

EuroHPC
Joint Undertaking

EuroHPC Joint Undertaking Multi- Annual Strategic Programme (2021 – 2027)

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Multi-Annual Strategic Programme (MASP 2021 -2027)

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1 Executive Summary

In 2026, six years since it started full operations, the EuroHPC Joint Undertaking (EuroHPC) has created one of the world's most powerful and versatile open infrastructures for High Performance Computing (HPC), Quantum Computing (QC), and Artificial Intelligence (AI) worldwide. It operates a large fleet of petascale, pre-exascale and exascale HPC systems as well as QC platforms. At the same time, EuroHPC funds a multitude of Research and Innovation (R&I) projects that are crucial to advance European HPC/AI/QC technologies and applications plus support education, training and international cooperation.

EuroHPC is currently extending its portfolio with additional Artificial Intelligence (AI) systems and services in the form of the AI Factories (AIFs) and AI factory antennas (AIFA) and with a strong initiative to federate infrastructure and services and provide the adequate network hyperconnectivity. Due to the growing importance of AI, strong support for the AIFs was given recently, which RIAG and INFRAG agree upon. However, this required a reprioritization of R&I activities, which caused the cancellation of post-exascale deployments earmarked at the end of the second regulation, a delay of initiatives for hardware and software technology development, and a shift of plans for QC deployments. It remains to be seen how the deployment of the upcoming *Gigafactories* [1] and the possible inclusion of the Quantum Flagship activities within the realm of EuroHPC will impact the global budget distribution. It remains crucial to **invest in the adaptation/optimisation of software and applications** to exploit heterogeneous HPC/AI optimised systems, so to **reach a reasonable Return on Investment (ROI) while ensuring energy efficiency from the deployed infrastructures**.

In a context of a fierce international competition on hardware and software resources and the rise of geopolitical tensions, one of the key contributions of EuroHPC is to **strengthen European sovereignty** by supporting the development and adoption of European HPC/AI/QC solutions. In this context, **Research and Innovation (R&I) activities of the technology pillar focussing on European hardware and software should continue** with a much **stronger commitment for the adoption of developed solutions** in the deployment of EuroHPC infrastructures, whilst seeking for international collaboration where useful and appropriate. Furthermore, more effort and coordination are needed to guarantee the security of HPC/AI/QC technologies and infrastructures and critical data. INFRAG and RIAG recommend **the establishment of a EuroHPC Security Task Force**, to enable greater cohesion in incident response as well as to align standards with common frameworks, such as Cybersecurity Certification Framework and EU AI Act.

Looking ahead, INFRAG and RIAG recommend to **strengthening the support of the ongoing convergence between HPC, AI and QC**. Here it is critical to better **rebalance the distribution of funding across the Pillars**, which is currently strongly focused on the deployment of HPC/AI/QC systems, and **dedicate more effort to the development of European HW and SW technology, applications, and skills including user support and training/education**. Investing

even a minimal part of the AIGFs into technology development would have an enormous impact on boosting European HPC/AI/QC industry and strengthen Europe's sovereignty.

To increase the effectivity of EuroHPC R&I initiatives, the administrative burden should be minimized. In particular, looking beyond 2027, it is highly recommended to implement a real **centralized funding management** in the future EuroHPC framework, with equal application and reporting conditions for participants from all member states.

INFRAG and RIAG agree on these main recommendations per Pillar:

Infrastructure: New HPC systems should be deployed after the two exascale systems (including upgrades or renewals of the first multi-petascale and pre-exascale machines), to continue to address the needs of HPC users. In addition, the emerging next generation of QC systems (delivering improved fault tolerance) should be deployed, and their proper integration with the evolving HPC/AI infrastructure must be ensured to accelerate take-up and quantum application development. Here it is important to keep updating the QC HW as quantum computing is a fast-moving field and falling behind the state of the art of usable quantum HW will leave European researchers, startups, developers and users at a disadvantage in a section where Europe is currently leading the way.

AI Factories and AI Factory Antennas: INFRAG and RIAG welcome the new AI-optimised supercomputers, which are complemented by a set of high value services, and advise to procure the systems in a phased approach to benefit from new AI-oriented acceleration technologies and to ensure variety both in the selected hardware and software solutions. Furthermore, AI and HPC applications must be developed, enhanced, and refined to efficiently make use of the AIF platforms (convergence is key), encouraging open-source initiatives, and open-weight AI models.

