Feedback opportunity for the work programme 2025

Cluster 4 - Digital, Industry and Space

Destination 1: Achieving global leadership in climate-neutral, circular and digitised industrial and digital value chains

<u>Draft expected impacts:</u>

Supporting net-zero manufacturing is a key objective of the Net-Zero industry Act and has a crucial role to play in the transition towards a green and sustainable society, going from ‘smart factory’ to a ‘smart sustainable value chain’. This includes flexible and ‘first-time right’ manufacturing systems and processes for innovative and sustainable materials, components and products, based on advances in manufacturing technologies, data spaces and digital twins. Smart manufacturing will help develop the materials and products needed to support net-zero and less polluting industries. Breakthrough technologies to be exploited beyond 2030 will also play an important role.

There is much scope for improvement in circularity technologies applicable to different value chains, with special attention needed for product design, re-use, disassembly, remanufacturing/upgrading, recycling, and ‘Zero-X’ – zero defects, zero breakdowns and zero waste. ‘Servitisation’ – the transformation from selling physical products to providing services for and through them – needs the combination of green and recycling technologies enabled by leveraging the data available in the industrial environment. Digital technologies, like big data, advanced computing, and networking (including quantum), artificial intelligence (AI), robotics, photonics and the industrial virtual worlds will transform the practices of research, design and engineering, with better performing net-zero solutions and increased productivity in all sectors. Quick-response services can support hyperflexible production using, e.g., trustworthy AI and digital twins, with digitally enabled certification and qualification of processes and products. It will be important to develop and test different circularity technologies throughout the entire value chain and life cycle and analyse market, cooperation, governance and business case conditions to facilitate deployment, further developing value chains for circularity and enabling systemic changes for specific markets and where possible across sectors, including fostering synergies between organisations along the value chain such as social economy actors.

The development of new and cross-cutting technologies will boost the transformation of existing value chains and the creation of new ones. One example is the addition of the bio-dimension to the existing technological base, particularly in the context of manufacturing (biomanufacturing), processing and materials. Energy-intensive industries need to embrace the circular economy as a key pillar in the design of their value chains. This will be fundamental to their resource efficiency (material, energy and water). Particularly important in this context is the innovative upcycling of secondary raw materials and waste and the development of sustainable and resource-efficient industrial processes. Further development and deployment of technologies identified in the ERA industrial technology roadmaps for circular technologies and for low-carbon technologies will be essential to achieve this goal. Manufacturing processes, supply chains, cyber-physical systems or cities will become more climate neutral and less polluting, and circular solutions will include AI and digital twins, and the deployment of common European data spaces like those under the Digital Europe Programme. These and other breakthrough technologies will be key for developing and implementing the pathways and new value chains that the Hubs4Circularity project will require.

The EU has set an ambitious goal for Europe to become the first climate-neutral continent by 2050. In some areas the key solutions for achieving significant reductions in emissions are already in the market. In crucial parts of the economy, as is the case for energy-intensive industries, many of the tools needed for such a significant reduction are still at an earlier stage of industrial or commercial development. Reducing these emissions in industrial sectors will require coordinated action throughout value chains to boost and accelerate innovation and deployment of all mitigation options, including: i) demand management; ii) energy and materials efficiency; iii) integration of renewable energies (use of green hydrogen or electrification), and circular material flows; iv) abatement technologies for emissions and pollution; v) R&I on systems´ modelling and management scenarios and vi) transformational changes in production processes. Other industries that make use of these industrial outputs, e.g., consumer products and construction, also face the need to modernise and can thereby help support transformation across the value chain. The process industries' climate neutrality goal is also strongly related to the objective of becoming independent from fossil fuels and fossil fuel imports and increasing the proportion of renewables in energy supplies.

To successfully move from innovation to deployment, a more effective transfer from small-scale industrial demonstrators to first-of-a-kind climate-neutral demonstrators is needed. In line with the EC 'demonstrators report', the aim will be to consolidate the relevant work strands to accompany the deployment mechanism for these industrial technologies in FP10 . It is also important to pursue breakthrough innovations and completely new approaches, with a high capacity to drastically reduce air pollutants, CO2 and GHG emissions at the source. Research and pilot projects would be needed on how low-tech alternatives combined with high-tech and data-driven innovation can reduce the climate and environmental footprint of products and sectors. This would include agri-food value chains, electronics, plastics, packaging, textile materials, manufacturing and reuse , repairing or transport, and drive them towards circularity. Importantly, moving from innovation to deployment will require significant human capacity, including workers with the right skills across key sectors, who are provided with quality job opportunities. The Cultural and Creative Sectors will also contribute to move from innovation to deployment. Europe's cultural depth and its human-centric approach to technology, are a perfect breeding ground for market-creating design.

Hubs4Circularity is a tool that allows for place-based innovation, whenever possible in conjunction with similar existing concepts or technology infrastructures, such as hydrogen valleys . This tool could build on the completion of projects devoted to industrial symbiosis research and on innovations resulting from ongoing hubs for circularity projects. Hubs4Circularity should deal not only with first-of-a-kind demonstrators, but also with the transformation of existing plants. Ultimately, Hubs4Circularity should combine the need for water and energy savings and promote the use of secondary raw materials. It will require that the place-based development of recycling technologies and materials research also benefits from cooperation between energy-intensive industries and cities and regions, including responsible sourcing, tracing and recycling of materials. Therefore, it will be pivotal to engage with Member States and regions in delivering on any commitments of additional funding".

Across industries, the human dimension (including gender differences) will be stressed via the Industry 5.0 paradigm (related to Expected impact 20).

