e.g., microelectronics, photonics).

Figure 13 Number of patent applications in all digital technologies – concentration within the EU absolute numbers (left) and corrected by the size of the country (right)



Source: Fraunhofer based on Patstat

1.3 Key R&I actors driving the development of digital technologies

The successful development of digital technologies needs a dynamic and interconnected research and innovation ecosystem that brings together a diverse range of actors such as higher education, research organisations, startups, scaleups, SMEs, large technology firms, and public institutions each playing a distinct role in driving scientific progress and technological generation. Effective collaboration among these actors is essential to ensure that breakthroughs in research translate into competitive digital solutions.

1.3.1 Universities and research and technology organisations

Technical universities and research and technology organisations (RTOs) are at the core of Europe's digital research and innovation ecosystem. They generate new knowledge, develop breakthrough digital technologies, provide the scientific and engineering expertise needed to address complex technological challenges, and translate research into industrial and societal applications. They underpin Europe's capacity to innovate in strategic digital domains, foster collaboration with industry and public authorities, and train the highly skilled talent essential for maintaining the EU's technological competitiveness. In this study, their performance and specialisation have been mapped based on existing studies and university rankings in order to provide insights into the strengths and evolution of Europe's digital R&I landscape.

The 2026 Times Higher Education World University Rankings in Computer Science⁵⁷ highlight Europe's strong international competitiveness in digital research. In the EU, the Technical University of Munich (TUM) is the highest-ranked institution, followed by leading technical and comprehensive universities such as KU Leuven, Delft University of Technology, Université Paris-Saclay, Paris Sciences et Lettres, and KTH Royal Institute of Technology. Spain is represented by Universitat Politècnica de Catalunya, which continues to strengthen its international standing in computer science. These institutions combine strong research performance with close links to industry, making them key contributors to Europe's digital innovation capacity. Institutions such as TUM, Delft, KTH and UPC perform particularly well because of their engineering-oriented research, industrial collaboration, and strengths in areas including Artificial Intelligence, software engineering, cybersecurity and digital systems.

The rankings suggest that the EU possesses a strong core of world-class digital research institutions, but excellence remains concentrated in a relatively small number of universities and countries. Maintaining global competitiveness will require broadening excellence across the European Research Area while strengthening collaboration between leading universities, research and technology organisations, industry and start-ups to accelerate the development and deployment of strategic digital technologies.

Regarding research and technology centres, the EU maintains a strong and broad university and research institute base across all twelve technology areas examined. Europe is home to 30% of the world's top technology universities and research centres and produces twice as many science and engineering graduates as the US⁵⁸. Moreover, based on the patent analysis conducted in this study, CEA (an RTO, based in France), Fraunhofer (an RTO, based in Germany) and CNRS (research centre, based in France) and IMEC (an RTO, based in Belgium) are among the leading top-30 EU27-headquartered patent applicants, across all analysed digital technologies. Benchmarked globally, only CEA remains among top-30 global leading patent applicants (the only research institute among private companies). Another of the EU's distinctive advantages is its network of research and technology organisations (RTOs) such as Fraunhofer, CEA, TNO, VTT, IMEC, RISE,

⁵⁷ <https://www.timeshighereducation.com/world-university-rankings/2026/subject-ranking/computer-science>

⁵⁸ Retrieved from: <https://content.dealroom.co/uploaded/2026/03/The-European-Deep-Tech-Report-2026.pdf>

AIT, Tecnalia. These RTOs bridge mid-to-high TRL research with industrial application across all twelve technology domains.

Table 5 Overview of key RTOs and universities relevant for technology areas

Technology area	Academia	RTOs	International benchmarking
Advanced Connectivity	Overview: Strong telecom and 5G/6G engineering universities with deep participation in EU connectivity programmes and standards research. Nordic and German institutions are especially visible in wireless systems and industrial communications. Examples of leading institutions: University of Oulu, KTH, KU Leuven, TU Delft, Télécom Paris/IP Paris, DTU, Aalborg, TUM, TU Dresden.	Overview: Large applied-research actors operating pilots, testbeds, semiconductor integration, and telecom experimentation platforms linking academia with telecom vendors and industry. Examples of leading institutions: CEA-Leti, Fraunhofer, TNO, IMEC, EURECOM, AIT.	Europe is globally strong in pre-standardisation telecom research and 6G collaboration, especially compared with the US university ecosystem. Main competitors include MIT, Stanford University, KAIST, Tsinghua University, and University of Tokyo. Comparable RTOs include NIST, NICT, and Electronics and Telecommunications Research Institute
AI	Overview: Europe has globally recognised AI research universities with strong publication output and interdisciplinary AI ecosystems. Examples of leading institutions: TUM, TU Delft, KU Leuven, University of Copenhagen, Sorbonne Université, Bologna, Amsterdam, Padua, Sapienza, Paris-Saclay, Aalto University of Copenhagen and TUM are among Europe's top AI publishers.	Overview: Large national AI research infrastructures combining fundamental and applied AI, often coordinating national strategies and industrial partnerships. Examples of leading institutions: Max Planck Society, Helmholtz Association, DFKI, CNRS, CEA, Inria, National Research Council Italy.	Europe has strong research institutes focused on AI research. Main competitors include MIT, Stanford University, Carnegie Mellon University, University of California, Berkeley, Tsinghua University, and Peking University. Competing labs include Google DeepMind, OpenAI, Microsoft Research, and Chinese Academy of Sciences.
Blockchain	Overview: Medium-sized but highly specialised blockchain and cryptography research hubs with strong interdisciplinary orientation across distributed systems, finance, and cybersecurity. Examples of leading institutions: ETH Zurich, EPFL, University of Zurich, Aarhus University.	Overview: Mostly EU-funded applied consortia focused on trusted digital infrastructure, governance, and industry pilots. Examples of leading institutions: European Blockchain Centre, UZH Blockchain Center, Austrian Blockchain Centre, European Digital Innovation Hubs.	Europe performs strongly in cryptography and digital trust research, especially in the DACH region. Main academic competitors include MIT, University of California, Berkeley, National University of Singapore, and Tsinghua University. Comparable research institutes include IBM Research. Switzerland remains globally competitive due to the Crypto Valley ecosystem.

Technology area	Academia	RTOs	International benchmarking
Cloud, IoT & Edge	Overview: Broad EU-wide academic network contributing to distributed systems, edge computing, industrial IoT, and skills development. Examples of leading institutions: Aarhus University, Politecnico di Milano, TU Dresden, Universitat Politècnica de València, NTUA Athens, EURECOM, Aalborg, University of Oulu.	Overview: Large public applied-research organisations focused on industrial testbeds, prototyping, interoperability, and digital infrastructure deployment. Examples of leading institutions: Fraunhofer, CEA, RISE, Tecnalia.	Europe has strong industrial IoT and edge-computing research capabilities but remains dependent on US hyperscalers (AWS, Microsoft, Google) for cloud platform leadership. Europe's positioning is strongest in industrial and sovereign cloud R&I. Main global competitors include Carnegie Mellon University, University of California, Berkeley, Tsinghua University, and National University of Singapore.
Cybersecurity	Overview: Universities typically host specialised cybersecurity labs focused on cryptography, secure systems, privacy, and cyber-physical security. Examples of leading institutions: KU Leuven, University of Amsterdam, TU Delft, TUM, Bologna, Politecnico di Torino, Aarhus, KTH.	Overview: Large national RTOs operating cybersecurity programmes, testing facilities, and industry-facing cyber innovation labs. Examples of leading institutions: Fraunhofer, INRIA, VTT, TNO, AIT.	Europe is highly competitive in privacy, cryptography, and regulation-driven cybersecurity research, but commercial cybersecurity scale is still dominated by US firms. Western and Northern Europe host the strongest concentration of cyber R&D capabilities.
Data	Overview: Broad academic coverage across data science, data engineering, governance, and digital infrastructures. Examples of leading institutions: TU Darmstadt, Chalmers, University of Vienna, Coimbra, Ghent, TU Eindhoven, University of Galway.	Overview: Large publicly funded infrastructures bridging research, HPC, data services, and industrial collaboration. Examples of leading institutions: Fraunhofer, Inria, AIT, DARIAH, PSNC, Cyfronet, BSC, CEA, GARR, CESNET, IMEC, VTT, TNO.	Europe is globally strong in data governance, federated infrastructures, and open science, especially through GDPR-driven frameworks and research infrastructures. However, hyperscale data platforms and cloud ecosystems remain dominated by US and Chinese companies.

Technology area	Academia	RTOs	International benchmarking
HPC	Overview: these institutions support advanced computational science and exascale research. Examples of leading institutions: Major academic and public HPC ecosystems linked to centres such as CINECA, BSC, CSC, SURF, HLRS, and universities connected to EuroHPC infrastructures	Overview: Large-scale national and European infrastructures operating Tier-0/Tier-1 supercomputers and supporting science and industrial applications Examples of leading institutions: CEA, FZJ/Jülich, GENCI, GSC, PRACE, EuroHPC-linked centres.	Europe is globally competitive in public HPC infrastructure through EuroHPC and flagship systems such as LUMI, Leonardo, and MareNostrum5. However, semiconductor and GPU dependence on US suppliers remains a strategic weakness.
Microelectronics	Overview: Major engineering universities with semiconductor design, nanoelectronics, and clean-room capabilities training large technical talent pools. Examples of leading institutions: TU Delft, KIT, Politecnico di Milano, Aalto, TU Dresden, KTH, TU Wien, IST Lisbon.	Overview: Highly specialised applied-research organisations operating pilot fabs and advanced semiconductor research facilities. IMEC is one of the world's leading nanoelectronics R&D centres. Examples of leading institutions: IMEC, CEA-Leti, Fraunhofer institutes, Tyndall, AIT, FBK, IHP, LIST.	Europe is globally competitive in semiconductor R&D and equipment ecosystems (ASML, IMEC, CEA-Leti), especially in specialised chips and lithography. However, it lacks large-scale advanced logic manufacturing capacity comparable to Taiwan, South Korea, and the US.
NGI (Next Generation Internet / XR)	Overview: Universities with strong Horizon Europe participation in XR, immersive internet, and digital sovereignty projects. Examples of leading institutions: KU Leuven, TU Delft, Trinity College Dublin, ParisTech, TUM.	Overview: Mid-to-high TRL institutes bridging immersive technologies and industrial deployment through EU collaborative projects. Examples of leading institutions: Fraunhofer, B&Com, INRIA, FZI, TNO, VTT.	Europe is strong in collaborative XR and human-centric internet research but trails US and Asian firms in platform commercialisation and consumer ecosystems. The EU's comparative advantage lies in open and trustworthy digital infrastructure initiatives.
Photonics	Overview: Universities with dedicated photonics institutes and strong optics/photonics engineering capabilities. Examples of leading institutions: Vrije Universiteit Brussel (B-PHOT), TU Delft, RWTH Aachen, Friedrich Schiller University Jena, Politecnico di Milano.	Overview: Large public or semi-public photonics centres spanning lasers, integrated photonics, telecom optics, and sensing. Examples of leading institutions: Fraunhofer ILT/IOF/HHI, IMEC, CEA-Leti, ICFO, Leibniz IPHT, VTT.	Europe is one of the world leaders in photonics research and industrial applications, especially in Germany, Belgium, and Spain. Strong integration with industrial manufacturing gives Europe a competitive advantage over many regions.

Technology area	Academia	RTOs	International benchmarking
Quantum	Overview: Strong concentration of world-class quantum physics and computing research groups producing much of Europe's quantum talent. Examples of leading institutions: ETH Zurich, University of Copenhagen, TU Delft, TU Munich, Innsbruck, IQOQI Vienna, DTU, ICFO, Paris-Saclay	Overview: Medium-to-large applied-research organisations translating quantum science into prototypes and industrial validation. Examples of leading institutions: DLR, Fraunhofer, CNRS, CEA, TNO, Observatoire de Paris.	Europe is globally competitive in quantum science and talent generation, particularly in Germany, the Netherlands, France, Austria, and Switzerland. The US still leads in private-sector quantum commercialisation and venture-backed scaling.
Robotics	Overview: Major robotics universities with strong labs spanning industrial, medical, autonomous, and cognitive robotics. Examples of leading institutions: TU Munich, KIT, Sant'Anna, KTH, TU Delft, Aalborg, Universidad de Sevilla, KU Leuven, University of Patras.	Examples of leading institutions: Fraunhofer, DFKI, DLR, TNO, VTT, INRIA, CEA List, IIT, Tecnalia, LAAS-CNRS. Overview: Large applied-research organisations with extensive industrial collaboration and robotics demonstrators.	Europe is globally strong in industrial robotics, automation, and collaborative robotics research, especially in Germany and Italy. Main competitors include Carnegie Mellon University, Massachusetts Institute of Technology, Stanford University, University of Tokyo, and KAIST. Industrial and applied robotics leadership is heavily concentrated in Japanese, Korean, Chinese, and US ecosystems such as Boston Dynamics, Fanuc, and ABB.

Source: Technopolis Group based on desk research

1.3.2 Tech companies driving advanced digital R&I

The mapping of EU tech companies shows that only about 4.75% of ICT firms in the EU actively develop advanced digital technologies, with activity concentrated in AI and Cybersecurity, followed by areas such as NGI, Data Analytics, and Advanced Connectivity. The ecosystem is dominated by micro and small firms, especially in AI, where 85% of companies have fewer than 50 employees, while more hardware-intensive fields such as Photonics, Microelectronics, and Quantum feature a stronger presence of larger firms.

Tech companies that develop digital technologies drive R&I and play a central role in shaping frontier research, technological progress, and societal outcomes. The information and communication services sector comprised approximately 1.27 million companies in the EU in 2023⁵⁹ as measured by Eurostat but there are no official statistics on how many companies develop specific advanced digital technologies. To this end, this study carried out a large-scale company mapping exercise by text mining information about more than 1 million companies in Europe and identifying those that develop digital technologies. This mapping of EU-27 companies developing digital technologies across the twelve priority

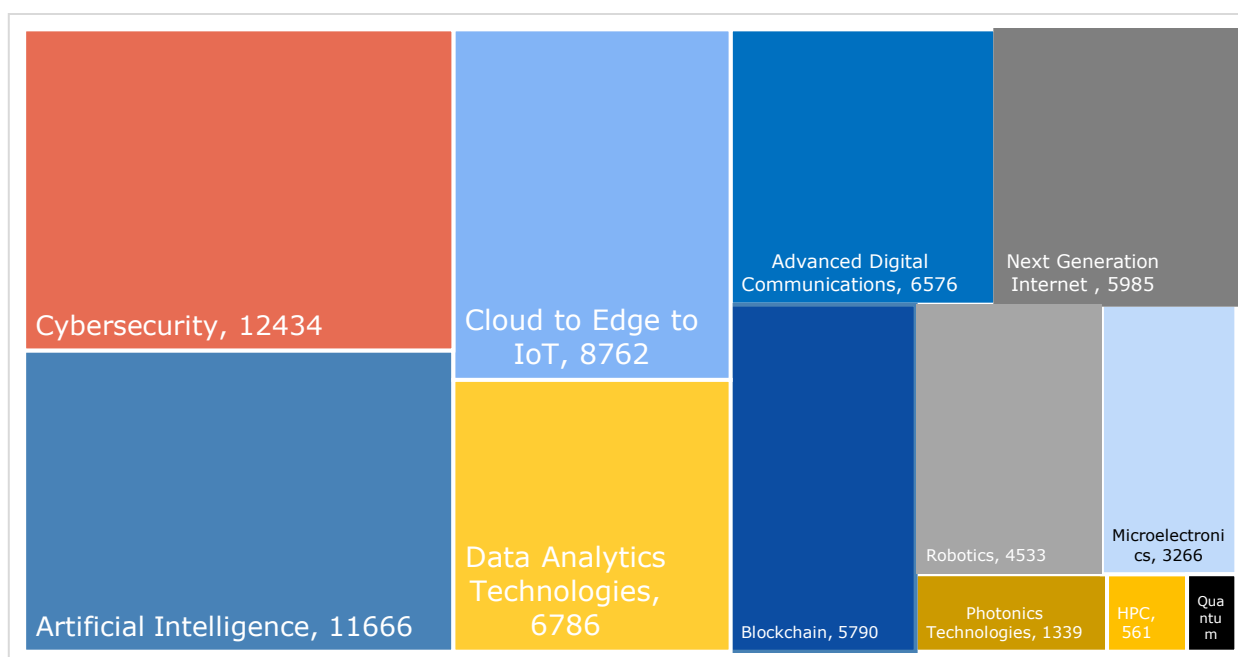
⁵⁹ Eurostat, Structural Business Statistics. Enterprises by detailed NACE Rev. 2 activity and special aggregates (sbs_ovw_act).

areas in scope of this study focused on corporate actors (start-ups, scale-ups, SMEs and large firms) that are actively building products, core software/hardware, or conducting applied R&D⁶⁰.

In total **60,411 EU tech companies have been identified that develop any of the 12 digital technologies in scope**, equivalent to **~4.75%** of the EU ICT business population. From cloud computing to AI platforms, cybersecurity, and connectivity, these companies develop innovations that underpin the economy and society.

These tech companies are mainly focused on Cybersecurity and Artificial Intelligence, accounting for 18.3% (12,434 entries) and 17.1% (11,666) of identified company technology records, respectively. A second tier follows with Next Generation Internet (12.9%; 8,762), Data Analytics (10.0%; 6,786) and Advanced Digital Communications (9.7%; 6,576), alongside Cloud-Edge-IoT (8.8%; 5,985) and Blockchain (8.5%; 5,790). The remaining areas are smaller in relative terms—Robotics (6.7%; 4,533), Microelectronics (4.8%; 3,266), Photonics (2.0%; 1,339), HPC (0.8%; 561) and Quantum (0.5%; 345). These shares reflect company-technology assignments (firms can appear in more than one area), which is why the sum of individual areas exceeds the unique-company count. The prominence of AI companies within the ICT sector is also reflected in the Eurostat ICT usage survey, which found that 23% of firms engaged in computer programming, consultancy, and information service activities developed AI technologies using their own employees in 2024⁶¹.

Figure 14 Distribution of mapped companies across technology areas in the EU-27



Source: Technopolis Group based on GlassAI

The size of companies developing advanced digital technologies within the ICT sector is heavily skewed toward micro and small companies (1–50 employees) in most technology areas. In Next Generation Internet (NGI), 94% of mapped firms are ≤50 employees (67% micro; 27% small), with only 2% at ≥201 employees. A similar micro-dominant pattern appears in Blockchain (92% ≤50), Data Analytics (89%), and Artificial Intelligence (85%).

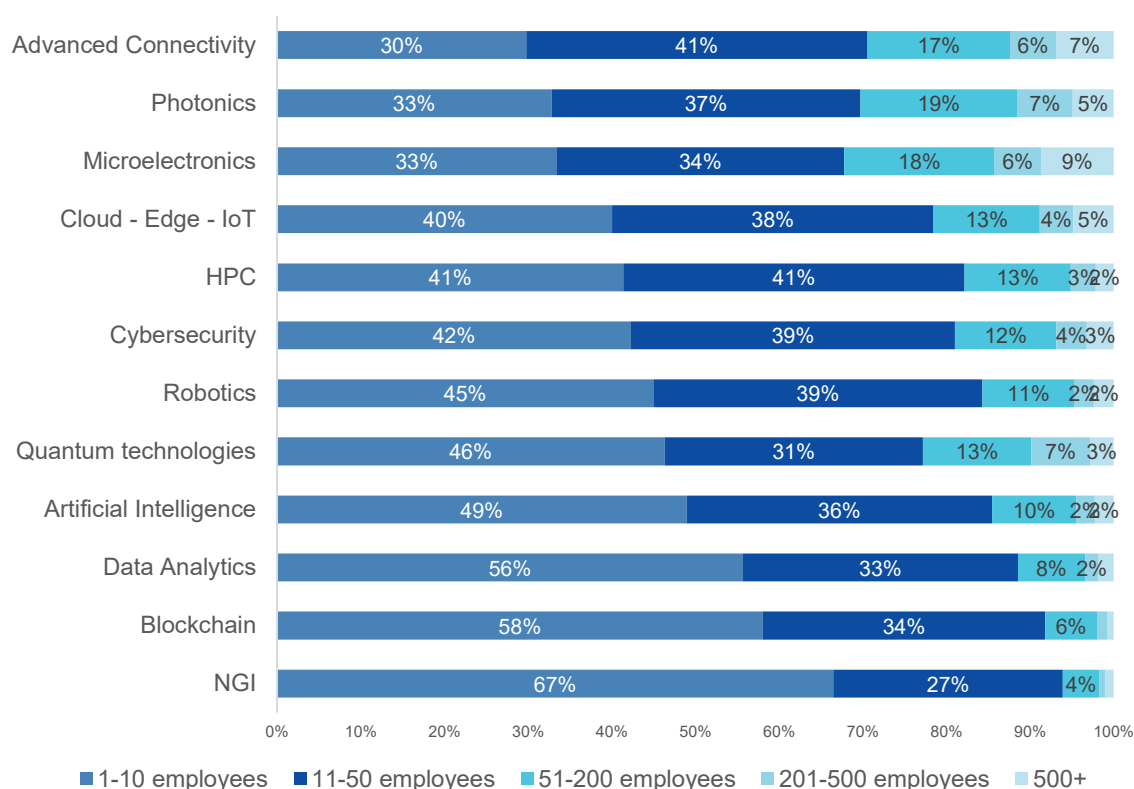
⁶⁰ Technopolis Group and Glass.ai conducted a web-scale review crawling each firm's full public website (including subpages) to capture product pages, technical documentation, hiring signals, and R&D updates. An NLP pipeline then classified firms into technology areas and clusters/sub-clusters, identified developer roles, inferred country presence within the EU-27, and normalised attributes such as employee bands. Each inclusion is evidence-based, with text snippets and source URLs retained for traceability.

⁶¹ https://ec.europa.eu/eurostat/databrowser/view/isoc_eb_ain2_custom_19129017/default/table

By contrast, areas with heavier hardware, infrastructure or capital intensity show a thicker middle and larger-firm tail. Photonics (19% in 51–200; 12% ≥ 201), Microelectronics (18% in 51–200; 15% ≥ 201) and Advanced Connectivity (17% in 51–200; 13% ≥ 201) exhibit the strongest presence of mid-sized and large firms. Quantum technologies also show a noticeable shift upward (13% in 51–200; 10% ≥ 201). Cloud–Edge–IoT sits between these patterns (78% ≤ 50 ; 9% ≥ 201), while HPC is balanced at the small end (41% micro / 41% small).

In particular, **AI firms are predominantly micro and small: 49% have 1–10 employees and 36% have 11–50, with only 10% in 51–200 and 4% at ≥ 201** . In other words, 85% of mapped AI companies are ≤ 50 employees and roughly 1 in 25 are large (≥ 201). This “thin middle and tail” contrasts with deeper hardware areas (e.g., photonics, microelectronics) where mid-sized and large firms are more common.

Figure 15 Employee-band composition by technology area



Source: Technopolis Group (2025) based on GlassAI

Many tech companies work across several sectors and provide solutions to a wide range of industrial applications, but some are focused on a set of industries. The heatmap below shows, for each technology area, the share of mapped firms operating in each sector.

Many technology areas are positioned as horizontal enablers: Advanced Digital Communications (82%), Cloud–Edge–IoT (80%), Cybersecurity (83%), Advanced and High-Performance Computing (77%), Data Analytics (74%), Artificial Intelligence (67%) and Quantum (51%).

The dominant sub-sectors are Information Technology & Services and Computer Software (e.g., Data Analytics 45% IT&S / 26% Software; AI 28%/28%; Cloud–Edge–IoT 35%/13%), while area-specific anchors appear where expected—Telecommunications & Wireless (51%) within Advanced Digital Communications, Computer Networking & Security (22%) within Cybersecurity, and Semiconductors & Electronic Systems (25%) within Microelectronics.

Alongside these horizontal patterns, some focus on specific applications: in Healthcare & Scientific, Quantum (34%), Photonics (25%) and HPC (16%) stand out (with Quantum notably concentrated in R&D & Scientific, 30%); in Industrial & Agriculture, Robotics (57%) dominates, followed by Photonics (25%) and Microelectronics (12%).

Consumer-facing hardware shows up in Microelectronics (29% Consumer Goods & Services, largely Consumer Electronics 24%) and Photonics (18%), while Professional Services captures integration and advisory activity in Data Analytics (11%), Cybersecurity (10%) and AI (8%). Finally, Blockchain & Distributed Ledger is mostly related to finance: about 26% of blockchain firms are primarily positioned in Financial Services. These companies cluster around payments and remittances, digital-asset issuance and tokenisation, post-trade and settlement rails, custody and key management, with smaller niches in insurance and fund administration.

Figure 16 Distribution of mapped companies across technology areas

	Consumer Goods & Services	Energy & Environmental	Financial Services	Healthcare & Scientific	Industrial & Agriculture	Leisure & Hospitality	Media & Arts	Professional Services	Real Estate & Construction	Supply Chain & Transport	Technology
Advanced Connectivity	4.2%	0.8%	0.4%	1.4%	4.5%	0.3%	1.9%	1.7%	1.0%	1.3%	82.4%
Artificial Intelligence	1.1%	1.3%	2.6%	9.7%	3.8%	2.3%	2.4%	8.2%	0.7%	1.2%	66.6%
Blockchain	1.4%	1.4%	25.7%	1.0%	0.5%	2.9%	2.0%	5.0%	1.0%	0.8%	58.3%
Cloud to Edge to IoT	3.2%	1.4%	0.8%	1.7%	3.6%	0.6%	2.5%	4.1%	1.2%	1.3%	79.7%
Cybersecurity	1.3%	0.2%	1.2%	0.8%	1.4%	0.2%	0.7%	10.2%	0.5%	0.4%	82.9%
Data Analytics	0.5%	1.3%	2.4%	5.4%	2.1%	1.4%	0.5%	11.4%	0.7%	0.9%	73.5%
HPC	0.6%	0.2%	0.8%	15.8%	4.0%	0.0%	0.2%	1.4%	0.0%	0.4%	76.6%
Microelectronics	28.6%	2.8%	0.3%	7.7%	11.8%	0.1%	0.4%	1.8%	0.7%	1.2%	44.7%
NGI	1.8%	0.2%	0.4%	3.2%	2.0%	9.8%	14.3%	12.8%	3.5%	0.4%	51.5%
Photonics	17.7%	2.9%	0.4%	24.5%	24.6%	0.2%	0.4%	2.6%	1.5%	0.5%	24.6%
Quantum technologies	4.8%	0.3%	1.8%	33.5%	3.9%	1.5%	0.9%	1.5%	0.3%	0.0%	51.4%
Robotics	4.8%	1.7%	0.2%	8.9%	57.2%	1.2%	1.3%	2.6%	2.3%	3.5%	16.3%

Source: Technopolis Group (2025) based on GlassAI

1.3.2 Digital technology start-ups on the EU R&I landscape

The EU digital startup ecosystem grew strongly between 2015 and 2025, with AI emerging as the fastest growing and most important technology area. Overall growth has slowed from the earlier boom, and shifted now toward scaling existing firms, however, still prevalent EU market fragmentation and limited late-stage funding restrict startups from scaling into global leaders.

Digital tech start-ups play a key role in research and innovation in the European economy by driving the next major wave of European technological progress. They also contribute to addressing major societal challenges such as climate change, healthcare, and energy, while also enabling the creation of entirely new markets⁶². In doing so, they act as a bridge between scientific discovery and real-world application, accelerating the development and deployment of viable technologies. Their activities also generate knowledge spillovers (such as transferring the new ideas and technologies to other firms and employees) that extend beyond individual firms, strengthening the broader economic and societal ecosystem⁶³.

⁶² Dealroom.co. (2025). The 2025 European Deep Tech Report, <https://content.dealroom.co/uploaded/2024/11/2025-European-Deep-Tech-Report.pdf>

⁶³ De la Tour, A., Portincaso, M., Gourevitch, A., Goedel, N., & Chaudhry, U. (2021). Deep tech: The great wave of innovation.

In 2025, the EU had **20,720 advanced digital technology startups⁶⁴** which collectively form the backbone of the EU's startup-driven R&I ecosystem. These firms play a foundational role in transforming cutting-edge digital technologies into commercially viable products and services, thereby strengthening Europe's capacity for technological development, competitiveness, and long-term innovation-led growth. Of these start-ups, 728 had scaled⁶⁵ up and remained active (3.5%), while 40 achieved unicorn status (0.2%), according to calculations conducted for this study that take into account the specific scope of each technology area.

Table 6 Number of digital tech startups, scaleups and unicorns in 2025

	Technology	Startups	Scaleups	Unicorns	Total
	Data analytics	6,272	260	7	6,539
	Cloud-Edge-IoT	5,205	220	9	5,434
	Artificial Intelligence	5,037	305	15	5,357
	Blockchain	2,738	121	3	2,862
	Cybersecurity	2,176	95	1	2,272
	NGI	1,360	51	0	1,411
	Robotics	944	58	2	1,004
	Advanced connectivity	582	27	7	616
	HPC	422	38	6	466
	Photonics	186	29	1	216
	Microelectronics	130	40	3	173
	Quantum technologies	94	24	2	120
	Total (removing deduplications)	19,952	728	40	20,720

Source: Technopolis Group (2025) based on Crunchbase

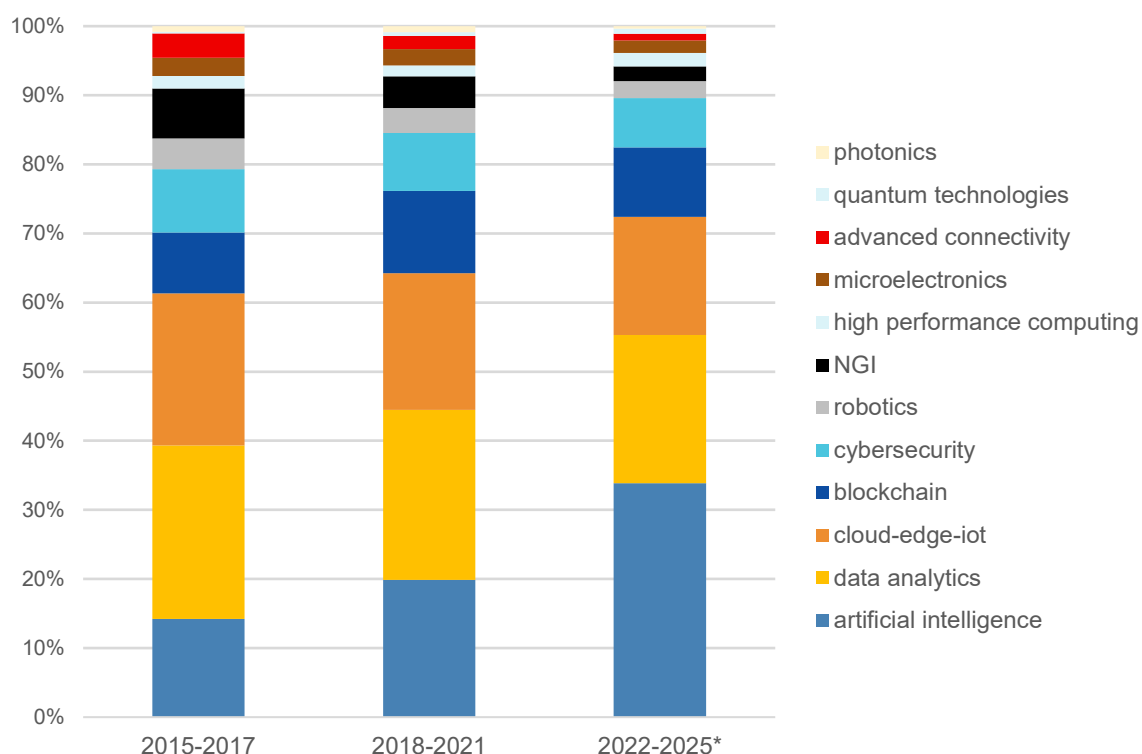
Across three-year intervals, the distribution of digital technology startups shows noticeable changes, with AI startups gaining the most prominence over time (see figure below). Between 2015 and 2025, the largest share of digital tech startups was concentrated in data analytics (6 539 firms), followed by Cloud-to-Edge-to-IoT (5 434) and AI (5 357).

However, when comparing periods, AI stands out as the fastest-growing category in relative importance, while Cloud-Edge-IoT shows a decline and data analytics remains broadly stable in its position as the dominant segment. This indicates a gradual shift in focus toward more AI-driven innovation within the digital startup landscape.

In contrast, more specialised and emerging technological domains remain comparatively small in scale. Areas such as Quantum technologies (120 startups), HPC (466), and Photonics (216) account for limited numbers of firms, reflecting their greater technological complexity and longer paths to commercialisation. Similarly, Microelectronics startups also represent a smaller share of the ecosystem. This is largely due to the sector's high capital requirements, extended development timelines, reliance on established industrial players, and the cautious investment behaviour it tends to attract.

⁶⁴ For this analysis, startups are defined as established after 2015, the analysis takes into account the 12 advanced digital technologies in the focus of this study excluding interoperability since related technologies are included under other fields such as data and cannot be captured via specialised startups in the field

⁶⁵ Scaleups are defined as young fast-growing companies 10 years old or younger that have received at least €10 million within the past 10 years.

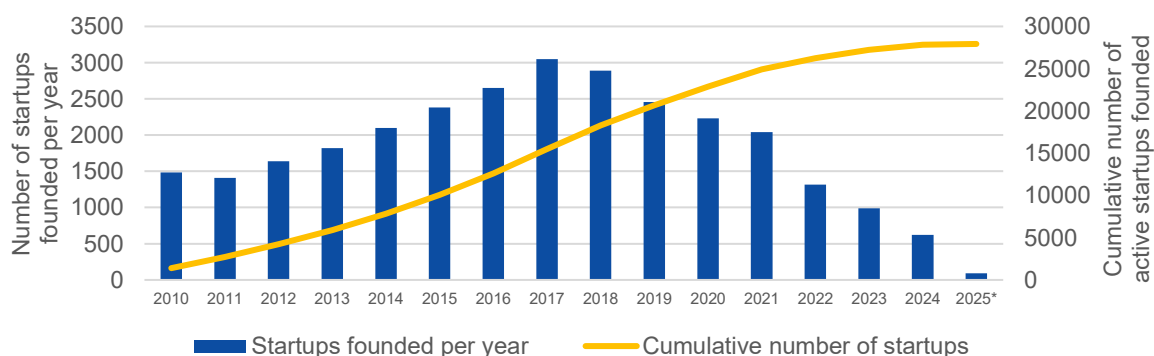
Figure 17 Distribution of digital tech startups per 3 year period in the EU

Source: Technopolis Group (2025) based on Crunchbase

The EU digital startup ecosystem shows strong overall performance, with a marked acceleration in startup formation over the past decade. Multiple indicators confirm this growth trajectory. By 2025, the stock of active digital technology startups in the EU was approximately three times larger than it was in 2015, reflecting sustained growth in entrepreneurial activity and the continued creation of new digital ventures over the past decade.

A similar trend is visible in the stock of active firms: in 2025, the number of active digital tech startups is estimated to be about twice as high as in 2018, based on a comparison between the Crunchbase dataset used in this study and earlier benchmarking analyses. This points to a clear long-term strengthening of the EU's digital innovation base.

At the same time, the pace of new firm creation slowed down. After a pronounced boom between 2010 and 2018, the annual rate of new digital tech startup formation has gradually slowed in subsequent years. This might suggest a transition from an early expansion phase—characterised by rapid market entry—to a more mature stage of ecosystem development, where growth is increasingly driven by consolidation, scaling, and survival of existing firms rather than continuous waves of new entrants.

Figure 18 Digital tech startups created over time in the EU27

Source: Technopolis Group (2025) based on Crunchbase

Scaling up remains one of the main structural challenges within the EU's digital innovation landscape, although recent years show signs of gradual improvement.

The figure below illustrates the distribution of digital technology scaleups across different technology areas in the EU27 in 2025, highlighting where firms are successfully transitioning from early-stage innovation to full market penetration.

The scaleup landscape is clearly concentrated in Artificial Intelligence and Data Analytics, which together account for the largest share of high-growth firms. This indicates that these areas are not only generating significant startup activity but are also more effective at converting innovation into scalable business models with measurable economic impact. As also confirmed by related other research⁶⁶, Artificial Intelligence is the main driver of scaling in Europe's digital and deep-tech ecosystem. It attracts the largest share of venture capital, generates the most high-growth scaleups, and accounts for roughly half of deep-tech VC investment, making it the central pathway for growth and expansion.

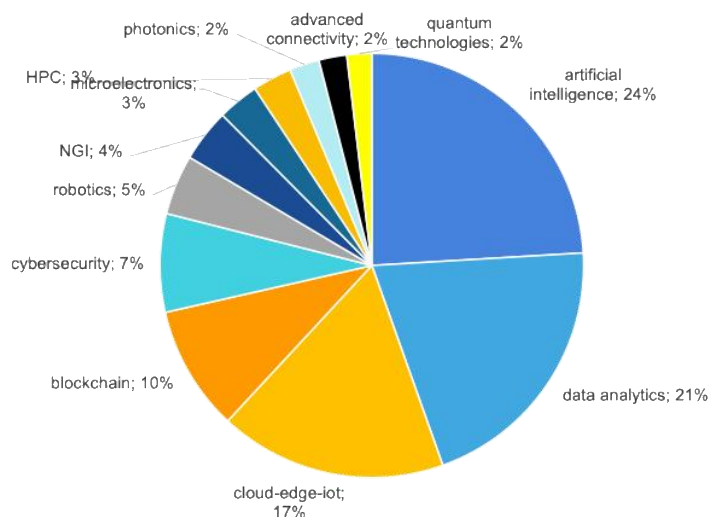
By contrast, technologies such as Quantum computing and Advanced Connectivity remain at the lower end of the distribution. This reflects their earlier stage of technological maturity, higher uncertainty, and longer time horizons required to reach market readiness and scalability. These fields are still primarily in the R&I-intensive phase, where value creation is strongly tied to research breakthroughs rather than rapid commercial expansion.

The key challenge for scaling up is related to access to markets, highlighting the importance of better connecting R&I to deployment, as interviews with start-ups and experts engaged in this study show. Despite being a large economic area, the EU remains fragmented into multiple national markets with different languages, regulations, procurement systems, and consumer preferences. This fragmentation increases the cost and complexity of expanding across borders, slows down customer acquisition, and often prevents startups from achieving rapid continent-wide scale. As a result, firms frequently scale within individual countries rather than the EU as a single integrated market.

In addition to market fragmentation, scaling is constrained by limited access to growth capital and supporting ecosystem conditions. Europe has fewer late-stage funding options compared to the US, making it harder for start-ups to secure the large investments needed for rapid expansion. This is reinforced by relatively risk-averse investment behaviour, weaker exit opportunities such as IPOs, and regulatory complexity that can slow market entry. Combined with gaps in scaleup management talent and uneven ecosystem integration across regions, these factors make it difficult for European startups, especially in capital-intensive fields such as digital technologies, to grow into global leaders⁶⁷.

⁶⁶ Dealroom.co. (2025). The 2025 European Deep Tech Report, <https://content.dealroom.co/uploaded/2024/11/2025-European-Deep-Tech-Report.pdf>

⁶⁷ See in Dealroom (2025). 2025 European deep tech report. <https://content.dealroom.co/uploaded/2024/11/2025-European-Deep-Tech-Report.pdf>; European Commission (2025). Startup and scaleup strategy. <https://commission.europa.eu/>; Stam, E., & van de Ven, A. (2021). Entrepreneurial ecosystem elements. Small Business Economics, 56(2), 809–832. <https://doi.org/10.1007/s11187-019-00270-6>

Figure 19 Distribution of digital tech scaleups per technology area in the EU27 in 2025

Source: Technopolis Group (2025) based on Crunchbase

Indeed, another key challenge is that a substantial portion of Europe's most promising technology start-ups are ultimately being acquired by firms based outside the EU, particularly from the United States. As found in this study by analysing acquisitions of tech start-ups, on average, 29% of the acquisitions of EU tech startups are executed by US acquirers. Higher shares are observed in the areas of Cybersecurity (38%), Artificial Intelligence (34%) and Next Generation Internet and XR (34%). Young and small firms in the United States tend to demonstrate a stronger ability to scale in high R&D-intensive sectors compared with their European counterparts, reflecting differences in both financing conditions and ecosystem dynamics.

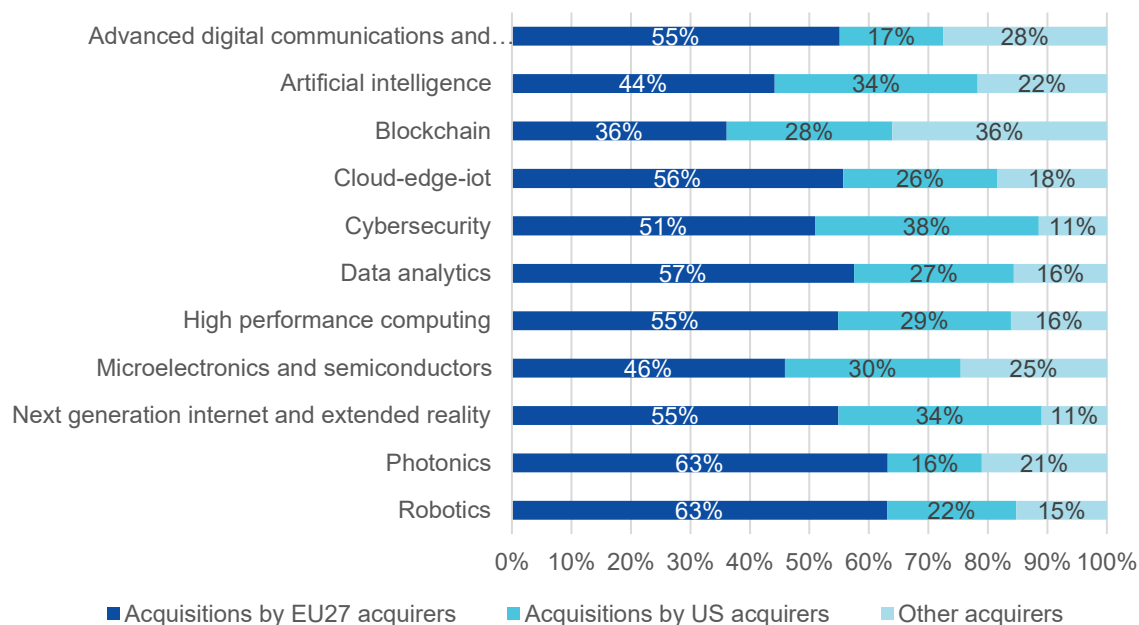
Over the past decade, financial markets in Europe have generally been more conservative, placing tighter constraints on long-term and high-risk R&D investment than in the US, where deeper capital markets and a stronger risk appetite have enabled sustained funding for innovation-intensive growth⁶⁸. Commercialisation dynamics further reinforce this divergence, as the translation of research into market-ready solutions is increasingly driven by the creation and scaling of academic and corporate spin-offs⁶⁹. In the US, a particularly vibrant start-up and scale-up ecosystem, combined with substantial investment from large technology incumbents has generated a reinforcing cycle of supply and demand in emerging high-tech industries. This ecosystem effect is especially visible in deep tech sectors, where strong venture capital availability, dense innovation networks, and aggressive scaling strategies support rapid global leadership. US dominance is further strengthened by the systematic acquisition of high-potential start-ups worldwide, allowing major firms to continuously integrate frontier innovations and consolidate leadership across fast-evolving technological domains⁷⁰.

Figure 20 Acquisitions of EU start-ups by different acquirers

⁶⁸ Martinsson, G. (2010). Equity financing and innovation: Is Europe different from the United States? *Journal of Banking & Finance*, 34(6), 1215–1224. <https://doi.org/10.1016/j.jbankfin.2009.11.015>

⁶⁹ Pisoni, A., & Onetti, A. (2018). When startups exit: Comparing strategies in Europe and the USA. *Journal of Business Strategy*, 39(3), 26–33. <https://doi.org/10.1108/JBS-02-2017-0022>

⁷⁰ Pisoni, A., & Onetti, A. (2018). When startups exit: Comparing strategies in Europe and the USA. *Journal of Business Strategy*, 39(3), 26–33. <https://doi.org/10.1108/JBS-02-2017-0022>



Source: Technopolis Group based on Crunchbase

1.3.3 Type of organisations attracting R&I public funding

Public R&I funding plays a central role in shaping Europe's digital R&I ecosystem, particularly through the EU's Horizon Europe programme, which is the largest pan-European research and innovation funding framework. It supports a wide range of actors, including universities, research and technology organisations (RTOs), SMEs, large firms, and public-private consortia in developing and scaling emerging digital technologies. Prior research⁷¹ shows that such funding not only reduces early-stage technological risk but also helps structure collaborative networks that are essential for knowledge diffusion and commercialisation in complex deep-tech domains. In this context, this section provides insights into the R&I ecosystem by mapping the type of actors that attract the largest amount of Horizon Europe funding (from 2021 to 2025) for the development of various digital technologies in the focus of this report.

The **highest volume of funding across most of the digital technologies was absorbed by private for-profit companies (PRC)**, except for HPC and Quantum technologies (where research and education organisations and higher education attracted the most funding). This underlines the emphasis on applied research.

Table 7 Distribution of Horizon Europe funding for digital technologies per type of stakeholders

Type of Stakeholders	EU funding (€)	Share of EU funding	Total project number	Share of projects
Microelectronics and Semiconductors				
HES	€ 115,505 m	19.6%	355	24.1%
REC	€ 176,836 m	30.1%	244	16.6%
PRC	€ 282,832 m	48.1%	843	57.2%
PUB	€ 955 m	0.2%	2	0.1%
OTH	€ 12,198 m	2.1%	29	2.0%

⁷¹ European Commission (2024). Horizon Europe and the digital & industrial transition. Prepared by Technopolis Group Publications Office of the European Union. <https://op.europa.eu/en/publication-detail/-/publication/44b1b11b-7fa2-11ef-a67d-01aa75ed71a1>

Type of Stakeholders	EU funding (€)	Share of EU funding	Total project number	Share of projects
Grand Total	€ 588,327 m	100.0%	1473	100.0%
Photonics				
HES	€ 118,911 m	19.8%	303	21.7%
REC	€ 136,784 m	22.8%	225	16.1%
PRC	€ 295,151 m	49.2%	800	57.2%
PUB	€ 28,036 m	4.7%	25	1.8%
OTH	€ 20,493 m	3.4%	45	3.2%
Grand Total	€ 599,374 m	100.0%	1398	100.0%
High-Performance Computing				
HES	€ 25,889 m	31.2%	77	33.3%
REC	€ 38,185 m	46.1%	93	40.3%
PRC	€ 12,756 m	15.4%	42	18.2%
PUB	€ 2,929 m	3.5%	12	5.2%
OTH	€ 3,122 m	3.8%	7	3.0%
Grand Total	€ 82,882 m	100.0%	231	100.0%
Quantum				
HES	€ 119,794 m	34.5%	219	37.0%
REC	€ 110,584 m	31.9%	140	23.6%
PRC	€ 102,850 m	29.7%	206	34.8%
PUB	€ 2,684 m	0.8%	8	1.4%
OTH	€ 10,937 m	3.2%	19	3.2%
Grand Total	€ 346,848 m	100.0%	592	100.0%
Artificial Intelligence				
HES	€ 359,485 m	29.0%	765	25.6%
REC	€ 293,068 m	23.6%	597	20.0%
PRC	€ 465,978 m	37.5%	1286	43.1%
PUB	€ 32,331 m	2.6%	94	3.1%
OTH	€ 90,758 m	7.3%	243	8.1%
Grand Total	€ 1,241,620 m	100.0%	2985	100.0%
Data Analytics				
HES	€ 262,955 m	24.2%	629	23.2%
REC	€ 281,214 m	25.8%	589	21.7%
PRC	€ 423,331 m	38.9%	1171	43.1%
PUB	€ 46,969 m	4.3%	136	5.0%
OTH	€ 73,667 m	6.8%	189	7.0%
Grand Total	€ 1,088,136 m	100.0%	2714	100.0%
Robotics				
HES	€ 142,903 m	27.8%	267	22.7%

Type of Stakeholders	EU funding (€)	Share of EU funding	Total project number	Share of projects
REC	€ 137,794 m	26.8%	246	21.0%
PRC	€ 189,882 m	36.9%	534	45.5%
PUB	€ 6,642 m	1.3%	29	2.5%
OTH	€ 37,518 m	7.3%	98	8.3%
Grand Total	€ 514,740 m	100.0%	1174	100.0%
	Cybersecurity			
HES	€ 70,154 m	19.2%	214	19.9%
REC	€ 70,640 m	19.3%	186	17.3%
PRC	€ 183,644 m	50.2%	545	50.6%
PUB	€ 21,214 m	5.8%	68	6.3%
OTH	€ 20,003 m	5.5%	64	5.9%
Grand Total	€ 365,656 m	100.0%	1077	100.0%
	Cloud-Edge-IoT			
HES	€ 90,215 m	20.5%	232	21.5%
REC	€ 72,509 m	16.5%	161	14.9%
PRC	€ 250,114 m	56.8%	612	56.7%
PUB	€ 6,134 m	1.4%	19	1.8%
OTH	€ 21,657 m	4.9%	56	5.2%
Grand Total	€ 440,629 m	100.0%	1080	100.0%
	Blockchain			
HES	€ 3,105 m	19.1%	13	18.8%
REC	€ 2,810 m	17.2%	14	20.3%
PRC	€ 7,142 m	43.8%	30	43.5%
PUB	€ 1,015 m	6.2%	5	7.2%
OTH	€ 2,219 m	13.6%	7	10.1%
Grand Total	€ 16,292 m	100.0%	69	100.0%
	Advanced Connectivity			
HES	€ 129,156 m	23.6%	295	22.9%
REC	€ 112,378 m	20.5%	204	15.8%
PRC	€ 288,710 m	52.8%	721	56.0%
PUB	€ 5,094 m	0.9%	17	1.3%
OTH	€ 11,763 m	2.2%	34	2.6%
Grand Total	€ 547,101 m	100.0%	1288	100.0%
	NGI and XR			
HES	€ 104,904 m	23.7%	224	28.1%
REC	€ 125,072 m	28.3%	146	18.3%
PRC	€ 162,571 m	36.8%	312	39.1%
PUB	€ 10,785 m	2.4%	20	2.5%

Type of Stakeholders	EU funding (€)	Share of EU funding	Total project number	Share of projects
OTH	€ 38,972 m	8.8%	96	12.0%
Grand Total	€ 442,304 m	100.0%	798	100.0%

Source: Technopolis Group based on Horizon data analysis (Cordis, May 2025)

Notes: HES – Higher Education Sector, REC – Research Organisation / Public Research Establishment: Non-university research institutes. PRC – Private / Commercial Company: Industry or corporate entities, PUB – Public Bodies - authorities, OTH – Other

The above presented distribution also reflects the broader strategic role of Horizon Europe in supporting the EU's digital and industrial transition⁷². The programme is designed to balance responsiveness to emerging technological and policy priorities with sustained investment in long-term capabilities, enabling Europe to remain competitive in key strategic domains. Compared to previous framework programmes, the current Horizon Europe programme has been more tightly aligned with EU industrial policy objectives, reinforcing linkages between research, innovation, and industrial deployment. Its impact-driven approach promotes not only technological advancement but also wider goals such as decarbonisation, economic resilience, and the strengthening of strategic value chains. The programme also ensures continuity in longer-term research domains, such as space and other capital-intensive technologies, where stable and predictable funding remains essential.

At the same time, Horizon Europe demonstrates a capacity to address rapidly evolving technological areas such as AI through adaptive priority-setting and targeted funding calls. However, the structure of large, multi-year projects can limit flexibility at implementation level, making it more difficult to respond dynamically to fast-changing market or technology developments.

1.3.4 Skilled professionals in digital technology R&I

Europe has a strong and growing digital tech talent base supported by a dense ecosystem of universities, research centres, and industry actors across all technology areas.

However, despite its capacity to train high-quality talent, Europe struggles to retain them in a highly competitive global labour market.

In 2025, over 10 million people were employed as ICT specialists across the EU according to Eurostat⁷³. The number of ICT specialists grew rapidly between 2014 and 2025, by over 59.4%, far outpacing overall employment growth accounting for about 4.8% of total employment⁷⁴. ICT is generating employment not only within the ICT sector but increasingly across all industries, as most jobs now require some level of digital competence. Germany accounted for the largest share of ICT specialists, employing 2.3 million specialists, or 22.2% of the EU total. France followed with 1.4 million ICT professionals (13.7%), while Spain employed close to one million specialists (10.2%) in 2025⁷⁵.

Demand for ICT specialists, including those with AI-related expertise, has been rising driven by the growing adoption of data-driven and AI technologies in all sectors. However, supply is not keeping pace: shortages persist, particularly for advanced roles such as AI specialists, data scientists, and cybersecurity experts, constraining firms' ability to innovate and adopt new technologies effectively⁷⁶. According to the European Commission's Education and

⁷² European Commission (2024). Horizon Europe and the digital & industrial transition. Prepared by Technopolis Group Publications Office of the European Union. <https://op.europa.eu/en/publication-detail/-/publication/44b1b11b-7fa2-11ef-a67d-01aa75ed71a1>

⁷³ https://ec.europa.eu/eurostat/statistics-explained/index.php?title=ICT_specialists_in_employment

⁷⁴ Eurostat. (2024). ICT specialists in employment. European Commission. <https://ec.europa.eu/eurostat/statistics-explained/SEPDF/cache/47162.pdf>

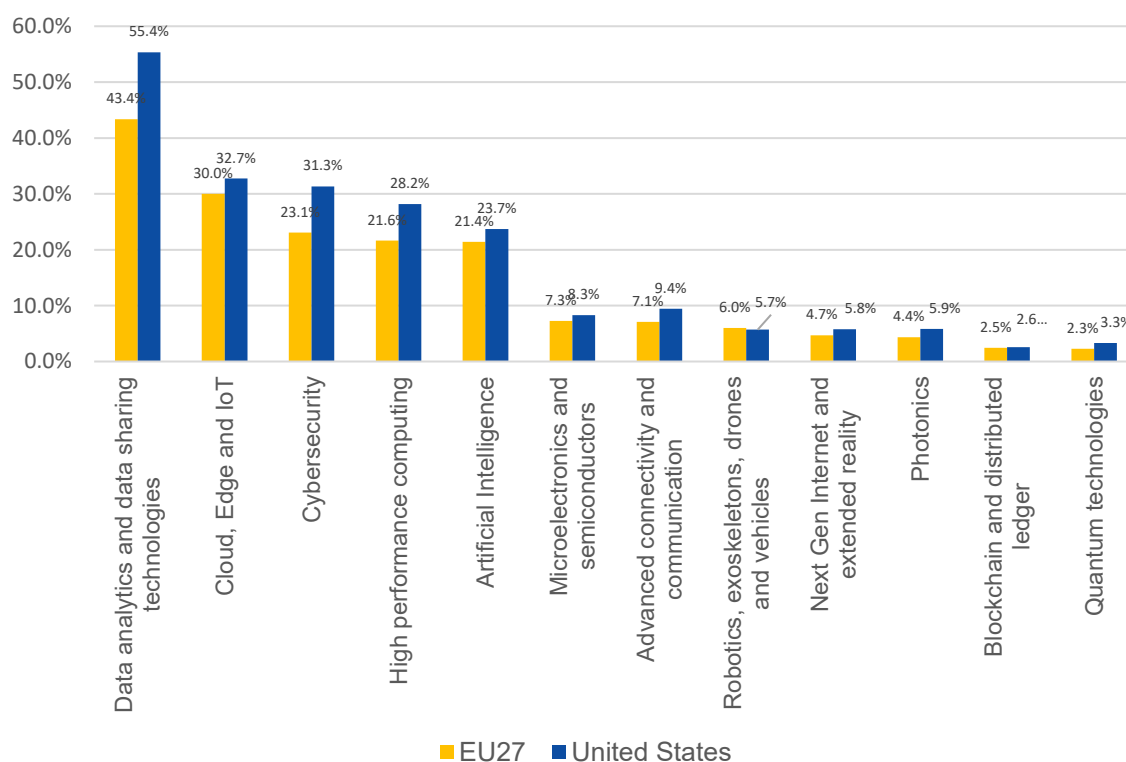
⁷⁵ https://ec.europa.eu/eurostat/statistics-explained/index.php?title=ICT_specialists_in_employment

⁷⁶ OECD (2025). OECD skills outlook 2025. OECD Publishing. https://www.oecd.org/en/publications/oecd-skills-outlook-2025_26163cd3-en.html

Training Monitor 2025⁷⁷, drawing on Cedefop's Skills Forecast and Eurostat's data, ICT graduates have a high employment rate of 88.6%, while demand for ICT professionals is projected to grow by 36% between 2022 and 2035. Europe's education pipeline remains limited, as the EU produces only 2.6 ICT tertiary graduates per 1 000 people aged 20–34, the lowest rate among the advanced economies compared to others⁷⁸. This points to a widening gap between rising demand for ICT professionals and Europe's capacity to produce them.