AI Gigafactories: While a set of 4 to 5 AI Gigafactories (AIGF) will be selected in 2026, it is crucial to apply the lessons learned in from the implementation of the AIFs and ensure a long-term collaboration between the AIF/AIFA instances providing AI services (education and training, expertise, access to data/models/tools) and the planned AIGFs providing infrastructures services. AIFs/AIFAs will enable the whole AI ecosystem including joint public/private research and creation of startups, while the AIGFs will provide the infrastructure needed to scale up their commercial activities. For Europe, such unique public/private collaboration is a strong differentiator compared to overseas initiatives and should ensure sustainability of AI Factories. On the same way as AI optimised supercomputers for AI Factories, INFRAG and RIAG recommend phasing the installation of AIGFs to benefit from the latest, fast evolving HW technologies and provide diversity of AI-optimised HW. We also recommend reserving a fraction of the global AIGF budget to support the development of European HW and SW technologies in a public/private collaboration, especially in the field of AI inference where recent trends are changing the game and could allow Europe to become a significant actor.

Quantum Technology: EuroHPC is now giving access to the most versatile HPC/AI/QC infrastructure worldwide, supporting EU quantum startups and establishing Quantum Competence Centres. For Europe to maintain such leadership in QC development, key priorities include developing quantum applications, creating a full interoperable HPC/AI/QC software stack, and preparing for next-generation QCs (such as transitioning from noisy to fault tolerant quantum systems and supporting quantum memories and communications for their scale out). A significant development that will shape future quantum activities is the proposed amendment to the EuroHPC regulation to support a comprehensive Quantum Technology Pillar. If the Governing Board adopts this amendment, most Quantum Flagship activities will transition to EuroHPC. This would position the JU to lead fundamental developments across the quantum technology domain—including quantum computing, quantum communication, and quantum sensing. INFRAG and RIAG welcome such initiative that will accelerate the whole QC development in Europe but express strong concerns regarding the staffing of EuroHPC to support such integration and the risk with the creation of a specific advisory body to see Quantum as a siloed activity.

Federation and Hyperconnectivity: INFRAG and RIAG welcome the deployment of the EuroHPC Federation Platform (EFP) and strongly encourage to rapidly extend it to the AIFs/AIFAs and QC systems, as well as private data centres (including later AIGFs) and Cloud services. This would enable EuroHPC and European Cloud providers to offer an end-to-end sovereign Cloud that supports the full spectrum of HPC/AI use cases from open research to commercial activities. In effect, INFRAG and RIAG urge the launch of a call for creating a Sovereign AI Cloud. In this context, it is important that solutions are put in place integrating the different data repositories, platforms and European data lakes with the EuroHPC JU HPC/AI/QC infrastructures. In that respect the ongoing initiative toward establishing AI DataLabs and the EFP Federation platform will be crucial to foster interoperable access to various datasets using standard protocols like SIMPL.

Technology: INFRAG and RIAG encourage EuroHPC to increase support for the development of European hardware and software technologies, in synergy with other entities (such as Chips JU and the upcoming integration of the Quantum Flagship activities). Such investments will be essential in the field of processors and accelerators (ARM and RISC-V based), memory technologies, disruptive technologies (like neuromorphic and cryogenic computing), high speed networking technologies, innovative cooling and megawatt rackscale dense integration. Investments in software technologies should be relentless and continuous, leading to capable and efficient European HPC/AI/QC software stacks that integrate layers from system software up to programming models and frameworks, with particular emphasis on supporting European processors/accelerators and the need of European customers, end users and developers. Meeting ambitious energy and carbon footprint reductions will require concerted and systemic advances across all hardware and software layers.

Applications: Europe is a world-leading player in HPC applications and in generating data from scientific instruments, IoT and edge devices. To maintain this position, increased funding and

support for scientific and industrial applications remains crucial. This shall target flagship applications as well as emerging codes, and the related application communities in their effort to develop, port and optimise their codes, in particular to accelerated, heterogeneous architectures. Code modernization based on the “separation of concern” concept and use of best practices should also be encouraged. An important objective is to realise benefit from xPU acceleration, support of mixed/reduced precision and hybridisation of HPC and AI methods. Support should be provided to expand supercomputing usage to new fields (digital twins in health, agriculture, smart cities, humanities, public administrations, urgent computing supporting public or private decision making) and create innovative and efficient hybrid HPC, QC and AI applications and workflows. Effective systemic collaborations from hardware experts to application experts via system software experts should be strengthened to developing hybrid HPC/AI/QC applications.