<u>Main expected outcomes:</u>

Manufacturing – Re-manufacturing and De-manufacturing

- Make substantial progress in circularity beyond secondary raw materials, reaching circularity targets of up to 25% for products which are currently at or below the average circularity rate of 11.5%, through a range of innovative and automated de- and re-manufacturing technologies and processes, building on advances in AI and data use and sharing;
- Enable cost-efficient mass de-manufacturing, such as physical collection of products, disassembly, separation and sorting – including high-value products and net zero-technology products;
- Stimulate a new circular manufacturing and business eco-system, through the combination of technologies and processes, circular-by-design approaches, and innovative business cases;
- Support the implementation of the digital product passport and Eco-design for Sustainable Products Regulation (ESPR), in particular through circular-by design demonstrators, also showing the way to appropriate re-skilling and training;
- Contribute to relevant up-skilling and re-skilling.

Manufacturing – GenAI4EU: Automating the road to flexible and resource-efficient value chains

- Increased productivity by high quality, flexible and resource-efficient manufacturing, both on the shop floor and in engineering/business processes, in particular for high-mix manufacturing, and through vertical and horizontal integration and interoperability at factory level and across value chains;
- Significantly improved product and process certification and compliance, as well as the reliability, efficiency and sustainability of manufacturing processes, and product and process certification and compliance are significantly improved through the adoption of robust and trustworthy digital technologies, in particular Generative and Explainable AI;
- Significantly facilitate the commissioning and decommissioning of product facilities, through tools that enable faster industrialisation of factory automation well beyond the pilot phase, while reducing the need for "physical" fine-tuning and on-site interventions.

Manufacturing – Human-machine interactions

- Empower workers in factories (as well as engineers in the design phase) through technologies embodying the next stage in human-machine interactions;
    - As an example, interactions with currently complex interfaces should be simplified and benefit from language models can transcribe complex data in a simple and synthetic way;
- Reduce human strain and stress through cognitive and physical augmentation technologies, leading to enhanced flexibility, efficiency and sustainability in the industrial environment;
- Build on breakthrough technologies in the area of human augmentation;
- Foster the Industry 5.0 model, through insights into how technology changes the work environment (and the associated job profiles); and assess inclusiveness / attractiveness;
- Contribute to relevant up-skilling and re-skilling.

Energy-intensive Industries – electrification of production

- Develop and demonstrate new electrically driven industrial processes substituting electrified heating processes which currently absorb 60% of the overall renewable energy allocated to the energy-intensive industries;
- Increase energy efficiency of such new electrically driven processes and thus reduce industrial emissions by additional 25% compared to industrial heating processes;
- Build on mechanical energy input (in separation processes: high gravity distillation, membrane technology, vapour recompressions; but also relevant for cement); electricity induced forces, electrochemical processes or activation of reaction by other form of energy than heat;
- Contribute to the future 2040 GHG reduction targets[1] and to the 100% of total CO2 eq. emission reduction potential by 2050;
- Boost competitiveness and enable industries in Europe to lead in a more cost-efficient way on the global clean technology markets of the future.

Energy-intensive Industries – green and resilient production processes

- Adapt production processes to make them flexible to the variations of renewable energy sources thus contributing to achieve EU Climate 2040 target, making Europe more resilient;
- Ensure stable and resilient production processes reconciliating productivity with energy supply, leading to productivity gains;
- Offer a step change in the capacity of production plants to promptly change loads and throughputs in large ranges;
- Address any adverse effects for equipment, including the risk of higher costs as well as higher energy consumption compared to 2030 targets.

Energy-intensive Industries – integration of renewable energy carriers

- Enable the successful integration of a wide range of renewable carriers of energy (electricity, hydrogen, solar heat) into industrial sites composed of different process industry plants;
- Save up to 55% in primary energy and enhance the operational flexibility of the grid as a lead case for industrial symbiosis;[2]
- Make best use of existing patterns of hubs of circularity in such industrial sites;
- Develop technologies for, and prototypical design of, the physical assets and plants integrated into such industrial sites.
- Enable the use of advanced digital technologies, including AI, for the improved, safe and efficient operation of the site including the interaction with different plants and grids;
- Contribute to achieving the 2040 climate targets and make Europe more resilient in the use of different renewable energy carriers.

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[1] Europe's 2040 climate target, Impact Assessment, part 3, p. 59
[2] Hubs for circularity – Keeping local with a global impact

Energy-intensive Industries – upcycling technologies

- Increase the use of secondary resources from the 12% that are recycled today to up to 25%, leading to significant increase in resource and energy efficiency across the value chain and overall positive environmental impact;
- Reduce raw materials demand, thus decreasing the industrial GHG emissions by 20% in 2040;[3]
- Increase the competitiveness of the European process industry; new business opportunities and revenue flows for recycling companies, benefiting particularly SMEs, which dominate this sector of the market;
- Address in an integrated way the technologies and the implementation (including logistics and economics) of circular schemes for the upcycling of waste and by products;
- Foster the use of digital tools as well as the data sharing, and FAIR (Findability, Accessibility, Interoperability and Reusability) digital assets principles;
- Make best use of existing hubs of circularity funded at European, national or regional level as a place for innovating new technologies and exploring new business models.

Energy-intensive Industries – pollution abatement

- Enable novel processing technologies and products with reduced health, safety, and environmental impacts;
- Reduce the use of substances in production processes and products that pose a risk for human and environmental health and safety and ensure the avoidance of their proliferation into products;
- Reduce the risk and negative health impacts at work by empowering employees and promoting a participatory approach;
- Establish link to substances of concern[4], emerging pollutants[5] and methods of monitoring;
- Address any adverse effect on the function of the materials, the production cost, the associated risk or recyclability.