Compared to these statistics, there have been **3 276 706 professionals employed in ICT-related functions with relevant digital skills related to the 12 digital technology areas** covered in this report, as found by the analysis of LinkedIn data⁷⁹. In relation to overall ICT employment, this represents 32% of all ICT and engineering specialists. In the EU in 2025, the largest share of ICT professionals had skills in **Data analytics (43%), followed by Cloud-Edge-IoT technologies (30%), and Cybersecurity (23%)**. The low share of professionals with skills in Quantum technologies, Blockchain, and Photonics reflects the more limited current relevance and adoption of these technologies across the broader economy. As these fields are still emerging and have fewer mainstream applications compared to other digital technologies, supply of specialised talent remains relatively low.

Figure 21 Share of professionals with specific tech skills working in ICT and engineering functions within the total ICT professionals in the EU and the US



Source: Technopolis Group (2025) based on analysis of LinkedIn data

Specifically in the field of AI, **Europe has a strong and growing AI talent base, supported by a dense ecosystem of universities, research centres, and industry actors**⁸⁰. Europe

⁷⁷ European Commission. (2025). Education and Training Monitor 2025: Comparative report. <https://op.europa.eu/webpub/eac/education-and-training-monitor/en/comparative-report/chapter-1.html>

⁷⁸ Ibid

⁷⁹ Same analysis has been conducted also in European Commission: Directorate-General for Communications Networks, Content and Technology, Technopolis Group, Izsak, K., Simmonds, P., Ploeg, M. et al. (eds), Study on the EU's critical digital capacities deployment beyond 2027 – Final report, Publications Office of the European Union, 2026, <https://data.europa.eu/doi/10.2759/0673677>

⁸⁰ EIT Deep Tech Talent Initiative. (2025). Europe's AI workforce: Mapping the talent behind the code. European Institute of Innovation and Technology. <https://www.eitdeeptechtalent.eu/news-and-events/news-archive/europes-ai-workforce-mapping-the-talent-behind-the-code>

has a relatively high per-capita concentration of AI professionals and a significant pipeline of highly educated talent, with most AI specialists holding advanced degrees and entering the field through diverse educational and geographic pathways⁸¹. In the 2020–21 academic year, there were 1 085 bachelor-level and 1 371 master-level university places with AI content in the EU⁸². Similar and more recent data is not available, but as a comparison, the masters portal lists 803 master's degrees in AI in Europe including the UK⁸³. AI-related education has slightly more capacity at master's level than at bachelor's level, reflecting a focus on more specialised, advanced AI training. At the same time, demand for these skills is growing rapidly. AI is currently a net creator of IT jobs in Europe, despite high-profile tech layoffs, with net hiring expected to increase by 27% in 2026 and 17% in 2027⁸⁴. However, this growth is not evenly distributed across the talent pipeline: entry-level technical roles are expected to contract by 3% in Europe, creating a potential bottleneck in the development of the mid- and senior-level AI professionals that Europe will need to sustain its future AI capabilities. Europe therefore has a substantial foundation of AI talent and education, but maintaining and expanding the pipeline will be critical to meeting growing demand.

As another example, **Quantum technology** also shows signs of emerging growth in Europe in terms of skills. The QED-C Quantum Technology Workforce Monitoring Report⁸⁵ found that Europe's quantum-technology labour market shows signs of emerging growth, with new job postings rising 5.2% in April 2025 and the trailing 12-month total up 2.6%. Although no comprehensive figure is available for the number of quantum scientists in Europe, the Quantum Europe strategy highlighted that the EU has the highest number of graduates in quantum technology-relevant fields worldwide, with over 110 000 graduates annually in physics, ICT, engineering, and related disciplines⁸⁶. In this report, the number of professionals with quantum-related skills in the EU was estimated at 210 506 in 2025, based on an analysis of LinkedIn data⁸⁷. Building on this existing talent base, the EU has been developing a coordinated quantum skills ecosystem⁸⁸, recognising that both a specialised workforce and broader societal awareness are essential for the development of quantum technologies. Education efforts are structured at EU level through initiatives such as QTedu⁸⁹, which provide common frameworks, pilot programmes, and coordination across countries to standardise skills and training pathways.

The European digital workforce is characterised by strong international mobility and competition, making the attraction and retention of talent a critical challenge across all technology areas. Europe is simultaneously attracting global AI talent while also experiencing substantial outflows, particularly to the United States⁹⁰. LinkedIn data analysis performed in this study indicates that in 2025 the EU experienced a net outflow of AI talent to the United States, with more professionals leaving the EU for the US than moving in the opposite direction. However, the gap is not large, and the data also show that the EU continues to attract a meaningful inflow of AI talent, indicating a relatively balanced but negative net position. The reasons behind this outflow are manifold as talent mobility is shaped by factors such as education systems, language, immigration policy, and the attractiveness of research and industry opportunities⁹¹.

⁸¹ Ibid

⁸² European Commission, Joint Research Centre. (2021). AI Watch – University places with AI content in the EU (S6 indicator). https://ai-watch.ec.europa.eu/ai-watch-index-2021/s-societal-aspects/s6-university-places-ai-content-eu_en

⁸³ <https://www.mastersportal.com/search/master/artificial-intelligence/europe>

⁸⁴ The Linux Foundation. (2026). *2026 State of tech talent Europe: AI, technical hiring, and the skills gap in Europe*. <https://www.linuxfoundation.org/hubfs/Research%20Reports/State-of-Tech-Talent-Europe-2026-REV-1.pdf>

⁸⁵ Quantum Economic Development Consortium. (2025, May 5). Quantum technology workforce monitoring report: May 5, 2025. QED-C report

⁸⁶ European Commission. (2025). Quantum Europe strategy: Quantum Europe in a changing world (COM(2025) 363 final

⁸⁷ Technopolis Group based on LinkedIn

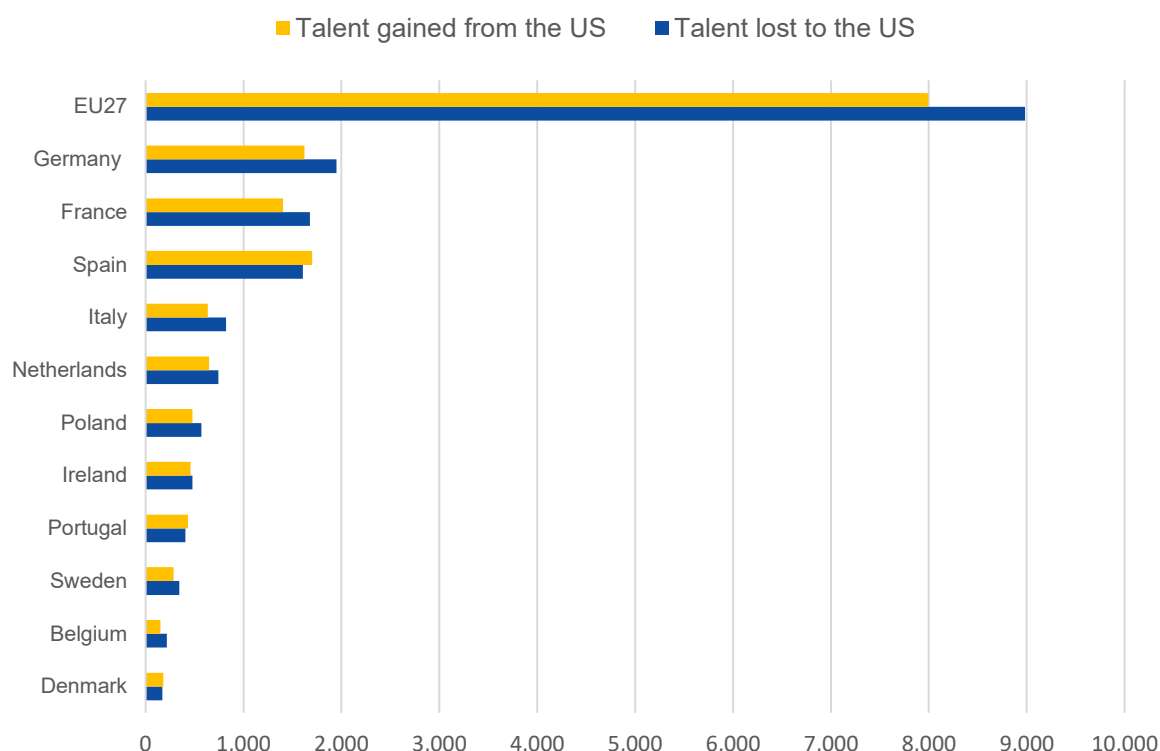
⁸⁸ Quantum Flagship. Education and training ecosystem. <https://qt.eu/ecosystem/education-and-training>

⁸⁹ <https://qtedu.eu/>

⁹⁰ Atomico. (2025). State of European Tech 2025. Atomico. <https://www.stateofeuropeantech.com/>

⁹¹ EIT Deep Tech Talent Initiative. (2025). Europe's AI workforce: Mapping the talent behind the code. European Institute of Innovation and Technology. <https://www.eitdeeptechtalent.eu/news-and-events/news-archive/europes-ai-workforce-mapping-the-talent-behind-the-code>

Figure 22 AI talent inflows and outflows between EU and US locations in 2025 (number of professionals with AI skills with a profile on LinkedIn moving across locations in 2025)



Source: Technopolis Group (2025) based on analysis of LinkedIn data

Interestingly, LinkedIn data also shows that the country outside Europe from which the EU has gained most AI talent from in 2025 was India. Similarly, the Stanford AI Index⁹² found that India is one of the largest producers of AI talent globally, but also one of the biggest net exporters of that talent. Despite a rapidly growing AI workforce and strong skill penetration, India records the highest net outflows of AI professionals worldwide, primarily for destinations such as the United States but also Europe.

Europe's digital talent challenge is also about effective deployment of digital skills in the economy. While Europe produces strong digital expertise across many areas (often highly educated and research-oriented), there is a gap between academic output and industry demand for example for applied AI engineers, contributing to persistent skills mismatches and reliance on international recruitment.

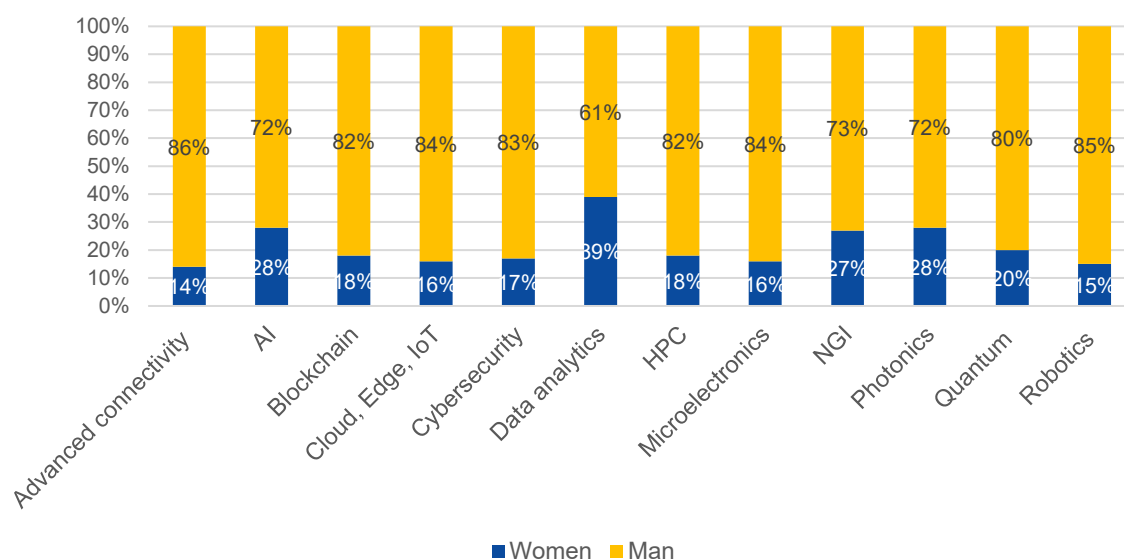
Across all technologies, the share of professionals with specific digital skills within ICT and engineering functions has been systematically higher in the US than in the EU. This reflects a more advanced digital ecosystem in the US, where the supply of high-level technological competencies is stronger. As a result, professionals in the US are more likely to possess and apply specialised skills in areas such as Artificial Intelligence, Cybersecurity, Data analytics, and other emerging technologies, contributing to the country's competitive advantage in digital transformation.

The gender gap is pronounced both in the EU and in the US given that 82% of the professionals with skills related to the 13 technology areas are men and only 18% are women, with similar percentages in both global regions. This is slightly below the general statistics for employed ICT specialists, where in 2024 only 19.5% of the workforce were

⁹² Stanford University, Human-Centered AI Institute. (2025). AI Index report 2025. Stanford University. <https://aiindex.stanford.edu/report/>

women in the EU⁹³. This percentage has not changed much over the past five years. The gender gap is presented per technology area in the Figure below.

Figure 23 Share of professionals with specific tech skills in total ICT professionals in the EU and the US – men vs women



Source: Technopolis Group (2025) based on analysis of LinkedIn data

ICT and AI specialists tend to be highly concentrated not just among men but also among highly educated workers (with two-thirds holding tertiary education), highlighting both the increasing importance of digital skills for the EU economy and persistent structural gaps in talent supply⁹⁴. Addressing these gaps requires not only expanding specialist training pipelines but also strengthening continuous upskilling, improving the alignment between education systems and labour market needs, and broadening participation to ensure a more inclusive and sufficient talent base.

1.4 EU positioning and resilience in the international landscape

1.4.1 Technology positioning of the EU

Existing research highlights a persistent gap between the EU and leading global innovation powers in the translation of research strength into technological and industrial leadership⁹⁵, and stresses the need to reinforce Europe's research and innovation capabilities in advanced digital technologies to remain competitive⁹⁶. Notably, China has rapidly improved the performance of its innovation system in recent decades, including in areas such as R&D intensity and the scale of technology development, challenging both the EU and the US in key areas such as R&D investments or patent application⁹⁷. In this section, the most recent trends have been assessed based on a Delphi survey, bibliometrics and patent data.

Compared to the perception of experts, data from patent statistics and bibliometrics as analysed in the chapters above shows that:

⁹³ https://ec.europa.eu/eurostat/databrowser/view/isoc_sks_itsps__custom_17014129/default/table?lang=en

⁹⁴ Eurostat. (2024). ICT specialists in employment. European Commission. <https://ec.europa.eu/eurostat/statistics-explained/SEPDF/cache/47162.pdf>

⁹⁵ DIGITALEUROPE "EU Critical Tech Gap" (2024), Available at: <https://www.digitaleurope.org/resources/the-eus-critical-tech-gap-rethinking-economic-security-to-put-europe-back-on-the-map/>

⁹⁶ <https://digital-strategy.ec.europa.eu/en/news/commission-proposes-tech-sovereignty-package-strengthen-europes-digital-autonomy-and-resilience>

⁹⁷ See the analysis of the US FED: <https://www.federalreserve.gov/econres/notes/feds-notes/an-assessment-of-chinas-innovative-capacity-20250805.html>

- On the one hand, the **EU research output stands out across several digital technology fields** as captured by the number of publications⁹⁸. For example, related research also confirms that the EU has a strong AI public research community with the highest number of peer-reviewed scientific publications on AI in the world in 2022⁹⁹. However, trends over time also indicate a weakening position of the EU challenged globally across technology areas as presented in the detailed analysis in the technology annexes.
- In terms of commercialisation as captured by patent applications, we see a large variation between the technology fields that point out weaknesses in the EU's competitive position. In terms of trends, the position of the EU is slightly declining or stable, in particular due to the rising share of China in most areas.

The results of this study indicate that the European Union is at the forefront of scientific research in digital technologies when it comes to volume of publication and measured by the share of publications in the world, while the United States lag in scientific production but lead in innovation. At first glance, these findings appear counterintuitive, given the well-established sciento-metric evidence that scientific research and innovation evolve in parallel¹⁰⁰. The ability of the corporate sector to recognise, assimilate, and apply new knowledge, referred to as absorptive capacity, is essential for the commercialisation of scientific research. When such capacity is lacking, a country not only fails to benefit from its own publicly funded research but is also losing competitive advantage, as its own knowledge may be exploited by more capable international competitors.

Research funded by the European Research Council (ERC) is widely recognised for its scientific excellence and impact. ERC publications receive more patent citations than comparable European science, and its patents show higher quality, as indicated by forward citations. However, even ERC-funded results rarely reach the European corporate sector. Instead, US organisations, both large corporations and startups, lead in exploiting these outputs. Around 55% of all patent citations to ERC-funded science come from USPTO patents, compared to just 9.48% from EPO patents (a figure only slightly higher than citations from Chinese patents)¹⁰¹. A significant share of scientific commercialisation occurs through Technology Transfer Offices within universities and public research institutions. US TTOs typically employ more qualified staff with greater industry experience, which helps explain the much higher number of licensing agreements concluded in the US compared to the EU¹⁰². Despite the identified strong position in share volumes of publication, when analysing citation percentiles, it is evident that EU research performs below the world average.

Across most digital technology domains, the EU's share of top-10% cited papers is consistently lower than that of China and/or the US, suggesting a gap in internationally leading research impact despite strong overall publication volumes. The largest disparities appear in Advanced Connectivity, where the EU trails both China and the US, NGI and XR, and Robotics, where China is particularly dominant in the top-10% tier. In Quantum, the EU also lags behind China and falls below the US.

At the top-1% citation level, the EU's relative underperformance is most pronounced in Microelectronics and semiconductors, as well as Photonics, where China leads

⁹⁸ Please note that other studies also have slightly different results, for example according to Stanford University's Artificial Intelligence Report 2023, China accounted for almost 40% of all publications on AI in 2021, surpassing EU and the UK (15%) and the US (10 %). In addition, papers from China accounted for 29% of all AI citations in 2021, again exceeding those from Europe and the UK (21.5 %) and the US (15 %).

⁹⁹ https://www.eca.europa.eu/ECAPublications/SR-2024-08/SR-2024-08_EN.pdf

¹⁰⁰ Szczygielski, K. & Mycielski, J. (2024). The mutual reinforcement of scientific and technological knowledge — a technology-level analysis. *Scientometrics*, 129(11), 6533–6549.

¹⁰¹ See also Nagar, J. P., Breschi, S., & Fosfuri, A. (2024). ERC science and invention: Does ERC break free from the EU paradox? *Research Policy*, 53(8), 105038. <https://doi.org/10.1016/j.respol.2024.105038>

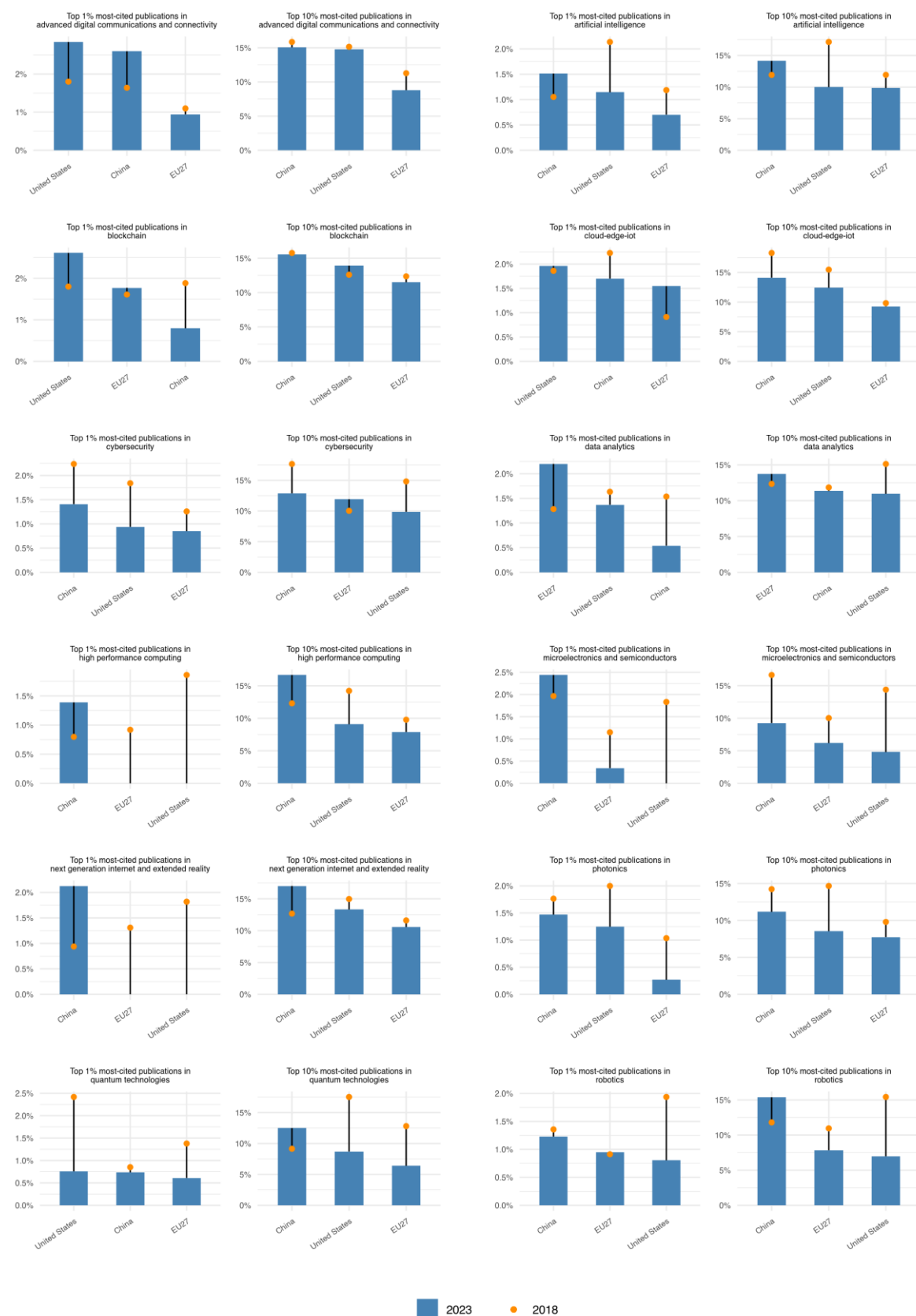
¹⁰² Conti, Annamaria & Gaule, Patrick, 2011. "Is the US outperforming Europe in university technology licensing? A new perspective on the European Paradox," *Research Policy*, Elsevier, vol. 40(1), pages 123-135, February.

and the EU's presence among the most highly cited work is comparatively limited. By contrast, the EU shows its strongest relative position in Data analytics, where it leads both China and the US in the top-1% and top-10% layers. It also remains closer to peer performance in Cloud-edge-IoT and Blockchain at the top-10% level. These patterns align with prior findings that EU performance assessments are highly sensitive to whether one considers aggregate publication shares or field-normalised excellence indicators (top-1% and top-10%), with the US and increasingly China, more strongly represented at the very top of the global citation distribution¹⁰³¹⁰⁴.

103 European Commission, Joint Research Centre (JRC). (2021). *China overtakes the EU in high-impact publications*.

104 European Commission. (2024). *Science, Research and Innovation Performance of the EU 2024 (SRIP) – Chapter 1: Global R&I landscape*.

Table 8 Share of top-1% and top-10% most-cited publications by technology field (EU27 vs US vs China), 2018 vs 2023



Source: OPIX based on OPENAIRE

Case studies, such as that on GMR (Giant Magnetoresistance) used in hard disk drives and magnetic heads, illustrate how high-quality European research is frequently commercialised

by US firms¹⁰⁵. This pattern is also evident in the extensive exploitation of European scientific output by US corporations, particularly deep tech startups. The direction of knowledge transfer reinforces the notion of limited absorptive capacity and weaker innovation ecosystems within the EU.

Besides evidence from statistics, expert's perceptions of EU positioning are also relevant to monitor. In order to position the EU's relative competitiveness in R&I compared to other countries, experts were asked in the Delphi analysis to compare the EU to other leading countries (see Figure below).

In terms of positioning, experts participating in this study judge the EU to be currently slightly behind (in 2028), with the situation slightly worsening over the next MFF period in case the level of funding and investment directions remain the same as in the current Horizon Europe programme. Areas where the EU is considered on par include Advanced Connectivity, Data analytics, Photonics and Robotics. The areas with an anticipated positive trend include NGI and XR.

Figure 24 Expected international positioning per technology area based on experts' input

Technology	Positioning 2028	Positioning 2036
Microelectronics	Slightly behind	Slightly behind
Photonics	On par	Slightly behind
HPC	Slightly behind	Significantly behind
Quantum	Slightly behind	Slightly behind
AI	Slightly behind	Slightly behind
Data	On par	On par
Robotics	On par	Slightly behind
Cybersecurity	Slightly behind	Slightly behind
Cloud-edge-IoT	Slightly behind	Slightly behind
Blockchain	Slightly behind	Slightly behind
Advanced connectivity	On par	Slightly behind
NGI and XR	Significantly behind	Slightly behind

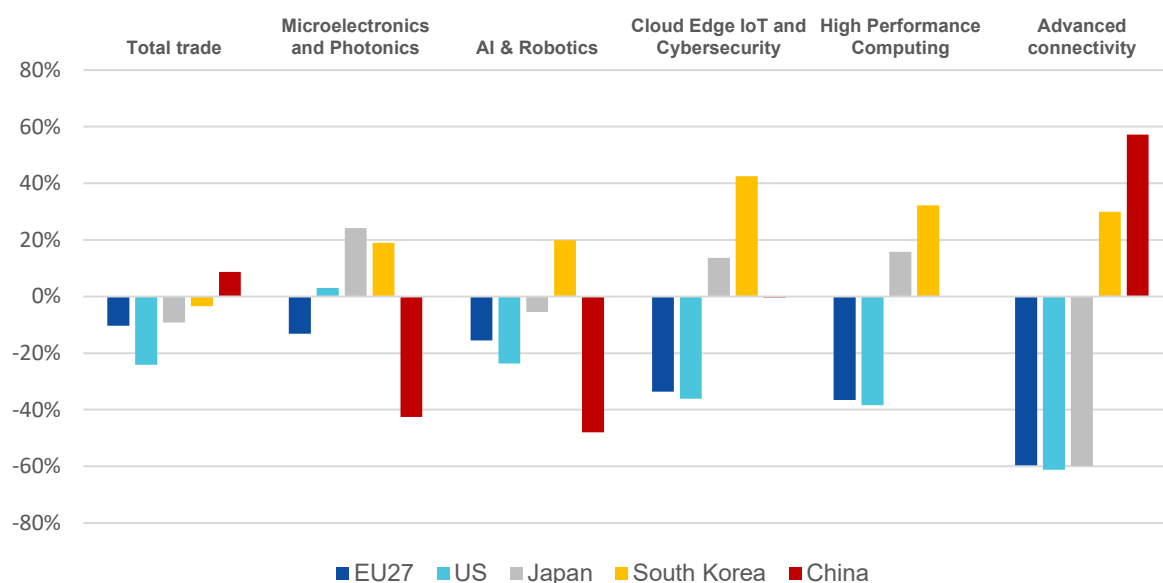
Source: Technopolis Group (2025) based on Delphi survey

The analysis of trade balance in technology areas provides further insights into the assessment of external dependencies and strategic positioning in key segments of the digital value chain. By examining imports and exports across selected technology categories, certain areas of strength can be identified.

The EU had a negative trade balance in all technology areas that could be included in this exercise, most importantly in advanced connectivity and high performance computing related products. The smallest relative trade deficit is in the field of microelectronics and photonics. Internationally, China has a positive trade balance or close to zero in advanced connectivity, high performance computing and cloud-edge-IoT and cybersecurity.

Figure 25 Trade balance in selected critical digital technologies

¹⁰⁵ Dedrick, Jason & Kraemer, Kenneth. (2015). Who captures value from science-based innovation? The distribution of benefits from GMR in the hard disk drive industry. Research Policy. 44. 1615-1628. 10.1016/j.respol.2015.06.011.



Source: Fraunhofer ISI based on Uncomtrade

1.4.2 Collaboration dynamics for the R&I of digital technologies

International collaboration in Horizon Europe Cluster 4 (that includes also other than digital topics) primarily takes place with the associated countries, in particular Serbia, Turkey, Norway, Ukraine and the UK in terms of participation figures.

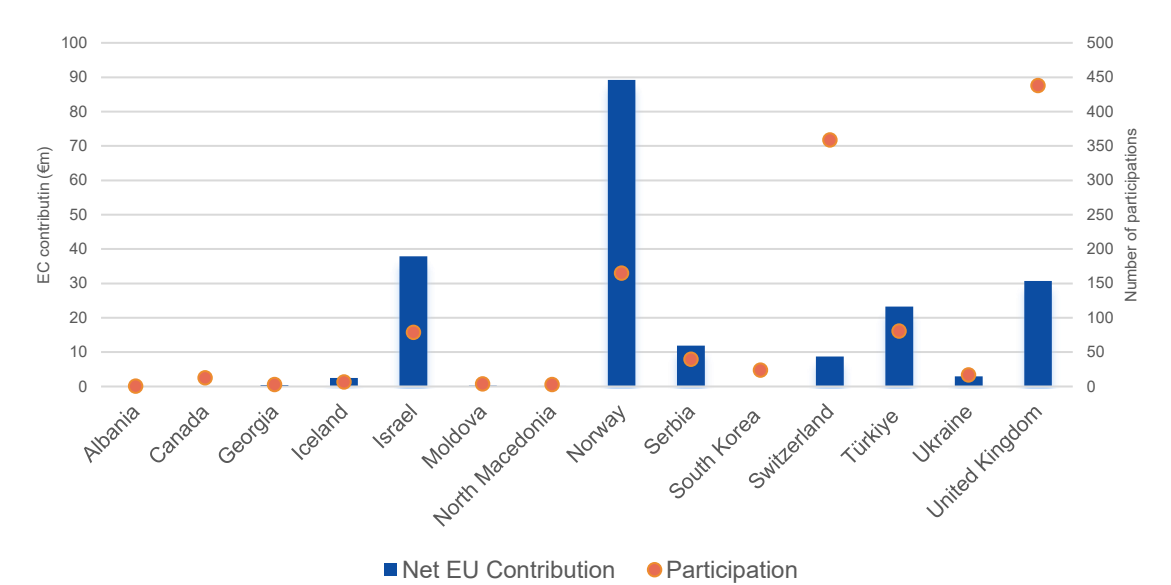
International cooperation in Horizon Europe is well defined in the EU's regulatory and policy context. Structurally, it distinguishes between associated countries with privileged access to Horizon Europe and third countries outside these arrangements. The latter can be subdivided between countries that are eligible for automatic funding from the EU (developing countries), and those that are not eligible but need to self-fund. Some calls are restricted to EU only (with or without access for associated countries), and safeguarding measures apply for individual participants. Finally, sanctions (such as those in the case of the Russian Federation) may also restrict cooperation. In terms of policy development, the EU follows the 'Global Approach for International Cooperation in R&I', which is built around principles such as reciprocity, values-based approaches, Sustainable Development Goals-orientation, with strategic autonomy for the EU and its partners increasingly being a topic on the agenda.

EU funding dedicated to international collaboration with third countries between 2021-2025 amounts to €226 m, which encompasses 1 335 participations. The bulk of the EU-funded collaboration involves participations from associated countries, accounting for €208 m including 1 234 participants.

While the highest numbers of participations are seen for organisations from the UK and Switzerland (438 and 359 participations, respectively), the highest EC contributions are allocated to Norway (€89.1 m) and Israel (€37.8 m).

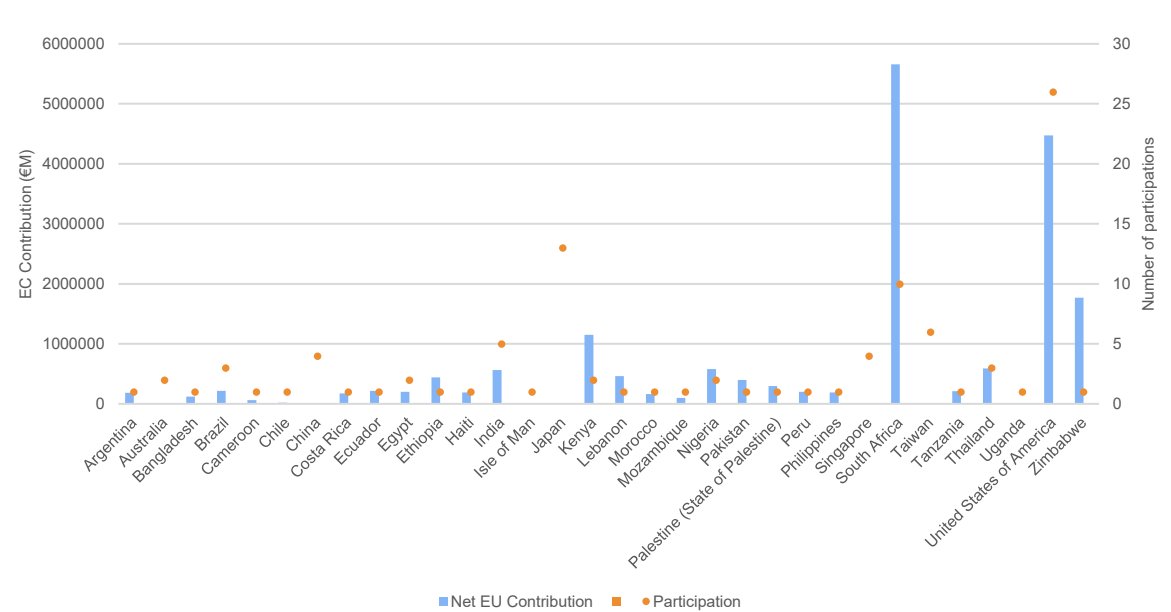
Non-associated countries account for 8% of the total, amounting to €18.6 m and 101 participations. In terms of the number of participations, organisations from the United States rank first among non-associated countries, with 26 participations and a total of €4.47 m of EU funding. Organisations from South Africa recorded 10 participations and a total €5.6 m.

Figure 26 International Cooperation with Associated Countries in Horizon Europe’s supported digital technologies research



Source: Cordis, retrieval data 21/6/25

Figure 27 International Cooperation in Horizon Europe’s supported digital technologies research - third countries



Source: Technopolis Group based on Cordis data, retrieval data 21/6/25

Looking beyond Cluster 4, including all digital-related funding in Horizon Europe in Pillars 1-3, there is a similar pattern with a total collaboration of €756 m across all technology areas. Key countries include Switzerland, UK and Norway, and other associated countries, with more limited participation such as the US or China.

Table 9 Share of projects with more than 1 non-EU partner

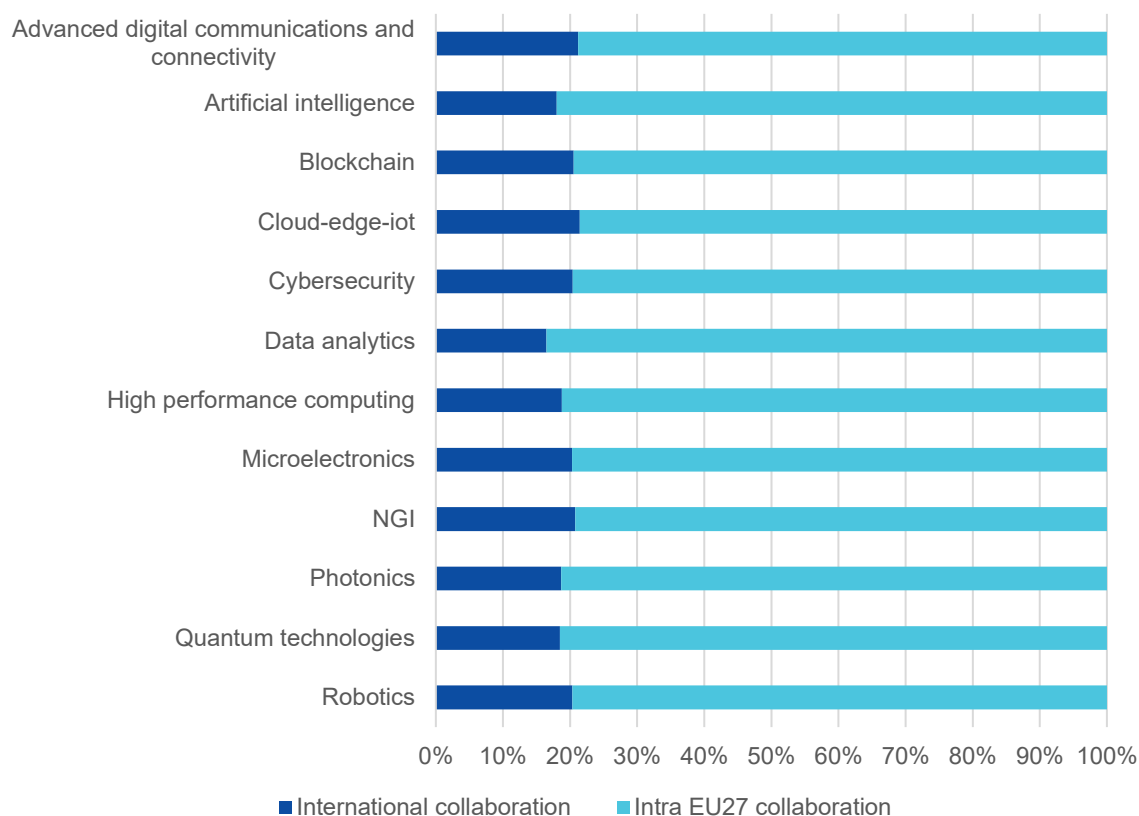
Technology area	Horizon Projects	Projects with ≥1 non-EU partner	Share (%)
Advanced Digital Communications and Connectivity	93	64	68.8
Artificial Intelligence	209	161	77
Blockchain	5	4	80
Cloud-Edge-IoT	71	58	81.7
Cybersecurity	78	51	65.4
Data Analytics	181	132	72.9
High-Performance Computing	20	9	45
Microelectronics and Semiconductors	84	58	69
Next Generation of Internet and Extended Reality	64	44	68.8
Photonics	99	68	68.7
Quantum technologies	52	15	28.8
Robotics	86	62	72.1

Source: Technopolis Group (2025) based on Cordis

Europe is one of the most collaborative scientific regions worldwide, with more than half of its scientific publications being international co-publications, although these collaborations occur predominantly within Europe itself¹⁰⁶. International collaboration patterns of EU27 co-publications reveal how European researchers engage with partners beyond the EU in the production of scientific output. Co-publications are a key indicator of research collaboration and knowledge exchange, and they provide insight into the EU's integration within the global science and technology system.

The analysis of co-publications shows that collaboration patterns between EU-27 and international partners are remarkably consistent across technology areas. For every field, roughly one fifth of publications involve international partners, while around four fifths remain collaborations within the EU-27. The share of international collaboration varies only slightly, from 17% in data analytics to 21% in NGI, Cloud-Edge-IoT, Blockchain, and Advanced Connectivity. This suggests that, at aggregate level, internationalisation is a cross-cutting feature of EU research rather than a characteristic of specific technologies.

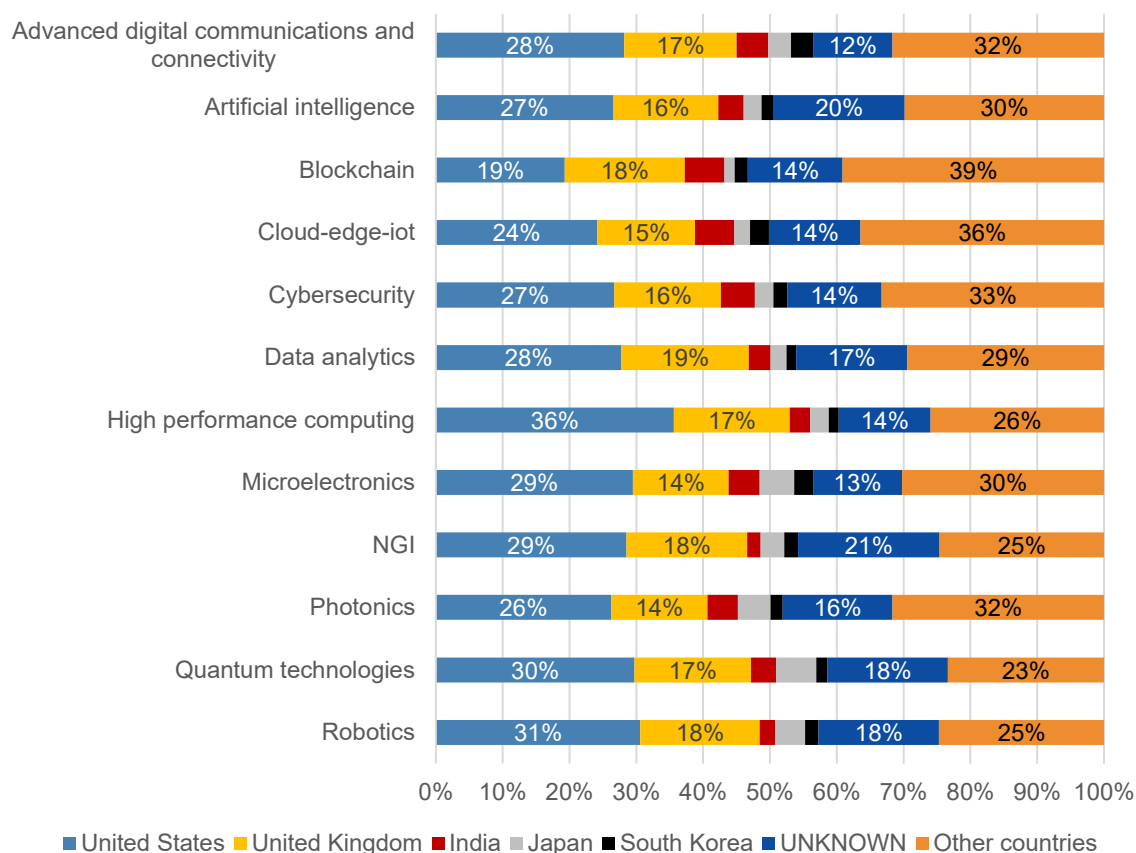
¹⁰⁶ European Commission, RTD. (2024). Science, research and innovation performance of the EU, 2024: A competitive Europe for a sustainable future. Available at: <https://op.europa.eu/en/publication-detail/-/publication/c683268c-3cdc-11ef-ab8f-01aa75ed71a1/language-en>

Figure 28 International vs intra-EU27 collaboration across key digital for co-publications from 2014 to present

Source: OPIX (2025) based on OpenAIRE

The United States is by far the dominant non-European partner across all technology areas in terms of collaboration in co-publications. Between 19% and 36% of international co-publications are with US institutions, with particularly strong links in high-performance computing (36%) and robotics (31%). The United Kingdom consistently appears as the second most important partner country, typically accounting for 14–19% of international co-publications, with slightly higher shares in data analytics, NGI, robotics and blockchain.

Other individual countries – notably India, Japan and South Korea – play a more modest but visible role. Each of these accounts for low shares in most areas (generally 2–6%), with stronger connections to India in cloud-edge-IoT and blockchain, and to India/Japan in photonics, microelectronics and cybersecurity. A significant portion of international co-publications is distributed across a wider set of “other countries”, pointing to a diversified global footprint beyond the main partners. This category reaches particularly high shares in blockchain (39%) and cloud-edge-IoT (36%), and remains above 25% in most other fields.

Figure 29 Geography of EU27 international co-publications across digital technologies for publications from 2014 to present

Source: OPIX (2025) based on OpenAIRE

The analysis of co-patenting provides further insights into collaboration dynamics across organisations patenting digital technologies and their country coverage. By examining patents that list multiple applicants or inventors from different entities, co-patenting analysis helps identify patterns of technological cooperation, knowledge sharing, and international partnerships.

EU27 applicants of digital technology patents collaborated most often with partner organisations from the US, followed by the UK and Switzerland. Collaboration patterns are anchored in a number of countries, but with different intensities across the different technology areas. In particular, data shows that collaboration within Microelectronics patents is more common with Japan, China, South Korea and Taiwan. In Photonics related patent applications, collaboration with Switzerland was relatively high. Lastly, in the area of AI we observed high co-patenting with Switzerland, Canada and India.

Table 10 Co-patenting of EU27 with international partners in digital technologies (sum 2018-2022)

	AI	Microelectronics	Photonics	Robotics	Blockchain	NGI XR	Cybersecurity	Cloud Edge IoT	Advanced Connectivity	HPC	Quantum	Data analytics
US	572	502	281	137	78	65	56	50	40	20	19	8

	AI	Microelectronics	Photonics	Robotics	Blockchain	NGI XR	Cybersecurity	Cloud Edge IoT	Advanced Connectivity	HPC	Quantum	Data analytics
UK	138	62	49	21	19	7	24	21	9	17	1	5
Switzerland	134	168	165	41	22	33	14	10	2		2	1
India	123	24	11	9	22	12	13	9	6	1	5	7
Canada	73	32	36	5	11	6	4	6	7	2	7	4
China	73	95	39	31	3	3	7	11	7	7		4
Israel	23	24	14	7	1	4	3	1			2	2
Singapore	18	41	16	3	3		1		1		4	
Japan	16	107	30	30	5	1	2	1	3			2
Brazil	14		2	1	2	1		2	1	1		
Norway	10	3	8	4	1	5			1		2	
Russia	7	6	11	4	5			1				1
South Korea	5	31	7			6	2					
Taiwan		41	7								1	

Source: Fraunhofer ISI (2025) based on Patstat

The EU private sector actors also collaborate on R&I, and/or may have dependencies across the value chain of their innovation and technology deployment activities.

For the majority of technology areas, the stakeholders surveyed by this study indicated the US as the most listed supplier, similar to or even ahead of the own country or other EU countries, with exceptions for Cybersecurity, Data and Robotics. Overall, these areas and Photonics, Quantum and Microelectronics show a strong supplier base in the EU. Other countries regularly used by the private sectors in their supply chain include the UK, Switzerland, Israel, Japan, South Korea, and Singapore. Norway, Canada, India and South Africa are more selectively relevant for specific technology areas.

In terms of markets for new products arising from R&I portfolios, surveyed EU companies also indicated where they sell their technologies. This could be considered a measure of competitiveness, as well as potential for reverse dependencies. Here we see that the largest markets for selling technologies are mostly within the EU and/or the organisations' own country. After that the US is a consistently important market for companies, with South Korea, Japan, Canada, Switzerland, Norway and Taiwan as important markets for a significant number of the technology areas. Countries such as India, South Africa, Singapore are relevant for selected technology areas. In general, when looking outside the EU and EEA/UK, Cloud-edge-IOT, Data, HPC, Photonics, Microelectronics have relatively high exports, with Cybersecurity, Blockchain, Advanced Connectivity, AI, Robotics and NGI/XR showing less technology exports.

Table 11 Sourcing: from which EU and non-EU countries does your organisation primarily source key supplies, materials, technologies or high-tech solutions/products related to the respective technology area?

	AI	Advanced connectivity	Blockchain	Cloud-edge-IoT	Cybersecurity	Data	HPC	Photonics	Quantum	Robotics	Microelectronics	NGI & XR
Same country as my organisation	47%	33%	50%	53%	69%	76%	57%	75%	63%	70%	50%	46%
Other country/ies in EU-27	55%	56%	33%	53%	46%	57%	57%	75%	88%	70%	80%	62%
UK	23%	28%	17%	18%	15%	33%	29%	13%	38%	10%	20%	31%
Norway	0%	17%	17%	0%	0%	0%	0%	0%	0%	0%	10%	8%
Switzerland	11%	11%	17%	0%	8%	10%	14%	13%	13%	10%	10%	0%
Canada	0%	17%	17%	0%	0%	0%	0%	0%	13%	0%	0%	8%
India	6%	0%	17%	0%	8%	0%	14%	0%	0%	0%	0%	0%
Israel	11%	0%	17%	18%	15%	19%	14%	0%	13%	0%	0%	8%
Japan	13%	17%	17%	18%	15%	5%	14%	50%	38%	0%	40%	8%
Singapore	5%	17%	17%	0%	8%	5%	0%	0%	0%	0%	10%	8%
South Africa	2%	6%	17%	0%	0%	0%	0%	0%	6%	0%	0%	8%
South Korea	11%	17%	0%	12%	8%	0%	14%	13%	6%	20%	20%	15%
Taiwan	27%	22%	33%	29%	15%	19%	29%	25%	13%	30%	60%	8%
US	64%	56%	67%	65%	54%	71%	57%	75%	75%	30%	70%	62%
Other	13%	11%	0%	12%	15%	5%	14%	38%	19%	0%	10%	8%

Source: Technopolis Group based on stakeholders' survey

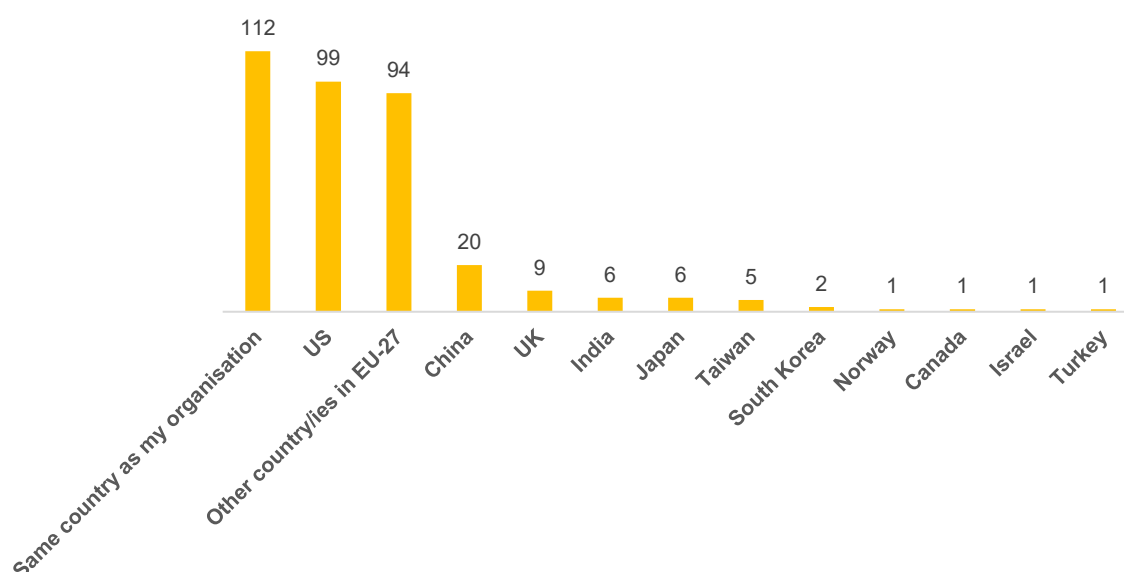
Table 12 Selling: to which EU and non-EU countries does your organisation primarily sell your technologies or provide access to your testing facilities/pilot lines, infrastructure/services, or export high-tech solutions/products, that leverage digital technologies?

	AI	Advanced connectivity	Blockchain	Cloud-edge-IoT	Cybersecurity	Data	HPC	Photonics	Quantum	Robotics	Microelectronics	NGI & XR
Same country as my organisation	47%	50%	40%	73%	79%	81%	57%	78%	63%	80%	70%	56%
Other country/ies in EU-27	44%	56%	40%	60%	64%	71%	57%	67%	69%	70%	90%	56%
UK	15%	25%	20%	33%	14%	48%	29%	33%	31%	0%	10%	33%
Norway	3%	19%	20%	13%	0%	0%	0%	0%	6%	0%	10%	11%
Switzerland	3%	6%	20%	13%	7%	24%	14%	11%	6%	0%	10%	22%
Canada	4%	13%	20%	13%	0%	10%	0%	33%	13%	0%	20%	11%
India	4%	6%	0%	7%	0%	0%	14%	33%	13%	0%	0%	0%
Israel	6%	0%	40%	20%	0%	19%	14%	11%	6%	0%	10%	0%
Japan	6%	6%	0%	13%	14%	10%	14%	33%	31%	0%	30%	11%
Singapore	0%	6%	20%	13%	0%	5%	0%	11%	6%	0%	10%	11%
South Africa	1%	6%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%
South Korea	5%	19%	20%	0%	0%	5%	14%	11%	31%	0%	10%	11%
Taiwan	5%	6%	20%	13%	0%	14%	29%	11%	13%	10%	30%	0%
US	23%	19%	20%	47%	21%	48%	57%	44%	38%	20%	40%	33%
Other	3%	19%	0%	13%	7%	10%	14%	22%	13%	0%	0%	0%

Source: Technopolis Group based on Stakeholders' survey

Similarly to the stakeholder survey, European companies that participated in the telephone-based market survey indicated that they source their key supplies and materials related to the critical technology they develop or adopted mostly from the same country where they are located, followed by the US in the second place. Many also source key supplies from other EU countries and from China (see Figure below).

Figure 30 Collaboration in terms of sourcing key supplies, materials and technologies (From which EU and non-EU countries does your company primarily source key supplies, materials, technologies or high-tech solutions/products leveraging digital technology?)



Source: Technopolis Group (2025) based on market CATI survey results, n=380

The main collaboration partners vary by technology area. For **AI, HPC, Blockchain, and Microelectronics**, organisations surveyed indicated that they most often collaborate with partners from the United States. For Robotics, Photonics, and Quantum, the main partners are typically located in other EU-27 countries. For all other technologies, collaborations are primarily domestic, involving partners from the same country as the organisation.

Table 13 Main collaboration partner to source key supplies, materials and technologies

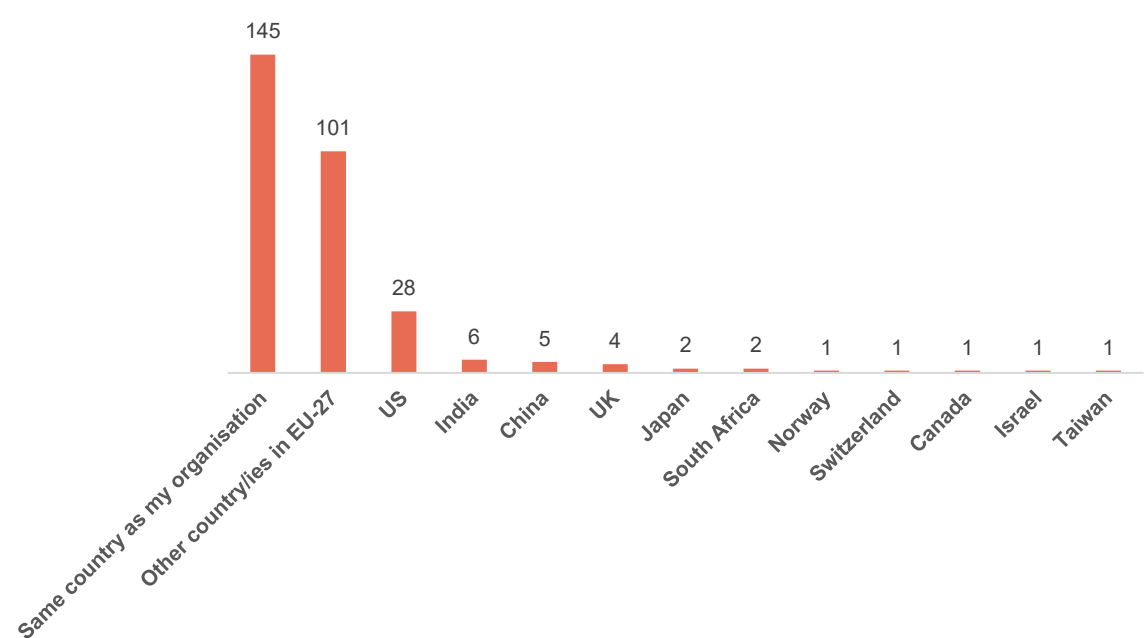
Technology	Main collaboration partner
Artificial Intelligence	US
Cybersecurity technologies and digital identity	Same country as my organisation
Robotics	Other country/ies in EU-27
Cloud, Edge, Internet-of-Things	Same country as my organisation
Data analytics and data sharing technologies	Same country as my organisation
Advanced digital communications and connectivity	Same country as my organisation
Next-generation internet and extended reality	Same country as my organisation
High-Performance Computing (HPC)	US

Photonics	Other country/ies in EU-27
Technologies for interoperability	Same country as my organisation
Quantum	Other country/ies in EU-27
Blockchain and distributed ledgers	US
Microelectronics	US

Source: Technopolis Group (2025) based on telephone based market survey results, n=380

In terms of sales partners, the surveyed companies primarily sell their products to organisations within their own country, followed by other EU-27 countries. This may indicate that EU tech companies, as well as their products and services, are focused more on domestic and intra-EU markets rather than on international expansion. The US, UK, India, and China also feature as important international markets.