On the AI applications side, INFRAG and RIAG recommend EuroHPC should promote the development of open-source and open-weight models, using permissive licensing models that allow commercial usage. Emphasis should be first and foremost on developing or expanding language models to support multiple modalities (text, code, images, video, sensor data, and beyond), to have reasoning and agentic capabilities, AI for science models and to model interaction with the environment (“world models”), focusing efforts on covering as many domains and areas of application as possible.

Skills & Usage: support for educating and training future HPC/AI experts and end-users should be increased (like by extending the EuroHPC Master’s programme by at least 10x in terms of trainees and covering HPC, AI and QC). It is important also to ensure that the skills and usage gap between EU countries is reduced as much as possible. Instruments for this are the National Competence Centers and now the AI Factories. Therefore, their continued support is very important to create and sustain a robust and inclusive HPC/AI/QC ecosystem. User support across HPC, AI and QC should also be strengthened by federating and expanding other existing initiatives.

International Cooperation: In addition, with existing initiatives with Japan and India, EuroHPC should continue, using existing or upcoming respective agreements with EC, to develop and strengthen relations with other countries and regions like Canada, South Korea, Singapore, Africa and Latin America to support cross-fertilisation of ideas between researchers as well as promotion of EU technologies, applications and skills. For this, a program like the AI Factory Antenna program could be expanded beyond EuroHPC members and mutual access to HPC/AI/QC infrastructures should be made possible to facilitate efficient joint HPC/AI/QC collaborative projects. International cooperation should be more intense and faster to implement with the EuroHPC members (Canada, Japan) and extend then to the external ones.

Additionally, EuroHPC should ensure that its **activities** are carried out in **close cooperation** and coordination **with bodies and activities organised by the European Commission (EC)**, in

particular in the areas of **Chips JU, AI, cybersecurity, data infrastructure, cloud, and quantum computing**.

Finally, before transitioning into the post-exascale era, INFRAG and RIAG advise EuroHPC to develop a clear-cut **roadmap for future key use cases in science and industry** for HPC/AI/QC launching an extensive bottom-up effort involving all relevant stakeholders. Objectives should include assessing the needs and expectations of (old and new) end user communities, identifying relevant scientific, industrial and societal challenges, and survey planned and emerging/disruptive HPC, AI, QC, technologies. A thorough Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the last period should be performed, benchmarking against other world regions, **aiming to determine the best European definition of post-exascale**.

2 Introduction

The **EuroHPC Joint Undertaking** (hereafter, EuroHPC) was established in 2018 by Council Regulation No. 2018/1488 and is fully in operation since 2020. In its few years of existence, EuroHPC has become the vehicle to expand infrastructures, research and innovation in High Performance computing (HPC) and Quantum Computing (QC) in Europe. In 2025, the scope has been extended to fully cover all aspects of Artificial Intelligence (AI) and Quantum Computing (QC), with the introduction of the new pillars on Gigafactories (AIGFs), see Section 5.3, and the Quantum Technologies, see Section 5.4.

EuroHPC is financed by the European Union (EU), complemented by national and private member contributions [2]. Full information on the history, role and scope of EuroHPC, is given on its website [3].

2.1 Mission

EuroHPC aims to establish a federated, energy-efficient HPC/AI/QC infrastructure, and foster European Research and Innovation (R&I) in the fields of HPC, QC, and AI. These HPC/AI/QC systems and solutions are mandatory to address grand challenges in science and society, including climate change, medicine and health, renewable energy supply, and industrial progress, amongst many others. Supercomputing, understood as the sum of Hardware (HW) and Software (SW) HPC/AI/QC solutions, accelerates drug discovery, personalised medicine, and sustainable product design while reducing costs and environmental impact. EuroHPC ensures widespread access to HPC/AI/QC resources, trains skilled professionals, and drives solutions for Europe's digital and climate transitions, enabling Europe's leadership in science, industry, security, and economic development.