Energy-intensive Industries – accelerate innovation in steelmaking

- Fast-forward fundamental knowledge in steelmaking processes based on hydrogen (e.g. direct reduction) and electricity (e.g. EAF, electrolysis), to accelerate transition to carbon neutral steelmaking and mitigate the impact of the phase out of the ETS free allowances in 2030. For instance, at present what we could consider clean steel depending on the electricity generation is produced via secondary route (EAF alone), which covers only 43% of the EU crude steel production;
- Use reliability to de-risk technologies: validate steelmaking products with relevant analytical approaches, methodologies, and data statistics, and correlate them to system variables with the scope and scale to achieve quality and extended product lifespan;

[3] Europe's 2040 climate target, Impact Assessment, part 3,, p. 59
[4] broader than ECA very high concern to be substituted if we have alternative.
[5] we start having the monitoring tools and that they are an issue – new pollutants.

- Use sensor technologies and digital techniques for large data collection and plan for rapid and efficient data processing and analysis. Develop enhanced models and integrate AI for comprehensive understanding of process mechanisms, including digital twin technology and circular materials models.

Energy-intensive Industries – deploy low-carbon technologies

- Promote programme and funding synergies and mutual learning among EU-level, national and regional initiatives; engaging all key actors for decarbonization of industry projects;
- Deploy technologies by enabling markets for green products (e.g. definitions, measurement methods, prenormative research) and Investment schemes building on existing investment platforms);
- Realise human-centric sustainable and resilient energy-intensive industries – Industry 5.0 paradigm. Empower workers and measure the impact of non-technological aspects (automation, skills demand, participatory work structures, decentralized management) into the narrative, sustainability, resilience and attracting talents to the process industries.

Construction

- Reduce time taken to carry out site operations of construction or demolition works;
- Increase application of on-site re-use, preparing for re-use and recycling;
- Reduce errors and of waste generated by construction works;
- Improve health and safety of construction workers.

Feedback opportunity for the work programme 2025

Cluster 4 - Digital, Industry and Space

Destination 2: Achieving technological leadership for Europe's open strategic autonomy in raw materials, chemicals and innovative materials.

Draft expected impacts:

A paradigm shift, as regards the availability, development, use and disposal of chemicals and materials is required to guarantee Europe's open strategic autonomy, technological sovereignty and capacity to deliver on the twin green and digital transitions.

To enable such a shift, an innovative, strong European R&I ecosystem for circular chemicals and materials is needed to work across different technology readiness levels. The Commission Communication on 'Advanced materials for Industrial Leadership'12 will be a stepping-stone for framing this ecosystem.

Bringing knowledge and skills together across the materials' value chains is key to ensuring that this shift can materialise. The requirements of the European Green Deal for safety, sustainability and circularity must be considered across the life cycle of a chemical or material. The 2022 Commission Recommendation[1] on 'safe and sustainable by design' sets out a new framework on how to achieve these objectives. Communicating results, impacts and achievements is important not only to the scientific community but also to stakeholders and citizens affected by the new approaches and innovative thinking.

R&I activities should contribute to strengthening EU's critical raw materials capacities along all stages of the value chain, increasing our resilience by reducing dependencies, increasing preparedness and promoting supply chain sustainability and circularity, in line with the Critical Raw Materials Act.

All critical raw materials should be addressed – particularly those used in strategic sectors like renewable energy, electromobility, energy-intensive industry, digital, and aerospace, and the corresponding manufacturing technologies. It is necessary to improve the energy and process efficiency of extractive and processing activities and minimise their environmental impact, including GHG emissions. As regards raw materials, R&I on exploration, sustainable sourcing from extraction to secondary raw materials, as well as increasing efficiency in the use of critical raw materials are important. Advancements need to be made on finding options for replacing critical raw materials with other (advanced) materials offering at least the same functionality and considering the existing environmental concerns.

Advanced materials (including amongst others nano- and 2D materials) and chemicals are designed with functionality in mind. Compared to conventional materials, they have novel

[1] Commission Recommendation of 8 December 2022 on establishing a European assessment framework for 'safe and sustainable by design' chemicals and materials, C (2022)8854, 8.12.2022.

properties that significantly step up performance. For the design and development phase of advanced materials there is a need for: i) research and technology infrastructures (e.g. open innovation testbeds, analytical facilities); ii) innovative digital tools opening up new avenues for design (smart sensing and imaging, making use of artificial intelligence, machine learning, robotics and high-performance computing); and iii) smart data management. New digital tools are needed such as common data spaces, digital twins, industrial virtual worlds, as well as novel (autonomous) design, synthesis, development, characterisation and fabrication tools as well as continuous training of scientists on these new tools. To secure unimpeded market entry, appropriate test methods are needed. New chemicals and materials should be developed using the 'safe and sustainable by design' framework and with the efficiency and circularity of materials in mind, also for their inclusion in products. This calls for tools, models and data for robust 'safe and sustainable by design' assessment, including animal-free new approach methodologies and systematic life-cycle assessments. Bio-based advanced materials/chemicals and the integration and interaction of biological and artificial materials and components offer new opportunities to reduce resource dependencies and maintain sustainability.

Achieving the circularity of both raw materials and advanced materials is a key future challenge. Establishing new material flows, recovery, recycling and upcycling of materials from waste are challenges in themselves, but they also require information sharing along and across value chains and development of new business models allowing to foster innovative solutions related to technological progress, such as in materials design. Uptake of advanced materials as well as a more efficient use of materials should be fostered in product and materials-based technology developments. This also requires new business models to be developed for the deployment of circular technologies and value chains as well as for providing product-as-a-service models, on-demand manufacturing, take-back-schemes and other service-based businesses. Strong support to SMEs is required so they can thrive in this materials ecosystem.