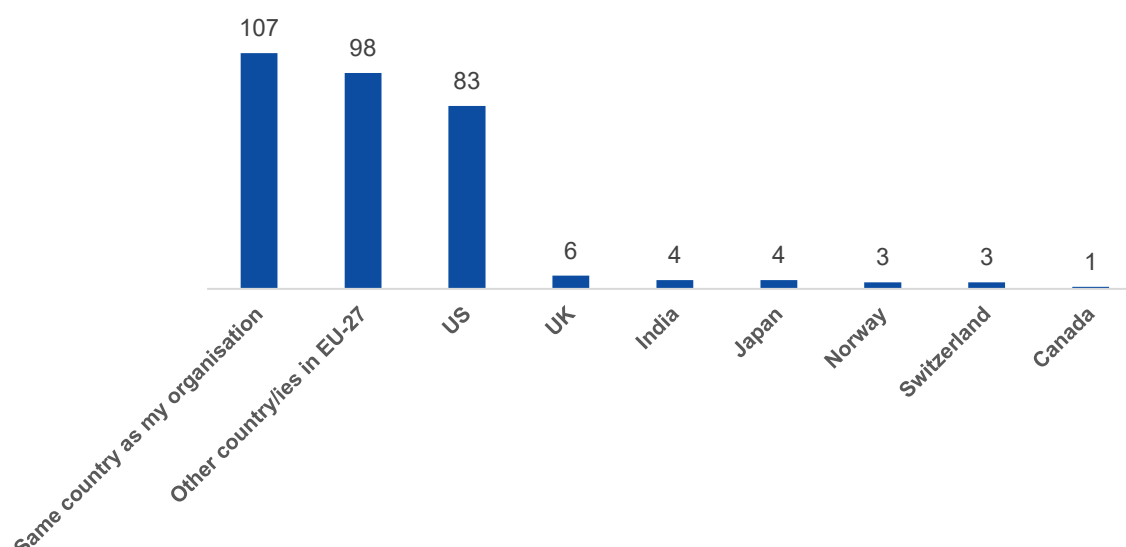
Figure 31 Collaboration in terms of selling partners (To which EU and non-EU countries does your company primarily sell key supplies, materials, technologies, access to infrastructure, or high-tech solutions/products leveraging Microelectronics-related technology?)



Source: Technopolis Group (2025) based on telephone based market survey results, n=380

Interestingly, companies see their main competitors actually coming from other EU countries or the same country within the EU-27 and much less internationally related to research and adoption of critical digital technologies which points out that European research is still seen strong within Europe. Other competitors companies mention come from the US, UK, Japan and India.

Figure 32 Origin of main competitors of companies related to the research & adoption of critical digital technologies (From which EU-27 and non-EU countries do your main competitors come from, related to the research & adoption of Photonics technology?)



Source: Technopolis Group (2025) based on telephone-based market survey results, n=380

1.5. Dependencies and reverse dependencies

The EU faces key strategic dependencies across several digital technology areas, particularly related to **hardware components, computing infrastructure, digital services and critical raw materials**¹⁰⁷. Many of these dependencies stem from the dominance of the US in services and software, and reliance on global supply chains especially in Asia for hardware inputs.

The current understanding of experts on dependencies and reverse dependencies based on the Delphi survey is presented in the Figure below. Overall, it is evident that somewhat higher dependency in R&I on the rest of the world than vice versa. This is particularly true for the area of 'technology excellence', where on most areas the dependency is rated as high. Dependencies are lower in terms of testing and experimentation facilities for R&D (except for AI, blockchain and interoperability). Dependencies on specific R&D actors are relatively balanced, with other countries strong in Advanced Connectivity, AI, Blockchain and NGI, while the EU has strong players in Blockchain, Data analytics, Interoperability, Microelectronics and also NGI.

Figure 33 Level of international dependencies of the EU in technology R&I

Technology	Technology excellence	Testing and experimentation facilities for R&D	Specific actors in the R&D ecosystem	Technology excellence	Testing and experimentation facilities for R&D	Specific actors in the R&D ecosystem
	Dependencies			Reverse dependencies		
Microelectronics	High	Some	Some	Some	Some	High
Photonics	Some	Some	Some	High	Some	Some
HPC	High	Some	Some	Some	Some	Some
Quantum	Some	Some	Some	High	Some	Some
AI	High	High	High	Some	Some	Some
Data	Some	Some	Some	High	High	High
Robotics	Some	Some	Some	Some	Some	Some
Advanced connectivity	High	Some	High	Some	Some	Some

¹⁰⁷ See also European Commission. (2023). Report on the state of the Digital Decade 2023 (COM(2023) 570 final). Publications Office of the European Union.

Technology	Technology excellence	Testing and experimentation facilities for R&D	Specific actors in the R&D ecosystem	Technology excellence	Testing and experimentation facilities for R&D	Specific actors in the R&D ecosystem
Cloud-Edge IoT	Some	High	Some	Some	Some	Some
Blockchain	High	High	High	High	Some	High
Cybersecurity	High	Some	Some	Some	Some	Some
NGI and XR	High	Some	High	Some	Some	High

Source: Technopolis Group (2025). Delphi survey analysis

As highlighted by expert discussions, dependencies are not inherently a problem, provided **the system can protect itself from closed environments and remain open**, however in current geopolitical contexts this cannot be assumed. Regarding the options to develop technological independence from the US, stakeholders participating in this study argued both ways some stating the importance to invest in the European stack vertically, others claiming that Europe should secure influence by integrating into the global tech infrastructure and creating high-quality, EU-standardised models.

As also highlighted in the study on the EU's critical digital capacities deployment beyond 2027¹⁰⁸, the EU faces **significant strategic dependencies across the digital technology stack**, from the physical inputs needed to produce semiconductors to the cloud infrastructure, AI models and software platforms that underpin advanced digital applications. In microelectronics, Europe remains a net importer of semiconductors and critical inputs, while its domestic production capacity remains well below the level needed to ensure strategic autonomy¹⁰⁹. This dependence extends to critical raw materials such as lithium, cobalt, nickel and rare earth elements, for which the EU relies heavily on non-European suppliers, particularly China¹¹⁰. These upstream dependencies translate into vulnerabilities in AI computing infrastructure. European data centres, high-performance computing systems and AI applications rely heavily on non-European accelerators, with NVIDIA holding a dominant position in the GPU and AI-accelerator markets¹¹¹. This concentration exposes European users to the availability, pricing and technology roadmaps of a small number of foreign suppliers and can become particularly problematic when export controls restrict access to advanced chips. Several major European supercomputers, including Leonardo, MareNostrum 5, MeluXina, Karolina, Vega and Deucalion, rely on NVIDIA GPUs, illustrating the limited availability of competitive European alternatives¹¹². Similar dependencies extend to AI infrastructure more broadly: European AI factories and other large-scale computing initiatives risk becoming reliant on foreign processors, potentially constraining Europe's ambitions for technological sovereignty¹¹³.

To address these dependencies, interoperability emerges as one of the solutions as a critical counterbalance. While it is unrealistic to expect dominant players to voluntarily adopt open, interoperable solutions, Europe could actively pursue and defend every opportunity to promote interoperability as a means of restoring fairness, resilience, and

¹⁰⁸ European Commission: Directorate-General for Communications Networks, Content and Technology, Technopolis Group, Izsak, K., Simmonds, P., Ploeg, M. et al. (eds), Study on the EU's critical digital capacities deployment beyond 2027 – Final report, Publications Office of the European Union, 2026, <https://data.europa.eu/doi/10.2759/0673677>

¹⁰⁹ European Court of Auditor (2025). Special report 12/2025: The EU's strategy for microchips-reasonable progress in its implementation but the Chips Act is very unlikely to be sufficient to reach the overly ambitious Digital Decade target. Available at: https://www.eca.europa.eu/ECAPublications/SR-2025-12/SR-2025-12_EN.pdf

¹¹⁰ European Commission Joint Research Centre. (2020). Critical raw materials for strategic technologies and sectors in the EU: A foresight study (ISBN 978-92-76-15336-8; Catalogue No. ET-04-20-034-EN-N). Publications Office of the European Union. <https://doi.org/10.2873/58081>

¹¹¹ JPR (2025). Global add-in board market. Available at: <https://www.jonpeddie.com/news/global-add-in-board-market-8-8-billion-in-q325-with-a-cagr-of-0-7-to-2029/>

¹¹² See at: https://www.eurohpc-ju.europa.eu/supercomputers/our-supercomputers_en

¹¹³ CEPS (2025). EU plans for AI (giga)factories: sanctuaries of innovation, or cathedrals in the desert Available at: <https://www.ceps.eu/ceps-publications/eu-plans-for-ai-gigafactories-sanctuaries-of-innovation-or-cathedrals-in-the-desert/>

strategic autonomy in the digital ecosystem. There are various payoffs such as fairness, by preventing dominant players from exploiting locked-in customers; resilience, by ensuring Europe can switch providers if one fails, withdraws, or is sanctioned; and strategic autonomy, by reducing Europe's vulnerability to decisions made by foreign companies or governments over infrastructure it cannot control.

Regarding reverse dependencies, the EU has strengths in the field of advanced communications and an opportunity to lead globally by investing in integrated 5G/6G infrastructure. EU-based **testbeds, open-source 5G/6G cores, and softwarised 5G testing platforms** are available and accessible to all, a capability that does not exist in some other countries like the US¹¹⁴. Projects such as 5GENESIS¹¹⁵, 5G-VINNI¹¹⁶ and 5G-EVE¹¹⁷, which together operate multi-site, end-to-end 5G testbeds explicitly designed for third-party access by industry, SMEs and international partners. These facilities support cross-border experimentation, network slicing, and vertical trials, and are open by design in a way that is uncommon outside Europe. This effort is also extended under the Smart Networks and Services Joint Undertaking¹¹⁸, which provides for the period 2021-2027 around €900 million in public funding for 5G-Advanced and 6G research, including federated 6G testbeds such as 6G-SANDBOX that allow pre-standard validation years ahead of commercial deployment¹¹⁹.

European companies like Nokia and Ericsson are seen as global leaders, and other regions and technologies are in part dependent on Europe's capabilities in this space. Both companies consistently rank among the top holders of 4G/5G standard-essential patents (SEPs), alongside or ahead of Asian and U.S. peers in declared 5G SEPs.¹²⁰

Another European strength includes leadership in open-source HPC software frameworks, domain-specific scientific codes, modular supercomputing architecture, and sustainable data centre design principles.¹²¹ EU institutions such as CERN¹²² provide valuable testbeds. However, these strengths are not irreplaceable, and the region faces the dual challenge of retaining talent and maintaining its influence in an ecosystem still dominated by foreign suppliers.

Europe's key technological position, on which other countries depend, lies in strategic infrastructure dominance in **lithography machines**, where ASML holds a global monopoly over the technology required to manufacture the most advanced semiconductors, making it indispensable to AI, cloud computing, and modern electronics worldwide. This positions Europe as a critical gatekeeper in the global chip supply chain, giving it structural power over foundational technologies¹²³. ASML's major investment in Mistral AI¹²⁴ also signals Europe's ability to link industrial hardware leadership with emerging AI ecosystems, showing that the EU's influence lies in deep-tech, core infrastructure, and strategic control points rather than consumer platforms or software dominance.

International dependencies on the EU exist and are evolving in the field of **quality datasets**. The potential for creating more reverse dependencies lies also in synthetic data that are increasingly essential for enabling functional, performance, security, and AI testing without exposing personal information. As experts interviewed in this study stressed, this is an

¹¹⁴ Based on expert consultation but see also here <https://digital-strategy.ec.europa.eu/en/news/eu-launches-eu104-million-call-boost-europes-leadership-6g>

¹¹⁵ <https://5g-ppp.eu/5genesis/>

¹¹⁶ <https://www.5g-vinni.eu/>

¹¹⁷ <https://www.5g-eve.eu/>

¹¹⁸ <https://smart-networks.europa.eu/>

¹¹⁹ More info: <https://digital-strategy.ec.europa.eu/en/news/europe-launches-first-large-scale-6g-research-and-innovation-programme#:~:text=Background%20of%20this%20decade.>

¹²⁰ LexisNexis (2025). Who is leading the 5G patent race? 2025 report. Available at: <https://www.lexisnexisip.com/wp-content/uploads/2025/01/2025-LexisNexis-5G-SEP-Report.pdf?>

¹²¹ Feedback received in Delphi survey

¹²² <https://home.cern>

¹²³ <https://medium.com/@hayatoutahar/asml-the-dutch-company-driving-the-global-semiconductor-race-5e1af1457911>

¹²⁴ <https://www.asml.com/en/news/press-releases/2025/asml-mistral-ai-enter-strategic-partnership>

important investment opportunity, although one has to take into account that generating such data is complex and requires constant maintenance to accurately reflect evolving production systems. In the field of AI, besides the strong dependencies, the EU also possesses critical capabilities which other regions rely on. Notably, the EU leads global discussions and implementation efforts on AI ethics and regulation.

Furthermore, the EU has an opportunity in creating reverse dependencies by investing in **quantum technologies and quantum photonics** and position itself to secure technological influence in the emerging quantum economy¹²⁵. As further analysed in the technology annex on quantum computing and photonics, the EU has strong research advantages in both fields and quantum represents a new area of disruptive technology with high expected impacts on various industries such as telecommunication, healthcare or manufacturing. However, it has to be noted that the future of quantum will depend on a range of raw materials that are used in quantum technologies and could face potential supply chain risks including helium, molybdenum, and certain rare earth elements such as ytterbium and holmium¹²⁶.

1.6 EU and national public investments in R&I for digital technologies

Europe's future success depends on strategic investment in cutting-edge research, and therefore robust funding for research and innovation is essential to sustain a competitive economy and a healthy society. This section presents an analysis of EU, national and regional investments in R&I of digital technologies.

1.6.1 The EU R&I programme's funding scope and volume for digital technologies

Horizon Europe has made significant investments in digital technologies, with €13.2 bn committed so far in the Horizon Europe Work Programmes 2021-2025 including the EIC/ERC 2021-2025 with a strong concentration of investments in microelectronics, AI, data and connectivity.

Following a mapping exercise using the Horizon Europe Work Programme calls, a total of €13.2 bn budget was mapped that is directed into the 12 technology areas in scope of this study. Despite the concentrated funding volumes, the programme still maintains a diversified support across a broader range of critical technologies. Across the full mapped budget of around €10.7 bn, Pillar 2 channels close to 78% of the digital technology investments, while EIC/ERC account for over 22%.

- Out of this amount, the largest commitments are allocated to Microelectronics with a total of €2.97 bn estimated funding, out of which approximately €2.6 bn (around 90%) comes from the Chips JU. **Within Pillar II alone, Microelectronics represents 24% of the mapped portfolio, making it by far the largest single technology field.**
- Second, around **€2.57 bn has been invested in Artificial Intelligence** and €1.56 bn in Data analytics, corresponding to 19% and 12% of the mapped budget respectively.
- Photonics (**€0.93 bn**) and Advanced Connectivity (**€0.97 bn**) each account for roughly 7% of the total.
- NGI & XR technologies receive around €0.94 bn (8%).
- Quantum technologies (€0.85 bn) and Cloud–Edge–IoT (€0.64 bn) each capture about 5% of the mapped funding.
- HPC (€0.58 bn), Robotics (€0.57 bn) and Cybersecurity (€0.61 bn) each represent between 4% and 5%.

¹²⁵ CEPS (2025). Strengthening the EU transition to a quantum-safe world

¹²⁶ <https://irtc.info/2024/08/21/quantum-technology-the-next-supply-bottleneck/>

- Finally, Blockchain receives only a very small share of the portfolio (around €23 m, well below 1% of the total).

Within EIC/ERC, funding is particularly concentrated on AI and deep-tech fields such as Microelectronics, Quantum and HPC, while still providing notable support across the wider set of digital technologies. A much larger share of the total investments in AI, quantum and HPC flows through EIC/ERC. AI receives about €0.68 bn under EIC/ERC (27% of the EIC/ERC digital portfolio and around 38% of total AI funding), Quantum technologies €0.34 bn (14% of the EIC/ERC portfolio and around 43% of total quantum investments) and HPC €0.28 bn (11% of the EIC/ERC portfolio and around 54% of total HPC funding). Other areas such as blockchain are also supported through EIC/ERC (close to €13 m out of a total of €23 m).

Table 14 Distribution of EC budget to the digital technology areas in Horizon Europe Work Programme 2021-2025

HE WP 2021-2025	Pillar 2 EC budget (€Million)	Pillar 2 EC budget (%)	EIC/ERC EC budget (%)	Share of Digital Funding in EIC/ERC %	Total EC budget (€Million)	Total EC budget (%)
Advanced Connectivity	€ 872,9	8%	€ 100,5	4%	€ 973,5	7%
AI	€ 1.884,6	18%	€ 689,2	27%	€ 2.573,8	19%
Blockchain	€ 10,3	0%	€ 12,8	1%	€ 23,2	0%
Cloud-Edge-IoT	€ 594,4	6%	€ 51,2	2%	€ 645,6	5%
Cybersecurity	€ 474,4	4%	€ 141,4	6%	€ 615,8	5%
Data analytics	€ 1.334,7	12%	€ 233,6	9%	€ 1.568,2	12%
HPC	€ 297,8	3%	€ 283,1	11%	€ 581,0	4%
Microelectronics	€ 2.619,4	24%	€ 355,5	14%	€ 2.974,8	22%
NGI & XR	€ 836,6	8%	€ 109,2	4%	€ 945,8	7%
Photonics	€ 867,7	8%	€ 63,8	3%	€ 931,5	7%
Quantum	€ 508,6	5%	€ 347,0	14%	€ 855,6	6%
Robotics	€ 448,8	4%	€ 122,8	5%	€ 571,7	4%
TOTAL	€ 10.750,0	100%	€ 2.510,2	100%	€ 11.094,7	100%

Source: Technopolis Group based on Cordis data retrieved in January 2026

In broader terms including other EU funding instruments, a recent analysis of the JRC estimated that €207 bn (21% of total analysed funds) support digital objectives between 2021 and 2027¹²⁷.

a. Funding scope and volume in national-level programmes for the R&I of digital technologies

The level of national investment in R&I of digital technologies differs markedly by Member State and per technology area.

European countries have launched significant national programmes to advance AI, data sharing, and cybersecurity, often complementing EU-level initiatives. France, for example, implemented a National AI Strategy between 2018 and 2022, allocating approximately €1

¹²⁷ TORRECILLAS JODAR, J. and NEPELSKI, D., Update of Mapping of EU funds to Digital Decade targets 2021-2027, Publications Office of the European Union, Luxembourg, 2025, <https://data.europa.eu/doi/10.2760/4123945>, JRC141966.

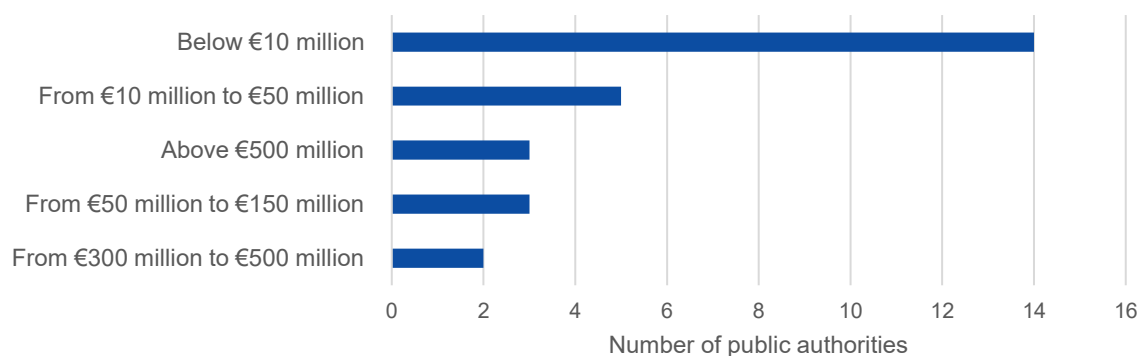
bn, with additional funding for 2022–2025. The strategy supports research, innovation, and education, including investments in supercomputing infrastructure, chairs of excellence, doctoral programmes, and interdisciplinary AI institutes. Additional initiatives include excellence clusters (€360 m), nationwide AI training (€87 m), priority research programmes (€45 m), and general-purpose AI projects (€28 m). France's PEPR programme contributes €73 m over six years, while Bpifrance provides up to €10 bn in public and co-funded investments through 2029, reinforcing the broader AI ecosystem.

Germany has similarly prioritised AI, initially allocating €3 bn, later raised to €5 bn for 2019–2025¹²⁸. The country supports AI Centres of Excellence with around €50 m annually, and in 2025 alone, €1.6 bn is committed under its AI action plan. Managed by the Federal Ministry of Research, Technology and Space, Germany's budget has grown more than twentyfold since 2017, reflecting the country's ambition to become a European hub for AI research and innovation. Other countries have also made targeted investments: Sweden supports applied AI research through Vinnova, Sweden's national innovation agency, which has invested over €9 m in the AI Sweden centre between 2020 and 2024, while Italy leverages national and EU recovery plan funds to mobilise around €1 bn, complemented by €114 m from the FAIR Foundation. Spain and smaller countries, including Belgium and Czechia, contribute through annual funding programmes ranging from tens to hundreds of millions of euros. Finland's Business Finland Data Economy programme (€135 m through 2027) and Estonia's Innovation Fund (€1.1 million) further illustrate the commitment to enabling national AI and data initiatives.

Data sharing and digital infrastructure are also central to national strategies. In France, €45 million from the Recovery and Resilience Plan supports the full data lifecycle, with ongoing investments in data-sharing initiatives. Bpifrance continues to fund projects related to data spaces through 2026, while countries like Estonia and Finland have established frameworks to ensure secure cross-sector data exchange. These programmes aim to build interoperable, secure, and scalable data infrastructures that enable both public and private sector innovation.

Cybersecurity represents another key area of national investment. Germany's federal strategy (2021–2025) funds projects on critical infrastructure security, cloud and IoT protection, and post-quantum cryptography research. France has implemented a national "Cybersecurity and Defence" investment plan of roughly €1 bn, while the Netherlands coordinates its National Cybersecurity Research Agenda to align university research and grants. Other Member States, including Belgium, Finland, and Italy, support national cyber research calls and specialised centres. Private investment complements these public efforts, with venture capital and corporate funding increasingly targeting AI-based security, endpoint protection, and cloud-native cybersecurity technologies.

Figure 34 What is the estimated yearly funding scale of national-level programmes supporting R&I of digital technologies?



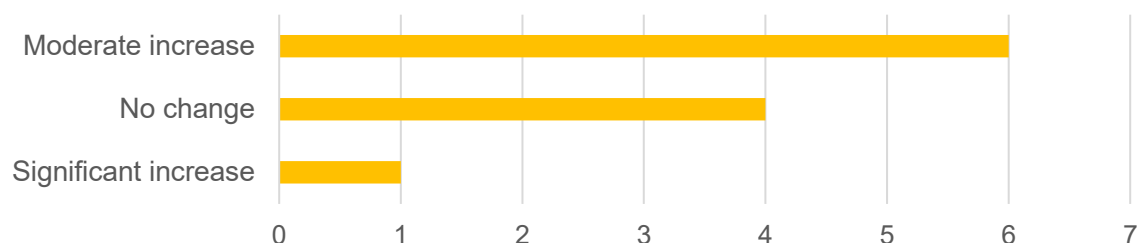
Source: Technopolis Group (2025) based on public sector survey on public investments, including

¹²⁸ The Federal Government (2025). The High-Tech Strategy 2025 Progress Report

the countries mentioned on the graph and estimated for the rest of EU based on the review of digital decade roadmaps

At national level, countries indicated a moderate increase in terms of supporting advanced digital technologies over the next years.

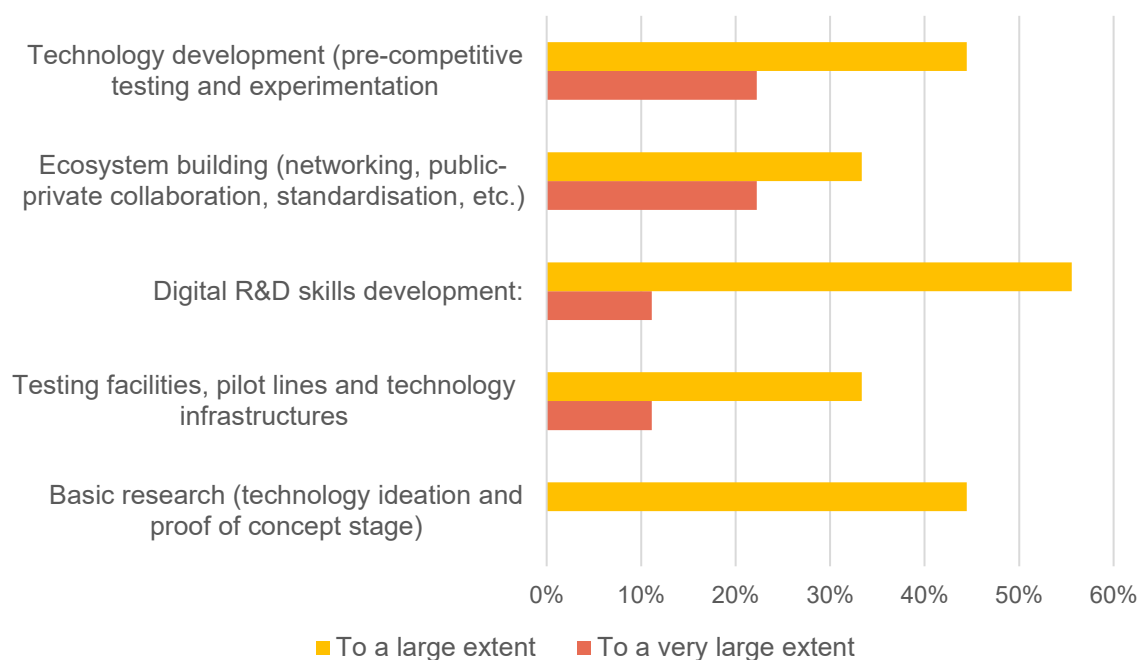
Figure 35 How is the scale of those funding programmes supporting advanced digital technologies at national level expected to evolve by 2028?



Source: Technopolis Group (2025) based on public sector survey on public investments

The most relevant support provided by national R&I programmes as indicated by the public stakeholder survey is related to technology development, followed by digital skills and ecosystem building.

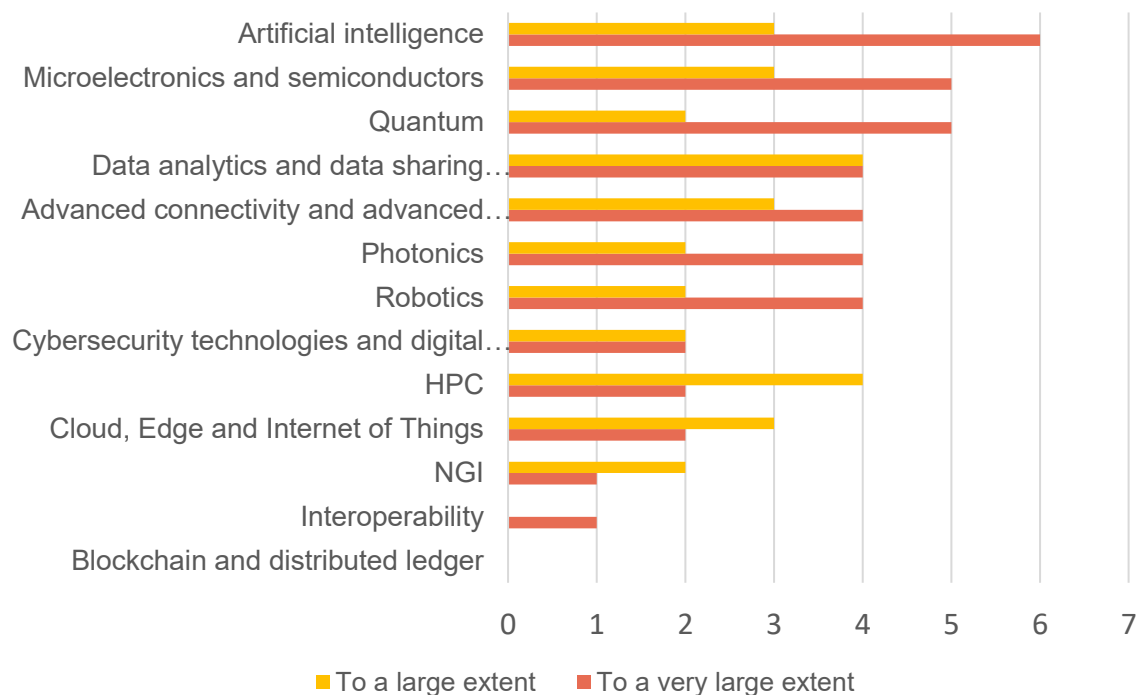
Figure 36 To what extent are these national programmes expected to provide the following types of support for the R&I of digital technologies by 2028?



Source: Technopolis Group (2025) based on public sector survey on public investments, n=21

National R&I programmes target most the development of AI followed by Microelectronics and Quantum.

Figure 37 To what extent are these national programmes expected to support R&I of these advanced digital technologies by 2028?



Source: Technopolis Group (2025) based on public sector survey on public investments, n=15

The text box presents a selection of examples of the types of initiatives being implemented by Member States.

Box 1 Example of national-level funding to support technology Research & Innovation

In December 2024, the Netherlands launched Project Beethoven, a €2.5 bn initiative in which government, industry and educational institutions are joining forces to create a complete semiconductor ecosystem through coordinated education and infrastructure investment, going far beyond R&D.

France has a national quantum research strategy that will invest €1.8 bn over five years (2021-2026), with around €1 bn from the national government and €800m from the private sector. This strategy, part of the larger France 2030 plan, focuses on various aspects of quantum technology, including computing, sensing, communication, and cryptography. The goal is to establish France as a leader in quantum technologies, ensuring national and European sovereignty in this key area. France also launched PROQCIMA, a program that aims to have two prototypes of universal quantum computers of French design by 2030. It was also announced that five companies received up to €500 million to develop those prototypes. The development of infrastructure, particularly to foster hybrid quantum-classical supercomputer use, continues to provide more French researchers access to these high-performance systems.¹²⁹

Italy's RESTART programme ("RESearch and innovation on future Telecommunications systems and networks, to make Italy smarter") will be overseen by the Ministry of University and Research (MUR) with 116 million euros, for a duration of 3 years, starting from January 2023. It is funded through the EU National Recovery and Resilience Programme. It focuses on topics such as high-capacity fixed networks, 5G/6G cellular networks, local area networks, satellite networks, the Internet, applications, and services in various sectors such as agriculture, commerce, energy, finance, industry, media, health, security, and transportation. RESTART will leverage and contribute to technologies such as distributed cloud, artificial intelligence, programmable hardware architectures, integrated optics and optical computing, optoelectronics, and sensing. The activities encompass seven "missions": 1) Research; 2) Laboratories, Proof of Concept, and Demonstrators; 3) Innovation and Technology Transfer; 4) Support for Start-ups and Spin-offs; 5) Education and Training; 6) Research Doctorates; 7) Communication, Standardisation and Open Source Solutions.

¹²⁹ Taken from the French National Quantum Update (March 2024).

Spain launched its Quantum Technologies Strategy (2025-2030) in April 2025 with an initial investment of €808 million, supporting quantum computing, communications, and sensing. Funding is drawn from the ERDF and Recovery, Transformation and Resilience Plan (RTRP) and is expected to reach €1.5 bn when including leveraged public and private capital. Seven technical priorities are defined: industrial capability building, quantum-AI algorithm convergence, leadership in communications, demonstrations in sensing and metrology, post-quantum privacy infrastructure, research infrastructure and skills, and coordinated national governance. In terms of applications, the strategy identifies several near-market opportunities: quantum sensing for navigation without satellite reliance, post-quantum cryptography for secure communications, quantum simulation for drug discovery, and modelling tools for climate risk and power grid optimisation.

France, Germany, and the Netherlands have awarded over €30 million in joint funding to a new set of quantum R&D projects under the first Trilateral Call for Quantum Innovation. The initiative, launched in March 2024, supports European cross-border collaboration in quantum computing, communication, and sensing technologies. French partners received €11 million in support from the France 2030 plan, while selected projects span the broader European quantum ecosystem.¹³⁰

Source: Technopolis Group (2025) based on desk research

1.6.2 Synergies among EU and national level programmes

According to the stakeholder consultation, **68% of the respondents find it important to a very large or large extent that a future EU programme supporting digital R&D should establish synergies with national R&D public funding schemes.**

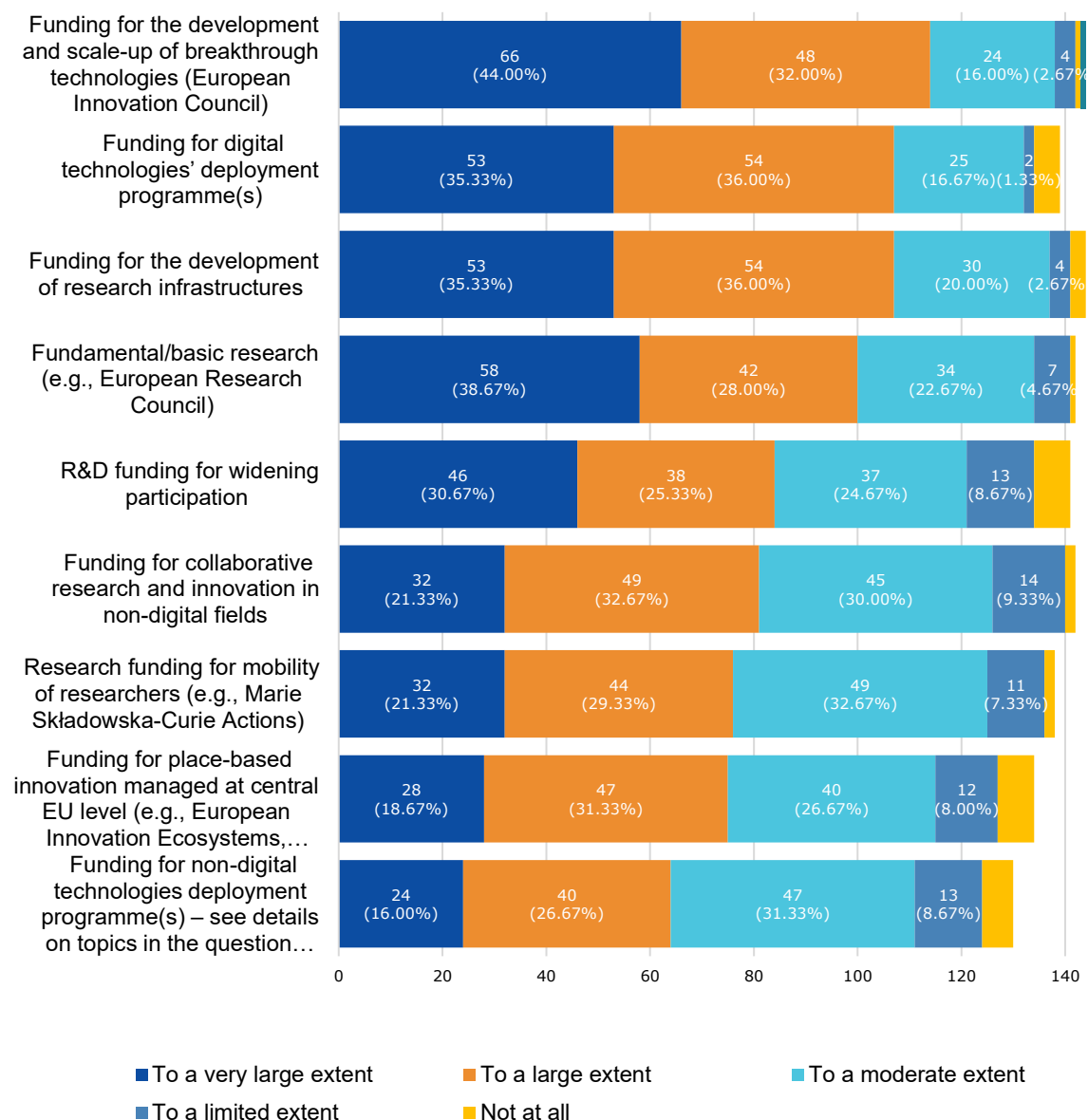
When asked to what extent a future EU programme supporting digital R&D should establish or reinforce synergies with other EU-level initiatives, the highest-ranked synergy was **funding for the development and scale-up of breakthrough technologies (European Innovation Council)**, with 44% of respondents selecting “to a very large extent” and 32% “to a large extent”.

Strong support was also reported for **funding for digital technologies’ deployment programme(s) and funding for the development of research infrastructures**, both with 35.3% responding “to a very large extent” and 36% “to a large extent”.

Funding for fundamental/basic research (e.g., European Research Council) received slightly lower, but still significant, support, with 35.3% and 38.7% of respondents indicating “to a very large extent.” Other areas, such as R&D funding for widening participation, funding for collaborative research and innovation in non-digital fields, research funding for mobility of researchers (e.g., Marie Skłodowska-Curie Actions), funding for place-based innovation managed at central EU level (e.g., European Innovation Ecosystems, Interregional Innovation Investments), saw 50-56% of respondents selecting either “to a very large extent” or “to a large extent”. Funding for non-digital technologies’ deployment programmes ranked lowest, with 31% selecting “to a moderate extent” and a relatively high 13% indicating “I don’t know.”

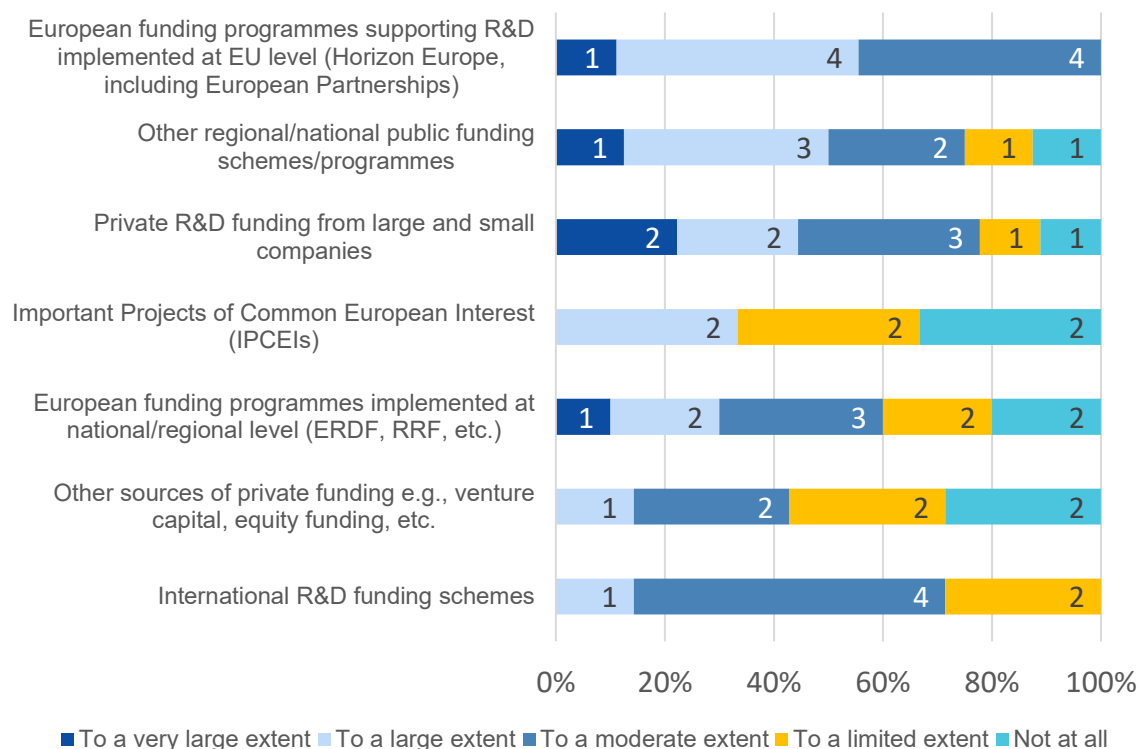
Figure 38 Extent to which an EU programme supporting the research and development of digital technologies (2028-2034) should establish or reinforce synergies with other EU-level initiatives

¹³⁰ <https://quantumcomputingreport.com/france-germany-and-netherlands-launch-e30m-33-8m-usd-trilateral-quantum-rd-funding-program/>



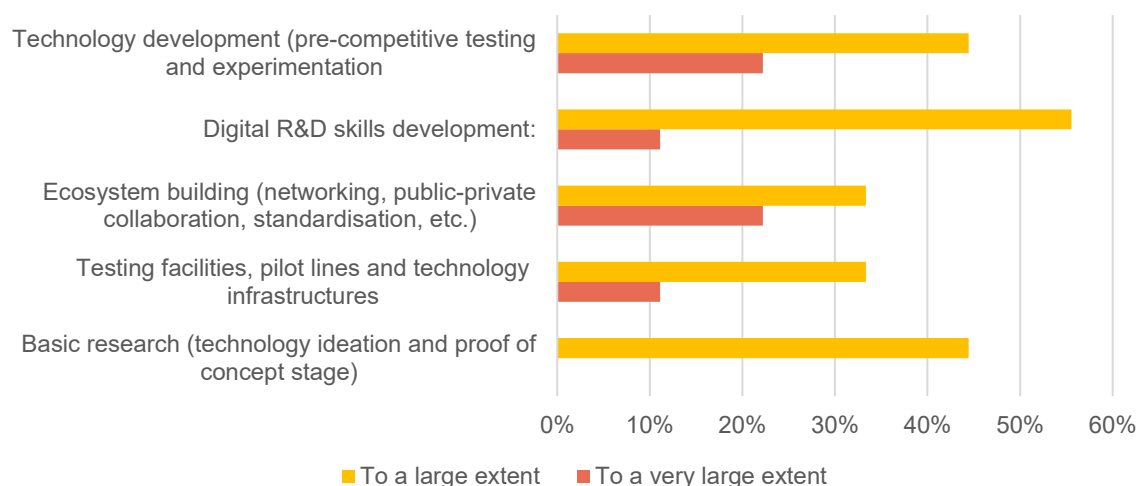
Source: Technopolis Group (2025) based on stakeholder consultation survey n=150

Figure 39 In your experience, to what extent are there synergies between these national programmes supporting advanced digital technologies with the following additional funding sources, for R&I?



Source: Technopolis Group (2025) based on public sector survey on public investments, n=32

Figure 40 To what extent are these national programmes expected to provide the following types of support for the research/development of advanced digital technologies by 2028?

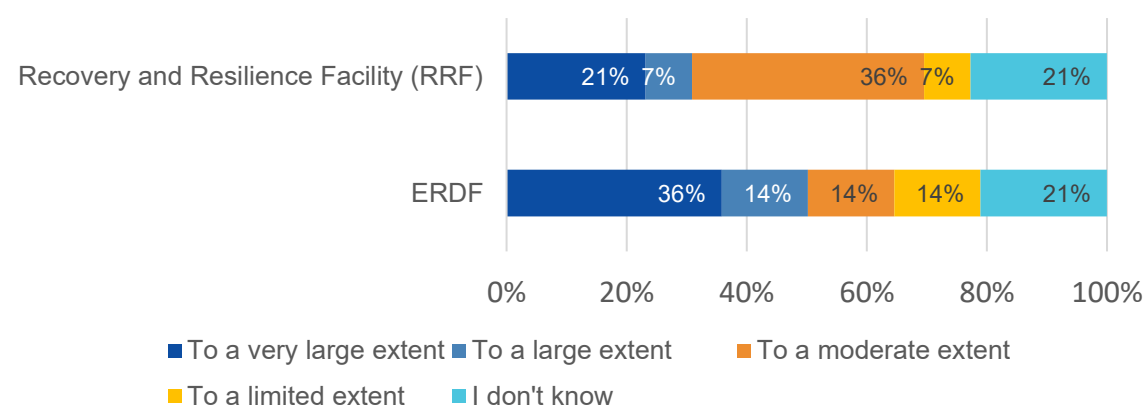


Source: Technopolis Group (2025) based on public sector survey on public investments, n=32

The European Regional Development Fund (ERDF) is given higher importance as relevant in complementing other national programmes in R&I. The European Regional Development Fund plays a key role in strengthening research and innovation in digital technologies by financing the infrastructure, capabilities, and projects needed for regions to develop advanced digital solutions. ERDF supports the creation of AI and data labs, cybersecurity and robotics testbeds, and other digital R&I facilities, it funds SMEs and research organisations to develop new software, algorithms, and digital tools, and strengthens regional ecosystems through Digital Innovation Hubs, clusters, and technology transfer centres. This support is provided in the context of the ERDF's broader objective to enhance economic, social, and territorial cohesion and aiming to make Europe's regions

more competitive and smarter. The focus is on strengthening innovation capacity, digital infrastructure, and smart specialisation within European regions and as such it is complementary to other European funds.

Figure 41 To what extent are the EU programmes implemented at national level supporting R&I in advanced digital technologies in your country?



Source: Technopolis Group (2025) based on public sector survey on public investments, n=21

Regional-level programmes for the R&I of digital technologies

Across Europe, regional initiatives play a key role in driving digital transformation, complementing national and EU-level strategies with targeted investments tailored to local strengths and needs. Many regions focus on supporting SMEs, innovation ecosystems, and emerging technologies through grants, infrastructure development, and strategic programmes. Examples include cybersecurity support schemes, AI innovation hubs, digitalisation vouchers, and large-scale ecosystem investments. The following cases illustrate diverse regional approaches to digital investment. These investments can be instrumental in driving R&I in regional and local technology clusters and improve the R&I performance of specific regions as also evidenced by recent studies. Between 2014 and 2023, some European regions improved their R&I performance where actions under ERDF supporting territories’ development, to enhance institutional capacity and to improve public administration were critical for promoting cohesion, counterbalancing potential closed-club effects and enhancing the overall competitiveness of the EU¹³¹.

Box 2 Examples of regional-level funding to support the digital transition

Austria (Styria). In Styria the Cyber!Sicher programme offers grants (ongoing since 2019) for SMEs to boost cybersecurity through consulting, investment, and training, typically offering up to €15,000 per project.¹³²

Belgium (Flanders). The Flanders Policy Plan Cybersecurity, launched in 2019 and extended in 2024, operates an annual budget of €15m and promotes cybersecurity research and the use of cybersecurity solutions by businesses.¹³³

Czechia (Ústí Region). Under the Just Transition Programme 2021–2027, the Ústí Region provides Digital Vouchers for SMEs, covering up to 80% of eligible costs with grants ranging from CZK 50,000 to CZK 500,000 to support digitalisation projects.¹³⁴¹³⁵

¹³¹ European Commission (2024). EU R&I ecosystems (Chapter 4). In Science, Research and Innovation Performance of the EU, 2024 (pp. 233–?). Publications Office of the European Union.
https://ec.europa.eu/assets/rtd/srip/2024/ec_rtd_srip-report-2024-chap-04.pdf

¹³² Cyber-solutions, Funding for digitalisation in Austria, [Online](#)

¹³³ EC (2025), Study on Digitalisation of Business in the EU Member States: Initiatives, Impacts and Contribution to the Digital Decade – Belgium, 2024 Report, [Online](#)

¹³⁴ Ústí Region, Business, [Online](#)

¹³⁵ Support to the implementation of the Just Transition in the Czech Republic, [Online](#)

Germany (Baden-Württemberg). The AI Innovation Park in Heilbronn received €50 million (from 2023) to build regional strengths in AI research, startups, and applied use cases.¹³⁶¹³⁷

Netherlands (North Brabant). Through Project Beethoven (2024–2030), national and regional authorities are investing €2.51 bn to reinforce the Brainport ecosystem, backing education, talent, housing and infrastructure for the semiconductor/chip-equipment industry.¹³⁸

Spain (Community of Madrid). GovtechLab Madrid operates with an annual €155 000 budget to run open-innovation challenges and technical assistance that connect public needs with digital/GovTech and AI solutions from startups and SMEs.¹³⁹

Sweden (Västra Götaland). AI Sweden, headquartered in Gothenburg and co-funded by Västra Götalandsregionen and ERDF partners, benefited from ~€9 million (2020–2024) from Vinnova to scale applied AI across sectors.¹⁴⁰¹⁴¹

Romania (North-East Region). The eDIH – Digital Innovation Zone (eDIH-DIZ), launched in 2022, has a budget of €4 million, for the period 2022-2025 (approx), and helps SMEs and public health institutions adopt AI and other key enabling technologies in the manufacturing and smart health sectors.¹⁴²

Source: Technopolis Group (2025) based on desk research

1.7 Private R&I investments in the development of digital technologies

1.7.1 Level of private investments by European companies

R&I investments into digital technology in Europe presents a mixed picture. Investments in digital technologies by EU companies have been growing over time and play an increasingly important role in driving economic growth in areas such as ICT, and more specifically in AI, Cloud, and digital infrastructure¹⁴³. However, the investments of top EU ICT companies were down 8.9% in 2024 and were stagnating in hardware, with exits from the top 2 000¹⁴⁴ and significant reductions in R&D from key players as concluded by the 2025 R&D Investment Scoreboard¹⁴⁵. EU investment in ICT faces significant challenges, including structural weaknesses, and a widening gap with global competitors¹⁴⁶. **Compared to the United States, the EU shows clear underspecialisation in digital sectors, with much lower investment shares and scale.** As found by the EIB, the EU invested €110 bn in software in 2024, while more than €350 bn was invested in the US and €60 bn in China. The gap is further reinforced by weaker capital expenditure, particularly in AI-related infrastructure, where EU firms are lagging behind.

The telephone-based market survey conducted in the framework of this study confirms the relatively lower levels of EU R&I investments in most of the digital technologies. The investment data reveals a highly uneven distribution across technology areas (see Table below). **While Photonics and Blockchain have the highest average investment level, Data analytics and NGI have the least.** Most digital technologies including AI exhibit a low

¹³⁶ Wirtschaft digital, IPAI – Innovation Park AI Baden-Württemberg, [Online](#)

¹³⁷ IPAI, A vision takes form: IPAI presents next development stage of the IPAI campus, [Online](#)

¹³⁸ Brainport Eindhoven (2024), State and region put 2.5 bn euros into public facilities in Brainport Eindhoven and national talent plan for growth of national chip industry, [Online](#)

¹³⁹ EIPA, Madrid Govtech, [Online](#)

¹⁴⁰ AI Sweden, About, [Online](#)

¹⁴¹ Vinnova, Artificial Intelligence, [Online](#)

¹⁴² Digital-Innovation Zone, EDIH-DIZ: The digitalization initiative for SMEs in the manufacturing and healthcare sectors, [Online](#)

¹⁴³ European Investment Bank. (2026). Investment report 2025/2026: Capitalising on Europe's strengths – Chapter 5. <https://www.eib.org/files/publications/20250379-030326-investment-report-2025-chapter5-en.pdf>

¹⁴⁴ The EU Industrial R&D Investment Scoreboard identifies the world's top 2,000 corporate investors in research and innovation, comprising firms that together account for approximately 85–90% of global business-funded R&D expenditure and serve as a benchmark for comparing innovation performance across sectors and regions.

¹⁴⁵ https://iri.jrc.ec.europa.eu/scoreboard/2025-eu-industrial-rd-investment-scoreboard#field_reportscoreboard

¹⁴⁶ Also reported by the EIB Investment Report 2025/2026

level of annual spending around €100 000¹⁴⁷. High R&D investment in Photonics is explained by its capital-intensive nature, as it relies on specialised infrastructure, advanced equipment, and long development cycles, and involves a relatively small number of highly specialised firms. Blockchain is driven by financial applications, platforms, networks, and digital financial infrastructures that also have high related R&D costs. Compared to these fields, areas such as Data analytics or even AI may appear to require lower average investment at firm level, particularly among SMEs, due to lower entry barriers and their software-based nature, although at large scale they can also involve substantial R&D spending. More specifically:

- **Photonics** stands out with a high, average investment level of **€2.95 m**. The companies investing in photonics R&D and responding to the survey are predominantly high-tech, specialised SMEs operating in deep-tech and advanced engineering sectors. Most focus on niche markets such as precision lasers, fibre optics, quantum materials, or customised robotic systems.
- **Blockchain also has a high average investment level.** The companies responding to the survey include mid-sized, innovation-driven firms operating in the blockchain and Web3 ecosystem, combining technology development, financial services, and investment activities. Their work spans tokenisation platforms, smart contract and decentralised application development, and enterprise blockchain integration, alongside investment in digital assets and early-stage ventures.
- Mid-level average funding is directed toward technology areas such as **HPC (€486 000)**, **Microelectronics (€441 000)**, and **Quantum (€239 000)**, reflecting their strategic importance alongside higher barriers to entry and longer development horizons.
- Technologies such as **Artificial Intelligence (€119 000)**, **Robotics (€147 000)**, and **Cybersecurity (€86 000)** receive comparatively lower average investment, due to their more software-driven nature and lower capital requirements. Moreover, the investment levels also reflect that there are a larger number of companies including SMEs doing R&D but they have fewer financial means, hence the average investments are lower.
- **Data analytics (€59 000)** ranks lowest.

Table 15 Average annual investments into the R&D of digital technologies

Technology areas	Average annual investment of companies
Photonics	€ 2.945.278
Blockchain and distributed ledgers	€ 1.344.500
Cloud, Edge, Internet-of-Things	€ 875.850
High-Performance Computing (HPC)	€ 486.273
Microelectronics	€ 441.250
Quantum	€ 239.126
Robotics	€ 147.870
Artificial Intelligence	€ 119.507
Advanced digital communications and connectivity	€ 94.068

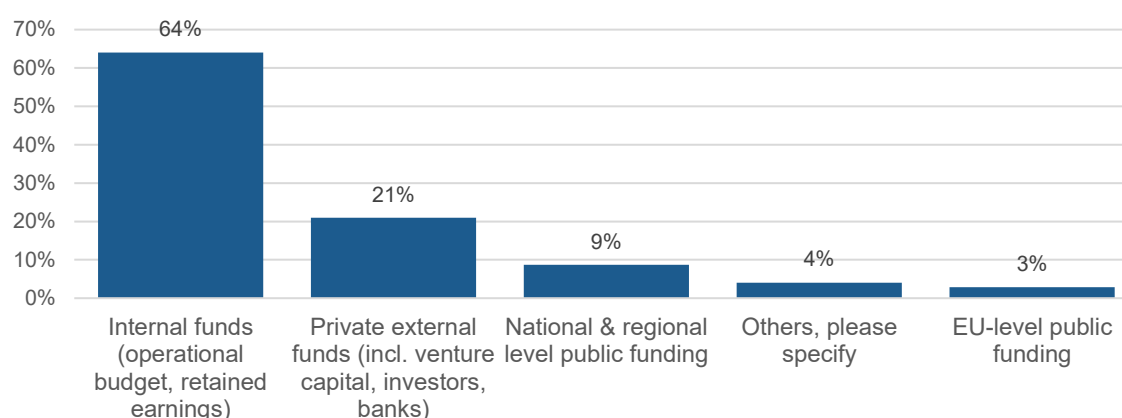
¹⁴⁷ The results of the market survey should be interpreted in light of the total number of respondents and taking into account the breadth of the 12 technology areas. While the survey was designed and stratified to be representative to the extent possible, the number of observations is still limited.

Cybersecurity technologies and digital identity	€ 86.361
Next-generation internet and extended reality	€ 80.542
Data analytics and data sharing technologies	€ 59.940

Source: Technopolis Group (2025) market CATI survey, n=398

According to the survey of this study, companies most frequently invest in in-house R&D activities and secondly R&D collaboration with other actors. R&D-related investments are also primarily applied research focused and aim at experimental development. **Companies interviewed use most often their internal funds (64% of those that invest in digital) to finance the development of advanced digital technologies** such as AI or Data analytics. 21% of companies interviewed indicated that they use private external funds and a smaller share (9%) that rely on national or regional public funding. Only 3% rely on EU level funding.