Main expected outcomes:

Safe and Sustainable by Design (SSbD) – alternatives to PFAS

- Safer and more sustainable alternatives to PFAS used throughout society will be available to industries offering products in Europe (exact target areas, excluding energy, mobility and health, with highest impact to be discussed, e.g. coatings, lubricants, surfactants, water and oil repellent, antifouling, antiadhesion);
- The Commission including regulatory agencies, Member States and associated countries will have access to publicly available knowledge about PFAS alternatives;
- The availability of safe and sustainable alternatives to PFAS will support REACH restrictions as well as requirements for the EU Ecolabel and the forthcoming Eco-design for Sustainable Products Regulation (ESPR);
- Industry will avoid regrettable substitutions, through the use of the SSbD framework.

Safe and Sustainable by Design (SSbD) – advanced life-cycle assessment (LCA)

- The European Platform on LCA (EPLCA) will be enriched with new tools, methods and data;
- Stakeholders and policy makers will through adoption of digital technologies gain access to more efficient tools and methodologies to support Life Cycle Assessment. In particular Small and Medium Enterprises (SMEs) will be facilitated in their task to implement the SSbD framework by having increased access to user-friendly tools and methods;
- Risk assessment will be enabled to seamlessly include safety and sustainability components and emerging environmental concerns will be better addressed via advanced modelling
- The implementation of EU strategies such as the proposed Eco-design for Sustainable Products Regulation (ESPR), the EU Ecolabel, the Batteries Regulation, the Critical Raw Materials Act and the Net Zero Industry Act will benefit from scientific evidence on sustainability throughout the whole life cycle of chemicals and materials.

Advanced Materials

- A federated digital infrastructure for advanced materials based on the EDIC model that serves as a long-term sustainable central hub for storing, managing, and sharing data, tools and resources related to advanced materials research and development;
- Researchers from industry and academia will have access to interoperable heterogeneous data sources and computational tools (incl. modelling and characterisation) that support the workflows for the design and development of advanced materials;
- State-of-the-art artificial intelligence (AI) technologies, machine learning algorithms, and predictive modelling techniques will become accessible to researchers in industry and academia.
- Continue low TRL research efforts and discovery of new 2-Dimensional Materials building on the established collaborations within the Graphene Flagship between academia and industry
- AMs (including 2DMs) with cutting edge functionalities addressing industrial needs in energy, mobility, construction and electronics sectors.Leveraging innovation procurement processes to stimulate innovation in advanced materials that address specific needs or challenges faced by public authorities.
- Driving market transformation by aligning procurement strategies with broader policy objectives, such as the twin transition.
- Establishing collaboration between public authorities, industry, and research organisations, fostering a dynamic ecosystem of innovation.
- Resilient value chains, materials development;

- Enabling tools and methodologies for safe, sustainable and circular materials;
- A robust innovation cycle.

Raw materials

- Boosting the EUs strategic autonomy along the raw material value chain, by strengthening the knowledge on primary and secondary critical and strategic raw materials. This includes exploration, extraction, processing and recycling for primary and secondary critical and strategic raw materials;
- Enhancing technological leadership, cost effectiveness and industrial competitiveness for extraction, processing, and recycling processes for primary and secondary critical and strategic raw materials;
- Further diversifying responsible and sustainable raw material supply on international supply chains through collaborations on different levels of the raw material value chain and further develop Strategic partnerships on raw materials with resource rich countries

Feedback opportunity for the work programme 2025

Cluster 4 - Digital, Industry and Space

Destination 3: Developing an agile and secure single market and infrastructure for data-services and trustworthy artificial intelligence services

Draft expected impacts:

The next stage of the data economy will shift data flows from consumer-to-business to business-to-business, business-to-consumer, consumer-to-consumer, business-to-government and government-to-business models. Supporting the development of technologies that are crucial for the next stages of the data economy, such as privacy-preserving technologies and compliance technologies, source and transaction integrity (such as blockchain), and technologies underpinning interoperable and compliant industrial, public and personal data spaces and secure data exchanges. Rebalancing the data, computing, and learning capacity across the cloud-to-edge/internet of things continuum will let businesses, public organisations and individuals exploit data for trustworthy and bias-free decision-making. Wide availability of reliable data, like from the European data spaces in the Digital Europe Programme, together with new interactive, immersive and context-aware technologies – digital twins, cyber-physical systems, internet of things and virtual worlds – will make this easier than ever before. This will help all groups benefit from the power of data and AI in a fair, unbiased and compliant way. Fully achieving the “compliant by design” goal will have the advantage of making compliance with the multitude of rules and regulations as easy as possible, reducing the administrative and reporting burden for businesses and individuals using the Data Spaces. Industrial virtual worlds that are open and interconnected bring alternative but realistic and coherent views on what are widely distributed, diverse and complex devices, processes and value chains. Beyond visualisation and simulation, and thanks to new types of interfaces (like XR/VR), secure data sharing and distributed computing technologies, they allow for safe and natural ways of interaction and control, high level of response to local events, real-time optimisation and dynamic re-configuration in key application areas like for: i) the integration of renewable energy sources, ii) smart farming, iii) agile supply chains and logistics, and iv) hyperflexible manufacturing and manufacturing-as-a-service. Similarly, data-driven tools, AI, language technology, adaptive and self-programmed robotics, and new energy-aware programming solutions will improve operational and energy efficiency in lead sectors like healthcare, manufacturing, mobility, and the energy sector itself.

Main expected outcomes:

1. AI/GenAI

Effective, Sustainable and Trustworthy General Purpose Artificial Intelligence

- New assessment and validations methodologies developed allowing to evaluate General Purpose AI (GPAI) models and systems’ capabilities, energy efficiency and risks.
- Use of the research outcomes by GPAI providers, policymakers and other relevant stakeholders to create benchmarks for evaluating GPAI models and systems’ capabilities, energy efficiency and risks.

Compliance technologies, Data Spaces

- Enabling and empowering existing data spaces to facilitate automatic compliance with EU regulations (GDPR, Data Governance Act, Data Act, AI Act, sectoral legislation…) and other rules, reducing manual effort, administrative burden and human errors.
- Increased interoperability and standardization for effective data sharing across platforms, data spaces and sectors.
- Comprehensive user training and support, ensuring adaptability and scalability to accommodate evolving regulations and diverse organizational needs.

2. 3C Networks

- Setting up large scale pilots of end-to-end telco edge cloud integrated infrastructures and platforms, bringing together players from different segments of the connectivity value chain and beyond, such as operators, system integrators, network/cloud/edge suppliers, IoT platform providers et al.
- Validating open orchestration platforms across the telco edge cloud continuum, unlocking the transformative value of AI for European businesses and driving business growth in multiple industries strategic for Europe, while ensuring high level of security, privacy as well as low ecological footprint.
- Enabling new innovations and services for European digital supply industry while strengthening the industrial ecosystems in areas like mobility, smart communities, energy, health, farming, logistics and manufacturing.
- Interconnected industrial virtual worlds bringing realistic and coherent views on what are highly distributed, heterogeneous and complex devices, processes and value chains.
- Networked, agile and green IoT-edge computing solutions for an extended decentralisation of virtual word concepts.
- Novel AI-enabled Cloud and Edge management solutions tailored for the processing needs of AI workloads across the cloud-edge-IoT continuum that boost innovation via the integration of AI models, digital twins and cyber physical models.
- Strategic industrial cooperation in data processing across the Cloud-Edge-IoT cognitive computing continuum to support future hyper-distributed AI applications by building open platforms, underpinning an emerging industrial open edge and cloud ecosystem to establish a mature European supply chain.

Feedback opportunity for the work programme 2025

Cluster 4 - Digital, Industry and Space

Destination 4: Achieving open strategic autonomy in digital and emerging enabling technologies

Draft expected impacts:

A key impact is to ensure Europe's strategic autonomy while preserving an open economy in those technologies that will be key for a deep digital transformation of industry, public services and society, while fully playing its enabling role in the twin transition.

The cloud/edge/internet of things will be transformed into an agile and situation-aware infrastructure that converges with advanced connectivity to bring data to where and when it is needed. Within these smart digital infrastructures, end-to-end artificial intelligence, from the core to the edge and across all technology layers, will be key for on-demand supply of optimal data-, communication-, and computing resource orchestration, with optimal use of energy while preserving privacy and ensuring resilience.

The way in which the virtual world meets the physical world will continue to evolve, thanks to all kinds of robots and other smart devices that involve self- and context-awareness, spatial intelligence, exploiting the best in bias-free AI, engineering and design for game-changing physical characteristics, functional or cognitive capabilities, acute perception, autonomy and safe interaction.

Artificial intelligence underpins many of these changes and Cluster 4 will strengthen and consolidate R&I in this area. For example, today's generative models are a preview of how virtual worlds and multimodal user-experiences could be produced on-demand. Research on core learning and analysis techniques (incremental, frugal and collaborative), as well as next generation smart robotic systems, will keep Europe at the cutting edge of AI.

Europe's long-term competitiveness in the digital area requires continuous scouting and early, low-TRL cross-disciplinary work on new and emerging technologies, dissociated from the main roadmaps. This would encourage collaboration in research and cross-fertilisation between disciplines and sectors on new approaches in microelectronics, power electronics, photonics and photon/phonon/spin/electron integration, and unconventional, hybrid, neuromorphic, nature-inspired or bio-intelligent paradigms and novel systems and infrastructure architectures.

Europe's strength in quantum technologies is a strategic asset for its future security and independence. The investments will support early and mature quantum technologies and stimulate their industrial uptake, e.g. through experimentation and testing environments for integrating them into standard industrial design and manufacturing.

Equally transformative, two-dimensional materials (2DM) could positively affect many industries, including ICT. While further exploring the vast range of 2DMs, we will also work towards completing a fully European supply chain and scaling up the development and piloting of 2DM technologies and devices for more industrial fields.

Main expected outcomes:

Photonics

- Reinforced leadership of European research and industry in sensor technologies such as LIDAR, 3D imaging techniques and multispectral/hyperspectral sensors including algorithms to drive medical, industrial, agricultural, safety, security and environmental applications.
- Light-based access technologies to interact with virtual worlds are provided, starting from professional environments
- Europe's manufacturing industry equipped with the best and most versatile production tools using lasers and cutting-edge sensing technology

Ground-Breaking Technological Foundations in AI, Data, Robotics and in software Engineering

- Achieve new capabilities, like planning, mathematical reasoning and awareness of the environment by combining the existing self-supervised learning with additional types of learning such as active learning, reinforcement learning, and continuous and incremental learning.
- Computing infrastructure & Software Engineering: AI-enabled Software Engineering methods and tools to increase efficiency of SW processes to optimally deliver and deploy AI algorithms and the development of (hybrid) quantum software are available and improved.

GenAI4EU: Next generation smart embodied Robotic systems

- Established sophisticated foundation models in robotics that dynamically learn and understand the physical environment in real-time in order to empower robots to plan actions aligned with high-level goals, ensuring a higher level of autonomy, adaptability, and reliability in complex and dynamic scenarios.
- Increased exploitation of novel materials, design methods, and control techniques for soft robotics, enabling the creation of inherently safe and versatile robotic systems, enhancing functional resilience, adaptability in disruptive situations and multi-robots collaborations with applications in various industries, including healthcare, manufacturing, agriculture, construction and transportation.