Figure 42 Source of investment into R&D and adoption by private firms



Source: Technopolis Group (2025) market CATI survey, n=398

Many companies expect their future funding sources to shift and diversify, with a mix of internal financing, public investment, and EU or national grants as found by the market survey. Some foresee relying more on self-generated revenue as they grow, aiming for greater financial independence, while others hope to access additional external support through European funding programmes, government initiatives, or private investors. A quarter of the respondents also indicated that they anticipate forming new partnerships, winning competitive grants, or leveraging technological advancements to secure new funding opportunities. Overall, there is a clear expectation of increased financial resources in the coming years, though the balance between public, private, and internal funding is expected to vary across organisations. Some anticipate a stronger increase in public funding, while others plan to rely more heavily on private investments or internal budget allocations depending on strategic priorities and the opportunities of the companies.

The leading private R&D investors in digital technologies in Europe are concentrated among a small number of large multinational firms, notably Siemens, Ericsson, Nokia and ASML according to the R&D investment scoreboard. These companies stand out as the highest R&D spenders in the EU digital landscape, driven by their global leadership in areas such as industrial digitalisation, enterprise software, telecommunications infrastructure, and semiconductor technologies. In addition, Europe's main software and IT services players, including SAP, Amadeus, and Dassault Systems, also contribute significantly to digital R&D investment. These firms are key actors in enterprise software and digital platforms but remain considerably smaller than the US Big Tech counterparts.

The primary motivations behind R&I investment in digital technologies include the increased revenues and/or market share (expansion) and the identification of promising technology and tailoring to specific needs. Revenue growth and market

expansion are the most common primary benefits in more mature technologies such as Advanced Connectivity, Cloud/Edge/IoT, and Cybersecurity. In these areas, firms invest in R&D mainly to scale up, compete, and capture market share, with productivity gains or diversification as secondary outcomes. In the case of Quantum, Robotics, NGI & XR and Data, the most relevant motivation is the identification of promising technology and tailoring to specific needs. In other fields such as Blockchain, HPC, and Microelectronics the main benefit is early adoption and first-mover advantage, reflecting a strategic focus on gaining a technological edge.

Table 16 Main benefits for R&D investments in digital technologies as reported by companies in the EU in 2025

	Top 1# benefit for R&D investments	Top 2# benefit for R&D investments
Advanced Connectivity	Increased revenues and/or market share (expansion)	Increased productivity
Artificial Intelligence	Increased productivity	Identification of promising technology and tailoring to specific needs
Blockchain	Early adoption of new technology (first mover advantage)	Increased revenues and/or market share (expansion)
Cloud-Edge-IoT	Increased revenues and/or market share (expansion)	Entry into new markets and/or sectors (diversification)
Cybersecurity	Increased revenues and/or market share (expansion)	Identification of promising technology and tailoring to specific needs
Data analytics	Identification of promising technology and tailoring to specific needs	Increased productivity
HPC	Early adoption of new technology (first mover advantage)	Increased revenues and/or market share (expansion)
Microelectronics	Early adoption of new technology (first mover advantage)	Identification of promising technology and tailoring to specific needs
NGI & XR	Identification of promising technology and tailoring to specific needs	Increased revenues and/or market share (expansion)
Photonics	Entry into new markets and/or sectors (diversification)	Identification of promising technology and tailoring to specific needs
Quantum	Identification of promising technology and tailoring to specific needs	Increased revenues and/or market share (expansion)
Robotics	Identification of promising technology and tailoring to specific needs	Early adoption of new technology (first mover advantage)

Source: Technopolis Group (2025) market CATI survey, n=398

US and other global tech giants are also a major source of digital investment, particularly in large-scale, infrastructure-driven projects focused on cloud computing and AI capacity. These investments show that US tech firms are injecting tens of billions of euros into Europe's digital ecosystem, primarily targeting hyperscale data centres, cloud infrastructure, and AI capacity. The strategic drivers are to comply with European regulatory requirements, to meet rising demand for AI services and establishing Europe as a key regional hub in global digital infrastructure networks. For example:

- Amazon¹⁴⁸ has announced one of the largest digital investments in Spain, committing €33.7 bn to expand cloud and AI data centre infrastructure. This includes building data centres, server manufacturing and logistics facilities, and is expected to significantly boost jobs and GDP while positioning Spain as a major European AI hub.
- Google is investing €5.5 bn (2026–2029) in data centres and offices in Germany, strengthening sovereign cloud and AI capabilities for European users and firms, while supporting local employment and digital infrastructure.

¹⁴⁸ <https://www.aboutamazon.com/news/company-news/amazon-spain-investment>

- TikTok owned by ByteDance is investing around €1 bn in a second data centre in Finland as part of a broader €12 bn European data sovereignty initiative, aiming to localise data storage and comply with EU regulatory requirements.

1.7.2 Venture capital investments

Europe's ability to increase private R&D investment in digital technologies depends significantly on strengthening its startup and scaleup ecosystem and its potential for unicorns, as these firms drive breakthrough innovation, attract venture capital, and enable the scaling of new technologies.

Venture capital plays a vital role in strengthening the EU's innovation ecosystem by providing the funding and strategic support that digital startups and scale-ups need to grow. However, **many of Europe's most promising tech companies struggle to access late-stage financing, limiting their ability to expand internationally and compete globally**¹⁴⁹. Beyond capital, VC also brings mentorship, market access, and business expertise, helping companies mature and navigate complex global markets. In the context of the Draghi report's call for bold action to secure Europe's competitiveness in critical technologies, VC plays an important role.

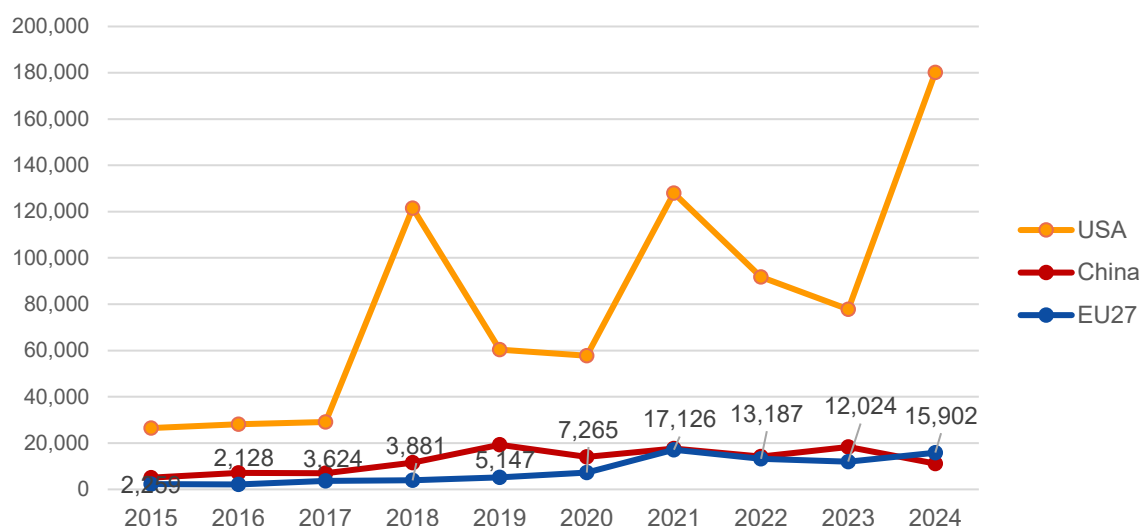
The EU landscape of 12 key digital technology areas attracted a total of €82 bn in venture capital since 2015 and €16 bn in 2024 only as the analysis of Crunchbase data particularly extracted for tech companies active in these technologies shows. Since 2015, investment in European startups has grown substantially, with early-stage funding more than doubling and growth-stage funding tripling. In line with global trends, investment into European digital technologies has expanded substantially over the past decade.

Between 2015 and 2024, capital invested in digital technologies in the EU grew at a compound annual growth rate (CAGR) of ~20% overall, with seed funding rising by 21.6% per year, early VC by 21.8% per year, and growth VC by 19.1% per year. A particularly sharp acceleration occurred in 2021 and 2022. From 2020 to 2021, investment volumes surged by 179%, while the number of funding rounds increased by 38%, peaking at €101 bn. Growth was visible across all stages, although it is the increase in Growth VC that is most revealing, where funding volumes rose by 266% and the number of rounds by 79%. Following these two exceptional years, the VC-backed ecosystem seems now to be entering a period of stabilisation. Investment levels have corrected downward from their 2021–2022 highs but remain well above pre-pandemic levels and broadly consistent with the long-term growth trajectory of European venture capital.

A small number of high-growth EU digital unicorns are emerging as key players in critical digital technologies, including Mistral AI (develops advanced AI models), Celonis (uses data to optimise business processes), DeepL (provides AI-powered translation tools), UiPath (automates repetitive digital tasks), and Klarna (offers digital payments and consumer finance solutions).

Figure 43 Venture capital investment (seed, early and growth without exits, debt financing, IPO, grants) into 12 digital technology areas in the EU over time in €m

¹⁴⁹ EIF (2024). The scale-up gap Financial market constraints holding back innovative firms in the European Union

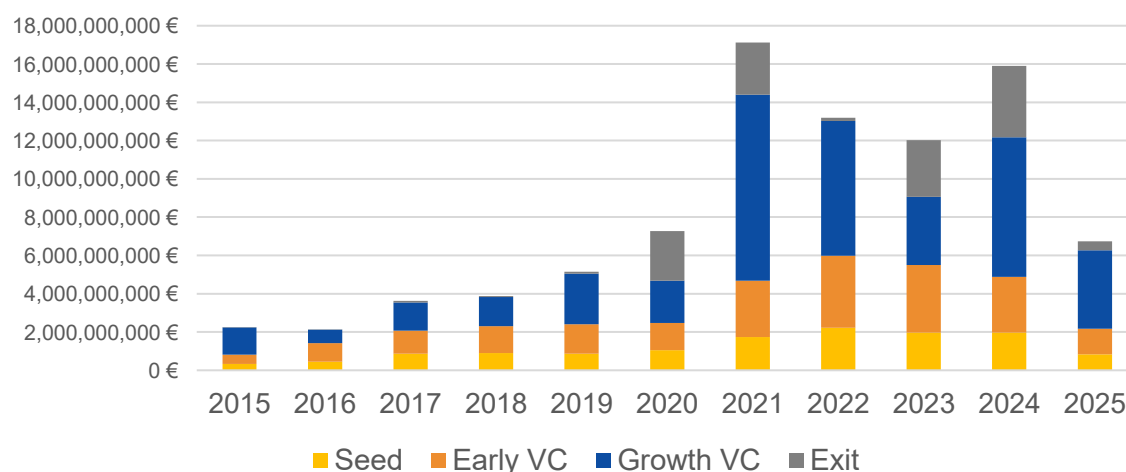


Source: Technopolis Group (2025) based on Crunchbase

Over the last decade, the number of seed financing rounds has climbed steadily, reflecting a growing availability of seed capital. In 2015, there were 607 seed-stage deals; by 2022, that count had more than doubled to 1,307 before easing slightly to 1,018 in 2023. Meanwhile, growth-stage venture-capital activity accelerated sharply around 2020–2021: early-VC deals increased from 98 in 2020 to 161 in 2021, a 64% year-over-year jump. Despite this surge in growth VC count, the 2021 spike in total funding was heavily skewed by top ten mega-rounds of at least €200 m, which together accounted for 54% of all 2021 funding volume. Notably, a single €2.3 bn round raised by Northvolt¹⁵⁰, which has since filed for bankruptcy, represented 19% of the entire VC funding pool that year. In other words, although more companies secured growth capital in 2021, over half of the funding was concentrated in just ten massive rounds, and nearly a fifth of that total flowed to Northvolt alone.

Trends also reflect that venture capital is withdrawing from early-stage investments due to the uncertain economic times, which creates a significant challenge for startups. Despite increasing integration, public stock markets remain largely national, highlighting an opportunity to establish a pan-European platform dedicated to technology companies.

Figure 44 VC investment into critical digital technologies in the EU over time and per funding stage

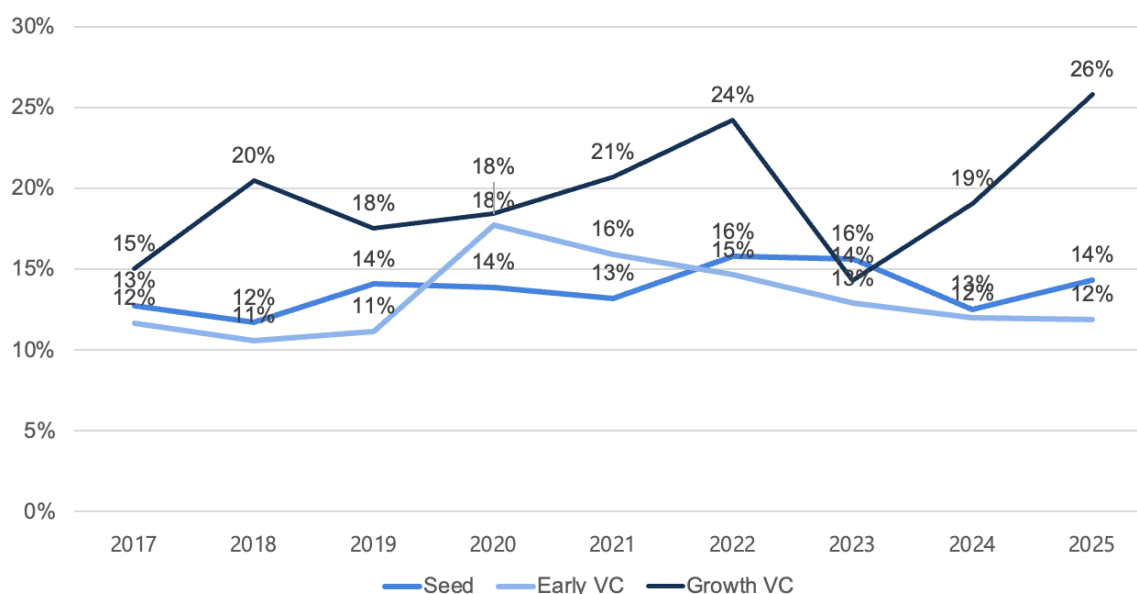


¹⁵⁰ <https://northvolt.com/>

Source: Technopolis Group (2025) based on Crunchbase

European investors have improved in supporting local growth-stage companies, but many still depend on foreign capital in particular US investors for later-stage funding. As shown in the Figure below, the share of US investors has been growing and represented 26% in growth VC in 2025. This evolution has contributed to a growing number of successful scale-ups, however, when companies reach the later stages of development, where funding rounds are typically larger and risks perceived to be lower, they often face a funding gap that domestic capital cannot fully cover. As a result, many high-potential European firms continue to rely on foreign investors, particularly from the United States, to secure the resources needed to scale globally. This dependency not only limits Europe's financial returns from innovation but can also lead to strategic assets and decision-making shifting abroad, reducing Europe's long-term competitiveness in the 12 digital technology areas.

Figure 45 Share of US investors backing up as main investors EU digital tech companies (in the 12 digital technologies monitored)



Source: Technopolis Group (2025) based on Crunchbase

Zooming into venture capital investments across the digital technology domains covered in this report reveals a highly uneven allocation of funding, with a strong concentration in a limited number of technology areas. In 2024, **Artificial Intelligence clearly dominates the EU VC landscape, attracting by far the largest share of investment volumes and deal activity. With a total of €3.67 bn invested**, AI alone accounts for the single largest portion of VC funding across the 12 digital technology fields considered, reflecting sustained investor confidence in its broad applicability and commercial potential. AI also captures the highest share of total deals, underlining both depth and breadth of investor interest. Yet, a key bottleneck on the EU VC landscape is that while European startups progressed at similar rates to their US peers, far fewer secure large funding rounds, with only 4.1% raising more than €15 m compared to 8.3% in the US, highlighting a significant growth-stage funding gap that has halved Europe's potential capital raised since 2015¹⁵¹.

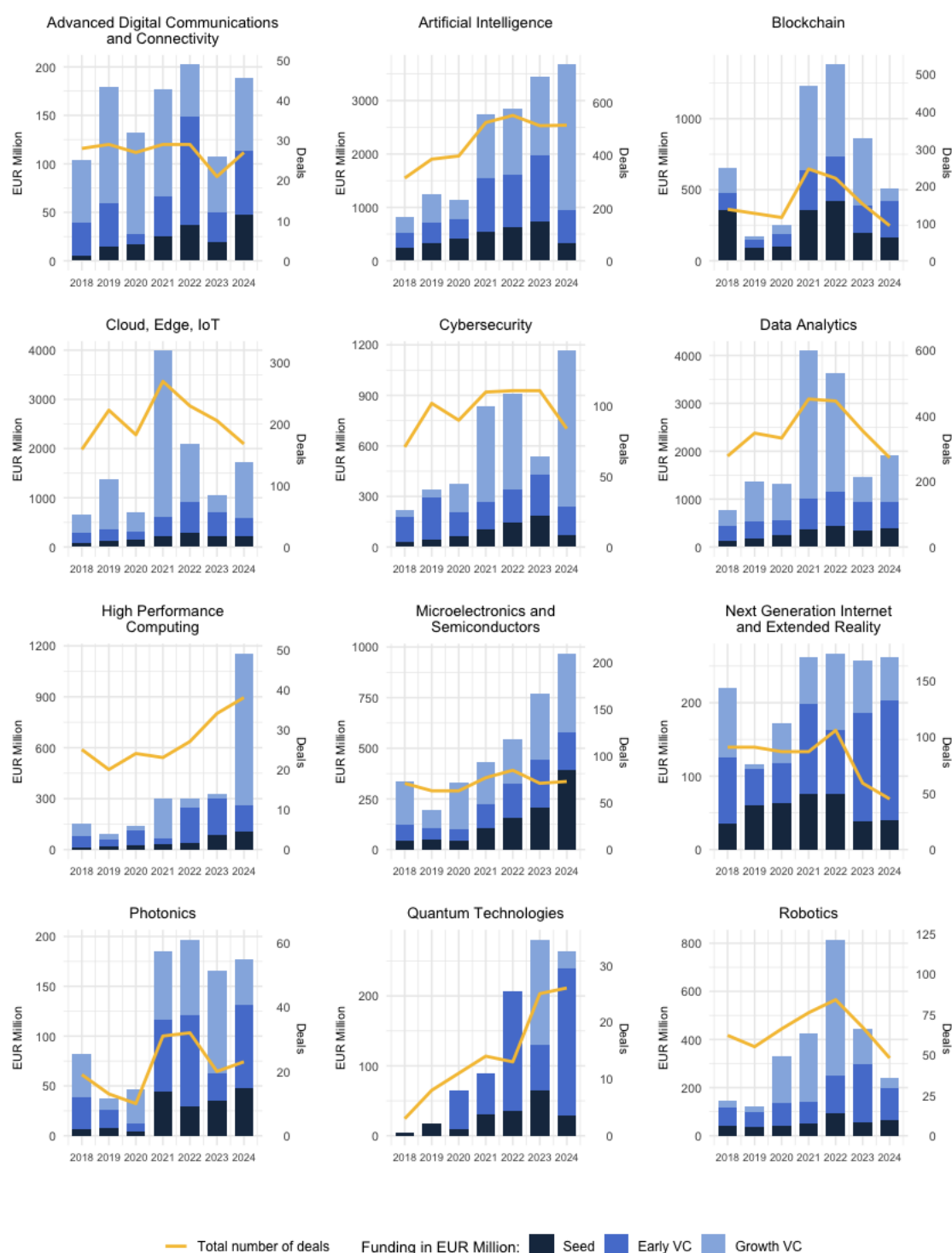
Several domains show pronounced boom-cooldown dynamics. Blockchain is the clearest example, with very high investment volumes in 2021–2022 followed by a sharp decline in 2023–2024, mirrored by falling deal counts - largely explained by the boom–bust cycle in crypto markets. Robotics also peaks around 2022 and then declines, while Next Generation Internet and Extended Reality remains relatively stable in total funding but shows a notable

¹⁵¹ Atomico (2024). State of European Tech

drop-in deal activity after 2022, suggesting fewer funded companies despite continued investment in selected players.

By contrast, smaller and emerging areas show a different pattern: lower overall funding, fewer deals, and a heavier reliance on earlier-stage rounds. This is particularly visible for Quantum Technologies, where activity ramps up mainly from 2020 onward but remains comparatively small and is dominated by seed and early VC, with little evidence of growth-stage rounds in the period shown. Photonics is also relatively small in total volumes, while Microelectronics and Semiconductors and High-Performance Computing show increasing momentum towards 2024 - especially in investment amounts - suggesting growing investor interest, but still with much lower scale than AI.

Overall, the figure points to a persistent EU challenge: many domains attract early-stage investment and steady deal-making, but only a subset reaches the scale required for repeated large late-stage rounds, contributing to a growth-stage funding gap in Europe

Table 17 EU venture capital investments and deal activity by digital technology domain


Source: Technopolis Group based on Crunchbase

From seed to scale: conversion rates across technology areas

Across all technologies, **the US shows systematically higher conversion rates than the EU27 at both financing steps**. On average, 14% of EU27 seed-stage companies progress to Early VC, compared with 21% in the US – meaning the EU27 performs at about two-thirds of the US level. The gap widens at later stages: 21% of EU27 Early VC companies reach Growth VC versus 38% in the US. The main structural weakness for the EU27 is

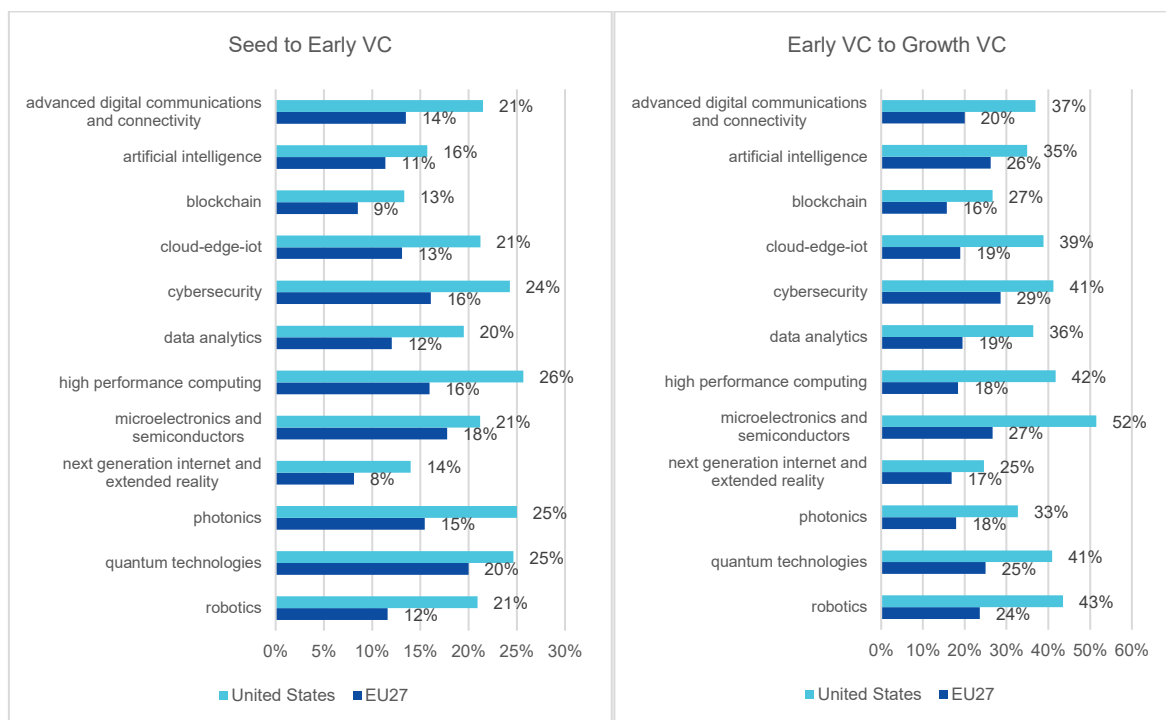
therefore clearly at the scaling stage from Early to Growth, rather than at initial early-stage funding.

Seed-to-Early conversion in the EU27 ranges from 8–20%, compared with 13–26% in the US. In every technology the US conversion rate exceeds the EU27 rate, but the size of the gap varies across technologies. Within the EU27, relatively stronger early-stage conversion is visible in quantum technologies (20%), microelectronics and semiconductors (18%), cybersecurity and high-performance computing (16%), and photonics (15%), all above the EU27 average of 14%.

The second step shows much more pronounced differences. EU27 conversion from 'Early to Growth' ranges from 16–29%, while the US spans 25–52%. In every technology, the US conversion rate is 8–25 percentage points higher.

Within the EU27, the strongest late-stage conversion is observed in cybersecurity (29%), microelectronics and semiconductors (27%), artificial intelligence (26%), quantum technologies (25%), and robotics (24%), all above the EU27 average of 21%. These are the areas where the growth pipeline is comparatively more developed, even though the US still converts a much higher share of Early VC companies into Growth VC.

Figure 46 Conversion rates from Seed to Early VC (left) and conversion rates from Early VC to Growth VC (right). Data for deals between 2015–2025*



Source: Technopolis Group (2025) based on Crunchbase

1.7.3 Leverage factor on private investments from public programmes

The Horizon Europe portfolio of digital technology projects identified in Cordis shows an overall leverage factor of around 9.9% on EU contributions, with marked differences between the technology areas. The analysis covers approximately €1.8 bn of leveraged funding in total. Direct leverage is understood here as the volume of private co-funding committed by beneficiaries relative to the Horizon Europe contribution, based on project-level information on total budgets and EU co-funding extracted from Cordis.

Across these areas, private leverage is particularly strong in capital-intensive deep-tech domains.

The highest leverage factors are observed in High-Performance Computing (22.9%), Microelectronics and Semiconductors (22.2%) and Photonics (20.0%), which combine relatively large funding volumes (€859 m in Microelectronics and Semiconductors and €504 m in Photonics) with above-average mobilisation of private finance.

Intermediate levels of leverage are found in Cloud-Edge-IoT (8.7%), Data Analytics (6.7%), Artificial Intelligence (6.5%), Cybersecurity (6.1%), Quantum technologies (6.1%) and Robotics (6.0%).

More modest leverage is recorded in Advanced Digital Communications and Connectivity (5.7%), Blockchain (5.2%) and, in particular, Next Generation of Internet and Extended Reality (2.5%). As with other framework-programme analyses, these figures capture only the direct co-funding by project beneficiaries and do not account for additional investment at end-user level, where firms and public authorities further invest (in cash or in kind) in digital transformation in response to the initial Horizon Europe support.

Figure 47 Direct leverage factors of the Horizon Europe (in m € and %)

Technology area	Total leveraged investments (€M)	Leverage factor
Advanced Connectivity	37.24	5.7%
Artificial Intelligence	124.58	6.5%
Blockchain	2.36	5.2%
Cloud-Edge-IoT	74.00	8.7%
Cybersecurity	23.31	6.1%
Data Analytics	87.58	6.7%
High-Performance Computing	45.51	22.9%
Microelectronics and Semiconductors	859.20	22.2%
Next Generation of Internet and Extended Reality	15.82	2.5%
Photonics	503.94	20.0%
Quantum technologies	6.96	6.1%
Robotics	41.45	6.00%
Total	1821.93	9.88%

Source: Technopolis Group (2025) based on Cordis

2. EU strengths, challenges and opportunities in digital technology R&I

This chapter synthesises the key strengths, opportunities, challenges and threats across the different technology areas, highlighting the main findings and overarching conclusions derived from the detailed assessments in the individual **technology annexes**. The detailed technology analysis includes a dedicated SWOT and further reflections on technology trends, the European ecosystem, research infrastructures, and skills with an outline for investment needs and actions to be taken. The analysis is based on a combination of expert interviews, stakeholder consultations, and desk research, triangulated with patent data, bibliometric and start-up statistics as presented in Chapter 1.

2.1 Overview of cross-cutting trends across the stack

Emerging technologies continue to be key drivers of system-level socio-economic transformations, with innovation resulting not only from single breakthroughs but also from the **convergence of various critical digital technologies and related adjacent technologies**. This shift is accompanied by growing challenges related to trust, security, and governance.

Despite the challenges of excelling in the digital domain, the EU demonstrates strong capabilities across a wide range of research areas within and across critical digital technologies. As evidenced by patent, publication, and start-up analyses (see Chapter 1), the **EU holds a strong position in key digital technologies such as photonics, quantum, and robotics**. Many of these research strengths link closely to market and societal objectives, for example, robotics plays a critical role in improving the productivity and competitiveness of European industries or quantum research is expected to provide solutions for climate modelling or data privacy. Investing in European capabilities in **microelectronics, AI, cloud-edge-IoT, quantum technologies, advanced connectivity, and cybersecurity** are critical to prioritise as also put forward in the recent technology sovereignty package. Despite the EU lagging behind internationally, it has several key opportunities and can take leadership in subdomains as presented later.

There are several cross-cutting technology trends where experts involved in this study suggest the EU to position on:

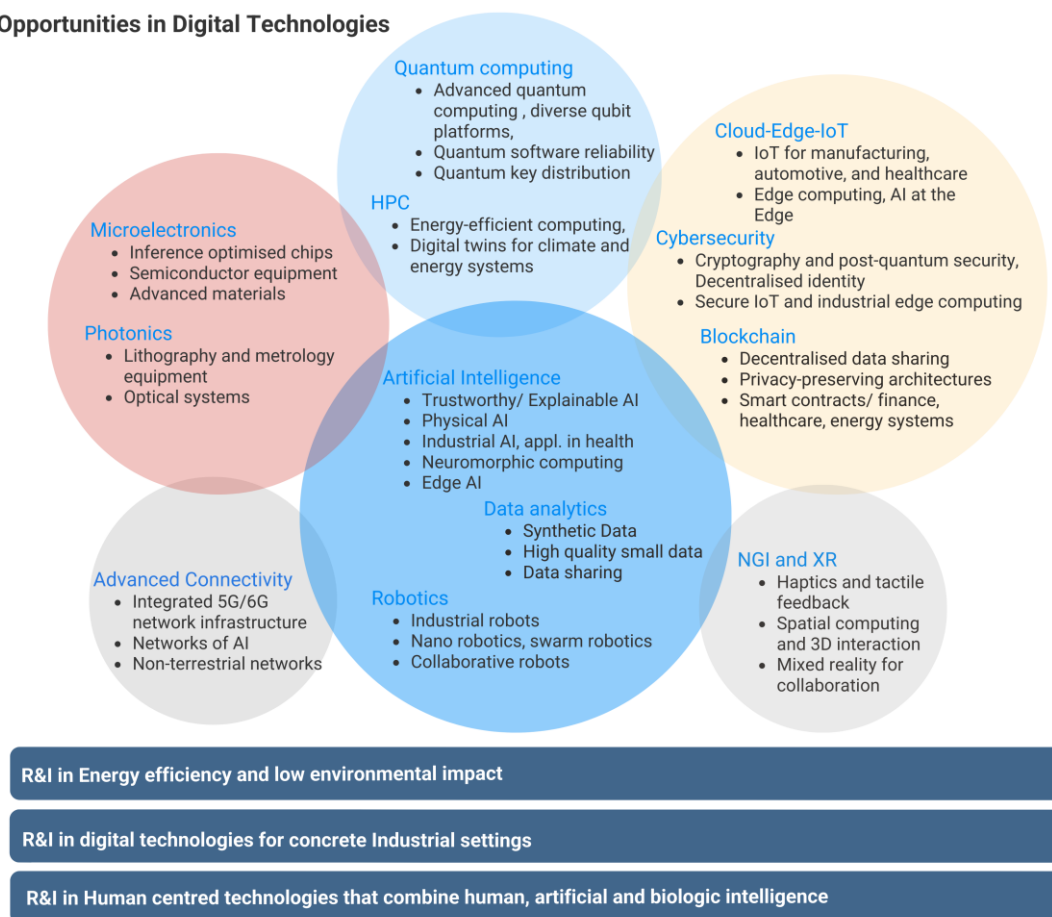
- **Future technological leadership will increasingly depend on Europe's ability to exploit synergies between complementary digital technologies.** Innovation is systemic, with breakthroughs emerging from the convergence of AI, photonics, semiconductors, quantum technologies, cloud-edge computing, and cybersecurity rather than from isolated technological advances. Strengthening a single technology in isolation may yield limited benefits if bottlenecks persist in related enabling technologies, manufacturing capabilities, software ecosystems, or access to specialised infrastructure. Building resilient and interconnected technological ecosystems is therefore essential to maximise innovation, accelerate commercialisation, and enhance Europe's technological sovereignty.
- **AI unlocks several promising cross-technology R&I pathways, where Europe has both advantages and opportunities across multiple integrated technology domains.** From quantum AI (including quantum neural networks, quantum learning, and hybrid quantum models), to specialised AI accelerators that meet rising computational demands, and edge-AI solutions, AI plays a foundational and pervasive role across the entire digital landscape.
- **R&I into energy efficient solutions is a cross-cutting priority among all technology areas.** New AI architectures need energy efficient access, exposing the limits of traditional chips, which creates a clear opportunity for specialised inference hardware, energy-efficient chips designed specifically to run AI close to users. In the field of HPC, European leadership is recognised in areas such as energy-efficient

computing, application of digital twins for climate and energy systems. Europe has also demonstrated scientific excellence and collaborative capacity in climate modelling relying on HPC systems and large-scale numerical simulations.

- **Anchoring digital technology research in concrete industrial contexts is a recurring theme across multiple technology areas to address sector-specific challenges**, ranging from supply-chain coordination to production system integration. This is further evidenced by the strong impact and high citation performance of related EU publications
- **The tailored and human-centric approach to technology emerges as a cross-cutting strength**. It reflects a consistent emphasis on aligning R&I in technology with specific contexts, tailored to particular industry requirements and situational realities within a human-centric framework.
- **Strengths and opportunities are pronounced in specific subdomains within each technology**, where the EU maintains global leadership, as well as in niches that hold significant innovation potential and often span multiple technologies. Some of these opportunities are presented in the Figure below and are further discussed in the subsequent sections and in the technology annexes.

Figure 48 EU strengths and opportunities across technology areas and subdomains

EU Strengths and Opportunities in Digital Technologies



Source: Technopolis Group based on technology annexes

R&I Ecosystem

Europe's diverse and well-established R&I ecosystem is seen as a foundational strength across most technology areas. Strengths are anchored in academic and applied research networks, with major research and technology organisations and leading universities providing continuity from fundamental research to mid-TRL validation. Geographically, Europe hosts clusters of R&I concentration across several regions.

Open-source software development is increasingly shaping the future of R&I across many critical digital technologies in the EU and offers transparent, collaborative, and customisable alternatives to proprietary solutions. This shift supports Europe's goals for digital autonomy. Digital sovereignty should not be about exclusivity but control over a technology. In this regard, open-source software and hardware play a strategic role in strengthening Europe's digital sovereignty, as they shift control from ownership to capability, governance, and deployment. With open source, the EU can ensure transparency and freedom to adapt and evolve the technology without depending on a single vendor. In this regard, the European Simpl Programme¹⁵² serves as a practical example of how the EU is enabling interoperability and secure data sharing through an open-source, open, modular, and reusable infrastructure that supports the creation and scaling of European data spaces.

A persistent cross-cutting challenge is the fragmentation of the EU AI ecosystem as highlighted during the expert discussions for each technology area. While Europe has a strong research base and a wide range of AI initiatives, these remain dispersed across institutions, funding programmes, and national and regional strategies, limiting coordination, knowledge transfer, and commercialisation. This fragmentation weakens links between research and industry, reduces the visibility and uptake of research results, and can limit participation by SMEs. As a result, resources are not fully leveraged, slowing the scaling and deployment of AI innovations.

Research and technology infrastructure

The EU has initiated powerful pan-European R&I infrastructures in digital technologies that benefit from a well-developed base supporting research, testing and early-scale validation. For example, the supercomputing ecosystem through the European High Performance Computing Joint Undertaking (EuroHPC) unites the EU, Member States, and private partners to pool resources and develop world-class HPC and data infrastructure. As such, Europe's capabilities are expected to extend beyond exascale performance, placing the EU among the global leaders in high-performance computing¹⁵³. In cybersecurity, EU-level coordination through the European Cybersecurity Competence Centre, together with access to high-performance computing resources via EuroHPC and emerging AI Factories, supports advanced security research, testing and automation. In blockchain, existing infrastructures are well suited to early-stage research and prototyping, supporting development and validation at TRLs 3–6.

Nonetheless, the EU's research and technology infrastructures face significant gaps such as the shortage of compute and hardware capacity. Europe currently accounts for only a small fraction of global AI computing power, relying heavily on non-EU cloud providers. Dedicated AI chips, GPUs, and high-performance computing resources remain scarce and costly, leaving researchers and smaller organisations at a disadvantage. Financing challenges also exist, particularly regarding the costs associated with data management in European Data Spaces.

Research and technology infrastructures are often fragmented and underutilised with uneven access and high costs as highlighted in the expert consultations across all technology areas. While Europe has invested significantly in technology infrastructures (such as for example in HPC), some are utilised less and unevenly accessed, especially by SMEs, non-digital industries, and interdisciplinary researchers. Systems remain too complex, disconnected, or inaccessible for many users. In some cases, only researchers working on flagship projects are aware of or able to use them as highlighted in the interviews. Sectoral pilot lines and mission-oriented testbeds are still limited, and there is insufficient integration of ethical, social, and technical dimensions. The absence of a unified and interoperable framework limits scalability and cross-border deployment, while access to testbeds remains uneven, particularly for SMEs and actors in underserved regions.

¹⁵² <https://simpl-programme.ec.europa.eu/dashboard/home>

¹⁵³ European Commission (2024). The added value of European investments in research and innovation

Similarly, the 2025 European Strategy on Research and Technology Infrastructures¹⁵⁴ concluded that, although SMEs have access to research and technology infrastructures, their participation is significantly constrained by practical, financial, informational, and cross-border barriers. These challenges have prompted the European Commission to propose measures such as one-stop-shop access systems, harmonised access charters, and dedicated support mechanisms to facilitate SME engagement and improve the accessibility of infrastructure services. Although the Expert Group on Technology Infrastructures¹⁵⁵ found that 80% of enterprises participating in the public consultation rely on tech infrastructure to develop new technologies and processes, these results are biased by the type of stakeholders responding. Despite this, the survey provides relevant insights as it highlights that SMEs face several barriers to accessing research and technology infrastructures, including limited awareness of available services, financial constraints related to access costs, complex administrative procedures, geographical distance from facilities, and a mismatch between the services offered and their specific business needs.

Another recurring concern mentioned by stakeholders is the **speed at which research and technology infrastructures can be established, upgraded, and made operational**. Compared with other global innovation leaders, Europe often faces lengthy planning, permitting, procurement, and funding processes that delay the deployment of new infrastructure and the modernisation of existing facilities. As technologies evolve rapidly, these delays risk leaving European researchers and industry without timely access to state-of-the-art capabilities, reducing Europe's ability to translate research into market-ready innovations and respond quickly to emerging technological opportunities. Accelerating investment decisions, streamlining administrative procedures, and enabling more agile governance and funding mechanisms are therefore increasingly recognised as essential to ensure that European R&TIs remain globally competitive and capable of supporting industrial innovation at the pace required.

R&I skills and talents

Regarding skills and talent, while **top-tier universities deliver high-quality education across digital technology areas**, the EU faces an insufficient talent pool and shortages of hardware engineers, digital designers, technicians, and data specialists¹⁵⁶. Talent attraction and retention are constrained by global competition, salary differentials and the pace of technological change, which requires continuous upskilling. These salary gaps and limited career visibility reduce Europe's attractiveness compared to other regions, notably the United States.

Skills shortages cut across technology areas with specialists lacking in specific domains: there is a lack of sufficient professionals capable of bridging cloud, edge, IoT and hardware layers, as well as specialists in secure edge computing, confidential computing and real-time AI inference. In HPC, demand exceeds supply for specialists combining domain expertise, mathematical modelling and advanced computing skills, while training pathways remain insufficiently aligned with evolving system architectures. In quantum technologies, although Europe has strong theoretical expertise, shortages persist in applied, interdisciplinary and software-oriented skills. In blockchain, skills remain concentrated in finance- and crypto-oriented applications, with limited interdisciplinary expertise at the intersection with AI, cybersecurity and public-sector use cases.

The subsequent sections highlight some of the key EU's strengths and challenges across various technology area groups and in particular at the intersection of technologies with

¹⁵⁴ European Commission. (2025). A European strategy on research and technology infrastructures (COM/2025/497 final/2). Publications Office of the European Union.

¹⁵⁵ European Commission. (2025). Technology infrastructures: Final report of the expert group on technology infrastructures. Publications Office of the European Union. <https://op.europa.eu/en/publication-detail/-/publication/ebbad86c-ea87-11ef-b5e9-01aa75ed71a1/language-en>

¹⁵⁶ European Chips Skills Academy, Skills Strategy 2024, 2024. <https://chipsacademy.eu/wp-content/uploads/2024/11/ECSA-Skills-Strategy-2024.pdf>

further analysis included in the technology annexes. The identified trends represent important opportunities for the EU, as they either contribute to strengthening technological sovereignty or point to emerging research areas in which Europe can still establish a competitive advantage through timely investment. For example, advances such as neuromorphic computing offer the potential to overcome major limitations of conventional computing architectures, particularly in terms of energy consumption, real-time processing, and artificial intelligence applications. Below we provide some highlights and summary of the key trends and more details are presented in the technology annexes.

2.2 AI, Data, and Robotics

At the intersection of AI, data, and robotics, the EU has distinct strengths, with its long-standing engineering and manufacturing heritage constituting a major competitive asset as highlighted by the expert consultations.

In AI, the landscape is increasingly shaped by large-scale, general-purpose foundation models that can be adapted across domains such as language, vision, and biology, supported by advances in computing infrastructure and enabled by emerging paradigms such as quantum computing.

At the same time, innovation is moving beyond monolithic systems toward more modular and adaptive approaches, including **AI agents, specialised domain-specific models, physical AI and hybrid neurosymbolic methods** that aim to improve reasoning, explainability, and trust. These developments are complemented by advances in human-centric interaction through embodied AI and enhanced human-machine interfaces, while growing emphasis is placed on ensuring that AI systems are **trustworthy, secure, and sustainable, with a focus on fairness, robustness, and energy efficiency**.

Strong industrial bases in automotive, machinery, chemicals, pharmaceuticals, aerospace, logistics, and healthcare generate vast amounts of high-quality, real-world operational data and provide natural testbeds for AI applications and for physical systems driven by robotics¹⁵⁷. Europe has a strong global position in professional and industrial robotics, supported by robust research, a skilled talent pool, and numerous small and mid-sized companies¹⁵⁸. The EU is considered to be strong also in **nano and micro robotics** where the full potential of miniature robots at this scale remains largely untapped¹⁵⁹. Underlying AI and robotics applications, the EU boasts **high data quality and data spaces focusing on trustworthy AI**. For the latter, an EU strength and opportunity is in data provenance and data documentation that are critical enabling technologies for fast-moving, compute-centric innovation, providing the trust, traceability, and transparency needed to operate at speed without sacrificing integrity. Provenance enables full lifecycle tracking of data supporting scientific validity, ethical compliance, and regulatory accountability, while data documentation makes datasets understandable, interoperable, and reusable through structured metadata, standards, and machine-readable descriptions.

Insights from scientific publications:

In scientific publications, the EU's top 1% most cited scientific outputs focus on AI domains that span most importantly healthcare, communications, mobility, energy, industry, and finance, alongside growing attention to privacy-preserving methods and trust. This is in line with the highlighted EU strengths as seen via qualitative research. In the most highly ranked EU publications, trustworthy and explainable AI emerges as a cross-cutting priority, with emphasis on transparency, governance, bias mitigation, and regulatory compliance in high-stakes uses. A further focus is on AI-enabled digital infrastructure, notably the integration of AI with 5G/6G, edge computing, IoT, and digital twins to support low-latency, energy-efficient applications. Autonomous and cyber-physical systems form another major domain, spanning robotics, autonomous mobility, smart grids, and real-time control.

In robotics research, top EU scientific publications include medical and industrial R&I in robotics, emphasising intelligent, adaptive, and human-centered systems. In medicine, innovations include robot-assisted surgery, exosuits, and augmented reality guidance, enhancing precision and patient outcomes. Industrial and service

¹⁵⁷ WEF (2026). Europe can still win with AI. The key is focusing on physical AI

¹⁵⁸ EURobotics (2024). A Unified Vision for European Robotics, A Strategy for Innovation, Growth and Societal Impact

¹⁵⁹ https://cordis.europa.eu/programme/id/H2020_ICT-47-2020

robotics focus on collaborative robots, multi-robot coordination, and human–robot interaction, supported by advanced AI, deep learning, and model-based control for robust and autonomous behaviour. Advances in perception, tactile sensing, and multimodal learning enable more responsive robots, while work on microrobots, modular architectures, and control frameworks expands capabilities in specialised tasks. Additionally, companion and service robots also appear as a topic.

Opix based on OpenAire

Insights from patent classes:

Interestingly, the **EU's primary patent classes (where most patents have been applied for) in Artificial Intelligence are primarily application- and domain-oriented**. As this analysis finds, the EU patenting focuses on embedding AI into concrete societal, industrial, and institutional contexts, most notably healthcare diagnostics, medical imaging, biometrics, and organisational and industrial systems. Its defining characteristic is problem orientation: AI is framed as a tool to solve specific real-world challenges, improve services, and augment decision-making within established sectors.

US patent applications have a system-integration focus dealing with applications and infrastructure. The US combines foundational AI methods with operational platforms, linking perception, inference, diagnostics, and organisational processes into coherent, scalable systems. Its focus is not just on building AI models or deploying them in isolated domains, but on creating integrated AI ecosystems that function as continuous, inference-driven decision infrastructures across sectors.

China's primary patent applications are instead fully technology-driven. It concentrates on the core building blocks of AI itself, including neural architectures, pattern recognition, speech and image processing, optimisation, and training techniques. It is largely domain-agnostic and advancing the general capabilities, efficiency, and performance of intelligent systems.

Fraunhofer ISI and Technopolis Group based on Patstat

Threats:

The EU is constrained by insufficient infrastructure, particularly in terms of compute capacity, training data scale, and data availability. Europe lacks a strong ecosystem of sovereign foundation models and remains highly dependent on the US. Moreover, there is a shortage of domain-specific foundation models for key European sectors such as healthcare, law, and industry, and a strong need for trustworthy, multilingual and culturally aligned models. Foundational models require extremely high levels of energy, storage, and computational resources, raising also sustainability concerns.

2.3 Cloud-edge-IoT, Cybersecurity, and Blockchain

Strengths

Europe's technological strengths in these three domains include **cryptography and post-quantum security, confidential computing and root-of-trust architectures, secure IoT and industrial edge computing, and decentralised identity and data-sharing frameworks**. As discussed in the technology annexes, the EU has important research capacities in these technologies. Many of these capabilities are shared across cloud-edge-IoT, cybersecurity and blockchain and reinforce each other in practice, for example in trusted data spaces, secure industrial IoT deployments, and decentralised digital public services. These strengths are also underpinned by key Europe's regulatory and policy initiatives that generate further expertise such as NIS2¹⁶⁰, the EU Cybersecurity Act¹⁶¹, the Cyber Resilience Act¹⁶² and the European Blockchain Services Infrastructure¹⁶³, further strengthens this position by embedding security-by-design and trust as structural features of digital systems.

¹⁶⁰ <https://www.nis-2-directive.com/>

¹⁶¹ <https://digital-strategy.ec.europa.eu/en/policies/cybersecurity-act>

¹⁶² europa.eu/en/policies/cyber-resilience-act

¹⁶³ <https://ebsi.eu/>

The EU also has strength in the convergence of AI, IoT, and edge/cloud computing, enabling decentralised intelligence and data-driven decision-making. This includes federated and swarm learning, edge AI, sensor fusion, and real-time analytics applied to healthcare diagnostics, epidemic management, smart grids, agriculture, and intelligent transportation systems. These approaches respond to privacy constraints and scalability needs while enabling large-scale deployment of data-intensive applications. There is a strong research focus on next-generation digital infrastructure, including 5G and emerging 6G networks, network slicing, ultra-low-latency and high-throughput connectivity, and secure IoT architectures. These technologies underpin real-time, mission-critical applications and support the integration of AI and blockchain into future cyber-physical systems, positioning them as foundational enablers for resilient, scalable, and trustworthy digital ecosystems.

Insights from scientific publications:

The review of top 1% highly cited scientific publications shows a focus on cloud-centric and distributed computing architectures that integrate edge, fog, and end–edge–cloud systems to support intelligent, data-driven applications. This includes the AI and machine learning for predictive analytics and automation, IoT and smart systems for real-time monitoring and control, and big data platforms for large-scale storage and processing. The orientation also highlights healthcare and bioinformatics applications, network innovations such as 5G/6G and multi-access edge computing, and security and privacy technologies including blockchain and encryption.

In cybersecurity, the top EU publications with high impact focus on cybersecurity for industrial, IoT, and next-generation network systems, with a strong emphasis on protecting critical infrastructures, autonomous vehicles, healthcare systems, and 5G/6G networks. Key approaches include digital twins for threat modeling and simulation, AI and machine learning for attack detection and anomaly identification, federated and semi-supervised learning, and intrusion detection systems for edge and IoT devices. Additional focus areas cover privacy, secure control architectures, and resilience against adversarial attacks, as well as standardisation of datasets and security practices to address the growing complexity and heterogeneity of industrial and networked environments.

In blockchain, the EU has strong technological capabilities particularly in trust, security, and coordination layers. Strengths include decentralised data sharing, privacy-preserving architectures, smart contracts, and applications spanning finance (DeFi, NFTs), healthcare (EHRs, contact tracing), energy systems, supply chains, and smart mobility. Significant advances are also evident in post-quantum cryptography, anomaly detection, and blockchain–AI integration, addressing emerging security and resilience challenges.

Opix based on OpenAire

Insights from patent classes:

The EU's patent applications in cloud-edge-IoT focus on building the core digital infrastructure: distributed computing systems, network architectures, software execution environments (virtualisation, emulation), and foundational cybersecurity (authentication, access security, key distribution, data protection). Its focus is on enabling platforms: secure, interconnected systems that other technologies run on.

US patenting suggests orientations towards intelligence and autonomy. It adds machine learning, learning methods, and communication, emphasising systems that can learn, decide, and interact automatically. It also has a stronger focus on platform integrity, including secure booting, trusted platform certification, vulnerability assessment, and system verification. It is more about smart, self-operating infrastructure.

China's approach is the most holistic and operational. It integrates distributed computing, AI/learning, networking, cybersecurity, software control, and industrial automation into a single coherent system view.

Fraunhofer ISI and Technopolis Group based on Patstat

Threats

Across cloud-edge-IoT, cybersecurity, and blockchain, the EU faces structural dependencies on non-European technologies that constrain strategic autonomy. In cloud computing, the market remains dominated by US hyperscalers, with EU-based providers accounting for a limited share and remaining fragmented. This limits their capacity to invest in advanced R&I and pushes them toward foundational infrastructure services or the reselling of non-EU platform solutions. Similar dependencies extend across the computing

continuum, including operating systems, virtualisation and orchestration software, AI accelerators, and key hardware components such as semiconductors and microcontrollers for IoT and edge devices. These dependencies expose the EU to technological lock-in and supply-chain risks, particularly in a context of intensifying global competition and export controls.

2.4 Quantum and High-performance computing

Strengths

The EU's strengths in quantum lie in **advanced quantum computing research, including algorithm development, diverse qubit platforms, fault tolerance, and quantum software reliability** and in building secure, **scalable quantum communication networks that integrate quantum key distribution (QKD)** and hybrid quantum-classical models¹⁶⁴. It also leads in quantum and post-quantum cryptography, with strong capabilities in quantum-resistant algorithms. As further discussed in the technology annexes, the EU has important patenting activity in these areas and a strong research base.

European HPC leadership is recognised by the HPC community most in areas such as **energy-efficient computing, application of digital twins for climate and energy systems, and integration of AI into scientific workflows** as concluded by the technology area analysis.

Insights from scientific publications:

In scientific publications, the EU's top 1% most cited scientific outputs focus on quantum computing hardware (superconducting qubits, ion traps, germanium processors, Rydberg atoms, rare-earth emitters, microcavities, and single-photon sources), quantum algorithms and software (variational algorithms, quantum machine learning, quantum optimisation, quantum linear solvers, and NISQ-era algorithms), and quantum AI (quantum neural networks, quantum learning, and hybrid quantum-classical models). They also span quantum networking and the Quantum Internet (entanglement, teleportation, quantum repeaters, distributed quantum computing), quantum communication and cryptography (QKD, post-quantum cryptography, quantum-safe blockchain, quantum security for 6G), and quantum materials and photonics, reflecting an integrated ecosystem from fundamental physics to applied digital infrastructure.

The analysis of scientific publication data shows a similar pattern. Text mining of EU scientific publications that are in the top 1% most cited category indicate that these HPC related EU publications address most the intersection of high-performance computing, AI, and advanced algorithms and as such address frontier scientific challenges across materials science, life sciences, astrophysics, and climate research. They focus on developing scalable, energy-efficient computational methods, such as density-functional theory codes, exascale and distributed computing platforms, and task-based parallel programming models to fully exploit modern heterogeneous architectures. Across domains, the key technology areas include exascale and heterogeneous HPC systems, accelerator-aware software, data-driven and AI-enhanced scientific workflows, and energy-efficient computing paradigms such as neuromorphic and in-memory computing.

Opix based on OpenAire

Insights from patent classes:

European top patent applications in quantum have a broader system-integration and digital infrastructure scope, explicitly linking quantum technologies with identity/authentication systems, access-secured messaging, knowledge-based computing models, synchronisation/initialisation systems, and AI integration (machine learning). They frame quantum not just as a computing paradigm, but as part of a secure digital infrastructure and intelligent computing ecosystem.

The US is more quantum-core-technology focused, concentrating more tightly on quantum hardware, algorithms, software, manufacturing processes, and secure communication, with less emphasis on identity systems, system orchestration, and broader digital governance layers.

Fraunhofer ISI and Technopolis Group based on Patstat

¹⁶⁴ Based on expert consultations

Threats

The EU faces challenges in translating research excellence in both HPC and quantum technologies into sustained industrial and market outcomes. Access to advanced infrastructures remains uneven across user groups, with SMEs and researchers often facing barriers related to governance arrangements, cost, and limited awareness of available resources. While large-scale infrastructures and testbeds exist or are under development, access models frequently prioritise established consortia and flagship projects, limiting broader ecosystem participation.

Dependence on non-European technologies represents a significant vulnerability across both domains. In HPC, critical hardware components, including GPUs, CPUs and firmware, are predominantly sourced from non-EU suppliers, constraining Europe's ability to pursue full system-level co-design and increasing the risk of technological lock-in.¹⁶⁵ European cloud providers lag behind global hyperscalers, and domestic capacity for processor and accelerator design and manufacturing remains limited. In quantum technologies, Europe lacks sufficient access to R&D-scale semiconductor foundries, large-scale quantum communication networks and widely accessible testbeds, restricting large-scale experimentation, prototyping and system integration.

2.5 Microelectronics and Photonics

Strengths

Across microelectronics and photonics, the EU benefits from a mature R&I ecosystem structured around world-leading Research and Technology Organisations (RTOs), leading universities, and established industrial players.^{166 167} RTOs such as imec, CEA-Leti and Fraunhofer work with actors across the value chain and across technology domains, linking materials, devices, design, manufacturing, and application-level research.^{168 169} This model supports continuity from low- to mid-TRLs and is a European asset compared to more fragmented or predominantly market-driven innovation ecosystems elsewhere.

Europe's position is strong in enabling and upstream technologies that underpin multiple value chains in both microelectronics and photonics. These include **semiconductor manufacturing equipment and lithography (notably EUV and high-NA EUV)**^{170 171}, **metrology equipment**¹⁷², **certain materials**¹⁷³, **power electronics, sensors and high-performance photonic components**. Many of these capabilities are shared across microelectronics and photonics and support technological spillovers, for example in heterogeneous integration, advanced packaging, integrated photonics, and chip-system

¹⁶⁵ https://www.eib.org/files/pi/financing_the_future_of_supercomputing_en.pdf

¹⁶⁶ Council of the European Union, The semiconductor ecosystem: Global features and Europe's position (2022). <https://www.consilium.europa.eu/media/58112/220712-the-semiconductor-ecosystem-global-features-and-europe-s-position.pdf>

¹⁶⁷ European Commission Staff Working Document, A Chips Act for Europe (2022). <https://www.decision.eu/wp-content/uploads/2022/09/A-Chips-Act-for-Europe-Commission-Staff-Working-Document.pdf>

¹⁶⁸ See for example CEA-Leti and imec working with European and global equipment material suppliers to set up the NanoIC pilot line ([online link](#))

¹⁶⁹ Science Business, The ecosystem: EU Chips Act starts to shape innovation landscape (2022). <https://sciencebusiness.net/news/Digital/The-Ecosystem-EU-Chips-Act-starts-to-shape-innovation-landscape>

¹⁷⁰ European Commission Staff Working Document, A Chips Act for Europe (2022). <https://www.decision.eu/wp-content/uploads/2022/09/A-Chips-Act-for-Europe-Commission-Staff-Working-Document.pdf>

¹⁷¹ European Commission, Electronics ecosystem – Microelectronics (2024). <https://data.europa.eu/doi/10.2873/986855>

¹⁷² Photonics21, Position paper – Investing in light: The vision to secure Europe's competitiveness in the global tech race (2025). https://www.photonics21.org/download/ppp-services/photonics-downloads/Photonics21_Position_Paper_Investing_in_Light_The_Vision_to_Secure_Europes_Competitiveness_in_the_Global_Tech_Race.pdf

¹⁷³ Key suppliers of materials used by the semiconductor industry, such as chemicals and wafers, are based in Europe ([online link](#)).

co-design. As a result, Europe retains strategic leverage in critical segments of the value chain even where it is weaker in final system integration or wafer fabrication.¹⁷⁴

Geographically, strengths are concentrated in regional clusters such as Grenoble¹⁷⁵, Eindhoven¹⁷⁶, Dresden¹⁷⁷, and Leuven¹⁷⁸, where microelectronics and photonics activities coexist within the same innovation ecosystems.¹⁷⁹ These clusters combine universities, RTOs, pilot lines, fabs, optics manufacturers, design houses and system integrators, providing a basis for interdisciplinary research and technology convergence. This environment is particularly relevant for application-driven domains where Europe is competitive, including automotive electronics, industrial automation, healthcare technologies, space and defence systems.

Insights from scientific publications:

The analysis of top 1% scientific publications in these technology areas shows that the EU is focusing on advanced micro- and nano-scale materials and photonics for computing, communications, and healthcare applications. Key areas include spintronics and quantum materials for next-generation microelectronics, nanophotonics and integrated photonic circuits for optical computing and AI, 2D materials and topological insulators for novel electronic and optical functionalities, and microfluidics and nanomedicine for targeted drug delivery and biomedical applications. Additionally, there is a strong emphasis on deep learning-driven design and inverse engineering in photonics, as well as high-performance optical devices such as modulators, meta-waveguides, quantum emitters, and mid-infrared communication components. The focus combines materials innovation, quantum/photonic engineering, and AI-assisted design to enable next-generation electronics, photonics, and nanomedicine technologies.

Opix based on OpenAire

Insights from patent classes:

European top patent applications are centred on light-emission and photonic semiconductor technologies (optoelectronic & light-emitting focus), with strong emphasis on OLED/PLED devices, electroluminescent systems, imager structures, radiation-controlled devices, and optoelectronic integration (e.g. devices structurally associated with light sources on common substrates). It blends electronics and photonics, positioning it as a display, imaging, and optoelectronics innovation cluster. The US (manufacturing & process engineering focus) is more process- and infrastructure-driven, prioritising fabrication technologies, manufacturing apparatus, wafer handling systems, deposition/etching processes, surface engineering, and industrial-scale production workflows. It is less application-specific and more focused on the industrial semiconductor manufacturing ecosystem itself.

Fraunhofer ISI and Technopolis Group based on Patstat

Threats

Despite these strengths, Europe faces persistent difficulties in both microelectronics and photonics in translating research excellence into industrial outcomes.¹⁸⁰ A common bottleneck lies in the transition from TRL 4-6 towards industrial deployment. While pilot lines are being established¹⁸¹, their role as effective lab-to-fab bridges remains uncertain. This reflects stakeholders' concerns over pilot lines not yet having clearly established

¹⁷⁴ European Commission, Electronics ecosystem – Microelectronics (2024). <https://data.europa.eu/doi/10.2873/986855>

¹⁷⁵ Invest in Grenoble Alpes, Grenoble Alpes: Pole d'excellence mondial de l'électronique et du numérique.

<https://www.investingrenoblealpes.com/decouvrir-grenoble-alpes/filieres-grenoble-alpes/electronique-numerique/>

¹⁷⁶ Brainport Eindhoven, Work on societal challenges & key technologies. <https://brainporteindhoven.com/int/work/work-on>

¹⁷⁷ Saxony! "Silicon Saxony" - more than just chips. <https://business-saxony.com/en/a-business-location-at-its-best/strong-industries/silicon-saxony-more-than-just-chips>

¹⁷⁸ Home to imec, world-leading RTO working on microelectronics ([see online](#))

¹⁷⁹ Huggins et al., The future of Europe's semiconductor industry: Innovation, clusters and deep tech (2022), <https://csconnected.com/media/ezlhpdhz/huggins-johnston-munday-xu-the-future-of-europes-semiconductor-industry.pdf>

¹⁸⁰ European Commission Staff Working Document, A Chips Act for Europe (2022). <https://www.decision.eu/wp-content/uploads/2022/09/A-Chips-Act-for-Europe-Commission-Staff-Working-Document.pdf>

¹⁸¹ Innovation News network, EU launches Chips JU pilot lines to boost semiconductor innovation (2025).

<https://www.innovationnewsnetwork.com/eu-launches-chips-ju-pilot-lines-to-boost-semiconductor-innovation/54679/>

coordination mechanisms, as well as governance and access models that limit systematic industrial participation, particularly by SMEs and scale-ups.

2.6 Advanced Connectivity, Next generation internet and XR

The EU is considered to be at the forefront of several technologies in both NGI and XR (incl. haptic technologies¹⁸², digital twins¹⁸³), and several technologies that are central to the development of next-generation communication infrastructures (incl. photonic components, wide-bandgap semiconductors, and energy-efficient radio frequency (RF) modules). The EU also leads in several strategic domains in advanced connectivity, with for example Ericsson and Nokia providing critical mobile network infrastructure, giving Europe leverage in both 5G and future 6G development. To facilitate the development of such technologies, the EU possesses a solid base of R&I infrastructures to support both NGI and XR, and advanced connectivity technologies as further presented in the technology annexes.

In both NGI and XR and advanced connectivity, the EU holds notable strengths in the composition of its R&I ecosystem. In NGI and XR, the EU has a robust community of deep-tech SMEs, with the ecosystem thriving at mid-TRLs; whereas in advanced connectivity, the EU is home to leading telecommunications firms such as Nokia and Ericsson. Across both technology domains, the EU hosts leading, specialised academic¹⁸⁴, industrial, and national research centres that foster interdisciplinary research groups and support experimentation and technology development.¹⁸⁵

Insights from scientific publications:

The top cited EU scientific publications point out strengths in convergence with AI and 3D digital environments, combining computer vision, sensor fusion, neural reconstruction, and intelligent agents with advanced 3D capture and digital twins. This integration supports a wide range of applications spanning healthcare, entertainment, education, training, wellbeing, and assisted living, while also reflecting growing maturity in addressing human factors, usability, and multisensory experience. Some specific examples are related to medical and surgical XR, where augmented reality integrated with robot-assisted systems enables hyper-accurate, patient-specific 3D modelling and real-time anatomical overlay, delivering measurable improvements in precision, safety, and clinical outcomes for complex procedures. EU scientific publications are also highly cited in the domain of XR infrastructure and enabling technologies, including ultra-high-throughput and ultra-low-latency connectivity (Wi-Fi 7, B5G/6G), edge computing, and distributed intelligence. These capabilities provide a robust technological foundation for scalable, real-time, and high-resolution XR applications across gaming, telepresence, and emerging Metaverse environments.

Opix based on OpenAire

Insights from patent classes:

Both European and US patent applications in NGI and XR centre on AI-enabled human–computer interaction, combining speech recognition, neural networks, pattern recognition, image analysis, and multimodal interfaces to enable natural, intelligent dialogue between humans and digital systems. Each integrates 3D interaction, GUI-based environments, and adaptive learning systems, aiming to create human-centric, responsive, and immersive digital experiences.

However, the EU has a broader systemic and service-oriented scope. It strongly emphasises services, sector-specific systems (e.g. vehicles, dashboards, embedded instruments), biometrics, regulatory/control systems, and data-processing infrastructures, positioning it as a platform-level digital ecosystem cluster spanning smart services, mobility, and intelligent systems.

The US is more interaction- and interface-centric, with a stronger focus on direct user interaction technologies: AR environments, head-up displays, 3D manipulation, sensor-based input (6-DOF, motion

¹⁸² XR4Europe (2025). European XR Industry Report. Available at: <https://xr4europe.eu/wp-content/uploads/European-XR-Industry-Report-2025.pdf>

¹⁸³ European Commission (2023). Staff Working Document: information, insights and market trends on web 4.0 and virtual worlds. Available at: <https://ec.europa.eu/newsroom/dae/redirection/document/97341>

¹⁸⁴ ParisTech (FR) and Technical University of Munich (DE) are examples of European universities leading research on XR technologies ([source](#)).

¹⁸⁵ In advanced connectivity, the University of Oulu's 6G Flagship is an example of such a research centre ([online link](#)); while in NGI and XR, the University of Barcelona hosts the Experimental Virtual Environments for Neuroscience & Technology Lab ([link](#)).

tracking), GUI dialogue techniques, and speech dialogue processes, framing it as a front-end immersive interface and interaction design cluster.

Fraunhofer ISI and Technopolis Group based on Patstat

Threats

In NGI and XR, the R&I ecosystem is fragmented, with several RTOs developing high-quality technologies, but often in isolation. This lack of collaboration is partly due to a lack of interoperability and harmonised standards, hindering collaboration, integration, and scaling up of ideas across the EU.¹⁸⁶ The lack of harmonised standards in NGI and XR stands in contrast to advanced connectivity, where European actors play an influential role in shaping the global agenda for 6G, not only through early research and pre-standardisation activities but also by contributing to international bodies such as 3rd Generation Partnership Project, European Telecommunications Standards Institute (ETSI), and International Telecommunication Union (ITU). However, despite Europe's strengths in advanced connectivity, the European ecosystem faces challenges in translating research excellence into commercial success, which limits the broader impact of its scientific and technological strengths.

2.7 Opportunities in cross-fertilisation of digital technologies

Cross-fertilisation of technologies has been highlighted as very important and key opportunity for the EU since breakthrough innovations emerge from the convergence of multiple technologies. Moreover, cross-technology R&I developments are critical to developing the integrated solutions needed to address future societal and industrial challenges. Following the comprehensive desk research, data analysis and expert consultations, this study identified the following cross-technology trends relevant for EU R&I to focus on:

Artificial Intelligence stands out as the central technology domain with the strongest interconnections across a wide range of other technological fields. Most importantly the following cross-fertilisation trends provide opportunities for the EU given their high potential impact:

- **Edge-IoT and AI:** Deploying AI on local devices enables real-time processing, lower latency, stronger privacy, and reduced reliance on centralised cloud infrastructure. Edge AI represents a major opportunity for Europe to build a new generation of intelligent, distributed systems where AI moves from centralised cloud infrastructure closer to where data is created such as in vehicles, factories, medical devices, robots, sensors and IoT systems. The opportunity is driven by the need for real-time decisions, lower latency, privacy, energy efficiency, resilience and digital sovereignty¹⁸⁷.
- **High performance computing for AI:** HPC for AI is essential because it provides the massive computing power, scalability, and efficiency needed to train advanced AI models, accelerate scientific and industrial innovation, and enable Europe's strategic AI sovereignty.
- **AI and Quantum Computing:** AI supports quantum research through qubit control, error mitigation, algorithm design, and optimisation, while quantum computing may eventually enhance some AI workloads.

Advanced connectivity and HPC act as foundational infrastructure for embedding and scaling other digital technologies. In particular, advanced connectivity is expected

¹⁸⁶ Input from stakeholder consultations

¹⁸⁷ See also at: EPoSS & INSIDE Industry Association. (2025). *Artificial intelligence at the edge: A joint European roadmap for Edge AI*. European Association on Smart Systems Integration (EPoSS) and INSIDE Industry Association. https://www.smart-systems-integration.org/app/uploads/2025/10/EPoSS-INSIDE-RoadmapEdgeAI_Oct-2025.pdf

to converge with AI and cloud-edge systems into a unified, programmable digital infrastructure.

- **High-performance computing, advanced connectivity (5G/6G, edge computing), cloud infrastructure, and semiconductors** provide the computational power, ultra-low latency, and scalability required for data-intensive technologies such as XR, AI, robotics, and quantum computing. Future communication networks depend on cloud-native architectures, edge computing, AI-driven control, and advanced chips.
- **Next generation virtual worlds increasingly depend on large real-time data exchanges, where advanced connectivity as well as high performance computing will play a central role, providing the supporting infrastructure that meets the computer power and data demands from emerging XR technologies.**
- **Connectivity, Robotics and IoT:** Low-latency, high-bandwidth networks enable robotic coordination, V2X systems, immersive XR, and real-time industrial IoT applications.

The development of the Cloud-Edge-IoT continuum relies on advancements in related domains. Significant cross-fertilisation with other digital technologies is expected to generate smarter, more secure, efficient, and innovative solutions.

- **Artificial Intelligence**, which enables low-latency processing, context-aware autonomous functions, personalised user experiences, and the deployment of sophisticated models on edge devices.
- **Advanced connectivity** and advanced communication also enable a faster and more reliable cloud-edge-IoT continuum by supporting real-time data exchange and seamless device coordination
- **Cybersecurity and digital identity technologies** provide a more secure continuum through end-to-end protection and user-centric privacy.¹⁶

Digital-physical convergence is a further cross-technology trend with high potential. It merges physical environments with real-time digital capabilities and creates intelligent ecosystems among robotics, AI and digital twins. In the future, research in this mix of technologies can enable real-time simulation, remote operation, predictive optimisation, and immersive industrial applications.

- **Robotics, data and digital twins:** Digital twins are emerging as a critical enabler for Robotics R&I, particularly for training embodied AI systems. A digital twin in the Robotics context is a high-fidelity virtual replica of a physical robot and its operating environment, enabling real-time monitoring, simulation and optimisation of robotic processes.
- **Artificial Intelligence** enables robots to learn from real-world interaction, adapt to unstructured environments and operate with greater autonomy. Advances in perception, reasoning, action planning and continual learning drive the next generation of general-purpose robotic systems.

Cybersecurity by design is an important cross-technology for R&I: as digital technologies become increasingly interconnected, cybersecurity emerges as a foundational requirement across XR, robotics, AI, communications, and quantum systems to ensure trust, resilience, and safe autonomous operation.

- The development of cybersecurity technologies also depends on advancements in other technology domains, creating interdependent innovation pathways rather than isolated research tracks. Areas such as AI and the cloud-edge-IoT continuum already demonstrate strong overlap with cybersecurity priorities.

- As critical services, data, AI workloads, and business operations move to the cloud, the resilience and security of cloud infrastructure become fundamental to economic and operational stability. As some point out, the biggest cyber risk is not cloud concentration itself, but lock-in, when licensing, architectural, or contractual barriers prevent organisations from switching providers, deploying multi-cloud strategies, or recovering quickly during incidents¹⁸⁸.

Hybrid quantum-classical computing is an emerging technological paradigm. Hybrid computing is a computing paradigm that combines different types of computing architectures such as classical HPC, AI accelerators, edge computing, and quantum computing to solve problems more efficiently. Rather than functioning as a full replacement for classical supercomputing systems, quantum processors are increasingly integrated as co-processors or accelerators within broader HPC workflows. Several further cross-technology trends are relevant here:

- **Photonics is fundamental to quantum technologies.** Advances in photonics could enable improvements in the stability and scalability of quantum devices. Moreover, photonics integrated circuits are a key enabler for future communication, sensing, and computing systems, and represent a focal point for cross-fertilisation with quantum research and also AI.¹⁸⁹¹⁹⁰
- **High performance computing:** Real quantum computers are scarce and have limited capability. As an alternative, HPC provides the computational power to simulate and test quantum algorithms and hardware. HPC is also needed to handle the massive datasets and complex computations involved in quantum research and for developing the classical infrastructure needed to support and integrate with quantum computers. Please also see for further reference the technology annex on High Performance Computing.

2.8 EU opportunities along the technology value chain

This section analyses the technology value chain in an expanded framework that incorporates the interlinkages between AI and other adjacent digital technologies. It examines how value is created, captured, and distributed and in which part of the value chain the EU has strengths, opportunities or dependencies. By mapping the AI value chain alongside its digital technology linkages, the report aims to provide a more comprehensive understanding of the structural drivers shaping the digital economy. As it will be shown, the EU has gained strengths in certain segments of the digital value chain. The experts consulted in the context of this study recommended investing strategically to keep the EU leverage in these positions rather than trying to control the whole value chain. Besides desk research, this section relies on the further analysis of scientific publications, startup data and firm level data.

Artificial intelligence is a foundational technology shaping research and innovation systems, intersecting with a wide range of other digital technologies and producing economic and societal outcomes across sectors¹⁹¹. Its development, deployment, and impact are deeply embedded in **international value chains that span data generation, hardware, infrastructure, model development, applications, and end use**. Moreover, the development of AI is strictly intertwined with other digital technologies such as cloud

¹⁸⁸ Bauer, M., & Pandya, D. (2026). Cloud resilience and security: Why exit, portability, and lifecycle design matter.

European Centre for International Political Economy (ECIPE). [Cloud resilience and security: Why exit, portability, and lifecycle design matter](#)

¹⁸⁹ Laser Focus World (2025). Photonic integrated circuit market to reach \$54B by 2035,

<https://www.laserfocusworld.com/optics/article/55269821/photonic-integrated-circuit-market-to-reach-54b-by-2035>

¹⁹⁰ PhotonDelta, Annual report 2024 (2025). <https://www.photondelta.com/wp-content/uploads/2025/09/PhotonDelta-annual-report-2024-Orignally-signed.pdf>

¹⁹¹ Rice, C., Taylor, J. B., Widom, J., & Zegart, A. Lin, H. S. (2025). The Stanford emerging technology review 2025: A report on ten key technologies and their policy implications. Stanford University

computing, semiconductors, advanced connectivity, Internet of Things, cybersecurity, and digital platforms.

The technology value chain in this report is defined as *a sequential and interconnected series of activities that enable technology development, its implementation and finally its diffusion in the economy*. The value chain spans the development of technological knowledge and digital capabilities and their translation into real-world products, services, and economic value. AI requires full-stack technology knowledge to be in place across multiple domains such as in hardware, infrastructure, models, data, but also related to applications, and their security (in line with the numerous studies that have already captured the AI value chain¹⁹²). AI is created in an ecosystem where AI models require infrastructure and high performance computing (data centres, advanced semiconductors, and reliable storage systems). AI runs on data, and every image analysed, every prompt answered, every recommendation generated requires vast storage. Training and running large AI models requires connecting thousands of GPUs in data centres, which in turn means moving vast amounts of data at extremely high speeds.

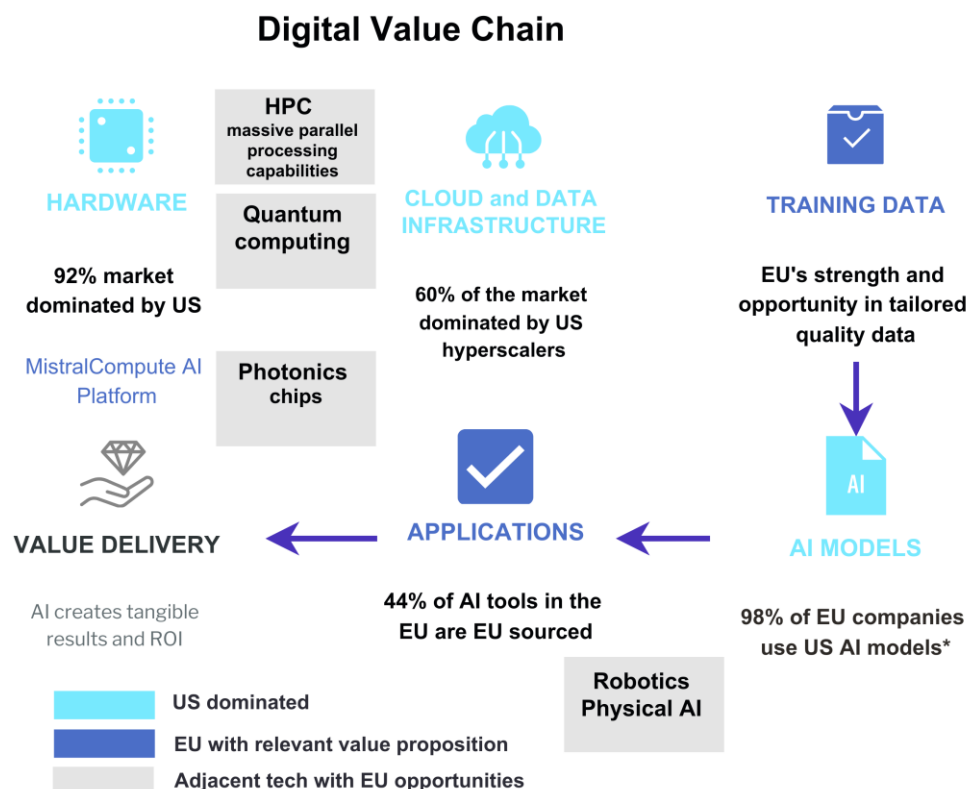
The AI value chain spans five tiers, beginning with a highly concentrated **hardware layer** dominated by chipmakers like Nvidia and AMD, followed by an **infrastructure layer** where cloud providers such as AWS, Azure, and Google Cloud offer access to computing power. **Training data** form the next input layer, supplying AI models with large volumes of text, images, and video drawn from both public and proprietary sources. Above this sits the **model layer**, where organisations like OpenAI, Meta, and Anthropic develop large foundation models that underpin the ecosystem. The **application model layer** is the broadest, comprising thousands of companies that fine-tune or embed these models into vertically focused or B2B solutions, while the consumer layer delivers AI directly to end users through assistants or integrated device features¹⁹³. Throughout the value chain, interoperability is critical to realise productivity gains from the use of AI, while the development of open standards and open-source software is fundamental to avoid vendor lock-in and to fight techno-feudalism of large companies. Moreover, it is important to keep in mind that AI is fuelled by energy and it is very energy intensive.

The value chain of AI is depicted in the Figure below, complemented with some key statistics about market shares and EU value proposition:

Figure 48 AI value chain

¹⁹² Gambacorta, L., & Shreeti, V. (2025). The AI supply chain (BIS Papers No. 154). Bank for International Settlements, Monetary and Economic Department., See also High Output AI talks ; Küspert, Sabrina, Nicolas Moës, and Connor Dunlop. 2023. "The Value Chain of General-Purpose AI." Ada Lovelace Institute. <https://www.adalovelaceinstitute.org/blog/value-chain-general-purpose-ai/> ; European Economic and Social Committee & Centre for European Policy Studies. (2025). Generative AI and foundation models in the EU: Uptake, opportunities, challenges, and a way forward (ISBN 978-92-830-6763-4; Publication No. QE-01-25-014-EN-N).

¹⁹³ Gambacorta, L., & Shreeti, V. (2025). The AI supply chain (BIS Papers No. 154). Bank for International Settlements, Monetary and Economic Department., See also High Output AI talks



Source: Technopolis Group, value chain stages based on Gambacorta, L., & Shreeti, V. (2025). The AI supply chain and complemented with additional statistics

Notes: * EMI Enterprise Survey 2025 found that 98% of responding firms answered they use AI models and tools originating from the US

** The market CATI survey found that 44% of tech companies answered that they primarily source their key supplies, materials, technologies or high-tech solutions/products leveraging Artificial Intelligence technology from an EU country

Europe's position in the AI value chain is defined by a mix of strengths, dependencies, and emerging opportunities. While the EU excels in areas such as advanced semiconductor equipment (with ASML), and research in various fields (edge AI, quantum AI etc), currently it remains heavily dependent on non-European suppliers for core AI hardware, cloud infrastructure, and high-performance chips. The market shares, dominant positions, EU strengths and opportunities are analysed per value chain segment in the following sections complemented with insights from various statistics collected in this study.

Hardware

The AI hardware and infrastructure layer is shaped by rapid innovation driven by intensive R&D but also high market concentration with significant barriers to entry. Crossholdings and investment partnerships are common, and state involvement is substantial through public funding and trade regulations, all of which influence how firms compete and collaborate across the ecosystem.

Current positions:

- **NVIDIA leads the AI chip market with a 92% market share of GPUs (2025)**¹⁹⁴ thanks to its software ecosystem, particularly CUDA, which enables far higher real-world utilisation of GPUs during large-scale model training. Over the years, popular AI tools like PyTorch and TensorFlow were built to work best with CUDA, meaning developers naturally optimised their models for NVIDIA hardware. This created a powerful lock-in effect: even if other companies make chips with similar raw speed, they struggle to compete because they lack NVIDIA's widely used ecosystem.

¹⁹⁴ <https://carboncredits.com/nvidia-controls-92-of-the-gpu-market-in-2025-and-reveals-next-gen-ai-supercomputer/>

- **Big technology companies such as Amazon, Google, Microsoft, and Meta invest heavily in NVIDIA GPUs**¹⁹⁵ (its data-centre-grade accelerator chips) as they are an effective and reliable way to train large AI models at scale, thanks to their tight integration with widely adopted software like CUDA.
- **Currently, the EU excels only in AI semiconductor equipment, particularly in advanced lithography and manufacturing tools**, with companies like ASML leading the world in cutting-edge chip fabrication technology. Otherwise, it is fully dependent.
- However, change is underway: in 2025, NVIDIA announced a strategic set of partnerships with European AI firms including Perplexity and Mistral AI to strengthen the continent's AI infrastructure and support the development of models suited to local languages and industry needs¹⁹⁶. As part of this initiative, **Mistral AI unveiled Mistral Compute, a sovereign AI platform in France**¹⁹⁷ built on thousands of NVIDIA's latest Blackwell GPUs, designed to provide integrated compute, orchestration, and tools for training and deploying advanced AI workloads within Europe's regulatory and data-sovereignty frameworks. Although Mistral Compute will keep on relying on NVIDIA's Blackwell GPUs and therefore does not achieve full hardware sovereignty, this move strengthens European strategic autonomy by keeping model development, data governance, orchestration, and regulatory compliance under European control.

EU opportunities:

- **Neuromorphic computing and non-GPU hardware:** In terms of scientific advances, the further development of GPUs, TPUs, accelerators, memory, networking, and chip architectures is essential because AI performance, cost, and scalability are tightly constrained by hardware. Knowledge development is crucial in parallel computing, latency, bandwidth, and energy efficiency. One of the long-term opportunities for the EU is neuromorphic computing that is emerging as a promising solution for the next generation of AI chips, particularly for edge inference¹⁹⁸. Besides, photonic chips¹⁹⁹ and memristors²⁰⁰ for AI can improve speed, memory efficiency, and energy use in applications such as autonomous driving and computer vision. These emerging technologies could outperform current hardware such as Google's TPUs, and multiple approaches may ultimately succeed (see also in the technology annexes on AI and on HPC).
- **Inference optimised chips:** AI is moving from large-scale training in data centres to real-world, continuous use. While training teaches models, inference is when AI makes decisions like answering questions or monitoring factories, and now it drives most costs, energy use, and impact. As AI increasingly runs on phones, vehicles, and local data centres with strict power and space limits and with traditional GPUs struggling, wasting energy on brute-force computation. Modern models require selective activation and fast, efficient data access, creating a strong opportunity for specialised, energy-efficient inference hardware that enables practical, real-time AI outside the cloud²⁰¹.

Insights from patent classes:

¹⁹⁵ <https://medium.com/@aidanpak/the-cuda-advantage-how-nvidia-came-to-dominate-ai-and-the-role-of-gpu-memory-in-large-scale-model-e0cdb98a14a0>

¹⁹⁶ <https://investor.nvidia.com/news/press-release-details/2025/NVIDIA-Partners-With-Europe-Model-Builders-and-Cloud-Providers-to-Accelerate-Regions-Leap-Into-AI/default.aspx>

¹⁹⁷ <https://mistral.ai/news/mistral-compute>

¹⁹⁸ <https://hello-tomorrow.org/cracking-compute-deep-techs-role-in-the-ai-chip-revolution/>

¹⁹⁹ <https://epthinktank.eu/2024/11/29/what-if-europe-championed-new-ai-hardware/>

²⁰⁰ A memristor (short for memory resistor) is an electronic component that stores information by changing its electrical resistance and retains that state even when power is switched off. <https://techxplore.com/news/2026-05-memristor-chip-merges-memory-ai.html>

²⁰¹ Based on expert interviews, see also here <https://www.morganstanley.com.au/ideas/ai-enters-a-new-phase-of-inference>

The US approach as evident from patent applications related to AI infrastructure is more conceptual and architectural, highlighting advanced orchestration, reasoning engines, and multi-network combinations. It is focused on the structural possibilities of AI systems.

The EU has a more operational and implementation-focused approach, emphasising training, execution, scaling, and efficiency. It is about the practical engine that makes AI work at scale.

China's related patent applications reveal a prioritisation of AI model architecture, learning methods, pattern recognition, neural network design, computational resource management

Fraunhofer ISI and Technopolis Group based on Patstat

Insights from the startup analysis:

European AI chip startups occupy a critical part of the AI hardware layer, designing specialised processors that enable high-performance AI computation as shown by the analysis of Crunchbase data. [Axelera AI](https://axelera.ai/)²⁰² (Netherlands) focuses on energy-efficient accelerators for edge and data-centre inference, moving toward mass production. [Innatera](https://www.innatera.com/) (Netherlands) demonstrates how brain-inspired architectures can unlock orders-of-magnitude efficiency gains. [SiPearl](https://www.sipearl.com/) (France) develops custom AI-optimised chips like the Rhea 1 for supercomputers and cloud platforms, reducing reliance on non-European suppliers. [Vybiu](https://www.vybiu.com/) (Austria) is building RISC-V-based AI accelerators for data-centre workloads, though still in early development.

Technopolis Group based on Crunchbase

Cloud and data infrastructure

The cloud and data centre infrastructure form a critical layer of the AI value chain, supplying the scalable compute, storage, networking, and energy capacity required to train, deploy, and operate AI models at scale. In comparison to other global markets, forecasts indicate that total worldwide data centre capacity stands at approximately 55-60 GW of which the EU27 accounts for around 20%. Approximately 12% of the total EU data centre capacity is estimated to be AI-ready. JLL²⁰³ forecasts global data centre capacity to be at 57 GW whilst Goldman Sachs²⁰⁴ forecast the current global market capacity to be approximately 59 GW. Total data centre demand across the EU27 is estimated to have reached around 15.3 GW in 2025, while available supply stood at approximately 12.4 GW, leaving an existing shortfall of about 3 GW. Looking ahead, demand is expected to rise sharply through 2036, driven primarily by the rapid expansion of AI training and inference workloads. In particular, GenAI has significantly boosted the cloud market, accounting for half of the global public cloud revenue growth since ChatGPT's launch in late 2022. In Europe, GenAI-focused services, including GPU-as-a-Service and GenAI PaaS, have seen exceptionally strong growth in recent years²⁰⁵. The cloud and data centre infrastructure behind AI is highly concentrated among a few dominant players.

Current positions:

- **On the computing side, cloud services and data centres are largely controlled by three hyperscalers, notably Amazon (AWS), Google, and Microsoft (Azure),** which together account for over 60% of the global cloud market and provide the massive computing power needed to train and run AI models²⁰⁶. These companies strengthen their position by owning data centres, networking infrastructure, and increasingly designing their own AI chips, as well as forming close partnerships with leading AI developers.

²⁰² <https://axelera.ai/>

²⁰³ JLL. (2025). 2025 Global Data Centre Outlook, Shaping tomorrow's digital infrastructure. Available at:

<https://www.jll.com/en-uk/insights/data-center-outlook>

²⁰⁴ Goldman Sachs (2025). AI to drive 165% increase in data center power demand by 2030. Available at:

<https://www.goldmansachs.com/insights/articles/ai-to-drive-165-increase-in-data-center-power-demand-by-2030>

²⁰⁵ Dawa L.A. Giuseppe Gianquinto Ometto (2025). Cloud Computing, Surf, https://www.surf.nl/files/2025-10/sf_tr26_en_cloudcomputing.pdf

²⁰⁶ OECD (2025). Competition in artificial intelligence infrastructure (OECD Roundtables on Competition Policy Papers, No. 330). OECD Publishing. <https://doi.org/10.1787/623d1874-en>

- At the same time, the **memory hardware essential for AI data processing is also concentrated**, with SK Hynix, Samsung, and Micron dominating both high-bandwidth memory (HBM) and standard DRAM chips, making them critical suppliers in the AI supply chain²⁰⁷.
- In this landscape, **European cloud providers focus on basic infrastructure rather than full-stack services**, and while initiatives like EuroStack²⁰⁸, or EuroCloud²⁰⁹ pilots for public-sector cloud federation, define principles for digital sovereignty and test sharing of available cloud capacity, actual adoption by industry and governments remains slow²¹⁰. Divergent procurement practices, security requirements and compliance obligations can limit the scalability of cloud services across the Single Market and contribute to uneven uptake, particularly for sensitive use cases.

EU opportunities:

- **R&I is driven by cloud platforms, distributed systems, data pipelines, storage, orchestration (e.g., Kubernetes), and MLOps.** Research is focused on building cloud infrastructure that can scale AI workloads efficiently, sustainably, and securely, while integrating edge and cloud environments to meet latency, privacy, and energy requirements.
- **Cloud-native AI offers significant potential through the integration of AI/ML workloads with purpose-built cloud infrastructures.** Developing open, interoperable cloud modules could enable smaller providers to collectively compete with US hyperscalers while offering governments and industry alternatives. Cloud-native AI leverages cloud computing technologies such as containerisation, serverless computing, and managed AI services to enhance scalability, flexibility, and efficiency²¹¹.
- As outlined already in the Cloud and AI Development Act²¹², an **EU opportunity is in moving from centralised data centres to edge computing**, which processes data closer to the user to enhance speed, privacy, and energy efficiency. By 2030, the EU plans to deploy 10,000 climate-neutral edge nodes and achieve 75% adoption of cloud-edge technologies among European businesses.
- **Most European banks currently rely on US cloud services. Enforcing the Digital Operational Resilience Act (DORA) effectively creates an urgent need for alternative, European-based cloud solutions.** EU banks are subject to strict rules under the DORA, which require them to have robust contingency plans, including the ability to quickly exit from cloud providers if necessary. This, in turn, could stimulate demand for homegrown cloud providers and help establish a market for sovereign digital infrastructure in Europe.
- **High Performance Computing offers a strategic opportunity as a foundational capability for large-scale AI training, scientific AI and industrial-grade simulation. Differently from cloud-native AI and edge AI, which have low TLR, HPC in the EU is already high TLR. The EU has already anchored this capability through the EuroHPC Joint Undertaking²¹³.** Building on this basis, the EU is explicitly using supercomputing to accelerate AI development via AI Factories²¹⁴, which combine AI-optimised supercomputers, associated data centres and AI-oriented services, and are designed to be open to public and private users with dedicated access conditions for start-ups and SMEs. The development of the

²⁰⁷ <https://introl.com/blog/ai-memory-supercycle-hbm-2026>

²⁰⁸ <https://eurostack.eu/>

²⁰⁹ <https://eurocloud.org/>

²¹⁰ <https://berthub.eu/articles/posts/the-european-cloud-2025/>

²¹¹ Veeravalli, P. K. (2025). Cloud-native AI solutions: Transforming enterprise application development. World Journal of Advanced Research and Reviews, 26(1), 3253–3261.

²¹² <https://www.eu-cloud-ai-act.com/>

²¹³ https://www.eurohpc-ju.europa.eu/index_en

²¹⁴ European Council (2024). Council adopts regulation on use of supercomputing in AI development <https://www.consilium.europa.eu/en/press/press-releases/2024/06/17/council-adopts-regulation-on-use-of-supercomputing-in-ai-development/>

EuroHPC Federation Platform creates a major EU opportunity to operationalise HPC, AI and data infrastructures as a federated, user-centric ecosystem, lowering access barriers for SMEs and researchers, enabling hybrid HPC–cloud–AI workflows, and accelerating the uptake of sovereign AI capabilities across Europe

²¹⁵.

Insights from patent classes:

The EU's patent applications in cloud-edge-IoT focus on building the core digital infrastructure: distributed computing systems, network architectures, software execution environments (virtualisation, emulation), and foundational cybersecurity (authentication, access security, key distribution, data protection). Its focus is on enabling platforms: secure, interconnected systems that other technologies run on.

US patenting suggests orientations towards intelligence and autonomy. It adds machine learning, learning methods, and communication, emphasising systems that can learn, decide, and interact automatically. It also has a stronger focus on platform integrity, including secure booting, trusted platform certification, vulnerability assessment, and system verification. It is more about smart, self-operating infrastructure.

China's approach is the most holistic and operational. It integrates distributed computing, AI/learning, networking, cybersecurity, software control, and industrial automation into a single coherent system view.

Fraunhofer ISI and Technopolis Group based on Patstat

Insights from the startup analysis:

Several EU startups are active in developing novel cloud infrastructure. Among the ones with the highest venture capital funding, the Dutch [Nebius AI](#)²¹⁶ is an AI-focused public cloud platform, launched in late 2023, designed to support the full lifecycle from data preparation and labelling to model training and inference. Another scaleup, notably the German [Northern Data Group](#)²¹⁷ has partnered to provide scalable European sovereign AI cloud infrastructure. Its collaboration with Core42 gives access to Cloud GPUs for rapid high-performance compute deployment. The collaboration follows a successful proof of concept and strengthens both companies' AI cloud capabilities across Europe.

Technopolis Group based on Crunchbase

Training data

Data is a crucial part of the AI value chain, as the end-to-end data pipeline captures real-time data from various sources such as the web, customer transactions, sensor readings from IoT devices to ultimately drive automated decisions and actions²¹⁸. The data segment is both foundational and highly uneven in its structure. Data acquisition, generation, and labelling are essential inputs for all downstream AI activity. The landscape is split between large incumbent platforms (such as big tech companies, telecoms, financial institutions, and industrial firms) that control vast proprietary datasets, and a long tail of specialised data companies that focus on data labelling, enrichment, annotation, and data engineering services²¹⁹. While raw data sources are widely distributed across industries, control over high-quality, large-scale, and continuously generated data is concentrated, giving major platforms a structural advantage in training and improving AI models. Smaller firms often compete by specialising in niche datasets, sector-specific expertise (e.g. healthcare or legal data), or compliance-ready data services.

Current positions:

²¹⁵ https://www.eurohpc-ju.europa.eu/paving-way-eurohpc-federation-platform-2024-12-19_en

²¹⁶ <https://nebius.com/newsroom/nebius-launches-new-ai-native-nvidia-cloud-platform-built-from-the-ground-up-to-accelerate-ai-innovation>

²¹⁷ <https://www.core42.ai/en/news/northern-data-group-and-core42-announce-strategic-partnership-for-large-scale-gpu-deployment>

²¹⁸ CXOTalk with Qlik

²¹⁹ <https://www.dawgen.global/decoding-the-artificial-intelligence-value-chain-from-data-to-competitive-advantage/>

- **Europe is structurally dependent on external ecosystems for the most critical AI resources such as large-scale datasets and pre-trained data.** Much of the data used to train modern AI systems is generated, owned, and controlled by non-European platforms, while the most powerful models and computing infrastructures remain concentrated in a handful of predominantly US-based firms. There are large-scale investments in data centres in the US and China that further sharpen competition. China's AI sector is rapidly accelerating following the rise of DeepSeek with a massive infrastructure build-out, and investment in data-centre power capacity and cloud providers are sharply increasing capital spending²²⁰. Chinese hyperscalers are becoming more self-sufficient by shifting from foreign to domestically produced AI chips and hardware.
- **This creates a strategic imbalance where Europe exercises normative power, setting rules, standards, and ethical frameworks for AI without equivalent technological sovereignty over the systems themselves.** Regulation without infrastructure limits autonomy, bargaining power, and long-term resilience, leaving Europe vulnerable to external policy shifts and technological dependencies. In practice, Europe shapes how AI should be governed, but not the data, compute, and models that define what AI becomes, positioning it more as a regulator and consumer of AI foundations than as a producer of them.

EU opportunities:

- **The EU has positioned itself in quality data.** While the United States and China rely on a volume-based approach with massive data lakes, the EU can differentiate itself by focusing on high quality and sector-specific datasets with initiatives around health and manufacturing already ongoing.
- **There is a strategic opportunity to focus on 'small data' and precision rather than scale.** Value will transition from energy-intensive data systems to those that refine and compress information into clear and relevant intelligence. AI that prioritises signal processing, compression, semantic precision, and minimalism is expected to deliver higher trust, lower energy use, and deeper insight creating a foundation for high-integrity, low-resource, high-value intelligence systems²²¹.
- **Creating public data trust that treats internet data as a shared digital 'commons'** offers another avenue for the EU in this part of the AI value chain. This trust would license data to AI developers in exchange for a share of revenues, ensuring that economic value from AI is fairly redistributed, negative externalities are addressed, and the public has a voice in AI governance²²².

Insights from patent classes:

The EU patent applications focus primarily on trusted data infrastructure. They deal with how data is collected, protected, shared, and governed for AI training and analytics, including secure access control, federated and distributed learning, encrypted communication, and protected data platforms. The central concern is not the models themselves, but ensuring that training data flows are reliable, compliant, and secure.

The US, on the other hand, emphasises data intelligence and learning pipelines. It concentrates on how data is structured, learned from, and transformed into knowledge, combining machine learning methods, ensemble learning, knowledge representation, and distributed computing. Data is treated as an intelligence resource: raw inputs are refined into structured representations, training sets, and learning systems that power analytics and AI models.

China focuses on operational data systems and is centred on how data is produced, synchronised, and used in live environments, such as enterprise systems. It is about continuous data creation, real-time analytics, and feedback loops, where operational data directly feeds training pipelines and model improvement.

²²⁰ <https://www.goldmansachs.com/insights/articles/chinas-ai-providers-expected-to-invest-70-billion-dollars-in-data-centers-amid-overseas-expansion>

²²¹ Based on expert consultations

²²² https://openfuture.eu/wp-content/uploads/2024/11/241113_Digital-Commons-as-Providers-of-Public-Digital-Infrastructures.pdf

Fraunhofer ISI and Technopolis Group based on Patstat

Insights from startups:

European startups offer new solutions for data analytics and data labelling. For example, [Innovatiana](https://www.innovatiana.com/en)²²³ is an impact-focused AI startup from France, specialising in ethically sourced data labelling to provide high-quality training data that accelerates the development of AI products.

AI models

The model layer of the AI value chain represents the software and algorithmic logic where AI models are trained, fine-tuned, and deployed to end users. This layer transforms that power into functional intelligence capable of generating text, code, or images²²⁴. It includes foundation models like GPT, LLaMA, and Stable Diffusion that serve as the base for other applications, as well as vertical or specialised models tailored for specific industries or business functions.

Although the EU operates its own testing and experimentation facilities, it remains dependent on technologies and models developed abroad. This vulnerability is most pronounced in the case of foundation models,²²⁵ with 73% coming from the United States and 15% from China since 2017.²²⁶

Scientific publications include machine learning fundamentals, deep learning architectures, training techniques, fine-tuning, evaluation, and optimisation. It also involves understanding trade-offs between accuracy, speed, cost, and robustness.

Current positions:

- **The generative AI market is largely led by US companies**, with major players including Meta, Anthropic, and xAI²²⁷, while OpenAI stands out as the dominant frontrunner. Companies operating in this layer have built competitive advantage by developing models with high performance, versatility, and adoption, often leveraging scalable cloud compute and advanced hardware.
- **In 2025, US organisations remained the global leader in AI model development²²⁸, with China rapidly closing the quality gap and Europe still trailing behind in both volume and performance.** While the US continues to lead in volume, Chinese models have quickly caught up in quality, with performance gaps on key benchmarks like MMLU and HumanEval narrowing from double digits in 2023 to almost equal in 2024.
- European companies often focus on fine-tuning and deploying external models rather than building foundational ones, reinforcing a reliance on foreign technological cores despite strong domestic scientific capacity²²⁹.

EU opportunities:

- **Europe has built significant strength in AI through world-class research in advanced algorithms**, and it can lead in developing AI models that are explainable, transparent, and compliant with EU regulations. Startups and research institutions can create models that prioritise fairness, privacy, and safety, giving European AI a global competitive advantage in trustworthy applications.

²²³ <https://www.innovatiana.com/en>

²²⁴ <https://businessengineer.ai/p/the-ai-value-chain>

²²⁵ Experts' consultation (workshops)

²²⁶ <https://carnegieendowment.org/research/2025/05/the-eus-ai-power-play-between-deregulation-and-innovation?lang=en>

²²⁷ <https://x.ai/>

²²⁸ Stanford University (2025). The 2025 AI Index Report <https://hai.stanford.edu/ai-index/2025-ai-index-report>

²²⁹ Based on expert interviews

- **Industry-specific AI models:** there are ongoing efforts and strong potential in tailoring AI models to European industries such as healthcare, manufacturing, automotive, energy, and finance. Medical imaging models adapted to EU healthcare standards, or industrial AI optimised for smart factories, can drive adoption and economic value.

Insights from patent classes:

Interestingly, the EU's primary patent classes (where most patents have been applied for) in Artificial Intelligence are primarily application- and domain-oriented. As this analysis finds, the EU patenting focuses on embedding AI into concrete societal, industrial, and institutional contexts, most notably healthcare diagnostics, medical imaging, biometrics, and organisational and industrial systems. Its defining characteristic is problem orientation: AI is framed as a tool to solve specific real-world challenges, improve services, and augment decision-making within established sectors.

US patent applications have a system-integration focus dealing with applications and infrastructure. The US combines foundational AI methods with operational platforms, linking perception, inference, diagnostics, and organisational processes into coherent, scalable systems. Its focus is not just on building AI models or deploying them in isolated domains, but on creating integrated AI ecosystems that function as continuous, inference-driven decision infrastructures across sectors.

China's primary patent applications are instead fully technology-driven. It concentrates on the core building blocks of AI itself, including neural architectures, pattern recognition, speech and image processing, optimisation, and training techniques. It is largely domain-agnostic and advancing the general capabilities, efficiency, and performance of intelligent systems.

Fraunhofer ISI and Technopolis Group based on Patstat

Applications

Applying AI effectively requires domain expertise and product thinking, understanding user needs, workflows, and where AI adds real value. This includes prompt design, UX integration, and measuring business impact. AI systems require knowledge of cybersecurity, model safety, interpretability, compliance, and responsible AI practices, especially as models become more autonomous and impactful. The deployment of critical digital technologies is further discussed in the Study on the EU's critical digital capacities deployment beyond 2027²³⁰.

Table 18 Overview of EU opportunities along the AI value chain

²³⁰ European Commission: Directorate-General for Communications Networks, Content and Technology, Technopolis Group, Murray, A., Adewusi, A., Marshal, T. et al., Study on the EU's critical digital capacities deployment beyond 2027. Annex 5, Technology area report blockchain and distributed ledger technologies, Publications Office of the European Union, 2026

	Hardware	Infrastructure	Data	Models	Applications
Market concentration	NVIDIA (92% market share) dominates AI accelerator chips, TSMC and Samsung lead advanced chip manufacturing	Amazon (AWS), Google, and Microsoft (Azure), which together account for over 60% of the global cloud market	Google, Meta, Microsoft, LinkedIn, Amazon, Scale.AI etc US market share of AI training data is 40%	Highly concentrated around a small number of companies such as OpenAI, Google DeepMind, Anthropic and Meta	Market for AI is expected to reach a value of €51.2 bn in 2025
EU tech company scaleup strengths	ASML holds a near-monopoly in EUV lithography equipment Challengers in next-generation AI hardware: Axelera AI Innatera SemiQon Sicoya Ephos (photonics)	OVHcloud, Nebius.AI Northern Data Group	The European AI data ecosystem is strong, with competitive companies such as Dataiku, Collibra, Talend, Mostly AI, Sifflet, Innovatiana operating across data preparation, governance, annotation	Mistral.ai, Aleph Alpha, Pleias	Some of the drivers: Bosch, Stellantis, Renault, VW, Airbus, Safran, L'Oréal, Siemens, Philips, EDF
EU Opportunities	Energy efficient computing Neuromorphic computing Photonics	Cloud-edge-AI Continuum HPC	High-quality, specialised 'small' data	Open source models, Trustworthy AI, Sector-specific models	Industry, Manufacturing Health Climate

Source: Technopolis Group based on desk research, Note: company names include examples

Cross-linkages with other technologies along the value chain

Analysing the AI value chain offers a practical way to understand how other advanced technologies, such as quantum, next generation internet (NGI), robotics technologies are developing and becoming increasingly interconnected. AI development highlights the key building blocks that underpin innovation across complex technological systems, notably **data availability, computational infrastructure and underlying models and algorithms**²³¹. Viewing these elements together helps to explain how progress in AI is shaped by constraints and dependencies that extend beyond the technology itself. Examining bottlenecks and dependencies along the AI value chain helps to identify the

²³¹ Lorente, A. (2025). Value Creation and Value Capture in AI: A Triple Helix Model. *Proceedings of the AAAI/ACM Conference on AI, Ethics, and Society*, 8(2), 1637-1646. <https://doi.org/10.1609/aies.v8i2.36662>

shared infrastructural, data-related, and hardware-related constraints that also affect other technology domains. In particular, AI progress depends on the alignment and maturity of all these components, as well as close interlinkages with other key technologies. For example, advance in robotics increasingly rely on AI models trained on large datasets and executed under strict latency and energy constraints, or quantum technologies are evolving in close integration with classical HPC and AI workflows for simulation, optimisation and control. Using AI as a reference value chain thus enables a system-level perspective on research and innovation, enabling the identification of cross-domain dependencies and helping to prioritise R&I investments that address shared bottlenecks rather than isolated technological silos.

Across quantum, robotics and NGI/XR, a consistent number of **interdependency patterns emerges**:

- **Bottlenecks amplification:** shared bottlenecks concentrate structural risk in a small number of upstream layers: advanced semiconductors, high-performance compute, energy efficiency, data access and cloud infrastructure. Because these inputs are common across domains, constraints in any one of them spread simultaneously across technologies, amplifying Europe's vulnerabilities where dependence on non-EU suppliers and platforms is highest.
- **Feedback loops:** cross-domain feedback loops increasingly shape technological trajectories. In particular, AI acts as a general-purpose accelerator, improving quantum calibration, robotic perception and control, and XR content generation, while downstream deployment in robotics and immersive environments generates new data that feeds back into AI models. These feedback loops are asymmetric in time: AI delivers immediate gains to other domains, while their contribution to AI remains longer-term and more uncertain, reinforcing advantages for actors already controlling AI compute and platforms.
- **Asymmetric value capture:** Europe consistently excels in upstream research, algorithmic innovation, system integration and applied experimentation, yet struggles to capture downstream economic rents. Control over data, compute, cloud platforms and core architectures allows a small number of global actors to extract disproportionate value, even when innovation originates elsewhere. As a result, Europe risks remaining a net creator of scientific and technological value without commensurate strategic or economic control, unless interdependencies at the infrastructure and platform level are explicitly addressed.

Quantum

The quantum value chain spans **upstream inputs** such as advanced semiconductors, photonics, materials, and precision fabrication. The **hardware layer** encompasses qubit platforms, cryogenic systems, photonics, control electronics, and advanced materials. **No dominant quantum architecture has yet emerged, meaning that the field remains technologically open and subject to rapid experimentation**²³². Several qubit modalities coexist, including superconducting qubits, trapped ions, photonics, neutral atoms, and spin-based approaches. At the moment superconducting qubits are the most commercially available quantum processing units, largely due to their relative maturity and the ability of large firms to scale fabrication and integration²³³.

The European Union has a meaningful presence with commercial and pre-commercial quantum processors spread across several countries, notably France, the Netherlands, Finland, and Germany²³⁴. However, this presence is more fragmented than in the United States, which leads in both the number and diversity of quantum computing platforms. Europe's strength lies less in a single dominant champion and more in a **network of**

²³² Ruane, J., Kiesow, E., Galatsanos, J., Dukatz, C., Blomquist, E., Shukla, P., "The Quantum Index Report 2025", MIT Initiative on the Digital Economy, Massachusetts Institute of Technology, Cambridge, MA, May 2025.

²³³ Ibid.

²³⁴ Information gathered via experts' consultations for this project (interviews and expert workshops)

national hubs, which creates depth but also challenges in scaling and consolidation²³⁵.

Concerning the **infrastructure**, it increasingly determines who can innovate and who can scale. This includes high-performance computing for simulation and hybrid workflows, quantum testbeds, fabrication and characterisation facilities, and cloud-based access models such as quantum-as-a-service. Most quantum computers today are accessed through cloud platforms or specialised partnerships rather than being widely installed on customer premises. Infrastructure is the main gatekeeper of participation in the quantum ecosystem, as **access to compute, fabrication, and experimental platforms directly conditions research productivity and industrial entry²³⁶**. Europe's public research infrastructures and coordinated initiatives provide a strong foundation, but access remains uneven and fragmented²³⁷. In quantum networking, the EU appears especially well positioned. The European Union's large number of quantum networking testbeds and the strategic importance of coordinated initiatives such as the Quantum Internet Alliance²³⁸, which aims to deliver a "quantum internet made in Europe." This reflects a deliberate European strategy to lead in infrastructure, standards, and long-term capabilities rather than short-term commercial dominance alone.

The **software and models layer** include quantum algorithms, compilers, control software, error mitigation techniques, and hybrid quantum–classical models, increasingly enhanced by AI. This layer represents one of the highest leverage points in the value chain, as software can scale faster than hardware and shape standards and interfaces. Europe is strong in foundational research and early-stage software development but risks losing ground where software is tightly coupled to proprietary platforms and cloud ecosystems.²³⁹

At the **downstream end** of the value chain are applications and system integration, including quantum computing use cases, quantum communication, and quantum sensing. These applications remain **largely at pilot or demonstrator stage**, with near-term traction mainly in security, defence, metrology, and critical infrastructure. On the research side, the EU represents a significant share of global quantum computing and quantum communications publications and performs particularly well in highly cited research, indicating strong scientific quality.

In terms of key players, large technology corporations dominate the upstream and platform layers of the value chain. Companies such as IBM, Google, Microsoft, Intel, and Baidu are identified as leading patent holders and major investors in quantum research and infrastructure²⁴⁰. Publicly listed and well-known quantum-focused companies such as IonQ²⁴¹, D-Wave²⁴², Rigetti²⁴³, and Quantum Computing Inc²⁴⁴. appear prominently in commercial communications and investor activity. In addition, younger but strategically important firms such as QuEra²⁴⁵ and Quantum Machines²⁴⁶ are highlighted for their funding rounds and growing influence, particularly in hardware scaling and control systems.

Interdependency patterns with AI

At multiple layers, this value chain overlaps directly with that of AI. In particular, **both technologies depend on the same advanced semiconductor nodes, non-EU foundries, and energy-intensive compute infrastructures**. High-performance computing

²³⁵ Ibid.

²³⁶ Ruane, J., Kiesow, E., Galatsanos, J., Dukatz, C., Blomquist, E., Shukla, P., "he Quantum Index Report 2025", MIT Initiative on the Digital Economy, Massachusetts Institute of Technology, Cambridge, MA, May 2025.

²³⁷ Information gathered via experts consultations for this project (interviews and expert workshops)

²³⁸ <https://quantuminternetalliance.org/>

²³⁹ Ruane, J., Kiesow, E., Galatsanos, J., Dukatz, C., Blomquist, E., Shukla, P., "he Quantum Index Report 2025", MIT Initiative on the Digital Economy, Massachusetts Institute of Technology, Cambridge, MA, May 2025.

²⁴⁰ Ibid.

²⁴¹ <https://www.ionq.com/>

²⁴² <https://www.dwavequantum.com/>

²⁴³ <https://www.rigetti.com/>

²⁴⁴ <https://quantumcomputinginc.com/>

²⁴⁵ <https://www.quera.com/>

²⁴⁶ <https://www.quantum-machines.co/>

plays a dual role, enabling the training and deployment of AI models while simultaneously underpinning quantum simulation, hybrid quantum–classical workflows, and hardware development.

At the software and control level, **AI is already essential to quantum research, where it is used to calibrate devices, mitigate errors, optimise control parameters, and manage large experimental datasets.**

This convergence means that **quantum does not develop independently from AI; rather, its progress is increasingly conditioned by the same infrastructure, talent, and platform dynamics that shape the AI ecosystem.**

Additionally, Quantum AI is not yet fully realised at scale, but it is moving beyond theory into early-stage experimentation and commercialisation. While large, fault-tolerant quantum systems capable of transforming AI do not yet exist, significant investment and pilot activity are underway across industry and research. Market forecasts suggest growing economic relevance, with Hyperion Research²⁴⁷ estimating that AI will account for 18% of quantum algorithm revenue by 2026. Major technology firms and start-ups, including Google²⁴⁸, IBM²⁴⁹, Microsoft²⁵⁰, AWS²⁵¹ are advancing hybrid quantum-AI platforms, quantum machine learning research and early commercial use cases.