AI in Science

- Accelerated AI-enabled scientific discovery in a selection of scientific fields through developing AI model(s) designed to facilitate scientific discovery and to optimise the research process in specific scientific domains.
- Wider access to AI technology for science by scientific communities, bridging the gap for scientists developing applications of that model in their scientific field.
- Develop specific know-how on developing AI technology for use in science.
- Facilitate reproducibility and promote open science and open-source AI models.
- Strengthen the network and community of scientists and stakeholders for AI in Science, including a Strategic Research and Innovation Agenda for AI in Science.

- Consolidate and federate the landscape for an effective coordination between the scientific, data and computing communities.

Quantum

- Continued support of the Quantum Technologies Flagship's activities, supporting the coordination of EU, national and regional activities in line with the aims of the Quantum Declaration, and discovering new ways of exploiting quantum technologies, to benefit Europe's entire quantum stakeholder community.
- Enhanced European quantum communication infrastructures, taking steps towards a quantum internet, and so providing solutions for secure communication and strengthening European digital autonomy.
- Integration of machine learning with quantum technologies: 1) emphasizing innovation in quantum device control and optimization, by optimising the physical design; 2) fostering innovative research and development in the creation of novel quantum machine learning algorithms and the integration of quantum computing with existing AI frameworks, in order to augment computational capabilities and transform traditional AI systems, and contribute to European leadership in this domain.
- Quantum Computing – Complementing the quantum computing FPAs with the development of a technology agnostic software stack and classical computing integration, with the aim of laying the foundations for a universal quantum computing ecosystem that supports interoperability, promotes standardization, and reinforces Europe's leadership in quantum computing.
- International research and development cooperation in areas of mutual interest (with US, [Japan and Republic of Korea – tbc]), opening up opportunities for European researchers and furthering Europe's economic security via mutually beneficial cooperation with like-minded partner countries.

Advanced/Graphene-2D materials:

- Continue fundamental research efforts and discovery of new 2DM (cf also destination 2).

Submarine Cables

- Defining specific R&I roadmap at EU level to establish leadership in all relevant submarine cable technology domains (EU research roadmap on submarine cables).

Feedback opportunity for the work programme 2025

Cluster 4 - Digital, Industry and SpaceCivil Security for Society

Destination 5: Achieving open strategic autonomy in global space-based infrastructures, services, applications and data.

Draft expected impacts:

People in Europe should be allowed to reap the benefits of space services, data and applications. Today, many sectors of the EU economy rely on services, data and applications from space. This includes satellite navigation for mobility and transport, agriculture and land management, banking and other financial transactions and energy management. In addition, satellite Earth observation is very important for i) environmental monitoring and follow-up, ii) mitigating pollution and climate change, whether on land, in the air or at sea and iii) emergency management situations. It plays a key role in the implementation of the European Green Deal objectives. Finally, some other technologies that also play a crucial role in security and resilience when dealing with threats, natural or human, include: (i) space-based situational awareness; (ii) telecommunications; (iii) satellite navigation and positioning; and (iv) in-space services. The EU space industry is an important part of the EU economy, being a global market leader in some sectors while being more of a challenger in others. Cluster 4's space component will help further strengthen the EU's capacity to: (i) conceive, develop, operate and exploit competitive space technologies, systems and data and the associated services and applications in space and on the ground; and (ii) develop new flexible, scalable, secure and sustainable system approaches, ensuring freedom of action and autonomy. The non-dependence and resilience of EU space technologies and strategic assets also need to be ensured. Space is a sector that helps to ensure that the EU is not dependent on other parts of the globe when security and/or political independence aspects come into play. It also helps to: (i) protect EU infrastructure and strategic assets from damage, be it from natural hazards or human threats; and (ii) increase the ability of EU infrastructures to scale up and adapt

Main expected outcomes:

1. In Accessing Space, supported EU independent access to Space via actions supporting the EU vision building on the three pillars set in the EU Space Programme, i.e. aggregating European institutional demand, boosting game-changing innovations supporting critical ground infrastructure. Supported not only the consolidation of new solutions to serve EU launch services needs through prizes, but also the interoperability of access to space ground facilities in Europe for European micro and mini launchers.
2. Developed capabilities in using Space on Earth related to telecommunications through innovations related to end-to-end flexible solutions, from large to medium and small satellites; on-orbit mission flexibility; ultra-high throughput capacities, enhanced cybersecurity; and, for IRIS2, the development of the infrastructure and services. For

GOVSATCOM, supported the development of critical building blocks in the satellite communication user segment terminals. In addition, demonstrated key space and ground technology building blocks in state-of-the-art areas such as cloud in space and edge computing, network protocols (5G&6G), distributed systems, automatic/intelligent data processing, inter-satellite links, innovative resources management software and orchestration of multi orbit space assets.