Bottlenecks amplifications

The implications of this convergence for the value chain are structural. First, it creates a strongly coupled dependency on **compute and semiconductor capacity**, transforming these into systemic choke points rather than technology-specific constraints. Limitations in access to advanced chips, foundries, or large-scale computing resources simultaneously affect AI and quantum research and development, amplifying the impact of existing European weaknesses. Second, as quantum computing remains scarce and costly, much of the emerging economic value is concentrated in control software, middleware, and cloud-based quantum-as-a-service models, areas that closely resemble the dominant value-capture mechanisms already observed in AI.

Feedback loops

AI techniques, particularly machine learning and deep learning, are already being applied to improve quantum system calibration, error correction, noise mitigation, chip design, reducing operational complexity and increasing hardware reliability²⁵². These improvements, in turn, enable more stable and capable quantum processors that can support increasingly sophisticated AI workloads.

In the short and medium term, **AI accelerates quantum development by improving hardware control, materials discovery, and experimental efficiency, thereby reducing time-to-iteration in quantum research**²⁵³. In the longer term, scalable quantum computing may enhance certain AI workloads, particularly in faster training, more efficient optimization, and new quantum-enhanced machine learning method, although these benefits remain uncertain and technologically distant. These feedback loops are asymmetric in time and impact: AI delivers immediate productivity gains to quantum R&I, while quantum's potential

²⁴⁷ Hyperion Research (2025). 5th Annual Global QC/QS Market Survey. Available at:

<https://hyperionresearch.com/product/5th-annual-global-qc-q-s-market-survey/>

²⁴⁸ Google is developing Quantum AI research. Available at: <https://quantumai.google/>

²⁴⁹ Launched a cloud-based quantum computing platform that supports AI applications. Available at:

<https://quantum.cloud.ibm.com/>

²⁵⁰ Investing in hybrid quantum-classical AI research. Available at: <https://azure.microsoft.com/en-us/blog/quantum/2023/03/08/microsoft-is-harnessing-the-power-of-the-cloud-to-make-the-promise-of-quantum-at-scale-a-reality/>

²⁵¹ Investing in hybrid quantum-classical AI research and in a new quantum computing chip. Available at:

<https://www.aboutamazon.com/news/aws/quantum-computing-aws-ocelot-chip>

²⁵² IQM(2025) Your Quick Guide to Quantum and AI: The Future of Computing or Just Hype? Available at:

<https://meetiqm.com/blog/quantum-ai-the-future-of-computing-or-just-hype/>

²⁵³ <https://meetiqm.com/blog/quantum-ai-the-future-of-computing-or-just-hype/>

contribution to AI remains largely prospective. Consequently, actors that already control AI compute and platforms may be best positioned to benefit from both sides of the interaction.

Value capture

The convergence between quantum and AI also magnifies asymmetric value capture, a pattern already visible in Europe's AI ecosystem. Europe demonstrates world-class capabilities in quantum science, algorithmic innovation, and talent generation, leading in publications and early-stage research. However, much of the infrastructure required to scale this advance, (large-scale compute, cloud platforms, R&D-scale foundries, and data-intensive service layers) remains concentrated outside the EU. As a result, while Europe creates significant technological and scientific value in quantum technologies, there is a high risk that economic rents and strategic leverage will accumulate elsewhere, particularly where quantum hardware is accessed via non-EU cloud platforms and integrated into globally dominant digital ecosystems. To conclude, the risk might be that European research excellence (both in AI and Quantum) does not translate into proportional value capture due to dependence on foreign platforms and compute infrastructures.

Robotics

The robotics value chain spans from upstream enabling technologies and foundational research to system integration, deployment, and downstream services. Across this chain, the European Union demonstrates strong structural advantages in research excellence, system integration, and human-centric design, while facing persistent weaknesses related to scaling, investment, and dependency on non-European suppliers for critical components²⁵⁴.

At the **upstream end of the value chain**, robotics depends on a complex set of enabling technologies including sensors, actuators, energy systems, advanced materials, microelectronics, communication technologies, and software frameworks. The European Union benefits from a strong industrial and scientific base in mechatronics, automation, advanced materials, and energy-efficient systems, supported by world-class research organisations and specialised SMEs²⁵⁵. However, the European Union remains structurally dependent on non-EU suppliers for critical high-performance components, particularly processors, GPUs, memory chips, and certain precision mechanical parts. This dependency represents a strategic vulnerability, both in terms of supply security and innovation sovereignty, and limits Europe's ability to fully capture value as robotics systems increasingly rely on AI-intensive computation embedded at the edge²⁵⁶.

At the level of **robot manufacturing and platform development**, the EU maintains a strong position in industrial robotics, collaborative robots, and professional service robotics. European firms are well established in sectors such as automotive manufacturing, logistics automation, healthcare robotics, and inspection and maintenance, and Europe hosts a substantial share of global service robotics companies. Leading European robotics manufacturers include KUKA²⁵⁷, Universal Robots²⁵⁸, Mobile Industrial Robots²⁵⁹, ABB²⁶⁰, Comau²⁶¹, Stäubli²⁶², and PAL Robotics²⁶³. System integration and large-scale deployment are driven by major industrial and engineering groups such as Siemens²⁶⁴, Bosch²⁶⁵,

²⁵⁴ Information gathered via experts consultations for this project (interviews and expert workshops)

²⁵⁵ euROBOTICS (2024) A Unified Vision for European Robotics. Available at: <https://eu-robotics.net/wp-content/uploads/euRobotics-A-Unified-Vision-for-European-Robotics-Dec2024-web.pdf>

²⁵⁶ Ibid.

²⁵⁷ <https://www.kuka.com/>

²⁵⁸ <https://www.universal-robots.com/>

²⁵⁹ <https://mobile-industrial-robots.com/>

²⁶⁰ <https://www.abb.com/global/en/areas/robotics>

²⁶¹ <https://www.comau.com/en/>

²⁶² <https://www.staubli.com/global/en/home.html>

²⁶³ <https://pal-robotics.com/>

²⁶⁴ <https://www.siemens.com/be/en.html>

²⁶⁵ <https://www.bosch.be/>

Volkswagen Group²⁶⁶, BMW²⁶⁷, Airbus²⁶⁸, and Thales²⁶⁹, which invest heavily in robotics research, development, and integration. Robotics manufacturing and deployment in the EU is characterised by a highly concentrated industrial structure, dominated by a limited number of large OEMs and integrators. Activity is strongly clustered in established industrial regions, most notably in Germany, with major hubs in Bavaria (Augsburg and Munich) and Baden-Württemberg (Stuttgart), as well as in Denmark, northern Italy, and parts of France and Switzerland. European manufacturers are particularly strong in industrial robotics and collaborative robots (cobots) for manufacturing environments, with a strong emphasis on automotive and advanced industrial applications. Competitiveness is built on system reliability, safety, regulatory compliance, and deep integration into complex production environments. Integration of AI into robotic platforms and manufacturing systems is a rapidly growing field, though adoption remains uneven and is progressing more incrementally compared with AI-native approaches emerging in the United States and China. European manufacturers often struggle to scale rapidly, in part due to limited access to growth-stage capital and ongoing reliance on imported hardware and digital infrastructures²⁷⁰.

Downstream integration, deployment, and robotics-enabled services represent a critical area of both strength and unrealised potential for Europe. European integrators, industrial users, and public-sector actors have deep expertise in deploying robots in real-world settings characterised by high safety, regulatory, and reliability requirements. Recent International Federation of Robotics figures (September 2024) indicate that Europe has some 36% of the service robotics companies in the world, more than the USA with 33%, in a market growing at 30% per annum²⁷¹. This is built on a strong underlying research base (strong universities and RTOs), small and medium companies specialising in the development of robotics and their integration and deployment into a wide variety of manufacturing and service sectors²⁷².

At the same time, widespread adoption remains constrained by skills shortages, high deployment and configuration costs, and the limited availability of user-friendly tools that reduce reliance on highly specialised personnel²⁷³.

Interdependencies patterns with AI

Robots provide the physical means of action, but the major performance gains arise when robotic systems are tightly integrated with artificial intelligence for perception, reasoning and decision-making. This integration, often referred to as physical AI, transforms robots from pre-programmed automation assets into adaptive systems capable of operating in dynamic, unstructured and human-centred environments²⁷⁴.

In industrial and service contexts, AI increasingly closes the loop between sensing, planning and execution. AI-based perception enables semantic interpretation of sensor data, including object recognition in point clouds and dynamic scene understanding, which in turn supports automatic collision-free path planning and rapid reconfiguration. Connectivity with PLC, MES and IoT layers, enabled through standards such as OPC UA, allows logic validation and controller co-simulation to be performed before deployment, significantly reducing commissioning time and operational risk. Digital twins act as the central coordination layer, ensuring design-to-execution continuity whereby product or process changes propagate automatically to task plans and robot trajectories, preserving productivity and quality while minimising downtime. At present, the maturity of AI-robot integration remains low (TRL 1–3). Increasing reliance on learning-based autonomy

²⁶⁶ <https://www.volkswagen-group.com/en>

²⁶⁷ <https://www.bmw.be/nl/home.html>

²⁶⁸ <https://www.airbus.com/en>

²⁶⁹ <https://www.thalesgroup.com/en>

²⁷⁰ Information gathered via experts consultations for this project (interviews and expert workshops)

²⁷¹ International Federation of Robotics, 2024. Retrieved from: https://ifr.org/img/worldrobotics/Press_Conference_2024.pdf

²⁷² euROBOTICS (2024) A Unified Vision for European Robotics. Available at: <https://eu-robotics.net/wp-content/uploads/euRobotics-A-Unified-Vision-for-European-Robotics-Dec2024-web.pdf>

²⁷³ Ibid.

²⁷⁴ Boru, B., & Erin, K. (2022). Novel technique for control of industrial robots with wearable and contactless technologies. Measurement, 192, 110850.

intensifies challenges related to explainability, trust, validation and human oversight, which are prerequisites for deployment in regulated and safety-critical environments²⁷⁵.

Bottlenecks amplification

The integration of AI and robotics faces several persistent bottlenecks. Data acquisition and sim-to-real transfer remain costly and technically challenging, particularly for contact-rich manipulation and safety-critical tasks. Many AI models demonstrate strong performance offline but struggle with real-time inference, deterministic latency and bounded failure behaviour required for robotic control. Certification and regulatory compliance represent further barriers, as black-box learning approaches are difficult to verify and validate using existing standards. Additionally, fragmentation across hardware, software, middleware and enterprise systems increases integration complexity and deployment costs.

Feedback Loops

AI–robot integration creates a self-reinforcing feedback loop between intelligence and physical capability. AI enhances robotic perception, planning and control, enabling robots to operate in more complex and unstructured environments. As these robots are deployed, they generate large volumes of high-quality, task-specific data from real-world interaction²⁷⁶. This data feeds back into the AI layer, improving model performance, robustness and generalisation, which in turn further expands robotic capability and autonomy. Digital twins and simulation environments strengthen this loop by supporting pre-training, validation and sim-to-real transfer, while human–robot interaction increases adoption and data intensity. Over time, this virtuous cycle generates cumulative learning advantages and increasing returns to scale, making deployment, data access and integration capacity critical determinants of long-term performance and value capture.

Value capture

Europe possesses a globally leading position in foundational robotics research, particularly in perception, manipulation, human–robot interaction, safety and dependable systems. This strength extends to AI–robot integration, where European research emphasises trustworthy, explainable and human-centric approaches. However, economic value is increasingly captured downstream in integrated platforms, software stacks, data ecosystems and system integration capabilities²⁷⁷. Without stronger mechanisms to translate research excellence into scalable products and platforms, Europe risks remaining a technology originator while value capture accrues elsewhere. Additionally, weaknesses persist in the translation of research outcomes into deployable technologies. Fragmented funding structures, insufficient incentives for industry participation, and limited alignment between academic research objectives and industrial timeframes contribute to long development cycles and slow commercial uptake²⁷⁸. As a result, Europe risks remaining a technology originator without capturing downstream economic value

NGI and XR

The NGI and XR value chain spans from foundational digital infrastructure to end-user applications and services, with value creation distributed unevenly across layers. Europe is strongest in research, applied experimentation, and specialised components, but weaker in platform control, large-scale deployment, and global value capture²⁷⁹.

²⁷⁵ euROBOTICS (2024) A Unified Vision for European Robotics. Available at: <https://eu-robotics.net/wp-content/uploads/euRobotics-A-Unified-Vision-for-European-Robotics-Dec2024-web.pdf>

²⁷⁶ Pan, Y., Hu, K., Cao, H., Kang, H., & Wang, X. (2024). A novel perception and semantic mapping method for robot autonomy in orchards. *Computers and Electronics in Agriculture*, 219, 108769.

²⁷⁷ Mohamed, Hoda (2025) : Moving backward or forward? Robots and value capture in the automotive global value chains, Jena Economic Research Papers, No. 2025-005, Friedrich Schiller University Jena, Faculty of Economics and Business Administration, Jena

²⁷⁸ The AI Data Robotics Association (ADRA), AI-powered robotics – Strategy for Europe. (2025). Available at: https://adr-association.eu/sites/default/files/2025-07/ADRA_AiPoweredRobots_Jun2025_FINAL.pdf

²⁷⁹ Information gathered via experts consultations for this project (interviews and expert workshops)

At the foundation of the value chain lie **connectivity, cloud and edge computing, and high-performance hardware components**. Europe has important strengths in network research and advanced infrastructure, supported by actors such as Nokia and by EU-level assets including EuroHPC and emerging AI Gigafactories. However, critical dependencies persist in semiconductors, GPUs, cloud services and XR-specific hardware, which are largely supplied by non-European providers. Uneven access to low-latency networks across regions further constrains the development and testing of real-time, data-intensive XR applications. As these foundational layers underpin all higher levels of the NGI and XR ecosystem, weaknesses here amplify structural vulnerabilities across the entire value chain.

The platform and middleware layer, encompassing operating systems, XR runtimes, development engines and interoperability frameworks, represents a decisive point of value capture. Despite a strong European tradition in open and decentralised internet architectures, XR development in practice remains heavily dependent on non-European engines, notably Unity²⁸⁰ and Unreal Engine²⁸¹. European alternatives such as Godot²⁸² align well with NGI principles but lack the ecosystem scale, assets and developer communities required for widespread adoption²⁸³. Fragmentation and limited interoperability further reduce Europe's ability to shape platform standards and extract strategic value from downstream innovation.

Above this layer, **Europe performs strongly in enabling technologies such as digital twins, modelling, simulation and applied AI**. Research organisations including Fraunhofer, INRIA, TNO and VTT play a critical bridging role between fundamental research and industry, while universities lead globally in interdisciplinary work combining computer science, engineering, neuroscience and human–computer interaction. These strengths support advanced XR use cases in industry, healthcare and training. Nevertheless, the integration of generative AI into XR development pipelines remains limited, and access to interoperable data spaces and large-scale compute environments constrains scaling and commercial deployment.

In hardware and devices, Europe hosts globally recognised niche leaders such as Varjo²⁸⁴ and Lynx²⁸⁵, which specialise in high-end, professional XR solutions. These firms show Europe's capacity for precision engineering and advanced design, particularly for industrial and enterprise markets. However, most remain SMEs with limited production scale and continued dependency on non-European components, making it difficult to compete in mass consumer markets or achieve significant global market shares²⁸⁶.

At the application level, Europe benefits from a wide range of XR and NGI use cases across sectors, supported by close links between research institutions, public authorities and industry. Value creation is high, particularly in domain-specific and human-centric applications, yet value capture remains constrained by reliance on external platforms, engines and cloud infrastructures²⁸⁷. The private sector's strong dependence on public funding and the limited availability of late-stage scale-up capital further weaken Europe's ability to consolidate and retain economic returns.

Interdependency patterns with AI

Artificial intelligence is the technology with the strongest cross-fertilisation potential across the NGI and XR value chain, as it increasingly highlights intelligent, adaptive and immersive virtual environments²⁸⁸. Through models such as Variational Autoencoders (VAEs) or Generative Adversarial Networks (GANs), virtual surroundings will become aware and

²⁸⁰ <https://unity.com/>

²⁸¹ <https://www.unrealengine.com/en-US>

²⁸² <https://godotengine.org/>

²⁸³ Information gathered via experts consultations for this project (interviews and expert workshops)

²⁸⁴ <https://varjo.com/>

²⁸⁵ <https://www.lynx-r.com/>

²⁸⁶ Information gathered via experts consultations for this project (interviews and expert workshops)

²⁸⁷ Information gathered via experts consultations for this project (interviews and expert workshops)

²⁸⁸ Information gathered via experts consultations for this project (interviews and expert workshops)

interactive, supporting more immersive and context-sensitive applications.²⁸⁹ Generative AI, including approaches such as GANs and VAEs, addresses a core bottleneck of virtual worlds by enabling the scalable creation of diverse, high-quality content that cannot be produced efficiently through manual processes alone. AI-generated content enables responsive and context-aware environments, supports advanced personalisation, and opens new pathways for the automated generation of 3D assets from user descriptions, analogous to current text-to-image or text-to-video systems²⁹⁰. At the same time, the convergence of AI and XR is laying the groundwork for interoperable virtual worlds and collaborative digital spaces across sectors such as education and healthcare, provided that data can move securely across platforms while respecting privacy and user control. These dynamics intensify demands on high-performance computing, advanced connectivity and ultra-low-latency networks, which are essential to sustain real-time interaction, large-scale data exchange and user-perceived immersion, making AI, XR and NGI mutually reinforcing components of a tightly coupled technological system.

Bottlenecks amplifications

Weaknesses in foundational layers of the digital stack have systemic effects across the entire NGI, XR and AI ecosystem. Europe's reliance on non-EU semiconductors, GPUs and cloud computing infrastructure constrains the capacity to train advanced AI models, limits real-time XR rendering performance, and hampers the scalability of digital twins and complex simulations. Because these technologies share common dependencies on compute, memory and data throughput, a single bottleneck, such as restricted access to high-performance computing resources, simultaneously affects AI development, immersive environments, robotics and simulation-based innovation.

Feedback Loops

NGI, XR, AI and adjacent technologies are linked through powerful feedback loops that drive mutual acceleration across the digital stack. Generative AI increasingly enables XR by accelerating world-building, supporting adaptive avatars and enabling personalised, context-aware virtual environments. In turn, XR systems produce rich, embodied and multimodal data derived from human interaction, which improves the training and performance of AI models. Europe's strong position in interdisciplinary research across these domains provides a solid foundation to benefit from such co-acceleration, but only if bottlenecks in compute access, platforms and infrastructure are effectively addressed²⁹¹.

Value capture

At the same time, these feedback loops intensify patterns of asymmetric value capture along the NGI value chain. **Control over data, compute infrastructure and core architectures enables a small number of global actors to extract disproportionate strategic and economic benefits, even when innovation occurs elsewhere.** Downstream users, system integrators and application developers contribute significantly to value creation but retain limited bargaining power and long-term control.

The table below summarises the key cross-dependencies linking AI, quantum, robotics, NGI/XR, highlighting shared bottlenecks and infrastructural layers that connect their development trajectories.

²⁸⁹ Zhou et al. (2025). Generative Artificial Intelligence in the Metaverse era: A review on models and applications. *Research*, 8. Available at: <https://doi.org/10.34133/research.0804>

²⁹⁰ Fernández-Caramés, T. M., & Fraga-Lamas, P. (2024). Forging the industrial metaverse for Industry 5.0: Where Extended Reality, IIoT, opportunistic edge computing, and digital twins meet. *IEEE Access*, 12. [10.1109/ACCESS.2024.3422109](https://doi.org/10.1109/ACCESS.2024.3422109)

²⁹¹ Information gathered via experts consultations for this project (interviews and expert workshops)

Table 19 Overview of the cross dependencies

Cross dependencies	AI	Quantum	Robotics	Next Generation Internet
Non-EU semiconductors, GPUs, and cloud compute	x	x	x	x
Advanced semiconductor nodes and specialised fabrication	x	x	x	
Access to large-scale compute (training, simulation, hybrid workflows)	x	x	x	x
Energy availability and energy efficiency constraints	x	x	x	x
Dependence on cloud-based access models and platforms	x	x		x
High-performance networking and low-latency connectivity		x	x	x
Shared reliance on AI-enabled software stacks and middleware	x	x	x	
Data access, governance and availability at scale	x		x	x

Source: Technopolis Group based on desk research and expert consultations

3. Roadmap of future EU R&I investments into critical digital technologies

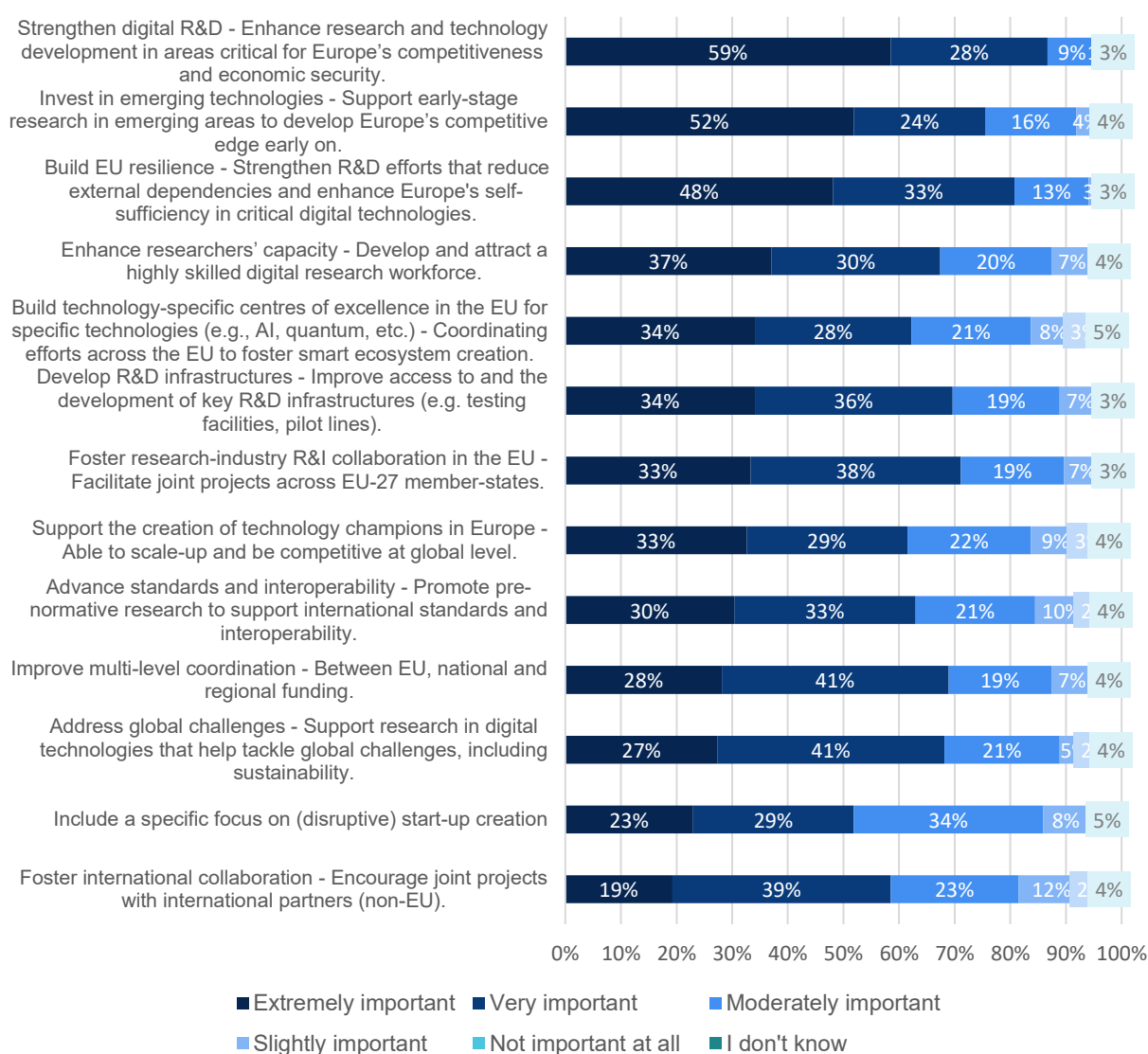
Future R&I investments need a roadmap that guides investment decisions and rely on a careful assessment of opportunities and risks, strengths and weaknesses of the EU in critical digital technologies. This chapter sets the vision and objectives for the next EU R&I programme for digital technologies based on a comprehensive stakeholder consultation, expert interviews and desk research.

3.1 Stakeholders view on objectives, prioritisation and added value

3.1.1 Objectives of public intervention to support the R&I of digital technologies

According to stakeholders, a future EU R&I programme should aim **most importantly to strengthen digital R&D in areas critical for the competitiveness and security of the European economy (concluded by 87% of stakeholders)**. An important objective is seen in investing in emerging technologies and supporting early-stage research in emerging areas to develop Europe's edge early on.

Figure 49 Level of importance of the following dimensions for a future EU programme supporting the R&I of digital technologies (2028-2034) (sorted by dimensions rated as extremely important)



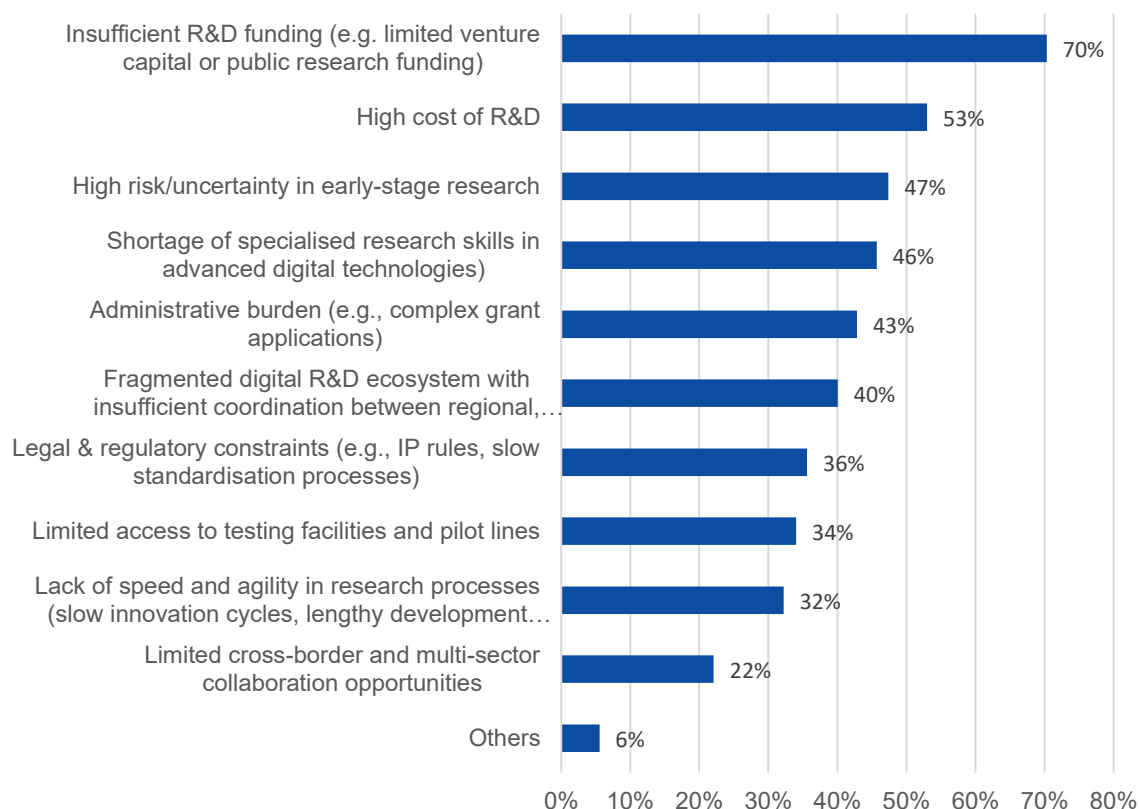
Source: Technopolis Group (2025) based on stakeholder survey results, n=135

Related to this, enhancing Europe's self-sufficiency in critical technologies is seen as a very important objective. While EU R&I investments in digital technologies addressing critical dependencies are needed, they have to be accompanied by measures that also address the regulatory fragmentation across EU Member States.

The stakeholder survey results show an almost equal support for a large number of dimensions, from focusing on building researcher capacity through to the inauguration of technology-specific European centres of excellence. Echoing the concern with external dependencies, there is less widespread support for the objective of funding joint R&I projects with non-EU partners (58%). Complementing the results of the stakeholder survey, semi-structured interviews carried out in the context of this study highlighted the need for research to be better tailored to industry and SME needs and stressed the importance of fostering startups in other related deployment programmes (further details are presented in the summary report on stakeholder and expert consultations).

Besides the main programme objective, there are concrete challenges stakeholders expect the EU to address. According to the stakeholders surveyed, the most important challenge is the insufficient R&D funding, which includes public research funding and private R&D capital (70% of stakeholders rating this as the most relevant to address and this is considered as a critical challenge across all technology areas). High cost of R&D, high risk and uncertainty in early stage research are also issues that EU should tackle. High costs are particularly problematic in Cloud-Edge-IoT, Photonics, Quantum, Robotics and Microelectronics. More than 40% of respondents rate the shortage of specialised research skills in advanced technologies, administrative burden, fragmented digital R&D ecosystem with insufficient coordination among EU, national and regional initiatives (in particular in the case of data analytics and HPC) very important issues to deal with. The table below presents the greatest challenges across the 12 technology areas.

Figure 50 Most important challenges that an EU programme for the R&I of digital technologies should address based on stakeholders' views [Please select the 5 most important challenges that should be addressed by an EU programme supporting R&D of digital technologies]



Source: Technopolis Group (2025) based on stakeholder survey results, n=126

Table 20 Overview of the most important challenges that an EU programme for the R&I of digital technologies should address based on stakeholders' views, per technology area

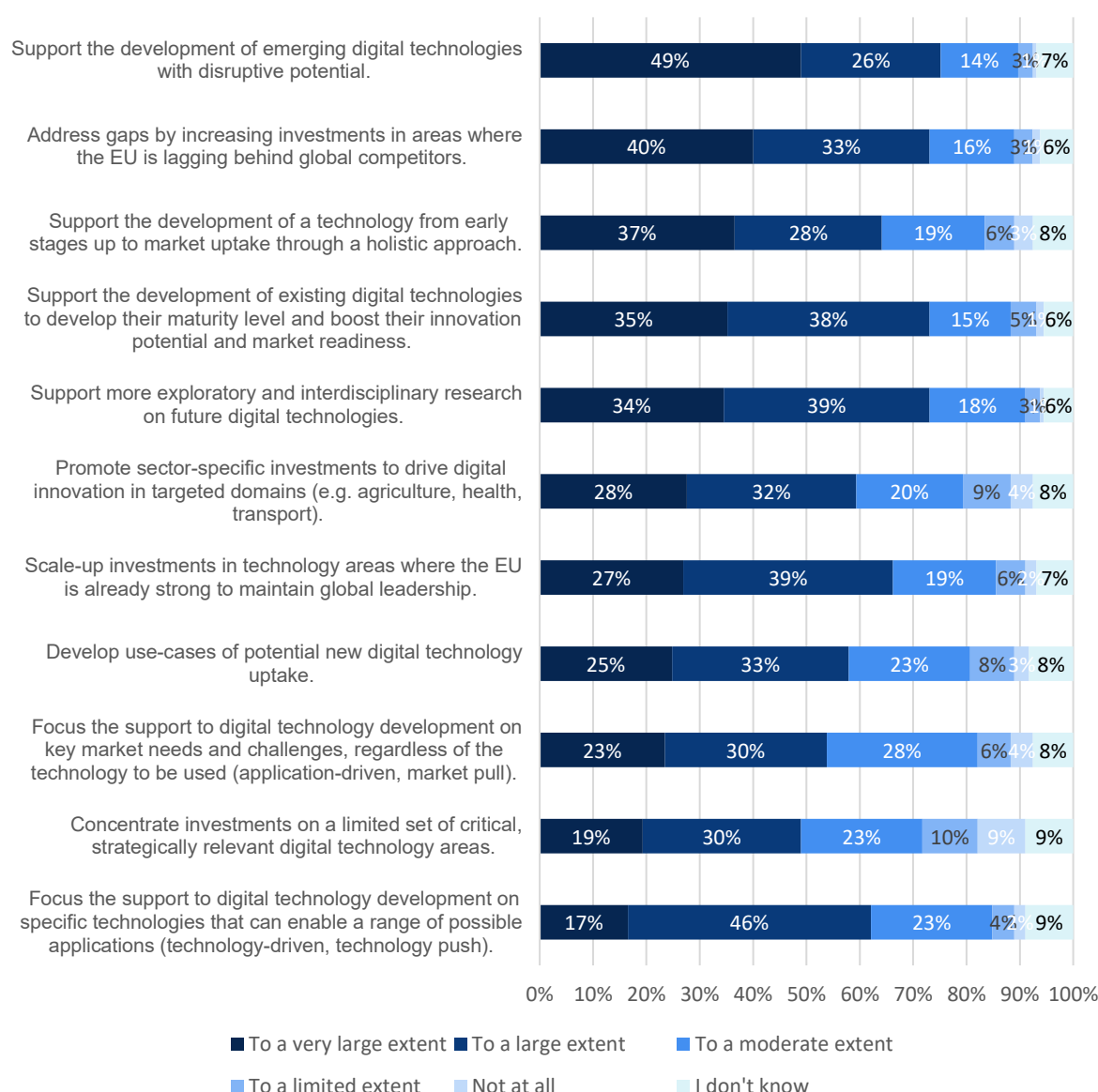
Please select the 5 most important challenges that should be addressed by an EU programme supporting the research & development of Artificial Intelligence technologies?	AI	Advanced connectivity	Blockchain	Cloud-edge-IoT	Cybersecurity	Data	HPC	Photonics	Quantum	Robotics	Microelectronics	NGI & XR
Insufficient R&I funding (e.g. limited venture capital or public research funding)	High	High	High	High	High	High	High	High	High	High	High	High
High risk/uncertainty in early-stage research	Medium	Low	High	High	Medium	Medium	Low	High	High	High	High	Medium
High cost of R&I	Medium	Low	Medium	High	Medium	Medium	Medium	High	High	High	High	Medium
Shortage of specialised research skills in advanced digital technologies)	High	Medium	Low	Medium	High	Medium	High	Medium	Medium	Low	High	High
Limited access to testing facilities and pilot lines	Medium	Low	Low	High	Medium	Low	Low	Low	High	Medium	High	Low
Legal & regulatory constraints (e.g., IP rules, slow standardisation processes)	High	Medium	Low	Medium	High	High	High	Low	Low	Low	Low	Medium
Administrative burden (e.g., complex grant applications)	Medium	High	High	Medium	High	High	Low	Low	High	Medium	Low	High
Limited cross-border and multi-sector collaboration opportunities	Low	Low	Low	Medium	Low	Medium	Medium	Low	Low	Low	Low	Low
Fragmented digital R&I ecosystem with insufficient coordination between regional, national, and EU-level initiatives	Medium	Medium	Medium	Medium	Medium	High	High	Low	Medium	Low	Low	Medium
Lack of speed and agility in research processes (slow innovation cycles, lengthy development times)	Medium	Medium	Medium	Medium	Low	Medium	Low	Medium	Medium	Medium	Low	Medium

Source: Technopolis Group (2025) based on stakeholder survey

3.1.2 Prioritisation

The table below presents the results from the stakeholder survey as regards the dimensions recommended to prioritise when investing in digital technologies through the next EU R&I programme. The feedback shows **a clear preference for calls that would support emerging digital technologies with disruptive potential**: 52% of respondents agree to a 'very large extent' that this should be a priority for the digital strand of the next EU R&I programme. By contrast, just 17% of respondents agreed that a future programme should prioritise technologies that are relevant to multiple applications.

Figure 51 Dimensions to prioritise in the next EU programme for the R&I of digital technologies



Source: Technopolis Group (2025) based on stakeholder survey results, n=145

Looking at the feedback from stakeholders that agreed to a very large extent and to a large extent across different priorities, the results show there are four dimensions that were endorsed by more than 70% of all respondents. **Besides focusing the support on**

disruptive technologies, there is also widespread preference for increasing EU R&I investment in areas where the EU is lagging behind the global leading edge (73% of stakeholders ranking it important to a very large or a large extent).

Moreover supporting the development of technologies from early stages up to market uptake through a holistic approach is also ranked high, together with developing the maturity level of existing technologies and boost their market readiness. This view reinforces the need for EU-funded research and innovation projects driving the development of cutting-edge European industry. These priorities are also in line with the aspirations of the European Commission to better align the future R&I and deployment programmes. Overall, views diverge between those who argue for prioritising exploratory research into disruptive technologies and those who favour more incremental innovation pathways.

Table 21 To what extent should a future EU programme supporting the research & development of digital technologies provide the following types of support (range of responses: 1 least to 5 most)

Rating	Microelectronics	Photonics	AI	Data	Robotics	HPC	Quantum	Cybersecurity	Cloud-edge-IoT	Blockchain	Advanced connectivity	NGI & XR
Basic research (TRL 1-3) - producing cutting-edge fundamental research in digital technologies	3,8	4,0	4,2	4,0	4,4	4,2	4,1	4,4	4,2	3,8	4,3	3,8
Applied research (TRL 4-6) - translating basic research into innovative digital solutions	4,7	4,9	4,4	4,7	4,9	4,2	4,6	4,6	4,5	3,8	4,4	4,2
Close-to-market innovation (TRL 7-9) - demonstrating innovative digital technologies' readiness for commercialisation	4,2	4,1	4,0	4,2	4,3	3,6	4,3	4,2	4,4	3,8	3,9	4,1
Advanced digital skills - ensuring access to skills for digital technology development and adoption	4,1	3,3	4,1	4,1	3,6	4,4	3,1	3,9	4,2	3,6	3,6	3,6
Testing and experimentation facilities, pilot lines and other technology infrastructures - ensuring access to test technologies and lower the risk of investments	4,3	4,0	3,8	3,8	4,1	4,0	3,6	3,9	4,3	3,6	3,8	3,5
Ecosystem and value chain integration - collaboration among industry, academia, research organisations and public bodies	4,1	4,3	4,0	4,0	3,5	4,6	3,9	4,3	4,2	3,4	4,0	3,7

Source: Technopolis Group (2025) based on Stakeholders' survey

Note: cells in blue are the highest ranked answer, cells highlighted in yellow or the second highest

3.1.3 EU added value for public intervention to support the R&I of digital technologies

According to stakeholder, the most important added value for a future EU R&I programme supporting critical digital technologies, as compared over national or regional programmes, is in first place **connecting European digital ecosystems** via cross-border collaborations and secondly, **enhancing the global positioning of European R&D players** developing digital technologies. Around 75% of respondents agree to a large or very large extent that EU R&I funding should deliver these types of added value. The table below presents the results from the stakeholder survey as regards the added value of an EU R&I programme for digital technologies.

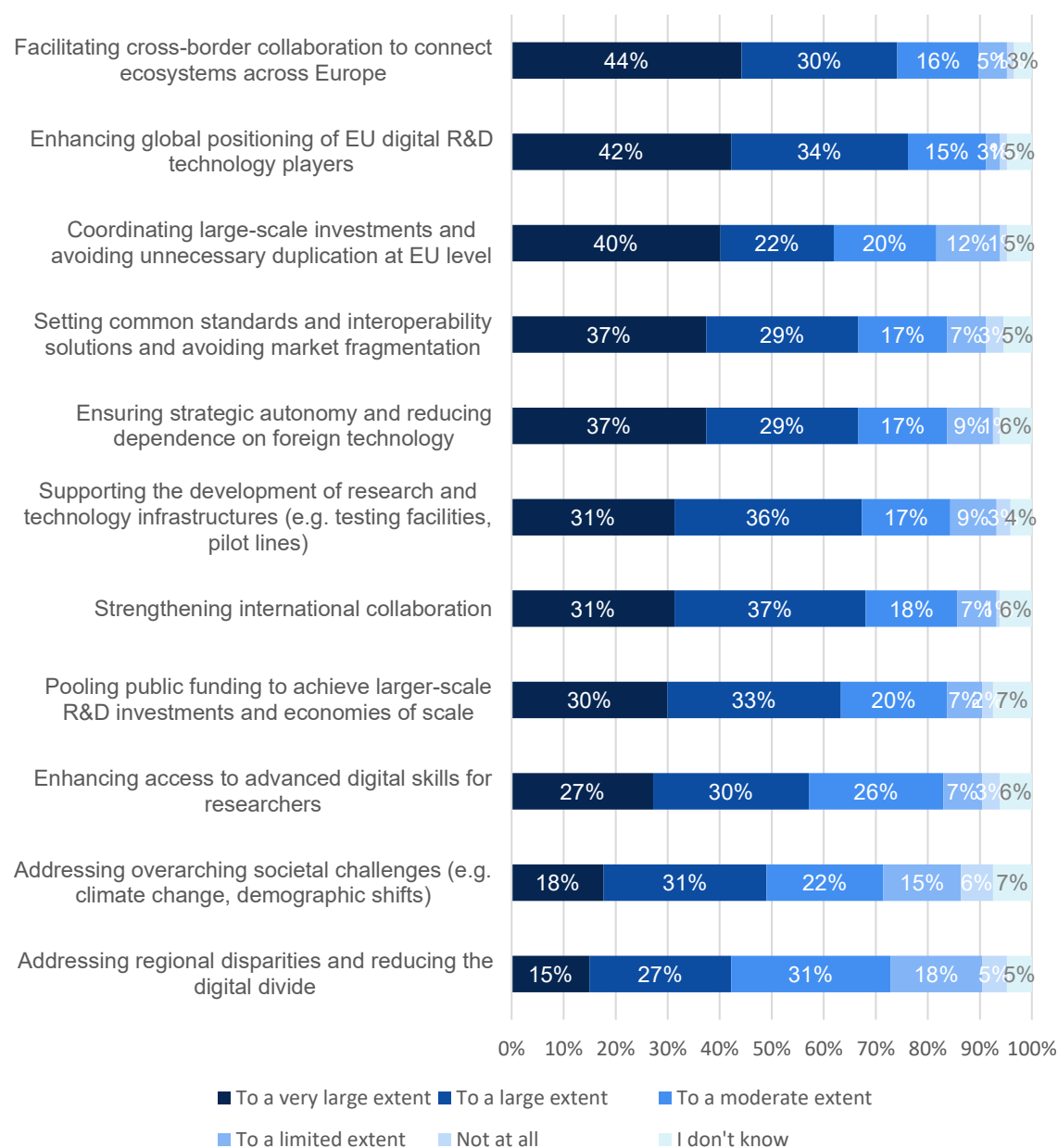
Around 65%-70% of the respondents consider EU R&I programmes better suited for **coordinating large-scale investments, setting common standards, supporting the development of pan-European research infrastructures, strengthening international collaboration and pooling of funds into larger budgetary envelopes**.

In a lesser extent, 42-49% of respondents foresee EU added value in addressing societal challenges and the regional digital divide. It is also notable that the feedback is less positive about an EU programme being especially valuable in progressing societal issues like the digital divide, perhaps reflecting the fact that Europe is a world leader in relatively few digital technologies and a judgement that its future R&I success is likely to rest on targeting key emerging technologies where the EU has a lead it can extend.

These pockets of excellence are often geographically specific, and one might expect the benefits of future investments in the further development of those technologies will benefit existing clusters. The wider European societal impacts should come later, through the deployment of the advanced digital technologies that benefited from EU R&I support.

Stakeholder interviews highlighted that EU-level support has been essential so far for enabling large-scale, cross-border research and innovation that would not be possible through national or private funding alone. Across domains such as climate and health, quantum technologies, AI, 6G, cybersecurity, immersive communications, data spaces, cultural heritage, and advanced manufacturing, EU programmes have provided the scale, risk-tolerance, coordination, and shared infrastructure needed to advance deep-tech and high-impact projects. This support has helped build strong European ecosystems, foster interoperability, create open-source communities, strengthen SMEs and startups, and enable access to cutting-edge testbeds, pilot lines, and supercomputing infrastructures. For further details please see the summary report on stakeholder and expert consultations.

At the same time, several challenges remain such as SMEs often struggle with complex application processes and lack follow-on funding to scale validated innovations. National systems remain often fragmented or under-resourced and some EU programmes tend to favour large actors or centralised infrastructures.

Table 22 Added value of an EU programme for the research & innovation of digital technologies compared to national/regional and private efforts

Source: Technopolis Group (2025) based on stakeholder survey results, n=147

3.1.4 Strategic implementation and programme design for R&I

To maximise impact and efficiency, the future Horizon Europe digital window should be underpinned by a comprehensive set of design requirements that support streamlined and effective user interactions.

First and foremost, the programme's procedures could be made faster and more agile to keep pace with the rapidly evolving technological and geopolitical landscape. Lengthy application, evaluation, and contracting processes can delay the deployment of critical technologies, reducing the programme's ability to respond to emerging industrial needs and strategic priorities. Streamlining administrative requirements, shortening evaluation timelines, and introducing more flexible funding mechanisms would enable innovative projects to move more quickly from concept to implementation. Greater procedural agility would also make the programme more attractive to industry, particularly

SMEs, which often lack the resources to navigate complex and time-consuming funding processes.

A key challenge is balancing responsiveness to emerging technological developments with continued support for the foundational research that enables progress. These two priorities should be pursued in parallel; however, the current structure of research funding in the EU makes rapid response difficult. From the recognition of a new trend to the launch of a project typically takes around two years, with a further three to five years before outputs are delivered²⁹². This delay contributes to Europe consistently taking a “late follower” role.

The analysis suggests that the distribution of funding across the pillars, and the implicit balance between support for science and innovation, is broadly appropriate. Similarly, the emphasis on directing investments primarily through Pillar II is unchallenged, indicating broad support for a digital programme that operates across all pillars while maintaining its centre of gravity within collaborative industrial research. At the same time, the future programme could adopt a more strategic approach by concentrating on fewer technology areas, placing greater emphasis on larger-scale interventions, and strengthening coordination across the pillars, as well as with other EU and national programmes.

The analysis indicates that dimensions such as social sciences and humanities are regarded as important considerations for a future EU digital R&I programme. Given this generally positive assessment, greater weight could be placed on those dimensions for which there is particularly strong agreement that they are essential elements of any future programme. Several design attributes relate to overarching principles, such as open science and Equality, Diversity and Inclusion (EDI), which are expected to apply across all actions funded under a future EU R&I programme, including those in the digital domain. While these principles are likely to remain universal requirements, the analysis suggests that they are not viewed as defining priorities for the digital programme itself. Similarly, the social sciences and humanities, public engagement, and cross-sector fertilisation are considered important enabling or cross-cutting elements rather than core areas of focus for a future digital R&I programme.

Human centrality and trustworthiness reflect longstanding priorities in digital research and innovation. They emphasise the need to ensure that digital technologies are designed, developed, and deployed with people's needs, rights, and experiences at their core. This includes engaging users and other affected groups throughout the design, development, and evaluation process, rather than relying solely on technology-driven approaches. These dimensions also respond to concerns that innovation can be led by technological capabilities rather than societal needs, resulting in solutions that are difficult to use, fail to gain user acceptance, or deliver limited practical or public value. Trustworthiness further encompasses the need for digital technologies to be reliable, transparent, secure, and accountable, thereby fostering confidence among users and society more broadly.

Other dimensions that stand out in terms of the breadth of support are skills development, sustainability, and strategic autonomy. These represent three distinct priorities, each addressing a different aspect of Europe's digital future. Skills development focuses on ensuring that Europe has the human capital required to develop, deploy, and adopt advanced digital technologies, recognising that shortages of digital talent remain a major constraint on innovation and competitiveness. Sustainability emphasises both the role of digital technologies in enabling the green transition and the need to reduce the environmental footprint of digital infrastructures and services. Strategic autonomy, meanwhile, reflects the objective of strengthening Europe's technological capabilities and reducing critical dependencies on external suppliers in key digital technologies and value chains. These priorities can reinforce one another, for example, developing digital skills

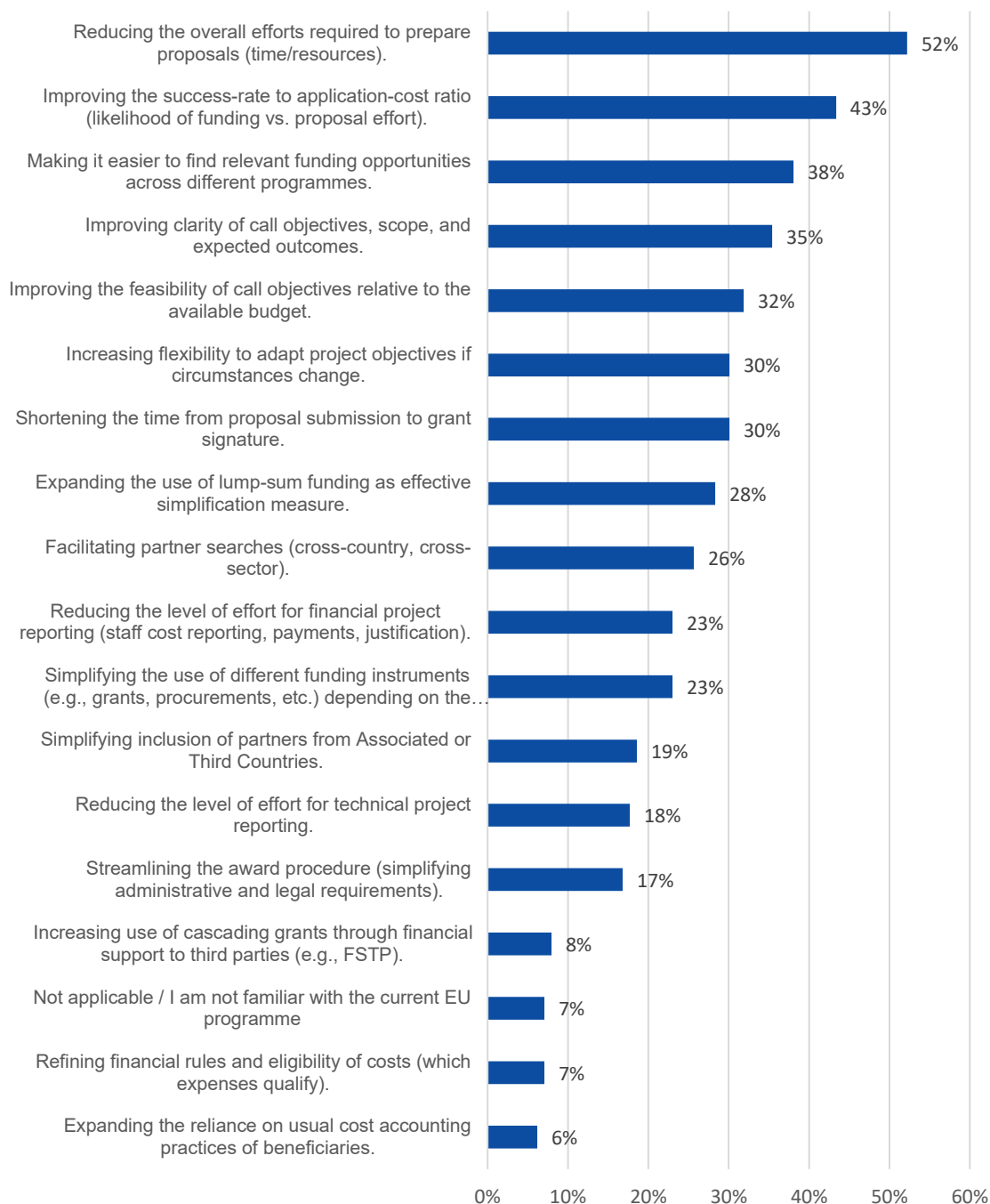
²⁹² euROBOTICS, A Unified Vision for European Robotics.

contributes to strategic autonomy, while digital innovation can support sustainability goals, their primary objectives, target interventions, and policy rationales still differ.

The combination of the high cost of preparing proposals and the low probability of success emerges as a principal concern underlying calls for simplification. Preparing applications is widely perceived as both technically and administratively demanding, requiring a substantial investment of time and resources. In highly competitive calls, low success rates mean that many applicants incur these costs without any prospect of funding, raising questions about whether the balance between effort, risk, and potential reward is appropriate. These concerns are compounded by perceptions that the budgets available under some calls are not always commensurate with the scale of the ambitions or the resources required to achieve the expected outcomes. Hence, the issue is not only the cost and uncertainty associated with securing funding, but also whether successful projects receive sufficient support to deliver on the objectives set for them.

There are concerns expressed about the multiplicity of funding instruments (creating uncertainty about the most appropriate measure) and the burden of post-contract monitoring and reporting. Few simplification issues relate uniquely to digital, however, perhaps the speed of decision making is especially pertinent for many digital technologies where developments are already fast moving and accelerating. This would apply equally to the metabolic rate of the programme overall, where the policy cycle unfolds over years rather than months. Other performance attributes of relevance would be the ease with which grant agreements can evolve in line with lessons learned through the research itself and a recognised need to adapt to or benefit from wider external developments.

Figure 52 5 Top 5 items that would constitute margins for simplification for a future EU programme supporting the R&D digital technologies



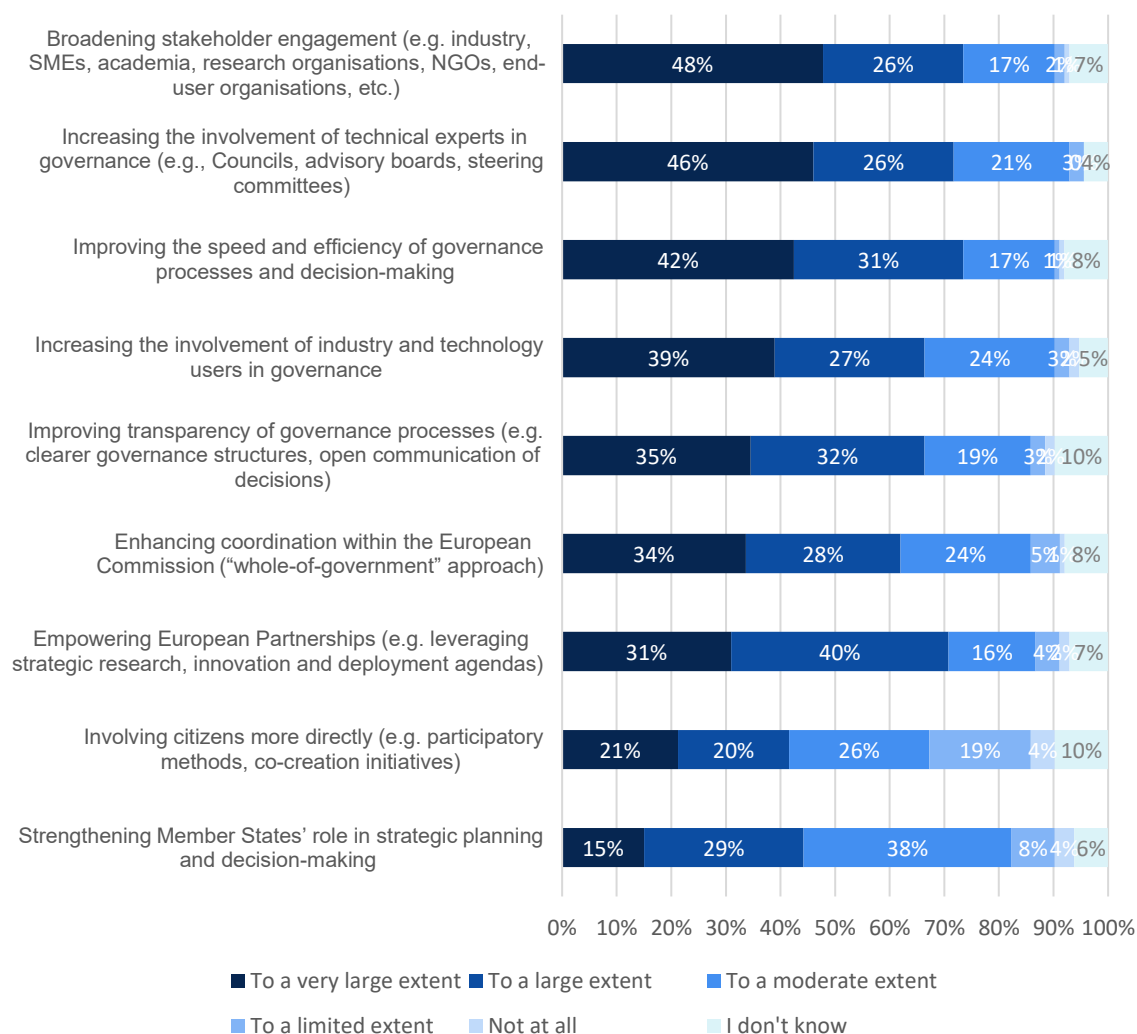
Source: Technopolis Group (2025) based on stakeholder survey results, n=113

Regarding governance arrangements of a future digital EU R&I programme, stakeholders expressed a broad support (>50% agree that a governance refinement would improve the effectiveness of a future digital R&I programme to a large or very large extent) for seven of the nine effectiveness measures rehearsed with stakeholders. The two exceptions are the suggestions that a future programme would be more effective if it were to involve citizens directly or if it were to strengthen the role of member states in strategic planning. Perhaps in reflecting the same underlying concern, the governance measure that is most widely endorsed (75% of respondents) relates to the speed and efficiency of decision making.

There is a clear desire for key stakeholder groups to be more fully engaged in the strategic planning of the programme and the subsequent development of specific work programmes. While this may be feasible within the context of individual R&I actions, where governance structures have a more immediate operational role to play, it is not clear how

stakeholder groups could be engaged more meaningfully in the overall programme design than is the case currently, through studies such as this. With many thousands of stakeholders, often with markedly different interests, it would be hugely complex to involve those actors directly in the process and conflicts of interest would abound. It would in any case run counter to the one recommendation most stakeholders agreed with here, which concerned the need to improve the speed and efficiency of decision making.

Figure 53 Stakeholders' views on the extent to which each of the following governance measures would enhance the effectiveness of a future EU programme supporting the research & development of digital technologies (e.g., strategic planning, work programme development, etc.)



Source: Technopolis Group (2025) based on stakeholder survey results, n=113

3.1.4 International dimension of the programme

The research conducted in this study confirmed that global leadership in frontier digital technologies, with the exception of quantum and photonics, is found outside Europe and that Europe's technological position has weakened over time against the US and especially China. There is a high degree of international dependence too: the analysis of co-patenting, trade statistics and the market survey also found that European businesses rely on their international partners for access to critical digital technologies and materials. The US is particularly dominant in these global technology supply chains, but there are also many other third countries in Europe (Switzerland, UK) and in the Far East (Japan, Korea, Taiwan) with relatively high levels of co-development.

In this context, the future digital R&I programme should have a stronger international logic than we see in the current programme. **A staged tiered governance approach not just in general but also based on TRLs should be adopted.** Overall, low-TRL research (fundamental and early-stage research) can remain largely open to international collaboration to support scientific progress, knowledge exchange, and innovation ecosystems. In contrast, higher-TRL activities, where technologies approach deployment, commercialisation, and operational use, should be subject to increasing restrictions, strategic oversight, and access controls to protect European interests, critical infrastructure, and security-sensitive applications. More specifically, the following scenarios can be distinguished:

- **EU leadership in specific digital technology subdomains:** where Europe has a leading or at least a strong position in specific fields (such as in quantum and photonics), international cooperation should be more closely scrutinised to preserve its comparative advantage;
- **Europe lagging behind in early phase research:** cooperation would be beneficial from a European perspective in order to import leading-edge knowledge;
- **EU leadership in areas with higher TRLs, close-to-the-market projects:** where the specific advantages of integrating digital solutions into a range of competitive European industrial sectors (e.g., greentech, biotech, chemistry/pharma, production technologies, etc.) are high, the specific areas of cooperation should be strategically vetted;
- **Europe lagging behind in early phase research:** cooperation would be beneficial from a European perspective in order to import leading-edge knowledge; Europe is lagging behind in areas where ICT is used to enhance applications (e.g., digital technologies for the automotive industry): here public-private partnerships with European frontrunners should be streamlined to support home-grown alternatives to hardware/software solutions from international counterparts;
- Last, Europe needs to ensure that the knowledge created in the EU through European funded projects within Horizon Europe remains in the EU after the project is finished.

The question on how to balance the benefits of openness with the need for greater strategic autonomy had been discussed by stakeholders via the consultations, workshops and focus groups. The EU has gained strengths in certain positions of the global digital value chain and investing in keeping these positions is recommended instead of trying to control the whole value chain.

Europe has a clearly defined set of values that must be protected both internally and internationally by ensuring that technologies developed and used within Europe uphold and strengthen those values rather than undermine them and hence foster the right international partnerships. This includes continuing and deepening cooperation with trusted partners such as Canada, Japan, India or South Korea, while carefully building a secure environment that avoids over-reliance on countries with shifting geopolitical positions.

Strategic dependencies extend to system engineering, integration, data sources, and data pipelines, which are cross border, relying on international data flows, supply chains, cloud infrastructure, and technical partnerships. Consequently, Europe is interconnected with other countries through shared datasets, platforms, and standards, making international collaboration essential. At the same time, this interconnectedness requires careful governance, trust-building, and alignment of values to manage dependencies securely and responsibly.

Applications involving personal or sensitive data should, as a general rule, be subject to strict access and sharing restrictions. Exceptions may be considered for countries that demonstrate strong alignment with GDPR principles, EU values, and high

standards of ethical research and data protection such as Japan, South Korea, and the UK. This approach is particularly critical in healthcare R&D, where high-quality, large-scale datasets are essential for identifying correlations, validating models, and achieving meaningful scientific and clinical outcomes, but where risks to privacy, misuse, and ethical harm are also highest.

Technologies with dual-use potential should be subject to targeted restrictions, especially in relation to countries that present strategic, security, or geopolitical risks. A differentiated access framework should be applied, balancing innovation and openness with security considerations, export controls, and risk assessments to prevent misuse in military, surveillance, or coercive applications.

Several stakeholders emphasised the need for stronger safeguards to ensure that technologies developed with EU public funding remain strategically anchored in Europe after project completion. Without protective mechanisms, innovations created through EU research programmes risk being transferred abroad through intellectual property acquisition, corporate buyouts, licensing agreements, or the relocation of start-ups and research teams. This creates a situation where European taxpayers effectively subsidise technological development that ultimately strengthens non-European ecosystems, undermining the EU's goals of technological sovereignty and strategic autonomy. While the EU has a relatively strong legal framework for patents, trademarks, copyrights, and designs, effective enforcement still depends heavily on national implementation²⁹³. More consistent enforcement mechanisms and closer cooperation would strengthen protection for innovators, improve legal certainty, and help maintain the EU's competitiveness in the global economy.

Concerns also extend to talent leakage, where highly trained researchers, engineers, and entrepreneurs, educated and funded within European institutions are recruited by foreign firms or relocate to regions offering better funding, infrastructure, or scale-up opportunities. In the absence of retention strategies, long-term industrial support, and EU-centred commercialisation pathways, Europe risks becoming an upstream innovation engine and downstream value loser: generating ideas and talent domestically, while economic value, control, and global influence accrue elsewhere.

3.2 Contextual scenarios influencing the future EU R&I programme

The current research landscape is increasingly shaped by rapidly shifting geopolitical dynamics, profound demographic changes, and evolving cohesion trends, all of which are redefining research priorities in digital technologies and the associated innovation needs. Shifts in global value chains, and energy security are also consistently viewed as highly relevant considerations.

The most impactful contextual factors have been investigated via a Delphi survey conducted in this study, which concluded that **Energy security, Cohesion of the EU, Geopolitical reconfigurations**, and **Shifts in global trade and value chain** influence the most the future trajectory of digital technologies.

According to the Delphi survey results, and the experts' opinion expressed during the following Delphi workshops (add reference to methodology), the following categories of context factors will have the most impact on the research and development of digital technologies in the time horizon 2028-2036:

Energy security: High energy prices and unreliable energy supplies could slow technological development and undermine competitiveness in energy-intensive sectors such as artificial intelligence, high-performance computing (HPC), and microelectronics.

²⁹³ Novak, W. (2024). European Union intellectual property protection: Challenges and solutions for effective rights enforcement. SSRN. <https://doi.org/10.2139/ssrn.4859164>

Stable, affordable, and clean energy is therefore considered essential for sustaining innovation, while uneven access across Member States risks exacerbating fragmentation and limiting technological progress. In the foresight exercise, the energy poverty abounds trajectory received the highest number of maximum-impact votes, reflecting concerns that energy scarcity and rising costs would significantly affect digital technologies, which are inherently energy intensive. The discussions further highlighted that, although digitalisation is crucial for achieving net-zero objectives, data storage entails substantial environmental costs. Large volumes of stored data are 'dark' or redundant, leading to unnecessary energy consumption and additional greenhouse gas emissions, issues that become increasingly important under growing energy constraints.

Cohesion of the EU: Strong cohesion enables harmonised rules, coordinated funding, and cross-border collaboration, supporting technology deployment and market scale. Low cohesion leads to fragmented regulation, duplicated efforts, and slower R&I. While niche strengths can emerge nationally or through selective cooperation, experts noted that strong cohesion is essential for Europe's competitiveness in advanced digital technologies. The Delphi results further highlight that the **technology areas will significantly depend on EU cohesion**.

Geopolitical reconfiguration: Global political and economic changes affect Europe's technology development through disruptions to supply chains, differences in standards, restricted market access, and limits on international collaboration. Experts at the foresight workshops emphasised that Europe's technological capabilities, industrial competitiveness, and strategic autonomy are closely tied to changes in the global political and economic landscape. A China-dominated world order trajectory is seen as the most impactful on the development of digital technologies in Europe. Another high-impact trajectory is a fully transactional world order with constant recalibration of issue-based alliances.

Shifts in global trade and value chains: Fragmented supply chains can slow research in areas such as HPC, AI, cloud, and robotics, but also encourage investment in local capabilities. Strengthening EU digital sovereignty and leadership can mitigate risks, while protectionist policies or limited access to global supply chains would reduce competitiveness and innovation.

The foresight exercise also identified a set of contextual factors with a moderate impact on digital R&I, these are:

Digital skills and demographic trends: EU digital literacy strongly affects research and innovation by shaping talent and capabilities. A widening digital divide would worsen talent shortages and limit understanding of advanced technologies, while a broadly skilled population helps sustain competitiveness as Europe adapts to an ageing workforce. High digital literacy has been rated as an influential scenario impacting technology pathways as it is crucial for retaining R&D and business in the EU, while the need to master daily digital tools drives literacy development across generations, fostering greater cohesion.

Access to critical materials and components: Dependencies on non-EU suppliers, particularly for microelectronics, rare earths, and high-end chips could disrupt semiconductor, quantum computing, HPC, and AI development. Access to such materials is critical for maintaining Europe's technological leadership. The foresight exercise concluded that access to critical materials significantly influences the future pathway of digital technologies.

Social disparities within Europe: Wide social and economic gaps may limit access to talent, infrastructure, and digital services, slowing R&I and reducing technology uptake, while cohesion and equitable policies support interoperability, innovation, and market demand. The scenario that 'EU is characterised by wide social and economic gaps between regions and groups' has been judged as very impactful.

Ethics, standards and law: Well-aligned ethical and legal frameworks support trust, interoperability, and societal acceptance, while fragmented or overly restrictive regulation

risks slowing innovation, in areas such as AI and robotics. Experts also note that Europe's strong ethical and legal frameworks can be an advantage but may limit agility if not balanced with competitiveness needs. The trajectories for this scenario are generally seen as moderately impactful on the future evolution of digital technologies.

Climate change: Extreme weather and shifting resource needs influence technology design, deployment, and use, while also creating opportunities to advance cleantech and digital solutions that support adaptation and societal resilience. Experts noted that innovation must be sustainable, flexible, and responsive to evolving environmental conditions. The most impactful scenario is seen in the EU facing multi-faceted climate emergency.

Global health challenges: Health system resilience influences productivity, labour availability, and the adoption of digital technologies, including automation, robotics, and healthcare-focused innovations like digital twins and personal health apps. A leading European health system is seen as a driver for technological innovation and interoperability, whereas declining health resilience or fragmented approaches would moderate the uptake and development of digital technologies. The trajectory that the 'EU experiences severe health crises' is rated to have a high influence, and at the same time there is strong view that the EU can lead globally in health resilience which would impact as well sector-specific digital technology pathways. The scenario that Europe is leading in health and medical technology innovation and hence positively impacting the development of related digital technologies is seen key for the future of the European economy and society.

Finally, the impact of a **global digital currency system** on digital R&I is overall seen as low. While widespread adoption of digital currencies could influence certain applications, such as automated transactions, e-commerce, gaming, or micropayments, it is not expected to significantly affect core technology development in areas like AI, HPC, cloud or telecom. The foresight exercise found that these trajectories have low-to-mid impact levels with comparatively few votes at higher levels. Digital currencies as primary means of transaction shows a slightly broader spread, indicating that digital technologies could somewhat be influential if digital currencies become very widespread, but in general digital currencies are not expected to have high impact.

Overall, some contextual factors are considered highly impactful across all digital technology areas, while others show more variation depending on the specific technology. For example, access to raw materials is particularly critical for advanced connectivity and microelectronics, the global digital currency system mainly affects blockchain applications, and climate change has a stronger influence on the development of NGI. Global health challenges are comparatively less impactful overall, though they remain relevant for advanced digital technologies, AI, cloud, and interoperability. Across the board, the relevance and impact of these factors are expected to grow over the period 2028–2036.

Table 23 Contextual factors

		Access to critical materials	Cohesion of the European Union	Demographics & Digital skills in Europe	Energy security	Ethics, standards & law	Geopolitical reconfiguration	Global digital currency system	Global health challenges	Shifts in global trade and value chains	Social disparities within Europe	Climate change adaptation & mitigation
Advanced Digital	2028	High	High	High	High	High	High	High	High	High	High	High
	2036	Very high	High	Very high	High	High	High	Medium	High	High	High	High
AI	2028	High	High	Very high	High	High	High	Low	Low	High	Medium	Medium
	2036	High	High	Very high	Very high	High	High	Medium	High	High	Medium	Medium
Blockchain	2028	Medium	High	High	High	High	High	High	Medium	High	Medium	Medium
	2036	Medium	Very high	Very high	High	Very high	High	Very high	Medium	High	High	Medium
Cloud	2028	Medium	High	High	High	High	High	Medium	Medium	High	Medium	High
	2036	High	High	High	High	High	High	Medium	High	High	High	High
Cybersecurity	2028	Medium	High	High	High	High	High	High	Medium	High	Medium	Medium
	2036	Medium	High	High	High	High	High	High	Medium	High	Medium	Medium
Data	2028	Medium	High	High	High	High	High	Low	Medium	High	Medium	Medium
	2036	Medium	High	High	High	High	High	Low	Medium	High	High	Medium
HPC	2028	High	High	High	High	High	High	Low	Medium	Very high	Medium	Medium
	2036	Very high	Very high	Very high	High	High	Very high	Medium	Medium	Very high	Medium	High
Interoperability	2028	Medium	High	High	High	Very high	Very high	High	Medium	High	High	Medium
	2036	Medium	Very high	High	High	Very high	Very high	Very high	High	High	High	High
Microelectronics	2028	High	High	High	High	Medium	Very high	Medium	Medium	High	Low	Low
	2036	Very high	High	Very high	High	Medium	Very high	Medium	Medium	High	Medium	Medium
NGI	2028	High	High	High	High	High	Very high	Medium	Medium	High	Medium	High
	2036	High	Very high	Very high	Very high	High	High	Medium	High	High	High	Very high
Photonics	2028	Very high	Medium	High	High	Medium	High	Medium	Low	High	Medium	Medium
	2036	Very high	High	High	High	Medium	High	Medium	Low	High	Medium	High
Quantum	2028	High	High	High	High	Medium	High	Low	Low	High	Medium	Low

Robotics	2036	High	High	Very high	High	Medium	High	Medium	Medium	High	Medium	Medium
	2028	High	High	High	Medium	High	High	Low	Medium	High	Low	Medium
	2036	High	High	Very high	High	High	High	Low	Medium	High	Medium	Medium

Source: Technopolis Group based on Technology Experts’ delphi survey

3.3 Investment needs stress-tested against contextual factors and scenarios

The future of R&I in critical digital technologies is shaped by the goal of integrating cutting-edge technologies with real-world challenges, ensuring innovation translates into meaningful impact. As artificial intelligence, advanced analytics, immersive interfaces, and cloud infrastructures mature, research needs to further shift from theoretical development to practical deployment in communities, industries, and public systems. Several types of investment needs emerge across all technologies. Following **the stakeholder and expert consultations, the R&I foresight workshops and desk research** conducted in this study, a number of priority actions along key investment needs has been drawn that are presented in the technology annexes and summarised as below:

In line with the strengths as presented above, the investment needs have been formulated around several technologies and technology subdomains where R&I funding invested today can ensure future competitiveness. Within each technology area there are sub technology domains that will reach maturity level ready for the market in the next MFF and have potential for applied research and emerging technologies that are still low maturity but expect disruptive impact.

This section provides a summary of the key investment needs per technology area that are further discussed in detail together with the identified investment pathways in the technology annexes.

3.4.1. AI, Data and Robotics

Artificial Intelligence

The expert consultations and foresight workshop identified several key pathways relevant to future AI-related research and innovation. In line with the assessment of strengths, opportunities, and threats, a set of R&I topics has been selected as suggested priorities for investment under the next EU R&I programme. For the detailed analysis, please see the Technological Annex on Artificial Intelligence.

Human-machine interface and AI: advance Europe's R&I strengths in human-machine interfaces that are shifting the use of AI toward more flexible processes and less restrictive ways for humans to interact with systems.

Trustworthy AI/Explainable AI: improve trustworthiness of AI systems with further R&I efforts and develop new techniques and metrics, covering different aspects of trustworthiness that include fairness, bias, explainability, robustness, accuracy.

Green/Frugal AI: develop AI models and systems that are resource efficient and more environmentally friendly, while maintaining high performance.

Neurosymbolic AI: create more flexible and explainable AI systems by combining neural networks and knowledge-guided symbolic approaches. Neuro-symbolic generative AI is a great opportunity for Europe as it has been largely developed in Europe and is getting global recognition. These methods are also needed to achieve the European vision of trustworthy human-centred AI.

Non-silicon based new paradigms: EU has strong opportunities in this area. Although these paradigms often differ from one another significantly, there are three common characteristics: the techniques are not based on the traditional silicon-based integrated circuit technology; the basic computing elements have been physically implemented; and many of them aim at miniaturisation.

Table 24 R&I topics to prioritise for AI

Maturity	Mature trends with high impact	Emerging trends with low TRL
Artificial Intelligence	Human machine interface (HMI) and AI Neurosymbolic AI (former Hybrid AI)	Explainable and trustworthy AI Frontier AI agents

	<i>Edge AI</i>	<i>AI evaluation</i>
	<i>Neuromorphic computing (cross-cutting with HPC)</i>	<i>Non-silicon based paradigms</i>
	<i>Green and frugal AI</i>	<i>Causal AI</i>
	<i>Foundation models</i>	<i>Narrow AI / Specific AI</i>
	<i>AI safety and security</i>	

Table 25 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	Invest in AI-dedicated data centres
	Expand sovereign HPC and cloud capacity in EU and secure continuous funding for capacity upgrading
	Improve accessibility of Testing & Experimentation Facilities (TEFs) and other research and technology infrastructures
	Develop a catalogue or single-entry-point that maps the existing initiatives in the ecosystem and support researchers in accessing relevant infrastructures
Skills	Creating European AI skills network supporting / funding / managing industrial PhDs, joint labs and apprenticeships
	Supporting researchers' upskilling and reskilling initiatives and interdisciplinary AI education (e.g., tailored programmes offered by AI Skills Academy for researchers focused on intersection between ethics, law, governance)
	Creating synergies between national/regional and EU-level strategies
	Continuation of programmes similar to Choose Europe and RAISE Networks of Excellence for researchers
Ecosystem	Implement mission-driven R&D initiatives comparable to DARPA/CERN-style models
	Coordinate EU and national level AI R&I initiatives
	Encourage collaborative R&I networks involving academia and industry across economic sectors (e.g., mobility, aerospace and defence)

Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: Achieving EU sovereignty across the AI, data, and robotics value chain by 2036 remains challenging due to persistent hardware dependencies and the need for sustained, capital-intensive investment and coordination. The viability of the above outlined actions and investments changes considerably across scenarios. It is conditionally achievable where Europe strengthens its innovation capacity, coordinates investment, and cooperates with like-minded partners. By contrast, sovereignty is unlikely in case weak internal coordination and continued dependence on non-EU hardware persist despite the strategic priority given to technological autonomy. As a result, intermediate objectives, such as achieving modular sovereignty in culturally grounded AI layers represent more realistic near-term milestones than full vertical integration. This approach enables the EU to strengthen strategic autonomy while avoiding costly attempts to achieve complete sovereignty before addressing foundational hardware constraints.

To successfully advance federated learning²⁹⁴ as a strategic pathway for European digital sovereignty the EU shall counteract critical dependencies on Chinese/US data pools, services, and intellectual property **by unifying federated learning with edge computing into a single sovereignty-preserving architecture**. This integrated approach leverages the EU's existing interoperability frameworks to transform supply chain vulnerabilities into

²⁹⁴ Federated learning (FL) is a machine learning approach that enables the training of a shared AI model using data from numerous decentralised edge devices or servers. This process occurs without the need to exchange the local data samples.

resilience, ensuring data sovereignty through citizen-controlled ecosystems while neutralising external standard-setting threats that would otherwise erode Europe's capacity for autonomous knowledge production.

Data analytics

The following R&I pathways have been compiled for this technology area:

Advanced and real-time data analytics: prioritise technologies that address the key challenges of scale, interoperability, and security within modern data ecosystems and leverage machine learning and AI in order to enable advanced and real-time data analytics.

Data storage technologies: this encompasses data storage technologies and novel data compression algorithms preserving data quality during storage and transmission, data security technologies protecting data from unauthorised access or alteration, and data technologies for automatic regulatory compliance enabling efficiently adherence to legal standards.

Privacy preserving techniques: prioritise technology trends that enable seamless exchange of data while reinforcing trust and transparency. Privacy preserving techniques for data sharing play a positive role in increasing trust in data transactions, by allowing data to be analysed and exchanged without exposing sensitive information.

New data architectures: In data structures, a key R&I technology trend is the emergence of new data architectures, from mesh to fabric and lake. Novel data structures help prevent data bottlenecks and improve scalability and agility, while enabling the development of targeted data products and offering cost-effective solutions.

For the detailed analysis, please see the technology annex on data analytics and data sharing.

Table 26 R&I topics to prioritise for Data analytics and data sharing

Maturity	Mature trends with high impact	Emerging trends with low TRL
Data analytics and data sharing technologies	<i>Data storage technologies and novel data compression algorithms</i> <i>Advanced data analytics (perspective), real-time analytics and implementing AI in Data Analytics</i> <i>Data security technologies</i> <i>Data interoperability</i>	<i>Privacy preserving techniques for data sharing</i> <i>New data architectures (mesh, fabric, lake, biomimetic)</i>

Table 27 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	Federated, vendor-neutral platform integrating data sharing and analytics with digital twins, AI, and HPC Sustainable and affordable sovereign compute infrastructure Testing capabilities by establishing secure, privacy-preserving testbeds and sandboxes, and integrating them directly into data spaces Pilot projects to enhance the interconnection between data spaces and computing infrastructures Extend and maintain experimental environments, such as sandboxes, to support long-term testing, benchmarking, and auditing of data-driven systems

Skills	Develop targeted upskilling opportunities in sectors with skills gaps, such as privacy-preserving data analytics and real-time data engineering
	Ensure that training programmes address the interdisciplinary requirements of data spaces, combining data with law, ethics, and domain-specific expertise
	Provide a mix of formal education and continuous learning opportunities, complemented by certifications
Ecosystem	Promote stronger collaboration between research and industry, for example through corporate co-investment in Horizon Europe or by strengthening technology transfer offices within universities
	Develop more agile funding frameworks to support fast-paced technological development and innovation
	Ensure long-term and stable funding mechanisms to sustain continuous R&I capacity

Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: Collaborative federative cross-sectorial data ecosystems, standardised technologies, and automated compliance are critically dependent on EU Member State cooperation and global collaboration. In fragmented or dystopian scenarios, privacy and rights might be sacrificed for transactional efficiency, whilst in more cooperative scenarios these pathways become highly promising. Sustainable business models for data ecosystems emerged as important, though their viability depended on whether the regulatory environment favoured SMEs. There is a risk that in crisis situations privacy, sovereignty, and rights in data sharing will be viewed as luxuries and sacrificed for speed and economic survival. Europe's SME-centric economy is both a unique strength and vulnerability: collaborative data ecosystems are especially valuable in fragmented markets with diverse players, yet standardisation efforts face the challenge that in crisis situations, organisations bypass lengthy standard-setting processes to simply purchase ready-made (often non-European) solutions that work immediately.

Robotics

In line with the assessment of the strengths, opportunities and threats, the following R&I pathways have been selected as suggested priorities to focus investments on under the next EU R&I programme. For the detailed analysis, please see the technology annex on robotics.

AI-robot integration: invest in R&I into enabling robots to perceive, understand, reason, and perform or orchestrate complex actions in the physical world.

Human-robot collaboration: foster resilient human–robot interaction (soft actuators, well-being, unified architectures) and scalable multi-robot coordination. In addition, an emerging technological trend is also related to biorobots (composed of a symbiosis between living tissues and cells (e.g. muscles) and artificial materials).

Robotics sensing techniques: R&I is needed in (ultra-low-latency vision, RF, 3D force, self-diagnosing and multimodal sensors) supported by 3D spatial models and 3D tactile sensors to manipulate smaller deformable objects.

Table 28 R&I topics to prioritise for Robotics

Maturity	Mature trends with high impact	Emerging trends with low TRL
Robotics	<i>Human-Robot collaboration and biorobotics</i>	<i>Robot-AI integration</i>
	<i>Robotics sensing of unfamiliar, unpredictable environments</i>	<i>Swarm robotics</i>
	<i>Novel actuation technology for higher power to weight ratios and energy efficiency</i>	

	Robot safety & dependability	
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Table 29 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	Physical testing and experimentation facilities focused on robotics R&I High-fidelity simulation platforms, digital twins, and XR test environments Deploy secure, EU-wide data-sharing infrastructures for robotics Invest in integrated platforms where new robotics technologies, spanning hardware, AI algorithms, and energy systems can be tested together
Skills	Establish attractive and sustainable robotics career pathways to retain PhDs and experts Ensure EU becomes competitive in global talent markets through improved working conditions and mobility pathways
Ecosystem	Enhance the use of innovative or pre-commercial public procurement to create a demand for robotic R&I Expand the role of EIC in administering challenge-driven funding in robotics Create a one-stop-shop for building synergies between cross-border robotics innovation hubs Joint research and innovation programmes/agendas (or their subsections) across initiatives in robotics, AI, materials science, energy systems, and computing

Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: Robotics pathways demonstrate strong potential across scenarios, particularly multi-agent heterogeneous teams, strong/lightweight robots with novel materials, and hybrid AI-robot systems, areas where Europe currently holds advantages.

The foresight process revealed gaps in European robotics investment despite identified strengths and draws the attention to the fact that robotics R&I pathways are vulnerable to supply chain dependencies.

Additionally, robotics faces unique social acceptability challenges, particularly in scenarios of job scarcity, where robots are perceived as subtracting from the labour pool. This means investment must be coupled with public explanation of why robotics are necessary. On the other hand, demographic shifts showing Europe's working-age population will shrink significantly, make robotics essential for maintaining infrastructure and services.

Within the context of robotics for autonomous exploration the EU faces significant challenges in establishing independent leadership due to China's dominance in cost-effective robotics manufacturing and market penetration, though modest footholds remain achievable through small-scale industrial proof-of-concepts and dual-use R&D acceleration that leverages existing EU research coordination. Pathway viability depends critically on geopolitical conditions: partnerships with Chinese firms could enable the EU to bridge US-China innovation divides, yet this approach risks strategic vulnerability as a secondary partner in scenarios where sovereignty constraints would limit technological autonomy. Consequently, success hinges on scenario-adaptive industrial alliances that prioritise sovereign niche development (e.g., ethical governance frameworks, specialised data ecosystems) while mitigating dependency risks.

In the case of biorobotics, acceptable levels of risk must be defined based on the specific application and societal context. The EU should complement innovation support by broader systemic factors, such as regulation, governance structures, infrastructure, public trust, and international partnerships.

3.4.2 Advanced microelectronics, semiconductors and photonics

Microelectronics

In line with the assessment of the strengths, opportunities and threats, the following R&I topics have been selected as suggested priorities to focus investments on under the next EU R&I programme. For the detailed analysis, please see the Technological Annex on Microelectronics.

Resilient electronics for extreme environments: Develop next-generation electronic systems that maintain performance under noise, jamming, and harsh environmental conditions. Progress will rely on discovering and implementing rare-earth alternatives to create more sustainable, reliable, and geopolitically resilient hardware.

Advanced materials for resilient electronics: Drive cross-fertilisation between materials science and electronics to develop advanced materials that enhance resilience and reliability. Focus on innovations in RF shielding materials to protect electronic systems from interference, enabling robust performance in complex and noisy environments.

European sovereignty in microelectronics and design automation: Strengthen European sovereignty by developing fully in-region Electronic Design Automation (EDA) tools, fabrication capabilities, and diversified chip supply chains. Building on the ECS SRIA 2025 framework, this pathway ensures Europe's capacity to design, prototype, and manufacture advanced microelectronics without dependence on non-European technologies.

Sustainable and PFAS-free microfabrication: Advance environmentally responsible microelectronics production by reducing and substituting PFAS compounds, minimising energy and water consumption, and preventing industrial incidents through transparent, regulated fabrication processes. This pathway aligns green chemistry with European industrial policy to ensure the long-term sustainability of semiconductor manufacturing.

Interdisciplinary innovation ecosystems and open FAB infrastructures: Build interconnected, interdisciplinary innovation ecosystems that unite electronics, physics, biology, and computing through “lab-to-fab” accelerators and hybrid academia–industry collaborations. Establish open, non-profit research and prototyping fabs that link academic pilot lines with industrial production, fostering a maker-culture that encourages experimentation, rapid prototyping, and the co-development of new materials and devices in real-world environments.

Table 30 R&I topics to prioritise for Microelectronics

Maturity	Mature trends with high impact	Emerging trends with low TRL
Microelectronics	<i>Ultra-wide bandgap (UWBG) material for high efficiency electronics (Advanced materials and Resilient electronics in extreme environments)</i> <i>High-NA EUV and alternative lithography techniques for Sub-2nm Nodes</i> <i>Domain-specific architectures for optimised processing</i> <i>Novel transistor architectures beyond traditional CMOS</i> <i>3D stacking and wafer-level packaging for high-density integration</i> <i>Chiplet and modular architecture for flexible system design</i> <i>In-Memory Computing and Emerging Memories Technology</i>	<i>Brain-inspired and neuromorphic chips</i> <i>Quantum and superconducting electronics for computing and sensing</i>

	Sustainable microfabrication	and	PFAS-free	
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Table 31 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	<i>Establish a connected, pan-European design infrastructure</i> <i>Embed industry participation from the outset in the governance and design of pilot lines</i> <i>Full-stack development environments, demonstrators and system-integration platforms that can accelerate the transition from component-level innovation to deployable solutions</i>
Skills	<i>Expand the European Chips Skills Academy</i> <i>Expand applied semiconductor academies linked to existing research hubs</i> <i>Establish more joint university-industry programmes</i>
Ecosystem	<i>Foster faster alignment between hardware innovation and software support</i> <i>Make targeted investments in coordination mechanisms and clearer EU-level frameworks that reduce duplication and simplify collaboration</i>

Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: For resilient electronics in extreme environments, the pathway highlights strategic opportunities: EU sovereignty can be strengthened through space-based resource discovery (e.g., quantum energy effects via automated mining) as a complement to terrestrial rare-earth supplies, while dual-use space drones represent an additional avenue for advancing autonomous deployment, monitoring, and protection of resilient systems. Viability varies across scenarios: in proxy-war contexts, energy-prioritised space deployments could yield defence-civilian breakthroughs (e.g., jamming-proof quantum communications), whereas terrestrial energy scarcity would collapse the pathway without concurrent progress on space-access infrastructure and ethical mining frameworks. Consequently, strategic traction builds on prioritisation of near-term dual-use applications. EU's sovereignty hinges on racing against China's supply-chain dominance.

For European sovereignty in microelectronics and design automation, the priority is translating mid-range technological progress into practical capability. Even incremental advances in materials, and packaging would constitute significant progress, provided they are supported by sustained investment in skills development and secure access to critical raw materials. **Across all scenarios, the analysis suggests that European sovereignty is strengthened not by attempting to catch up at the most advanced process nodes, but by expanding education and talent pipelines, advancing mid-range process technologies, and accelerating innovation in packaging and photonics-semiconductor co-integration** for both large-scale manufacturing and niche defence-critical applications.

For sustainable and PFAS-free microfabrication (eliminating toxic compounds while minimising energy/water use in semiconductor production) the EU's green chemistry ambition directly contradicts crisis-driven production imperatives, creating a sovereignty trap where PFAS substitution research could become a competitive differentiator only if energy access stability permits long-term environmental compliance, yet collapses catastrophically in wartime scenarios where "whatever works" pragmatism overrides ecological constraints.

Photonics

In line with the assessment of the strengths, opportunities and threats, the following R&I topics have been selected as suggested priorities to focus investments on under the next EU R&I programme. For the detailed analysis, please see the Technological Annex on Photonics.

Advanced photonics approaches: photonic accelerators, neuromorphic photonics, and integrated quantum photonic circuits are at low maturity but offer high disruption potential for low-power AI workloads and secure communications. Dedicated roadmapping and platform funding could help concentrate effort on scalable building blocks such as integrated single-photon sources, entanglement circuits, and cryogenic packaging.

Anchor technology development into clear application domains: In integrated photonics, telecommunications provides the primary market pull, as the continuous growth in data traffic drives demand for optical interconnects that deliver higher bandwidth with lower power consumption. This sustained demand supports investment, manufacturing scale-up, and technological innovation. Focusing R&I efforts around such high-volume drivers (areas where many customers and applications create strong, predictable demand) helps mature manufacturing processes and component platforms, which can then be transferred to smaller markets (e.g. sensing, medical devices).

Table 32 R&I topics to prioritise for Photonics

Maturity	Mature trends with high impact	Emerging trends with low TRL
Photonics	<i>Photonic Integrated Circuits (PICs)</i> <i>Heterogeneous integration and advanced packaging</i> <i>Advanced Packaging and co-integration</i>	<i>Optical Computing Architectures</i> <i>Quantum Photonics Devices</i> <i>Neuromorphic photonics</i>

Table 33 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	Expand pilot-scale fabrication capacity beyond flagship sites (e.g. PIXEurope) such as increasing the technical staff or building additional facilities in various regions. Establish shared reliability, thermo-mechanical, and environmental test laboratories for TRLs 4–6 to bridge research and manufacturability. Develop unified photonic-electronic co-design and simulation toolchains, integrating optical, thermal, and mechanical domains. Extend pilot line infrastructure beyond PICs to e.g. traditional optical components and high-power lasers, ensuring open access for research teams and SMEs.
Skills	Strengthen system-level design training combining photonics, electronics, packaging, and thermal management. Expand EU-level training initiatives (e.g. PHORTIFY, PhotonHub) and streamline curricula across Member States. Increase funding for PhD and postdoc positions, and mobility schemes to attract and retain R&I talent. Improve access to advanced fabrication and instrumentation training in cleanroom environments. Strengthen early-stage outreach to students to increase interest in photonics studies. Improve researcher retention through predictable career paths, mobility schemes, and stronger academia-industry partnerships. Update photonics curricula to include e.g. AI-assisted modelling and data-driven design automation.

Ecosystem	Support high-risk, long-term research Deepen collaboration between photonics and electronics communities through common roadmaps, joint working groups, and shared innovation priorities. Promote sustained coordination across national and EU programmes to reduce fragmentation and ensure long-term continuity of R&I investments. Enhance cross-sector collaboration between photonics, semiconductors, and quantum communities to build coherent innovation pathways.
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Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: For high-efficiency photonics, viability of the technology pathway sharply diverges across contexts: wartime pressures for short-term efficiency could sideline photonic R&D despite its energy benefits, whereas stable environments may leverage crystal innovation for sovereign quantum infrastructure where EU coordination offsets talent gaps through targeted educational pipelines.

The pathway of integrated photonics offers a distinct opportunity to build a competitive European industry, provided raw-material constraints and supply-chain gaps are addressed early. Strategic relevance grows across all scenarios as integrated photonics underpins both commercial innovations, especially for health and medical applications, but also dual-use capabilities.

In photovoltaics/solar power and energy-relevant projects where EU production lags China amid urgent energy-access imperatives the sovereignty dilemma crystallises into a stark fork: doubling down on terrestrial solar catch-up risks ceding all energy sovereignty to China's mass-production dominance, while pivoting to space-mined quantum energy effects offers an asymmetric pathway to leapfrog dependency if military-grade dual-use applications validate near-term viability.

For secure optical communication systems, the EU faces an asymmetric sovereignty imperative: there is a strong need to be leading in this area across all scenarios, yet commercial sacrifice (inability to globalise security-focused tech) becomes a strategic advantage in fragmented contexts where China's market dominance cannot undermine EU's sovereign networks if resilience-by-design (compromise detection) is hardwired into every layer.

For high-performance optical sensors the pathway remains vital across all scenarios: continued access to semiconductors is a foundational requirement, as sensor-enabled cost reduction in healthcare and environmentally efficient industry becomes essential for maintaining competitiveness with standards increasingly shaped by China. In stable contexts, reliable chip supply underpins deployment of advanced sensing for industrial optimisation and health-system efficiency, while in more volatile scenarios, secure EU-owned communication layers become equally important for protecting sensor data and enabling trusted applications.

For high-performance lasers all scenarios show their criticality for maintaining EU leadership in lithography and for advancing defence applications. Strategic advantages arise from securing access to key components, deepening photonics expertise, and ensuring that dual-use laser innovation contributes directly to long-term industrial and energy security.

3.4.3 Advanced computing and quantum technologies

High Performance Computing

The expert consultations and foresight workshop identified several key pathways relevant for future research in HPC. In line with the assessment of the strengths, opportunities and threats, various R&I topics have been selected as suggested priorities to focus investments

on under the next EU R&I programme (see Table below). For the detailed analysis, please see the technological annex on HPC.

Post-silicon HPC architectures for energy-efficient performance: Advance post-CMOS chip technologies that scale beyond current silicon limits, integrating quantum, neuromorphic, and photonic elements for higher energy efficiency and adaptive performance. This scientific progress will depend on diversified European fabrication capacity and secure supply chains, ensuring both technological independence and sustainable scaling across future HPC platforms.

HPC for natural complexity and quantum-inspired algorithms: Develop HPC systems capable of modelling turbulent and non-linear phenomena in nature, from aerospace turbulence to biological coherence, leveraging quantum-inspired and Floquet-engineered algorithms. By aligning computational design with natural principles, this pathway aims to enable breakthroughs in scientific prediction, decision-making, and general intelligence beyond traditional Turing architectures.

Space-ready and radiation-tolerant HPC systems: Design radiation-tolerant computing architectures capable of reliable operation in extreme environments, including space-based HPC and edge deployments. Advances in charge-state embedding and resilient system design will support quantum-enhanced navigation, communication, and sensing applications, extending Europe's leadership in autonomous, off-Earth computation.

Sovereign and secure European HPC infrastructure: Build a resilient European HPC ecosystem grounded in secure, transparent, and open-source foundations. This includes developing quantum and classical cybersecurity, maintaining core software infrastructures (Linux kernel, GNU, open libraries), and ensuring that data centres operate sustainably and in harmony with local communities. Together, these steps will safeguard Europe's digital sovereignty and make European HPC both globally competitive and socially resilient.

Table 34 R&I topics to prioritise for HPC

Maturity	(Mid) Mature trends with high impact	Emerging trends with low TRL
HPC	<i>Specialised AI accelerators</i> <i>Access to quantum computing capability</i> <i>Open-Source Software development</i> <i>Hardware / Software Co-Design - joint development of hardware and software systems to ensure optimal performance and resource efficiency</i> <i>Hybrid HPC/AI/quantum integration</i>	<i>High-productivity programming and language models</i>

Table 35 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	<i>Integrate open-source hardware, open-source software, and OCP system integration</i> <i>Create federated and flexible HPC infrastructures</i> <i>Integrate Cloud, AI, and Data Lake capabilities,</i> <i>Invest in energy-efficient architectures, and establishing experimental testbeds for hybrid and interconnected HPC systems</i>
Skills	<i>Expand advanced skill pipelines</i> <i>Achieve full integration of workforce development with the federated HPC ecosystem and cross-sector applications</i> <i>Implement cross-disciplinary training programmes combining HPC, AI, quantum, and data science</i>

Ecosystem	<i>Expand reskilling/upskilling initiatives aligned with evolving architectures</i>
	<i>Align scientific HPC deliverables with broader dissemination channels (publications, data sharing).</i>
	<i>Coordinate national HPC strategies to create synergies and reduce fragmentation</i>
	<i>Manage top-down programme management from EuroHPC R&D</i>
	<i>Maintain a fully autonomous European semiconductor value chain, including EU-made accelerators, packaging, chiplets, and memory technologies.</i>
	<i>Operate a fully federated EU HPC ecosystem integrating national data centres, HPC, Cloud, and Data Spaces, with seamless cross-border collaboration.</i>
	<i>Sustain long-term open-source ecosystems for hardware, software, and system integration.</i>

Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: the pathway towards post-silicon HPC architectures demonstrates strong promise where investment scale aligns with energy-scarcity realities, as specialised computing units could reduce EU dependency on energy-intensive data centres. However, viability remains highly contingent on scenario-specific conditions: in geopolitical settings, diversified technical capacity becomes essential for sovereignty, yet energy efficiency only emerges as a critical priority after baseline capability targets are met, rendering the approach neutral or even counterproductive in contexts where proxy-war dynamics or unstable energy supplies undermine stable HPC operations. Consequently, strategic success hinges on contextual calibration, prioritising dual-use applications (e.g., defence-compatible neuromorphic systems) and treating energy efficiency as a phase-dependent objective rather than universal prerequisite to transform post-silicon innovation into a resilience multiplier without overextending EU resources in scenarios where sovereignty gaps persist despite technological advancement.

Quantum computing

Quantum-classical hybrid hardware and algorithms: Achieve seamless integration of quantum processing units (QPUs) with classical GPUs and CPUs to enable hybrid computation. This will drive scientific progress by combining quantum capabilities with established high-performance computing architectures.

Quantum computing at higher temperatures: Advance quantum computing technologies capable of operating at higher temperatures by exploring competing architectures such as neutral atoms and superconducting qubits. This includes optimising energy systems, discovering sustainable materials, and scaling up infrastructure for industry and other users. It remains open whether green quantum computing will then still be needed.

Quantum translation of real-world problems: Advance the translation of complex analogue and classical problems into quantum representations to identify where quantum computing delivers true advantage. This requires systematic mapping of quantum applications across sectors and co-development of hybrid hardware–software stacks to ensure scalable, energy-efficient deployment within existing EuroHPC infrastructure.

Table 36 R&I topics to prioritise for Quantum

Maturity	(Mid) Mature trends with high impact	Emerging trends with low TRL
Quantum	<i>Development of quantum sensor technologies</i> <i>Green quantum computing</i>	<i>Quantum algorithm and software development</i> <i>Reduction of error rates in quantum computing</i>

	Application of quantum sensor technologies	Quantum stability and scalability
	Quantum key distribution (QKD)	Quantum networks
	Quantum random number generation	

Table 37 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	<i>Increasing researchers' access to quantum computing resources through mechanisms such as Quantum-as-a-Service (QaaS) models</i>
	<i>Large-scale quantum communication test networks providing realistic environments for developing and validating quantum repeaters, memories, and networking protocols</i>
	<i>R&D-scale foundry access agreements and European prototype fabrication and low-volume manufacturing facilities</i>
	<i>Dedicated testbeds for quantum sensing applications to accelerate experimentation, interoperability, and deployment of novel sensing solutions</i>
	<i>Improved transnational access to specialised metrological infrastructure, cleanrooms, and characterisation facilities</i>
Skills	<i>Increase funding for physics PhDs with a quantum mechanical focus, and improve the attractiveness and sustainability of academic career paths in quantum science</i>
	<i>Interdisciplinary master's programmes, doctoral schools, and postdoctoral fellowships integrating quantum physics, computer science, mathematics, and engineering</i>
	<i>Flexible interdisciplinary postdoctoral positions linking quantum physics with computer science and engineering, enabling mobility across universities, research centres, and companies</i>
Ecosystem	<i>Collaborative training initiatives: joint university modules, shared doctoral courses, summer schools, and cross-border researcher exchange programmes</i>
	<i>Coordination mechanisms to systematically map and align quantum investments at national and EU levels, reducing fragmentation and duplication</i>
	<i>Enhanced public-private collaboration and targeted funding for application-driven research and innovation to accelerate laboratory-to-market transitions</i>
	<i>Strategic partnerships with trusted international actors (e.g. Japan, the United Kingdom, and South Korea) for knowledge exchange and technological cooperation</i>
	<i>Sustained investment in domestic semiconductor manufacturing capabilities to reduce external dependencies and reinforce strategic autonomy</i>

Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: The pathway towards quantum-classical hybrid hardware and algorithms offers near-term strategic promise where EU specialisation mirrors ASML-like focus, enabling competitive distance, e.g. to Japan and other competitors, through dual-use applications (e.g., defence-compatible drones) and energy-efficient load distribution frameworks that optimise computational resource allocation amid volatile energy-access conditions. However, viability remains highly sensitive to geopolitical fragmentation, as proxy-war scenarios would likely undermine cybersecurity cohesion and erode returns on hybrid-system investments despite their scalability advantages, while energy constraints could neutralise efficiency gains if infrastructure fails to prioritise affordable access alongside algorithmic innovation. Consequently, strategic success hinges on scenario-adaptive implementation: coupling quantum-classical integration with modular cybersecurity protocols to sustain sovereignty advantages in moderate-polarisation contexts.

3.4.4 Advanced connectivity and next generation internet

Advanced Digital Communications and Connectivity

Microelectronics to realise the future connectivity: focus on reestablishing European microelectronics manufacturing and design capabilities through collaboration networks that link microelectronics, cloud, and telecom ecosystems while ensuring 6G and related technologies are developed within Europe's own industrial ecosystem. Requires strong EU capacity for microelectronics design and fabrication combined with IT/telecom knowledge and AI networking skills to achieve technological sovereignty by 2040.

Softwarisation of networks (helps flexibility but energy consumption heavy): aim to develop AI-driven, software-defined networks that provide enhanced flexibility and end-to-end automation across devices, applications, and services while addressing energy consumption challenges through cross-domain cooperation on green cloud/edge computing solutions. Balances network adaptability with environmental sustainability requirements to create intelligent, independent, and integrated communication systems.

Quantum applicability to networking: Develop quantum communication networks as a critical pillar for technological sovereignty, integrating quantum technologies into networking infrastructure to enable secure quantum communication capabilities across European networks. Establishes quantum networking as a foundational technology for next-generation secure communications while supporting the broader convergence of AI, quantum, microelectronics, and connectivity technologies.

Semantic Communication: develop communication systems that understand and process the meaning and context of transmitted information rather than just raw data, enabling more efficient and intelligent network operations. This approach supports the creation of human-centred communication systems that can deliver enhanced user experiences while optimising network resources through contextual understanding.

European leadership in telecommunications research and cross-disciplinary integration: reestablish Europe's position as a global leader in fundamental telecommunications research while promoting cross-fertilisation between telecom, materials science, and integration of social sciences and humanities. Enhances cooperation across disciplines and sectors as both a strategic opportunity and scientific necessity for maintaining technological leadership while ensuring human-centred innovation.

Table 38 R&I topics to prioritise for Advanced Connectivity

Maturity	(Mid) Mature trends with high impact	Emerging trends with low TRL
Adv. Connectivity	<i>Advanced Non-terrestrial networks (NTNs)</i>	<i>Mobile networks (6G, 7G)</i> <i>Reconfigurable and Adaptive Wireless Technologies</i> <i>AI-driven network management & network for AI</i> <i>Joint Communication and Sensing (JCAS) and Integrated Sensing and Communication (ISAC)</i> <i>Quantum technology for communication</i>

Table 39 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	<i>Invest in the provision of more pan-European experimental facilities with access for all relevant stakeholders, including SMEs</i> <i>Make testbeds and pilot lines accessible ranging from radio frequency and THz to sub-10nm digital devices, photonics, antennas, and optical fibres.</i>

Skills	<i>Expand labs and open innovation spaces for collaboration in R&I</i>
	<i>Cultivate talent in cloud software, AI/ML data science, cybersecurity, and quantum communication and cryptography that are key for next generation communication</i>
Ecosystem	<i>Support reskilling initiatives and interdisciplinary education approaches (e.g., software/hardware, green communication systems, cybersecurity, quantum communication, AI/ML in communication systems)</i>
	<i>Encourage collaborative R&D networks across sectors and technology areas</i>

Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: For developing microelectronics elements that are needed to realise the future connectivity, the EU's strategic positioning depends on consolidating microelectronics sovereignty to anchor interoperable infrastructure, though fragmented national approaches could delay cohesion despite widespread recognition of its critical role in military, commercial, and geopolitical contexts. Viability diverges constructively across contexts: within a coordinated EU framework, cross-institutional coordination via the EU Chip Coalition could establish leadership in lithography and connectivity for dual-use applications (directly addressing workshop emphasis on "safeguarding microelectronics capabilities"), whereas fragmented scenarios risk eroded competitiveness as unaligned national strategies undermine scale ("will suffer from national approaches") and cede strategic ground in semiconductor sovereignty despite opportunities to serve non-Chinese tech-aligned markets.

Next Generation Internet and XR

Multisensorial XR technology and interaction: seeks to develop comprehensive sensory interaction systems that include taste and smell in virtual experiences, alongside visual, auditory, and haptic feedback. Requires advancement in algorithms for high-fidelity 3D model generation compatible with XR technologies.

Multiuser multiplatform VR worlds (human-centric): aims to create digital twins of industrial virtual worlds and establish generic platforms that enable collaborative virtual environments. This involves developing scalable infrastructure for multi-user experiences across different platforms.

Table 40 R&I topics to prioritise for NGI and XR

Maturity	(Mid) Mature trends with high impact	Emerging trends with low TRL
NGI and XR	<i>Digital twins of objects active in the metaverse</i> <i>Human digital twin</i> <i>AI generated content (AIGC) – generative AR</i>	<i>Multisensorial XR technology</i> <i>Brain Computer Interfaces (BCIs)</i>

Table 41 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	<i>Promotion of data-sharing across sectors and reuse/repurposing of data.</i> <i>Invest in testing facilities, pilot lines, and technology infrastructure with a focus on supporting sustainable and ethical innovation.</i>

Skills	<i>Develop skills on designing and developing virtual environments for the general public so that professionals in different domains can customise virtual worlds to their specific needs.</i>
Ecosystem	<i>Establish common standards and interoperable systems to ensure seamless information flows while safeguarding privacy and security.</i> <i>Shared infrastructure initiatives such as the creation of innovation hubs led by key established industrial players.</i>

Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: For multimodal interaction devices the EU's differentiation potential depends on mitigating hardware and component dependencies on non-EU suppliers while advancing human-centric sensory frameworks, though fragmented development may limit the ability to capitalise on XR's strategic importance despite the pathway's foundational role within immersive ecosystems. Viability diverges constructively across contexts: within a coordinated EU framework, integration with future Chips Act 2 could establish leadership in privacy-enhanced sensory processing for high-value XR applications (e.g., medical training or cultural heritage), whereas fragmented scenarios risk slower adoption as supply chain dependencies on non-EU components (most from China/US) constrain differentiation. Consequently, a phased integration is recommended: prioritising EU-developed sensory algorithms for GDPR-compliant XR use cases and embedding digital sensing requirements in semiconductor initiatives to convert external components.

3.4.5 Cloud, Cybersecurity and Blockchain

Cloud-Edge-IoT

Unified and interoperable EU computing and networking environment: Seeks to establish a cohesive European computing and networking infrastructure that enables seamless interoperability across systems, platforms, and providers. Achieving this vision requires common standards, interoperable technological solutions, and continued investment in Europe's strong academic and research base to support innovation and deployment.

Development of orchestration tools for heterogeneous 3C (computing, communication, and control) networks: Focuses on advanced orchestration capabilities that can coordinate heterogeneous computing, communication, and control infrastructures across cloud, edge, and network environments. A key objective is to avoid ecosystem fragmentation by enabling efficient management and integration of diverse hardware and software components.

Drastic reduction in energy consumption: Targets substantial improvements in the energy efficiency of cloud, edge, and network infrastructures, recognising that computing platforms increasingly account for a larger share of energy consumption than communication networks themselves. This requires open hardware architectures, energy-efficient system design, and dynamic resource allocation mechanisms that optimise workload distribution across distributed infrastructures.

Cross-fertilisation between microelectronics, materials science, AI, and quantum technologies: Promotes interdisciplinary collaboration and knowledge transfer across microelectronics, materials science, artificial intelligence, and quantum technologies to accelerate breakthrough innovation. Integrating expertise from these domains is expected to enable novel architectures, advanced materials, and more capable computing systems that would be difficult to achieve within isolated research fields.

Table 42 R&I topics to prioritise for Cloud-Edge-IoT

Maturity	(Mid) Mature trends with high impact	Emerging trends with low TRL
Cloud-Edge-IoT	<i>Data Processing at the Edge contributing to a more resilient, green and secure computing ecosystem</i> <i>Intelligent IoT devices at the edge</i> <i>Dynamic Programming Tools and Environments to enable Decentralised and Distributed IoT Systems</i>	<i>IoT Digital Twins, Modelling and Simulation Environments for efficiency, intelligence and optimised maintenance</i> <i>Edge Computing and AI Convergence for real-time insights and intelligent decision-making</i> <i>AI Native Cloud / Cognitive Cloud offering scalability and flexibility</i>

Table 43 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	<i>Promote the unification of common standards and protocols to ensure interoperability across IoT devices, edge nodes, and cloud platforms</i> <i>Support the creation of testbeds enabling the integration and experimentation of AI services and 5G/6G technologies within the computing continuum</i> <i>Ensure the interoperability between cloud-edge-IoT, AI factories, and HPC centres</i> <i>Expand the offer of large-scale and realistic testbeds</i>
Skills	<i>Expand existing training opportunities to address skills gaps, including orchestration across computing layers, real-time inferencing, confidential computing, and security</i> <i>Provide incentives to retain skilled R&I professionals within the EU</i> <i>Foster the development of cross-cutting skills across the computing continuum, encompassing cybersecurity, data, AI, and open-source approaches</i>
Ecosystem	<i>Promote the development of an integrated research ecosystem with shared priorities, guidelines, and collaborative frameworks</i> <i>Enhance coordination of funding mechanisms and R&I activities across the EU to reduce fragmentation and duplication of efforts</i> <i>Support the integration of EU-based cloud providers through federations to strengthen competitiveness</i>

Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: For a unified and interoperable EU computing and network environment the EU's strategic positioning depends on resolving the tension between Chinese de facto standards and European leadership via sovereign Edge-Cloud governance frameworks, though fragmented hyperscaler-dependency could accelerate lock-in effects despite the overall recognition of Edge's critical role in risk management and energy efficiency. Viability diverges constructively across contexts: within a coordinated EU framework, interoperable Edge-Cloud sovereignty protocols could establish leadership in energy-optimised, risk-resilient infrastructure.

Cybersecurity

Ubiquitous post-quantum cryptography (PQC) algorithms: highly advanced PQC algorithms that achieve the optimum balance between performance, energy consumption, scalability, decentralisation and security/key length. These algorithms are tailored to their specific purpose, in particular, robust procedures for certificate handling. There is a need to

implement hybrid schemes where classical cryptography with pre-shared keys runs alongside PQC algorithm key distribution.

Lightweight post-quantum cryptography: tailored lightweight versions enable PQC integration in small and low power systems such as sensors and smartcards across the whole Internet of Things. Both algorithms and chips need to be tailored so they can run in small devices and need further R&I.

Secure and seamless PQC usage across society: the goal is to develop easy to use intuitive interfaces and interaction routines as well as strengthening of user awareness. To achieve the goal, collaborative research is necessary between engineers, interface designers and researchers.

Fully PQC secure blockchain infrastructure: the goal is to develop a blockchain infrastructure that enables secure transactions in a PQC environment. Blockchain scalability solutions such as layer two solutions, sharding and consensus algorithms are necessary to enable massive scalability without compromising the decentralisation or security.