3. In using Space on Earth related to Earth Observation, improved the Copernicus Services towards the uptake of Sentinels and other satellites in future reanalyses, soil-vegetation-atmosphere modelling and wildfire risk forecasting and emissions, ocean data assimilation and ensemble prediction; integration of digital technologies (e.g. artificial, machine and deep learning, HPC, cloud and edge computing, digital twins), in close coordination with Destination Earth as appropriate; horizontal applications across multiple Copernicus services, including, but not limited to, food security, attribution to extreme events and climate adaptation, health, support to monitoring, verification and enforcement of compliance with EU environmental legislation and rules, energy efficiency and autonomy; innovation related to higher end-to-end performance, multi sensor systems solutions, high reactivity and processing capacity, multi-layers capacity, etc.; and maturation of the most time-efficient high power end-to-end processing chains, together with significant imagery performance enhancements.
4. In using Space on Earth related to satellite navigation, further evolution of Galileo and EGNOS infrastructure engineering and technology, including finalisation of the development of Galileo 2nd generation (G2G); further development of critical technology (e.g. atomic clocks, both space and ground clocks); and development of new services, such as EGNOS for non-aviation users and/or services based on the exploitation of 30+ satellites when combined with LEO.
5. In using Space on Earth related to data coming from satellites, both Earth Observation and navigation, advanced the benefits for both citizens, authorities, and businesses via scaling up the use of space data, especially in selected priority areas that are strategic for Europe such as energy, climate adaptation, green financing (allocation of funds to support environmentally sustainable projects) and liveable cities; and fostering applications enhancing capabilities for a resilient Europe, supporting the operational work of crisis and security practitioners.
6. In Monitoring Space, built further resilience and autonomy of the Union's Space Surveillance and Tracking capabilities by leveraging complementary contributions from European private capabilities and commercial initiatives.
7. Developed capabilities to Act in Space through actions aiming at demonstrating in space a pilot mission by 2030 related to in-space operations and services (ISOS). The envisaged pilot mission aims at operations and services such as inspection, maintenance, life extension, upgrade, and transport in space as well as for enhanced technology demonstration in orbit, based on EU non-dependent technologies.

8. When it comes to Boosting space through non-dependence of the EU for key critical space technologies, developed the key technologies identified through the work of the COM-ESA-EDA joint task force and the EU Observatory of Critical Technologies, and responding to EU Space missions, including IRIS2.
9. When it comes to Boosting Space through developing innovative Space technologies for competitiveness, started international cooperation on the exploitation of Quantum Space Gravimetry data with a partnership between European and Japanese entities.
10. When it comes to Boosting Space through training and education activities, helped bridge the gap between supply and demand for talents in the European Space sector through a job placement scheme for university students and young graduates and a space camp for students aged 14-18.
11. When it comes to Boosting Space through IOD/IOV opportunities, continued to provide opportunities for experiments needing aggregation, as well as for read-to-fly satellites.

Activities launched previously and not yet needing a new activity under the 2025 WP continued to deliver their outcomes (Cassini Entrepreneurship, Space Traffic Management, Quantum Space Gravimetry pathfinder mission preparation, Space Weather and Near-Earth Objects, Space sciences, GOVSATCOM use cases)

Feedback opportunity for the work programme 2025

Cluster 4 - Digital, Industry and SpaceCivil Security for Society

Destination 6: Achieving open strategic autonomy in global space-based infrastructures, services, applications and data.

Draft expected impacts:

New ways of working, assisted by technologies for physical or cognitive augmentation (exo-skeletons, digital twins, collaborative AI, virtual and extended reality) will increase efficiency, safety and quality of work, provided they are trustworthy, safe and reliable, as well as human-centric and free from gender, racial and other social biases by design. Within the dynamic context of flexible organisation and process flows, workers will have to be empowered to co-create their new forms of working and collaboration within and across organisations, through participation, social innovation or living labs, where social economy actors and local grassroots initiatives are of particular importance. New job profiles and skills will emerge, often requiring digital competence, in addition to social and green skills (e.g. awareness of impact, circularity options). Continuous learning, through formal training, on-the-job learning or being immersed in virtual worlds, combined with appropriate certification and reward mechanisms can boost the attractiveness of careers in many sectors, including manufacturing. A new dynamic, in the spirit of Industry 5.0, will be brought to the workplace through better human interaction with production technologies, open innovation, supporting young professionals' innovations in e.g. manufacturing, as well as participation of new actors, such as fablabs. Digital environments and virtual worlds will enable new forms of collaboration in generating new product and process ideas, assisted by digital twins and AI, in an inclusive, trustworthy and ethical fashion.

Just like today's internet, the future internet will drive industrial, social and cultural innovation. The cluster will develop technologies for an inclusive, gender-equal, trustworthy and human-centric internet. This will build on a more resilient, sustainable, and decentralised architecture, empower end-users with more control over their data and their digital identity, and enable new social and business models that respect European values. The cluster will also spearhead the use of virtual worlds and digital twins where they can make a real difference. Industrial virtual worlds could increase productivity, improve working conditions and access to work, and address and anticipate skills gaps for highly complex products/services or for safety-critical operations. Smart communities and 'citiverses' can empower public authorities and people to fulfil their aspirations.

To reach the ambitious goal of achieving trustworthy AI, 'compliant by design' with the AI Act – challenges such as accuracy, robustness, transparency and efficiency have to be addressed, along eliminating biases in data entry to assure fairness in light of individual differences, e.g. in gender or age, and intersectional diversity. Increasing the cognitive level of AI systems (like from combining data-driven and symbolic learning) is crucial for their wider uptake and acceptance. Smart 'technology-for-trust' (e.g. blockchain for identity and transaction tracking, AI to counter biases, deep-fake recognition, fact checking) will also have a role. The Cluster will focus on particularly on generative AI (addressing algorithms, data and computational resources), foundational models and language technologies to gain strategic autonomy in this area. This is expected to trigger a whole range of new applications in entertainment, education and commerce, starting with assisted and virtual content production, and on-demand synthetic media. Beyond these, the possibilities in industrial settings (e.g. robotics, training, process planning, quality assurance), in public services and public administrations are largely untapped. Involvement of social sciences and humanities will help bring benefits and respect for European values.

Specific measures are needed to allow start-ups and smaller companies to use and benefit from AI, data (including by enabling access to the high-performance computing power needed), photonics and robotics, and to play an active part in developing the next generation of smart technologies within a diverse and open European innovation ecosystem. Similarly, the responsible use of AI in science, research and engineering is going to be key for keeping up the scientific and technological global competitiveness of the EU.