Unified secure formal verification techniques: today's fragmented landscape of competing identity standards, ID methods and verification protocols needs to be unified. To enable this, cutting edge mathematics research is needed complementing the engineering approaches. On the ecosystem side cross fertilisation is needed between academic research, industry, implementation, and government regulation.

Table 44 R&I topics to prioritise for Cybersecurity

Maturity	(Mid) Mature trends with high impact	Emerging trends with low TRL
Cybersecurity	<i>Post-Quantum Cryptography (Quantum-Safe)</i> <i>Decentralised Identity</i> <i>Lightweight Cryptography for IoT</i> <i>Digital Wallets</i> <i>Secure IoT Chips</i> <i>Embedded System Security</i> <i>Offensive AI & AI System Security</i>	<i>Zero-Trust Orchestration Platforms</i> <i>Use of AI/ML for Anomaly Detection & Behavioural Analytics</i>

Table 45 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	<i>Datasets at EU-level for AI-based anomaly detection</i>
Skills	<i>Investment into talent attraction programmes in cybersecurity</i>
Ecosystem	<i>Coordinated funding for advanced cyber technologies (e.g. AI-driven security, post-quantum cryptography, secure-by-design systems),</i> <i>Strengthened public-private research partnerships</i>

Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against context scenarios: In the domain of cybersecurity, all the scientific goals and pathways listed above are highly relevant across context scenarios. But depending on the context, they will encounter different challenges and need to be adapted accordingly.

Blockchain

Green blockchain: Focuses on energy-efficient blockchain designs that reduce environmental impact through low-power consensus mechanisms and sustainable infrastructure.

Decentralised physical infrastructure networks: Enable real-world infrastructure (e.g. energy, mobility, connectivity, sensing) to be owned, operated, and coordinated through decentralised blockchain-based networks.

Smart contracts: Self-executing digital agreements that automatically enforce rules and transactions without intermediaries, increasing efficiency and trust.

Zero-knowledge technology: Cryptographic methods that allow one party to prove a statement is true without revealing the underlying data, enabling privacy-preserving verification.

Self-Sovereign Identity: Systems that give individuals and organisations control over their digital identities and credentials, enabling secure, user-owned, and privacy-preserving identity management.

Blockchain scalability: Technologies and architectures designed to increase transaction speed, throughput, and network capacity to support large-scale real-world adoption.

New and emerging consensus mechanisms: Innovative protocols for achieving agreement in distributed networks that improve security, energy efficiency, decentralisation, and performance.

Table 46 R&I topics to prioritise for Blockchain

Maturity	(Mid) Mature trends with high impact	Emerging trends with low TRL
Blockchain	<i>Green blockchain</i> <i>Decentralised physical infrastructure networks (DePINS)</i> <i>Smart contracts</i> <i>Zero knowledge technology</i> <i>Self-Sovereign Identity / Verifiable credentials</i> <i>Blockchain scalability</i> <i>New and emerging consensus mechanisms</i> <i>Central Bank digital currencies</i>	<i>Blockchain governance</i>

Table 47 Summary of investment needs for future EU R&I programme

Dimension	Needs for Action and Investments
Infrastructure	Promote an EU-wide blockchain R&D network for cross-border interoperability and commercialisation pathways Expand secure hardware infrastructure (HSMs, secure enclaves, FPGAs, ASICs) Promote secure, scalable HPC nodes and low-latency edge/cloud hosting for enterprise-grade applications
Skills	Foster cross-disciplinary talent pipelines (blockchain-law, blockchain-economics, blockchain – AI) Develop advanced cryptography and quantum-resilience skills

Ecosystem	Promote EU-wide integrated and federated testbeds
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Source: Technopolis Group based on stakeholder consultation, expert interviews and foresight workshop

Stress-testing against scenarios: In the domain of blockchain, the scientific goals and development pathways outlined above are broadly relevant across different future scenarios. However, depending on how the broader context evolves, these pathways will face distinct challenges and will require continuous adaptation.

4. Recommendations

The future of European R&I in critical digital technologies is shaped by the goal of integrating emerging, cutting-edge technologies with real-world challenges and ensuring innovation translates into meaningful impact. **Continuing and significantly expanding EU support for R&I in digital under Horizon Europe 2028-2034** will underpin this objective considering the inherent market and system-level failures.

Within the EU's 2028–2034 Multiannual Financial Framework, the European Commission has proposed to **double the budget of the R&I framework programme to €175 bn**²⁹⁵. The renewed Horizon Europe programme will aim to strengthen Europe's competitiveness while financing solutions to major societal, economic, and technological challenges. The programme will foster the attraction of talent and adopt a 'Choose Europe' approach, mobilising private investment and empowering innovative start-ups. The EU's moonshots proposed by the European Commission include: the ambition to integrate **quantum computing** into everyday life, **develop a new generation of AI grounded in physics and biology**, and make Europe the **global leader and safest hub for critical research data**²⁹⁶, enabling breakthroughs from medicine to climate while attracting the world's leading scientific and industrial talent. In line with the stakeholder consultations, the expectations are that the future R&I programme will strengthen digital R&D in areas critical for the **competitiveness and security of European economy** and it will further move **towards applied research**.

In a rapidly evolving environment, continuous investment in foundational capabilities such as connectivity, data infrastructure, cloud and microelectronics is essential to ensure Europe maintains technological sovereignty and competitiveness. Nevertheless, the differences in technology readiness levels, sector-specific needs, and market dynamics need to be taken into account and avoid applying a one-size-fits-all approach.

Based on the study's quantitative and qualitative findings, stakeholder consultations, expert interviews, foresight exercise and validation workshop, the following 30 recommendations have been formulated for a future EU R&I programme:

Strategic positioning of the EU as a leader in emerging technologies

- 1. Focus on European alternatives that address critical dependencies:** the EU should proactively identify and address critical digital dependencies on external actors. The future EU R&I programme should foster strategic autonomy along the R&I digital value chain via dedicated investments in domestic capabilities, secure infrastructure, and skills development. Most importantly, EU R&D funding should be used to build European alternatives in critical technologies, such as replacing GPUs with distributed computational methods or investing into green technological solutions.
- 2. Adopt a cross-technology approach:** challenges and opportunities in the digital domain are deeply interconnected across many critical digital technologies and this interdependence is only expected to grow. Moving away from supporting technology silos towards a more integrated, mission-oriented framework would enable a more coherent R&I programme and projects. Rather than focusing on technology-specific grants, a cross-technology R&I pathway and approach would emphasise investment in coordinated system architectures, where value is generated through the interaction and synergy between components. Priority areas can include quantum-AI convergence, the development of specialised AI accelerators to meet rapidly growing computational demands, edge-AI architectures that enable real-time, low-latency intelligence at the point of use.

²⁹⁵ https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/horizon-europe-2028-2034-twice-bigger-simpler-faster-and-more-impactful-2025-07-16_en - July 2025

²⁹⁶ https://research-and-innovation.ec.europa.eu/document/download/a64d902e-c508-4694-a0da-60504d071f82_en?filename=ec_rtd_mff-moonshots.pdf

3. **Focus on emerging disruptive R&I domains:** an important objective is seen in investing in emerging technologies with disruptive potential and support early-stage research to develop Europe's next edge. Among the fastest-growing technological fields, the EU appears best placed to maintain an edge in Quantum computing, Photonics and Robotics. In these fields, sustaining and extending leadership requires continued and targeted investment at scale to ensure that this strategic advantage is not eroded. The EU has strengths and opportunities to seize in a set of other technology subdomains that are expected to have high impact such as *Explainable and Trustworthy AI*, *Neuromorphic computing and new Microelectronics architecture*, *Edge AI*, *Cryptography*, *Decentralised identity*, *DNA-based data storage*, *Nanorobotics* just to name a few²⁹⁷. Concentrated investment in these areas is likely to create disruptive technological leadership in the long-term future.
4. **Strike a balance between investment in emerging low-TRL technologies and support for more mature solutions with concrete applications:** gearing all funding towards specific technologies for strategic autonomy and industrial competitiveness risks prioritising incremental solutions for short-term needs at the expense of long-term competitiveness and resilience. Experts involved in this study suggested to keep a 50:50 ratio between low TRL research that secures Europe's future and high TRL that secures Europe's present. The appropriate balance in terms of focusing the investments should vary by technology area, maturity of the ecosystem, strategic relevance, and societal needs. There is also a need for continuity across TRLs and stronger links between research and deployment including follow-on funding and clearer pathways from low-TRL research to market uptake (lab-to-fab).
5. **Invest in human-centric digital R&I and in safe and trustworthy digital technologies that prioritise human needs, well-being, and societal values.** The EU's comparative advantage is in safe and trustworthy technologies, hence human-centric R&I should focus on developing technologies that meet people's needs and create innovations that are usable, accessible, inclusive, and ethically responsible. It prioritises user experience, privacy, safety, and positive societal impact, thereby fostering trust, acceptance, and widespread adoption.
6. **Strengthen and prioritise R&I in energy-efficient digital technologies:** energy efficiency emerges as a strategic, cross-cutting priority across all technology domains. Europe should actively invest in next-generation AI architectures that enable low-power, high-performance computing, addressing the growing limitations of traditional chip designs. This creates a clear strategic opportunity to accelerate the development of specialised, energy-efficient inference hardware, AI-optimised chips designed to operate close to end-users (edge AI), reducing energy consumption, latency, and dependency on centralised infrastructure.
7. **Invest in R&I via interdisciplinary innovation ecosystems:** collaborative networks bringing together experts, organisations, and stakeholders from multiple disciplines (computer science, engineering, social sciences, healthcare, law, business, etc.) to co-develop digital solutions making sure that technical developments are aligned with future societal needs and market realities.

Further strengthening links to industrial applications

8. **Bridge the investment gap prevalent at TRL 6:** the future EU R&I programme should move even more towards prototype validation and system-level demonstration. Investments should target not only R&I but activities that reduce technical uncertainty, strengthen integration, and prepare the technology for scale. This includes funding for

²⁹⁷ The detailed list of EU opportunities per digital technology area has been assessed and presented in the technology annexes.

advanced prototyping, pilot projects, and field testing that mimic real operational environments.

9. **Boost larger actions and significant co-financing by the private sector:** to generate transformative innovation at scale, large-scale projects are seen as more effective. This will require increased co-investment from private actors alongside stronger co-funding from Member States, enabling projects at a scale that no single actor could support alone. In turn, this justifies giving private partners a meaningful role in the governance of major initiatives. At the same time, future actions should build on the capabilities, infrastructure and momentum already created through EU and national programmes, avoiding starting anew and duplicating the efforts. This also brings its own challenges, inasmuch as it may favour those Member States with stronger pre-existing capacity and capability, favouring excellence over cohesion and equitable participation.
10. **Anchor digital technology research and innovation within industrial environments to systematically maximise impact, relevance, and adoption:** European R&I programmes should support application-driven research that directly addresses concrete industrial challenges such as supply-chain coordination, production system integration, and industrial interoperability across multiple technology domains. Moreover, there is a need for more market-pull actions. Coupling strategic investment in critical technologies with mechanisms that actively create and guarantee market demand (such as for example public procurement commitments, fostering purchasing agreements) could help creating a bridge between R&I and deployment.

Robust framework conditions for digital R&I

11. **Use open-source development more strategically across digital technologies:** open-source initiatives used strategically across hardware, software, and networks are seen and recommended as powerful vehicles to reduce dependencies and accelerate uptake of EU-based solutions. They can play a strategic role in strengthening Europe's digital sovereignty, as they shift control from ownership to capability, governance, and deployment. At the same time, they need to be accompanied with other measures, as open-source development alone does not guarantee digital sovereignty. While recognising its value, a context-specific approach is recommended.
12. **Emphasise an 'ecosystem of intelligences':** the future digital technology development is grounded on the combination of multiple forms of intelligence including Artificial, Human, Biological intelligence aligned with natural systems. Hence, the third wave of AI presents Europe with a strategic opportunity to prioritise human-centric technology development and personal data sovereignty through citizen-controlled 'Plain Old Data' structures, diverging from US/Chinese paradigms and embedding ethical governance into semantic data ecosystems.
13. **Strengthen protection of European research results:** Europe has extensive ecosystems in digital technologies; however, it has limited ability to ensure effective enforcement of European companies' intellectual property rights in foreign jurisdictions. The next R&I programme should pay more attention to ensure continuity of EU control over critical IP and talent after the projects' funding period ends, making sure that afterwards technology commercialisation and profits stay in Europe. Europe could create instruments that fund the path from research to platform control: e.g., larger follow-on grants, blended finance hooks, procurement pull, and support for EU-based deployment.
14. **Strengthen technology infrastructures that better adapt to changing framework conditions:** Europe currently accounts for only a small fraction of global AI computing power and relies heavily on non-EU cloud providers. Dedicated AI chips, GPUs, and high-performance computing resources remain scarce and costly, leaving researchers and smaller organisations at a disadvantage. To close this gap, there is a need to expand sovereign digital infrastructure. At the same time, the investments should take

into account the evolving nature of digital technologies and put in place infrastructures that can adapt to reconfiguration, and responsiveness to changing economic conditions.

15. **Foster access to digital infrastructures:** currently, EU infrastructures are often fragmented and underutilised by SMEs, with uneven access and high costs as highlighted in expert consultations. While Europe has invested significantly in technology infrastructures, some are utilised less and unevenly accessed, especially by SMEs, non-digital industries, and interdisciplinary researchers. Systems remain too complex, disconnected, or inaccessible for many users. Sectoral pilot lines and mission-oriented testbeds are limited, and there is insufficient integration of ethical, social, and technical dimensions.
16. **Increase cross-disciplinary skills development and talent attraction initiatives:** as skills shortages in technology are pertinent and cut across technology areas with specialists lacking in various domains. There is a lack of sufficient professionals capable of bridging cloud, edge, IoT and hardware layers, as well as specialists in secure edge computing, confidential computing and real-time AI inference. Talent attraction and retention are further constrained by global competition, salary differentials and the pace of technological change, which requires continuous upskilling.

More agile and effective implementation of the future EU R&I programme

17. **Put in place governance and funding arrangements following a phase-sensitive approach:** first, early-stage research funding should follow an open, bottom-up approach to ensure a broad diversity of exploratory pathways. Second, mid-phase collaborative R&D should actively foster the involvement of industry and society. Finally, the later phase should fast-track scaling, complemented by a diverse mix of financial instruments and targeted support for scale-ups. Governance arrangements and modes of private-sector engagement may differ across these phases. Strong institutional collaboration (ERC, pillar II, EIC, and other sectoral programmes) is therefore essential to accelerate the transition from research to market, enabling the effective 'handing over' of promising technologies between institutions, while also allowing downstream challenges to be addressed through renewed engagement with fundamental research when needed.
18. **Fund R&I in cross-technology portfolios instead of technology specific calls:** under Horizon Europe, AI, robotics, quantum and NGI/XR are largely funded through separate calls and work programmes, with HPC treated as adjacent enabling infrastructure rather than an integrated design axis. As a result, interdependencies are addressed opportunistically within individual projects, rather than systematically across a coordinated portfolio. Because progress in one domain accelerates others, the future EU R&I programme should explicitly fund cross-technology portfolios such as quantum AI, edge AI, advanced data analytics and AI for virtual worlds to name some examples.
19. **Expand fast-start mechanisms with shorter time-to-grant, challenge-driven calls, rolling cut-offs (applications assessed in cycles) for certain instruments:** in the next R&I programme, the Commission has explicitly indicated the introduction of simpler and faster approaches for the 2028–2034 programme²⁹⁸. As compute-centric innovation cycles move faster than traditional project timelines, there is a need for shorter time to grant approaches, while keeping excellence-driven funding intact. Rolling cut-offs can work as a mechanism where applications can be submitted continuously (or over an extended period), but are evaluated at regular intervals rather than waiting for a single annual deadline. Such an approach could respond more rapidly to emerging opportunities, enable fast prototyping, and support high-risk, high-impact experimentation without excessive administrative delay.

²⁹⁸ https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/horizon-europe-2028-2034-twice-bigger-simpler-faster-and-more-impactful-2025-07-16_en?

20. **Expand support for competitive, challenge-based funding:** more R&I programmes are needed where multiple teams pursue the same scientific or technological goal, with full funding awarded only to the strongest solutions as highlighted in the expert consultations. Inspired by Germany's Sprin-D and the US DARPA Grand Challenges, this model encourages rapid decision-making, bold experimentation, and higher performance, as teams push one another to deliver faster and more efficient results than traditional grant schemes typically produce.
21. **Better connect different programme strands:** The future R&I programme should also support EU project funding pathways where the outcomes of R&I projects in one tech area more systematically feed into another technology area. For example, AI acts as a general-purpose accelerator, improving quantum calibration, robotic perception and control, and XR content generation, while downstream deployment in robotics and immersive environments generates new data that feeds back into AI models. By making reusability and feedback loop from other projects along with data production and benchmark creation an explicit evaluation criterion (on par with scientific excellence or TRL progression), future R&I funding could unlock synergies across technology areas.
22. **Find ways to become more strategic without becoming slower, less responsive and more demanding of applicants:** there is an ambition to find ways to substantially expand investment in strategic areas and to do this in part through greater selectivity and in part through greater co-funding across the public and private sectors. Paradoxically, the push to work at a large scale is likely to require more structures and more processes to ensure the targeting of scarce funds is well judged case by case, which will tend to add to the costs (of programme management) and could mean slower starts and possibly less flexibility around reshaping or stopping actions. Scaling strategic investment requires stronger governance and coordination to ensure effective use of public funds, even where this increases administrative effort and may reduce implementation agility.
23. **Increase flexibility and simplify access to funding.** To better engage innovative companies, particularly deep-tech SMEs, funding programmes should combine strategic top-down priorities with more flexible bottom-up opportunities for low-TRL research, allowing researchers and companies to propose emerging topics that reflect rapidly evolving technological developments. At the same time, programmes should experiment with innovative funding and application processes that simplify participation and accelerate the time-to-grant, reducing administrative burden while maintaining the flexibility to adapt projects as technologies and market needs evolve. Such approaches could broaden participation, improve responsiveness to emerging opportunities, and help ensure that funding remains aligned with the pace of research and innovation.
24. **Allocate greater emphasis to strategic public-private collaboration to increase the likelihood that funded research will deliver advances of direct relevance to real-world challenges.** This collaboration should be embedded throughout the research lifecycle, including through governance structures that ensure meaningful engagement by both public- and private-sector stakeholders. It can be strengthened through co-designed research agendas, joint programme governance, and co-investment mechanisms within European Partnerships and Joint Undertakings. In parallel, improve complementarity between upstream R&I "push" measures and downstream "pull" instruments by systematically linking digital R&I projects to investment funds, blended finance facilities, procurement schemes, regulatory frameworks, and scale-up financing. This would create a continuous pathway from research to market, accelerating the uptake and impact of research outcomes.
25. **Strengthen the client orientation of the digital leadership strand under the next Horizon Europe programme,** as many actors, especially deep-tech companies, will be seeking support through multiple parts of the programme. This more systemic view of needs and opportunities should improve the likelihood of a successful outcome for their full innovation journey.

Strategic openness and international collaboration

26. **Focus international collaboration on value-based partnerships:** international collaboration should be strengthened in areas of mutual interest. While the EU is committed to strengthening its strategic autonomy, there is need to pursue international collaboration with key partners globally. Emphasis should be placed on building value-based partnerships and adapting the degree of openness to the criticality and EU positioning in the specific technology areas, rather than broad global openness, particularly in sensitive fields like quantum and cybersecurity. There is a need to pursue international collaboration with key partners globally in recognition of the absolute scale of the research challenges and the fact that the EU is not always home to world-beating technologies and its capabilities could benefit from closer ties with others looking to match or better the rate of development seen elsewhere. Potential is seen in cooperating more with countries such as Canada, Australia, India, Japan, South Korea, and some Latin American countries, as indicated by the stakeholder consultations.
27. **Pursue modular sovereignty, i.e. securing Europe's role across key layers of the digital technology stack, as a way to reduce dependencies:** AI development relies on a tightly interconnected ecosystem. Training advanced models depends on large-scale data generated through big data systems and the Internet of Things, and on cloud and computing infrastructures for storage, processing, and deployment. As these technologies are mutually reinforcing, investing in only one segment of the value chain is unlikely to eliminate strategic vulnerabilities. At the same time, building end-to-end capabilities across the entire ecosystem is not equally feasible in all areas. Full technological autonomy is more realistic where European strengths can be combined with those of like-minded partners, but much harder to achieve in fragmented or highly globalised value chains. As a result, a more pragmatic strategy is to secure control over the most critical layers of the technology stack such as specific components of the AI ecosystem, while maintaining strategic partnerships in others. This approach strengthens resilience and competitiveness without pursuing forms of self-sufficiency that could prove economically costly and fail to address underlying dependencies, particularly in advanced hardware and semiconductor production.
28. **Adopt a targeted, risk-based openness framework that protects Europe's strategic interests without undermining scientific excellence or international collaboration:** rather than imposing broad or blanket restrictions on international research partnerships, the EU should implement clearly defined, proportionate safeguards focused on genuinely sensitive domains (dual-use technologies, critical infrastructure, frontier AI, advanced semiconductors), based on transparent risk assessments and strategic relevance. Blind reliance on trust should be avoided where it may not be warranted. It is also suggested to establish selective protection with structured openness, enabling global collaboration in low-risk and fundamental research areas, while applying justified controls only where there is demonstrable risk to security, sovereignty, or strategic autonomy. Such a model would preserve Europe's attractiveness as a global research hub, sustain innovation and excellence, and avoid self-isolation, while ensuring that public investment does not unintentionally weaken Europe's long-term technological and geopolitical position.

Prepare for different contextual scenarios and uncertainties

29. **Maintain a robust forward-looking strategy, preparing for alternative future scenarios:** while some pathways prove robust across multiple scenarios, the viability of others is highly sensitive to changing contextual conditions. In particular, the fragmentation/coordination dimension is critical for the success of many EU technology pathways. Overall, the proposed technological trajectories tend to assume the emergence of supportive contextual conditions, an assumption that should not be taken for granted. Consequently, while investing in a prioritised set of technology areas and

technology trends, the EU should also explore and develop alternative science and technology options, enabling rapid shifts and targeted acceleration when contextual developments move toward less conducive scenarios. This portfolio approach is especially important for highly context-sensitive pathways, such as those related to energy security or geopolitical reconfigurations, while investment can be more selectively concentrated on a smaller set of options for pathways that demonstrate greater robustness across scenarios.

30. **Ensure monitoring:** regular monitoring and assessment of emerging technological, socio-economic, EU-political and geopolitical developments through horizon scanning is an essential pre-condition for a context-sensitive and adaptive approach to prioritisation and investment. This is the first step of future-oriented processes of scenario adaptation, sense-making and adjustment of R&I and investment priorities and should be conducted alongside the implementation of the future EU R&I programme.

Annex Technology scorecard for R&I

This technology scorecard includes a summary of the main indicators used to monitor R&I in the EU across the 12 technology areas.

Table 48 Technology assessment scorecard for R&I

Dimension	Subdimension	Indicator for technology assessment Scorecard	Microelectro nics	Photonics	HPC	Quantum	AI	Data analytics	Robotics	Cybersecuri ty	Cloud-edge- IoT	Blockchain	Adv. connectivity	NGI & XR
Current level of investments														
Technology potential for R&I	Current scope of EU programmes for R&I (€m)	Total EC budget (€ million) Horizon Europe	€ 2973	€ 931	€ 581	€855	€ 2 573	€ 1 568	€ 571	€ 615	€ 645	€ 23	€ 974	€ 945
Research and technology development and infrastructure														
Technology potential for R&I	Bibliometrics	Total number of publications in 2023	19 748	31 716	16 949	5 732	52 547	22 212	10 877	12 572	6,389	2 925	7 876	7 926
Market potential - applications and sectors for technology deployment	IPR	Total number of patent applications in 2022 in the EU27	1 960	1 408	17	162	1 439	44	711	112	74	125	38	210
Market potential - applications and sectors for technology deployment	IPR	Total patenting in the EU 27 trend based (vs 3yr avg)	1%	-2%	-53%	89%	18%	38%	1%	-17%	-21%	-21%	-27%	5%

Dimension	Subdimension	Indicator for technology assessment Scorecard	Microelectronics	Photonics	HPC	Quantum	AI	Data analytics	Robotics	Cybersecurity	Cloud-edge-IoT	Blockchain	Adv. connectivity	NGI & XR
Current (2028) Global Position of EU for R&I	Position of Digital Infrastructures, Skills and Competences and EU Digital Ecosystem	Delphi analysis Expert opinion (Round 1 - to be validated)	Slightly behind	On par	Slightly behind	Slightly behind	Slightly behind	Slightly behind	On par	Slightly behind	Slightly behind	Slightly behind	On par	Significantly behind
Skills														
Skills	LinkedIn	Share of professionals with specific digital skills within ICT total in the EU27	7.3%	4,3%	21%	2,2%	21,4%	43,4%	6%	23%	30%	2.4%	7.1%	4.6%
Skills	Current scope of EU programmes for deployment and associated funding (€m)	Funding allocated of current ('21-24) projects in DEP (excludes cross-cutting skills investments)	35	-	35	12	13	8	2	78	5	3	-	4
European ecosystem (tech developers - supply-side)														
Capability of the European ecosystem	IPR	Share of tech field within total volume of patents in EU27 (in 2022)	2.6%	1.87%	0.02%	0.21%	1.91%	0.058%	0.94%	0.15%	0.1%	0.17%	0.05%	0.28%
Capability of the European ecosystem	IPR	Share of tech field within total volume of patents in EU27 (Trend (vs 3yr avg))	2%	-1%	-52%	90%	19%	38%	2%	-17%	-21%	-21%	-26%	5%
Capability of the European ecosystem	Standards	Total number of standards	IEEE(6) ISO(311) ETSI(6)	IEEE(10) ISO(262) ETSI(5)	IEEE(2) ISO(21) ETSI(26)	IEEE(4) ISO(166) ETSI(75)	IEEE(114) ISO(309) ETSI(791)	IEEE(45) ISO(2694) ETSI(418)	IEEE(24) ISO(125) ETSI(47)	IEEE(129) ISO(345) ETSI(165)	IEEE(50) ISO(241) ETSI(628)	IEEE(39) ISO(81) ETSI(43)	IEEE(1366) ISO(715) ETSI(8121)	

Dimension	Subdimension	Indicator for technology assessment Scorecard	Microelectronics	Photonics	HPC	Quantum	AI	Data analytics	Robotics	Cybersecurity	Cloud-edge-IoT	Blockchain	Adv. connectivity	NGI & XR
Ecosystem – global positioning (tech adopters - demand-side)														
EU competitive position globally	Trade	Trade balance by sub-technology area (only possible at highest level of aggregation, Level 1) (last year 2022)	-13.11%	-13.11%	-36.54%		-15.50%		-15.50%		-33.61%		-59.66%	
EU competitive position globally	Scientific competitiveness	Share of Top 10% publications (%)-preliminary	8.7%	21.4%	9.9%	18.1%	13%		8.8%	9.5%		12.8%	12,2%	10.4%
EU competitive position globally	Trade	Trade balance by sub-technology area (only possible at highest level of aggregation, Level 1)	-15.99%	-15.99%	-1.37%		-3.75%		-3.75%		2.08%		2.04%	
Overall dependency on non-EU	Raw Materials; High Tech Digital Components; Technology excellence; Testing and experimentation facilities; Digital infrastructures and software; advanced skilled workforce; specific actors in the R&D system; specific	Delphi analysis Expert opinion (Round 1 - to be validated): Number of subdimensions rated 'high' in dependency	5	4	5	4	6	5	4	5	4	7	6	6

Dimension	Subdimension	Indicator for technology assessment Scorecard	Microelectronics	Photonics	HPC	Quantum	AI	Data analytics	Robotics	Cybersecurity	Cloud-edge-IoT	Blockchain	Adv. connectivity	NGI & XR
	sections of the value chain)													
Reverse dependencies on the EU	Raw Materials; High Tech Digital Components; Technology excellence; Testing and experimentation facilities; Digital infrastructures and software; advanced skilled workforce; specific actors in the R&D system; specific sections of the value chain)	Delphi analysis Expert opinion (Round 1 - to be validated): Number of subdimensions rated 'high' in reverse dependency	2	2	0	1	0	6	1	0	0	3	0	1
EU competitive position globally	IPR	Global Ranking of Countries (Latest Year and. Long term 3 year average (2017/19-2020/22))	JP (32.90%) 6.70% decrease CN (24.03%) 18.97% increase US (17.31%) 2.37% decrease EU-27 (14.02%) 2.03% decrease GB (1.13%) 19.55% decrease	EU-27 (24.53%) 1.79% increase CN (23.18%) 21.55% increase US (19.84%) 7.09% decrease JP (17.33%) 16.27% decrease GB (1.76%) 7.68% decrease	US (46.37%) 2.70% decrease CN (31.28%) 2.29% decrease EU-27 (9.50%) 0.09% increase GB (4.47%) 3.17% increase JP (1.12%) 34.39% decrease	EU-27 (33.47%) 54.66% increase US (27.07%) 42.43% decrease JP (10.74%) 89.29% increase CN (9.09%) 25.29% increase GB (7.02%) 56.34% increase	US (36.51%) 7.19% decrease EU-27 (18.98%) 14.31% increase CN (17.53%) 10.08% increase JP (7.40%) 26.51% decrease GB (4.43%) 6.55% decrease	US (31.40%) 9.36% increase CN (28.96%) 0.51% increase EU-27 (13.41%) 2.44% increase JP (5.79%) 18.40% increase GB (3.35%) 59.35% increase	CN (24.77%) 10.61% increase EU-27 (19.08%) 5.14% decrease US (19.08%) 16.76% decrease JP (18.76%) 14.39% increase GB (3.27%) 19.85% increase	US (31.87%) 13.16% decrease CN (21.46%) 11.84% increase EU-27 (18.21%) 13.78% decrease JP (9.43%) 46.33% increase GB (4.07%) 30.13% decrease	CN (37.50%) 20.77% increase US (35.92%) 2.31% increase EU-27 (11.71%) 26.54% decrease GB (2.53%) 4.31% increase JP (1.42%) 28.53% decrease	US (27.94%) 14.94% decrease CN (24.71%) 21.51% increase EU-27 (11.23%) 16.83% decrease GB (7.46%) 38.81% decrease JP (7.46%) 39.36% increase	US (40.58%) 0.85% increase CN (25.22%) 41.38% increase EU-27 (11.01%) 31.76% decrease JP (8.12%) 9.61% decrease	US (36.65%) 1.35% increase CN (18.57%) 8.78% increase EU-27 (14.60%) 3.94% increase JP (7.51%) 4.86% decrease GB (2.57%) 1.02% increase

Source: Technopolis Group (2025)

Annex Methodology

The study has been subdivided into four main tasks, each with a specific objective and aligned with the project's structure, which we declined into specific research questions in the table below. Such table thereby provides an overview of the objectives of the study.

Table 49 Research questions guiding the study

Main topics	Objectives	Research questions
Scoping	Identify the strategic critical and emerging technologies for addressing global challenges, ensuring EU industrial competitiveness as well as economic security and sovereignty, in a broad range of application sectors	- What are the strategic and critical digital cutting-edge and advanced technologies relevant for investments under FP10, including across different application sectors - What are the emerging digital technologies that will be essential for Europe to invest in FP10?
European landscape	Map the European R&I ecosystem around each technology based on their level of maturity in different application sectors, including levels of public and private investments and challenges, gaps and obstacles encountered for their scaling-up	- What is the level of maturity of the digital technologies identified, across different application areas or sectors (e.g., energy, transport, health, environment), incl. TRL, commercial viability, closeness to market, existing market applications? - What is the composition of the European R&I digital ecosystems around such technologies, incl. the types of actors involved, size, current and emerging champions, geographical differences? - What are the levels of public and private R&I investments to foster the development of digital technologies at EU, national and regional levels? What are the gaps and inefficiencies across the investment journey? What is the regulatory and market environment (incl. IPR laws and standards, supply chain, demand trends, competitive landscape, economic factors)? - What are the key R&I-related challenges, gaps and obstacles faced for the scaling-up of those technologies (main market bottlenecks, skills and infrastructures' gaps, sectorial and policy needs)?
International landscape and EU positioning at global scale	Analyse the global R&I digital ecosystem surrounding each technology , assessing the level of global competitiveness of the EU in the different areas of investments for both critical and emerging technologies, to identify the EU's strengths and unique competitive advantages, and assess dependencies	- Who are the R&I global technological leaders, competitors, market players in each of the technology areas? - What are the level and scope of public and private R&I investments in those technologies by the global leaders and main competitors (R&I programmes, GAFAMs)? What is the regulatory and market environment in the countries of global leaders and with largest scale of investments (incl. IPR laws and standards, supply chain, demand trends, competitive landscape, economic factors)? - What is the relative competitive advantage of the EU against the global competitors identified? What are the technologies and infrastructures that the EU currently has in its portfolio, and which do not appear as strongly for global competitors (high investments in Europe versus global competitors in strategic technologies or for specific application areas) - What are the dependencies and reverse dependencies in the R&I landscape and industrial value chains of the selected technologies

Main topics	Objectives	Research questions
Trends and foresight	Identify the foreseeable evolution of the digital technologies (technology, societal, market trends, ecosystem, investments, EU global positioning), and develop strategic (R&I investment) scenarios that can feed priority setting for an optimal design of FP10 supporting critical and emerging digital technologies, covering two time-horizons: 2028 (start of FP10) and 2040 (end of the last FP10 project)	- What is the foreseeable development of the digital technologies selected in task 1 (maturity, application, cross-sector fertilisation)? - What are the foreseeable changes in the composition of R&I digital ecosystems, market trends, investment needs (incl. skills, infrastructures, competencies preventing scaling up and market uptake), regulatory framework conditions for the development of these technologies that can impact EU's competitiveness? - What are the expected changes with regard to the coordination of the EU, national and regional R&I programmes supporting digital and the related foreseeable challenges? - What are the foreseeable variations in global technological leadership incl. areas/sectors in which the EU could improve its competitiveness, and what are those where the EU is expected to lose or stand-by? - How are contextual factors and megatrends shaping R&I digital ecosystems expected to influence future scenario (e.g., international cooperation policies, geopolitical factors, environmental factors, international regulation and ethical considerations, etc.)?
Towards FP10: strategic recommendations for digital technologies	Develop a set of strategy considerations to support the preparation of FP10, including the weight and focus that strategic digital technologies (critical and emerging) should have in the EU investment strategy to reach Europe's overall objectives (incl. priority areas, EU added value, synergies, etc.	- What are the positive and negative priorities for R&I investments in critical and emerging digital technologies needed by 2028 and 2040 across sectors and funding levels; and what could be the fork of minimum to desirable order of magnitude of R&I funding in each of the identified technologies to improve EU's competitiveness and autonomy? - What should be the implementation modalities and framework conditions for the FP10 programme design to strengthen the European R&I digital ecosystem to bridge the gap between basic research and the uptake of these essential digital technologies (incl. ecosystem building, infrastructural needs, skills, potential for cross-sectorial spillovers)? - What are the areas where the EU adds value for R&I public investments to support digital technology development, and those where multi-country collaborations could be envisaged? - How can the EU reinforce the continuity to support the evolving needs of the digital ecosystems along the investment journey, including coordination of funds and multi-level synergies, regulatory measures, etc.? - How should the EU position at global level to ensure a balance between "openness by design" and economic security, strategic autonomy and technological leadership, when developing its EU international strategy to support R&I of digital technologies?

Source: Technopolis Group, 2024

Methodology framework

The analytical framework has been developed to support the development of the EU strategy for research and innovation in critical and emerging digital technologies under the next Multiannual Financial Framework (MFF). This framework has been specifically tailored to the needs of this strategic study.

Phase 1 – Scoping and landscaping

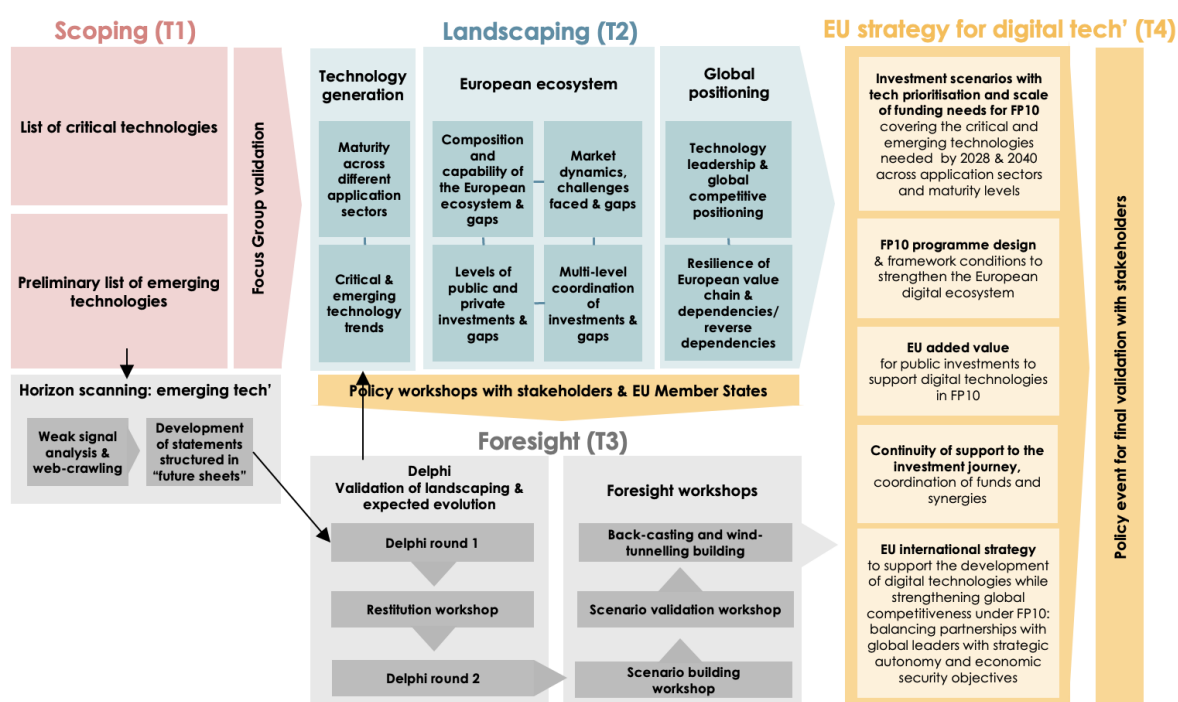
The first phase of the study, following inception, consisted mainly in the scoping (Task 1) and landscaping analysis (Task 2). The scoping phase, combined with the horizon scanning exercise, enabled the team to list the critical and emerging digital technologies relevant for

investment in FP10, which constitute the scope of the study. This list will be validated through both a focus group validation with technology experts and stakeholders, and through the Delphi process (especially for emerging technologies). The list of critical and emerging technology has then been enriched during the landscaping exercise, which provides a wide range of additional insights on the technology generation trends (incl. maturity and application sectors), the structure and dynamics of the European ecosystem (incl. current levels of public and private investments at EU, national and regional levels), as well as the positioning and competitiveness of the EU in the global landscape (incl. dependencies and resilience of European value chains). The results from the scoping and landscaping phases will be discussed and enriched through two hybrid workshops which will take place in Aalborg on 3rd July, and in Brussels on 10th July.

Phase 2 – Foresight and strategic considerations

The second phase of the study covers the foresight (Task 3) and considerations for the EU strategy for digital technologies (Task 4). The foresight phase will seek to validate the findings from the scoping, horizon scanning and landscaping analysis, and develop future scenarios covering each of the critical and emerging technologies identified with two time-horizons (2028 and 2040). The foresight exercise will also seek to build from the gaps identified in Task 2 and related objectives to fill those gaps and define the weight and dimensions of the models for the prioritisation of investments in digital technologies under FP10. These scenarios, developed per technology area in the foresight phase, will then be assessed together in the last phase of the study, for the development of evidenced based considerations for FP10. Such considerations will also cover the specificities of the programme design to support the development of digital technologies, as well as the EU added value of those investments, the need for continuity of support throughout the investment journey, and ultimately the EU internationalisation strategy tailored to each specific digital technology field. The output from the study will then be validated through a final policy event with stakeholders.

Figure 54 Analytical framework



Source: Technopolis Group (2025)

Methodological toolbox

The table below shows the mix of research methods for data collection and analysis that we propose for this study. We have adopted a mixed research approach for data collection & analysis, ensuring compliance with the Better Regulation Guidelines on integration and triangulation of the findings.

- We have relied on a **strong conceptual indicator framework** drawing from various data sources to analyse the adoption of advanced digital technologies by industry, and structured around capability assessment, market structure, composition and investments.
- A **large-scale stakeholder consultation strategy** was implemented and complemented by a dedicated communication campaign, to seize key changes in the technology deployment and the consolidation of digital ecosystems across application sectors, allowing us to define, test and prioritise options at every step of the project.
- The study has adopted a strong **forward-looking approach**, to test and develop a vision, beyond 2028 and up to 2034, accounting for uncertainty and criticality of action. The Delphi survey, with its forward-looking perspective, extended further to 2036/2040, recognising that the results of upcoming projects may only materialise after the end of the next MFF.

Table 50 Study's methodological toolbox

	T1 - Scoping		T2 - Landscaping and comparative analysis	T3 - Foresight	T4 – Recommendations for FP10
	Critical technologies	Emerging technologies	European Landscape	Global Landscape	2028/2034 horizon
Semi-structured Interviews	✓✓	✓✓	✓	✓	
Market foresight survey (CATI) Survey	✓	✓✓	✓✓✓	✓✓	✓
Focus groups	✓✓	✓	✓✓	✓	
Targeted survey	✓✓	✓✓	✓	✓✓✓	
Delphi survey		✓✓	✓	✓	
Foresight workshops					✓✓✓
Hybrid policy workshops			✓✓	✓✓	✓✓✓
Technology expert board	✓	✓	✓	✓	✓
Desk research	✓✓✓	✓	✓✓	✓	
R&I orgs portfolio & SRIA analysis	✓✓✓	✓✓✓	✓✓		
Use cases on national public investments				✓✓✓	
International benchmark & value chain case studies				✓✓✓	
Horizon scanning		✓✓✓			✓✓
Secondary data sources – tech generation & market			✓✓✓	✓✓	
AI-supported webcrawling		✓	✓✓✓	✓✓	✓
Portfolio & composition incl. HE ERC, EIC	✓✓	✓	✓✓✓		
Investment scorecards					

Source: Technopolis Group (2025), based on the Better Regulation Guidelines

Note: ✓ corresponds to the method coverage of the specific analytical dimension, three ticks corresponding to the most in-depth contribution of the methods to the specific analysis.

Table 51 Projections for Key Factors

	Projections 2040			
Factor	A	B	C	D
<i>Access to critical materials</i>	After achieving all strategic priorities outlined in the CRMa, the EU continues to strengthen each stage of strategic raw materials and has detailed continuous monitoring and mitigation a very diversified supply chain with no CRM controlled by third country suppliers.	The EU remains extremely vulnerable across most key technologies and supply chain steps including raw material acquisition, processing, and utilising CRM. Many supplies remain vulnerable to single third-party country suppliers.	While the EU has developed supply chain diversification for a selection of key technologies, there remain vulnerabilities in some raw materials and segments of the process supply chain. CRM Recycling has become a key technology that helps the EU meet CRM goals and is a technology export.	The EU has achieved resilience across most of the CRM supply chains central to key technologies, but that security is tied to international defence and aid agreements in an increasingly conflict-ridden world.
<i>Cohesion of the European Union</i>	EU in strong cohesion and unity. Reforms strengthen democracy, misinformation is countered, public trust is strong. Political divides diminish as citizens perceive the EU as strong and responsive. Europe has a unified voice on global issues	Extreme polarisation, spread of misinformation and loss of trust disrupts the EU. Very difficult to reach consensus, radical political movements arise. EU struggles to act collectively on global and regional challenges.	EU maintains a functional but limited cohesion with a mix of collaboration between Member States. National sovereignty shapes policy and political divides continue to surface.	Cohesion weakens but does not collapse. Some member states advance integration whilst others opt out. Public trust remains low, misinformation undermines stability. Shared visions of MS are missing
<i>Demographics & Digital skills in Europe</i>	Europe's digital literacy skills achieve a very good level across age groups and regions. Public investments and digital education with lifelong learning schemes bring the generational and regional gap to a minimum. A highly skilled and competitive workforce is emerging in Europe.	The digital divide becomes extreme in Europe. Older generations and marginalised communities are severely lagging behind whilst advanced skills concentrate in wealthy regions and social groups. Europe's competitiveness and social cohesion is being undermined.	Digital literacy improves, but unevenly. Most citizens have basic digital skills, but advanced skills are concentrated in specific sectors. Lifelong learning programs are in place and slowly help the gap between generations and marginalised groups.	Basic digital literacy becomes widespread, but higher-level competencies are still needed for a competitive workforce and civic engagement. Member States are working on boosting digital skills on their own terms, creating various levels of knowledge across Europe.
<i>Energy security</i>	Cheap green energy widely available in Europe due to ambitious policies & tech breakthrough. EU is becoming the preferred location for energy-intensive digital infrastructure, with digital twins optimising advanced energy networks across the continent.	Severe energy shortage & frequent disruptions across Europe as heavy reliance on external suppliers creates long-term vulnerability. Energy intensive digitalisation stalls across sectors due to surging energy costs.	Europe back on a fossil energy trajectory. Security is high but so is dependency on coal. The EU is splitting into energy-digital leaders and left-behinds, undermining cohesion.	Energy available but at very high prices. Energy poverty abounds, and member states prioritize national solutions, fragmenting EU energy market further.

	Projections 2040			
<i>Ethics, standards & law</i>	EU is world leader in setting ethical and legal norms, as trust and transparency become Europe's competitive advantages, standards are widely adopted and globally influential	Ethical frameworks and legal standards fail to keep up with technology, huge mistrust in technology, increasing violation of rights and algorithmic discrimination	Partial alignment on ethics and law, AI transparency and data rights are well-regulated but other aspects remain inconsistent across Member States	Regulations exist but they lag behind technological advancements, some sectors operate on strong standards (like health and finance) whilst others do not, citizens generally trust technologies, but occasional controversies arise
<i>Geopolitical reconfiguration</i>	Revival of Multilateralism with a strong role of the global South. EU research excellence attracts global talent, and technology partnerships with allies create innovation networks rivalling superpower programs.	A world order dominated by China and Chinese institutions, fragments long-standing alliances, and undermines the EU's strategic compass on defense, infrastructure, and R&I.	A multipolar world with a strong Europe as one of the centres of power next to others such as US, China, India. Research partnerships remain open but compartmentalized by topic.	A world without fixed alliances dominated by transactional approaches and non-alignment. EU carves out unique niche as a technological broker but remains vulnerable to disruptions arising from conflicts.
<i>Global digital currency system</i>	State backed and supported Digital Currencies are the primary means of transactions used in a majority of key global economies, reducing corruption and squeezing many black markets out of existence. Energy demands of such systems remain high but remain on par with the production and management of physical currencies.	There is no unified global digital currency system, and the few remaining digital currencies carry little of the promised anonymity and fluidity with which they were initially sold. There is dwindling skill and interest in pursuing these technologies.	Digital Currencies maintain a healthy ecology and remain popular in some use cases for people around the world. This does not make them a global currency, but rather a loosely related collection of digital instruments for conducting various types of exchanges both legal and illegal.	Many states have issued digital currencies, and back their use through procurement, state employment, and various types of social welfare. However, the appetite for other stores of value and exchange instruments remains high, as many seek to avoid the transactional transparency and accompanying surveillance it enables.
<i>Global health challenges</i>	Europe's health resilience is leading globally, the One Health approach is fully integrated promoting human, animal and ecosystem health. Pandemics are quickly detected and contained, healthcare access reduces inequalities, mental health is prioritized.	Health crises occur often and have severe impacts, antimicrobial resistance (AMR) makes common infections deadly, pandemics spread with almost no control and access to healthcare is very unequal. Mental health related to eco-anxiety worsens; public trusts erode. Healthcare system is underfunded.	Europe is managing health risks better than most regions. The One Health approach keeps most outbreaks under control, but gaps remain. Access to healthcare has improved but vulnerable groups are still facing more difficulties. Mental health problems are acknowledged but challenges remain to help them.	Antimicrobial resistance (AMR) is still growing but slower and pandemics strain the health systems. Access to healthcare is uneven across Europe with growing mental health problems. The One Health approach is applied inconsistently; therefore, results are patchy, and trust is weaker.

	Projections 2040			
<i>Shifts in global trade and value chains</i>	The digitally sovereign EU is a global leader in clean-tech solution exports, and as champion for equitable green trade and just supply chains is viewed as the key 'trusted partner' to balance US-China technological bi-polarity.	War times economies and climate disasters - Major and minor conflicts around the world have made most international trade inconsistent and unreliable. Small alliances and singular trade partnerships are common and further destabilise global trade partnerships.	Only some EU regions achieve digital autonomy while others remain dependent on external supply chains. Multiple sectors split between self-sufficient and import-dependent areas. Internal EU market fragments, creating two-speed digital transformation with significant regional disparities and uneven global competitiveness.	The rise of multilateral national alliances (e.g. BRICS, ASEAN) as the core organising principle for trade creates new partnerships and challenges for the EU. New partnerships are prioritised over strategic autonomy, but digital sovereignty remains a key
<i>Social disparities within Europe</i>	Europe has invested in education, healthcare and digital inclusion and closed gaps between regions and social groups, high mobility across the EU and opportunities are widely shared.	Social and economic divides become dramatically wide, only a few regions and higher social classes have great wealth and opportunities, inequality fuels polarization and social stability declines.	Disparities exist but are actively managed, EU programs reduce extreme inequality, but differences remain in income, digital access and literacy and opportunities.	Wealth inequality stabilized but at a high level, climate justice causes more tension as benefits and burdens are distributed unevenly. Some groups benefit from education and healthcare whilst others remain excluded.
<i>Climate change adaptation & mitigation</i>	Europe achieves net-zero emissions and climate resilience. Industries, cities, agriculture are well-prepared for extreme weather conditions, renewables are widespread and circular economy is flourishing.	Europe is facing constant climate disruptions - floods, heatwaves, droughts, storms are causing great damage that is straining economies. Fossil dependencies persist and mitigation strategies fail, social tensions arise.	Europe reduces emissions and builds some climate resilience bottom-up. Climate aware communities organise their own renewable energy systems and climate-neutral city areas profit from reduced energy needs. The efforts and benefits are not distributed evenly across the European society.	Europe implements innovative green solutions in some parts; the change to renewable energy is still slow. Due to political and economic trade-offs, as well as widespread greenwashing, mitigation strategies face barriers and the costs of impacts of climate change are increasing.

A short description of the contextual factors analysed as part of the foresight exercise is provided in the following overview table.

Table 52 Descriptions of contextual factors

Contextual factor	Short description
Access to critical materials	Reliable access to critical raw materials (CRMs) is considered crucial for producing key components of high-tech products, renewable energy technologies, and advanced manufacturing. Materials such as rare earth elements, lithium, and cobalt play a critical role in the production of electric vehicles, batteries, and digital devices amongst others. Given that a significant share of CRMs is sourced from outside the EU, supply chain dependencies, trade policies, and geopolitical developments influence availability. Any changes in supply presents challenges for industrial production, innovation cycles and technology development

Contextual factor	Short description
Cohesion of the European Union	The spread of misinformation and declining public trust in institutions contribute to political polarisation and social fragmentation, further complicating the EU's attempts to strengthen cohesion. If unaddressed, increasing political divides could lead to a 'multi-speed' Europe, where integration levels vary significantly among member states. Discontent with traditional political elites, combined with economic grievances, drive marginalised communities to support radical political alternatives, making consensus-building within the EU more challenging. These dynamics may influence future governance models, institutional stability, and the EU's capacity to maintain unity while navigating diverse political and economic interests.
Demographics & Digital skills in Europe	Digital skills and literacy are increasingly important for the European Union's competitiveness, sustainability, and social inclusion. Beyond employment, digital literacy plays a role in civic participation, critical thinking, and the ability to navigate information, including distinguishing facts from misinformation. However, demographics influence the varying levels of digital skills and literacy among policymakers, citizens, scientists, and communicators, highlighting disparities across age groups, education levels, and regions.
Energy security	Global energy consumption continues to rise, with renewable energy sources playing a growing role as their costs decline. However, energy supply disruptions and price fluctuations may impact economic stability, particularly in energy-intensive sectors. Ongoing investment in fossil fuel infrastructure coexists with efforts to transition to greener energy sources, while factors such as the availability and cost of critical raw materials and grid capacity constraints affect the pace of this shift. Disparities in access to energy services become apparent.
Ethics, standards & law	The integration of emerging technologies is shaped by ethical considerations, influencing their development, deployment and societal acceptance. Balancing between fostering innovation and implementing safeguards is crucial to mitigating risks while enabling progress. Particularly significant in the field of Artificial Intelligence (AI), the AI Act serves as a key regulatory framework designed to address ethical concerns surrounding AI development and deployment. Standardisation plays a vital role in this process, providing clear guidelines and technical benchmarks that promote transparency, interoperability, and accountability in ICT.
Geopolitical reconfiguration	Geopolitical alliances continue to evolve in a multipolar world shaped by competition for resources and emerging technologies, influencing the European Union's strategic positioning. Regional conflicts and shifting international dynamics contribute to adjustments in the EU's foreign policy approach. In response to a changing global landscape, the EU engages in diplomatic efforts and explores new alliances that support democratic norms and values. Cooperation with ASEAN countries, African nations, and other global partners reflects an interest in diversifying strategic relationships.
Global digital currency system	The global payment landscape is changing driven by digitalisation. The use of cash is steadily declining as online shopping, and digital payments through new service providers (outside the traditional banking sector) are becoming more prevalent. Cryptocurrencies built on distributed ledger technologies are becoming increasingly popular and there is a growing global interest among central banks to develop central bank digital currencies. The EU is introducing the digital euro – an electronic form of central bank money to complement traditional banknotes and coins. These developments point to the potential emergence of a global digital currency system, which could enhance transaction efficiency, reduce currency exchange costs, simplify international trade, and promote financial inclusion beyond national borders. However, this potential shift could come with challenges, including regulatory complexities, political considerations, and concerns related to privacy, control, and security.

Contextual factor	Short description
Global health challenges	Biodiversity is globally declining and environmental degradation is accelerating. Biodiversity loss undermines critical ecosystem services, including pollination, water purification, and climate regulation. The degradation of these services can lead to reduced agricultural productivity, increased vulnerability to climate change, and compromised human health, which are particularly concerning for the EU's food security and public health systems. The risk of a global health crisis is growing ever stronger, driven by the emergence of pandemic-level infectious diseases, increasing antimicrobial resistance and deteriorating and unequal conditions in access to health care. Increasing intergenerational inequality, unregulated social media, insecure employment and the climate crisis (eco anxiety) are worsening the global mental health state particularly among youth. The European One Health approach addresses this issue across a broad range of policies by highlighting the interplay of people, animal and ecosystem health.
Shifts in global trade and value chains	Over the past 30 years, the stability of the global economic and trade regime, coupled with advancements in digitalisation, has led to the proliferation of globally dispersed value chains. Their stability is challenged by recent disruptive developments, from pandemics to security and military threats. In response, governments are implementing measures to mitigate risks related to science, technology, and innovation (STI) interdependencies. Such efforts include enhancing industrial performance through targeted investments and strengthening international STI alliances among like-minded economies. These shifts in global value chains and international scientific collaboration potentially contribute to reshaping long-established trade and innovation networks.
Social disparities within Europe	While the number of people living in extreme poverty has declined globally, economic inequalities persist as the distribution of wealth shifts and concentrates in an ever-smaller group of people. Environmental challenges also influence economic stability. Beyond financial disparities, factors such as access to education, healthcare, technology, and intergenerational equity shape social inclusion. Issues related to climate justice, democracy and equal opportunities affect different groups in distinct ways. In Europe, variations in social and economic conditions among and within member states contribute to ongoing tensions on cohesion and democracy.
Climate change adaptation & mitigation	Climate change continues despite efforts to reduce human-induced emissions, with rising temperatures and shifting climate patterns. Increasingly severe weather events impact ecosystems, infrastructure, human safety and health. Environmental degradation, including pollution and the depletion of water, land, and other natural resources contributes to lasting ecological and economic disruptions. Climate change mitigation efforts are being implemented to reduce greenhouse gas emission, while adaptation strategies are playing a growing role in addressing the degree of exposure and vulnerability to ongoing impacts. As environmental limits are increasingly reached or exceeded, established lifestyles, belief systems, and business practices face scrutiny and are subject to ongoing transformation, particularly in high-income societies.

Source: Technopolis Group, Fraunhofer ISI and AIT (2025)

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