A well-functioning European ecosystem of digital commons, based on open technologies and driven by European values, and a thriving culture of collaboration and social innovation are essential for ensuring sovereignty, trust and user empowerment. New software engineering techniques are needed that are applicable from core to edge and across the entire software stack to build the open distributed systems that the cluster envisages. AI-driven as well as low-code methodologies will help address shortages of digital skills, increase productivity and allow for point-of-use configuration and personalisation.

Ultimately, industrial and digital technologies should empower everybody, from individuals to small and large public and private organisations, to actively take part in co-creating Europe's green and digital future. The cluster will engage with people at a broad level to address ethical and societal concerns and examine legal and regulatory questions. An integral part of the human-centric approach will be to pay attention to the impact on physical and mental health and well-being, e.g. in the context of virtual worlds and advanced interfaces, or on society like for democracy and mitigating divides. To fully achieve these objectives, synergies with the Cultural and Creative Industries will be essential.

Main expected outcomes:

AI, Next Generation Internet (NGI) and Virtual Worlds (VW)

- Demonstrate the value of human-machine collaboration and interaction and how collaborative decision-making improves over human decision-making and that the collaborative decisions cover all stages of reasoning.

- Generative AI for Virtual Worlds: realistic environments and personalised avatars, digital assistants and 3D chatbots, removing language barriers, dynamic storytelling or scenario, AI-generated creativity.
- Supporting the emergence of open and sustainable (i.e. much greater efficiency in energy and material) internet ecosystems in strategic areas through open-source Next Generation Internet technologies and technological commons, piloting mature NGI technologies to industrial/societal use cases and supporting implementation of EU policy areas
- NGI and Virtual Worlds: Next Generation Internet for Web 4.0 / Virtual Worlds: human-centric internet with a focus on technology building blocks (trust, interoperation, transaction, resource access, identity and attribute verification, ...)
- Making available Petabyte-scale, curated, analysed and annotated Web crawling data to enable the development by European companies of General-purpose AI Models, Large Language Models and Web Search.
- Virtual Worlds: Better and more realistic immersion multimodal interaction for Virtual Worlds: multimodal interaction, especially combination of a few of them (force-feedback and haptics, touch, sensing, smell, speech), across sectors and applications.

International cooperation

- Support EU's international priorities, as set out in Europe's Digital Decade and Global Gateway
- Promote EU values for a human-centric digital transformation and contribute to Sustainable Development Goals (SDGs)
- Support to trade and industrial policy aspects by promoting European technologies and standards in key international markets

Standards

- A structured information system on the standardisation landscape is accessible for all actors of the R&I ecosystem which includes a search tool for standardisation deliverables;
- Improved valorisation mechanisms that ensure the market relevance and scalability of R&I results.

Valorisation of Knowledge

- Increased capacity in industry, academia and public sector by operating cross-disciplinary and cross-sectoral collaborations which taps on value-creation opportunities;
- Cross-disciplinary and cross-sectoral scale-up pilots which facilitate the transfer of mature results toward deployment.

- A dedicated AI tool to accelerate the transfer of research results with high commercialisation potential to markets and to society;
- AI tools available for all R&I actors connecting IP owners and potential licensees in different industries, identifying valuable but unexploited IP.

Intellectual asset management

- A set of recommendations based on research security practices and measures in Member States and their implication for intellectual assets management;
- Practical guidance on licensing of patents related to critical technologies or sharing of data and know-how to all R&I ecosystem actors for the management of intellectual assets from the research security perspective.

Technology infrastructures

- Better understanding of the landscape of Technology Infrastructures and their services in selected pilot areas;
- Increased availability of Technology Infrastructures services for enterprises across the EU, in particular SMEs and start-ups, with increased opportunities for testing, up-scaling and deployment of new technologies.

AI in urban planning and management

- Use the potential of AI to develop innovative solutions for cities engaged in the "Cities Mission";
- Bring together developers of existing digital twin tools, developed under the "Cities Mission", to adapt and enrich their models;
- Develop new tools that will enrich the pool of solutions that is offered to other (Mission) cities;
- Engage with local businesses and citizens by developing tangible models of digital twins, to be displayed at local events.

Incentives for Industry 5.0

- Incentives for systemic transformation towards industry 5.0 and for adopting organisational and business models needed for efficient adaptation of EU industries to post-twin transition era;
- Demonstrate enabling conditions, processes and tools for systemic transformation and upgrading of organisational capability for complex Industry 5.0 environments in the participating learning organisations and ecosystems;
- Increased organisational learning capacities, organisational agility, and capability for rapid adaptation to change in uncertain and complexity-driven value chains and environments, contributing to achieve Industry 5.0 goals of human-centricity, sustainability and resilience;

- Increased investments in human-centricity, sustainability and resilience purposes of companies.

Cooperation for Industry 5.0

- Empower industrial ecosystem stakeholders to identify and solve industrial challenges identified under the Industry 5.0 pillars at regional level, in accordance to their RIS3 and/ or industrial strategies [perhaps in collaboration with Pillar III Regional Innovation Valleys];
- Mobilise science-, AI and data-driven scientific solutions, and, where relevant, bio-inspired and human-centric solutions for the identified Industry 5.0 industrial challenges and the industrial players' industrial transformation needs, fostering market adoption of AI-driven and Industry 5.0 solutions and technologies;
- Facilitate Industry 5.0 transformation of factories with the identified AI-driven scientific solutions and human-centric organisational practices, according to the Industry 5.0 paradigm, also leveraging Industry 5.0 Community of Practice results.