2.2 Strategy

EuroHPC coordinates European and national resources to deploy world-class exascale supercomputers and foster a sustainable, inclusive, and innovative HPC ecosystem. It focuses

on advancing research, industrial competitiveness, and EU digital sovereignty¹ by developing cutting-edge supercomputing infrastructure and promoting carbon-efficient technologies. EuroHPC also supports scientific excellence, collaboration, and skills development while minimizing environmental impact. Its goals include enhancing the EU’s HPC supply chain, enabling access for diverse users, and integrating HPC/AI/QC systems with data and cloud services. By aligning with Horizon Europe and global sustainability goals, EuroHPC addresses scientific, societal, and industrial challenges effectively. To achieve its goals, EuroHPC is organised in 9 pillars (see Figure 1): Infrastructure, AI Factories, Gigafactories, Quantum Technologies, Federation and Hyperconnectivity, Technology, Applications, Skills & Usage, and International Cooperation. These areas are tightly interlinked with each other. Section 5 describes the strategy for each of the pillars, and Section 6 the cross-sectional topics that link them.

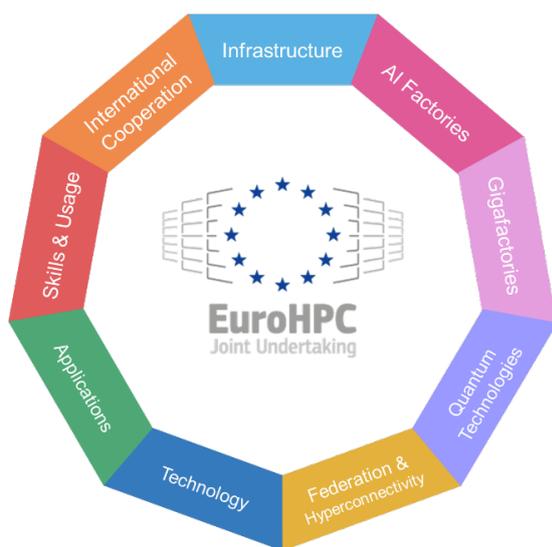


Figure 1: Nine Pillars of EuroHPC

EuroHPC coordinates activities across pillars via an annual work programme approved by its Governing Board (GB), which is defined following the Multi-Annual Strategic Programme (MASP). It ensures R&I outputs are deployed, disseminated, and monitored for HPC infrastructure and technologies. Progress is shared through events, communications, and the Annual Activity Report. Operating until 2033 under current regulations, EuroHPC oversees grant implementation, project completion, and supercomputer operations.

2.3 Multi-Annual Strategic Programme (MASP 2021-2027)

The Multi-Annual Strategic Programme (MASP) is aligned with the mission set out in the updated EuroHPC Council Regulation [4] and lays out the mid-and long-term strategy of EuroHPC based on which the annual work programmes are formulated. The MASP is created by the two advisory groups (AG) in EuroHPC: the Research and Innovation Advisory Group (RIAG) and the Infrastructure Advisory Group (INFAG), who also consult external experts whenever their expertise is deemed necessary. It is then provided to the Executive Director of EuroHPC and presented for approval to the EuroHPC Governing Board (GB).

The first MASP was formulated in 2021, and updates were done in 2023, 2024, and 2025. The present document is the 2026 update of the MASP, based on the latest issue from 2025. For a

¹ Sovereignty is an important part of EuroHPC’s mandate, and often referenced topic in the MASP. Therefore, a definition and the associated objectives of sovereignty are included in Section 3.

review of the previous issues of the MASP, we refer to the relevant location in the EuroHPC website [5].

In 2026, it is expected that a third advisory group for Quantum Computing (QTAG) will be established, to cover the entry of the new pillar in the EuroHPC landscape. It will be crucial to establish a good coordination between the RIAG, INFRAG and QTAG. In all three advisory groups there is Quantum expertise required, with different background. Just concentrate all the Quantum Expertise only in a new formed Quantum Advisory Group, will not be enough, and will create too much focus on early TRL levels. A possible split could be:

- **INFRAG:** QC expertise on the operationalization (TRL 8 – 9)
- **RIAG:** QC expertise on productization, industrialization and end-users (TRL 1 - 8).
- **Quantum AG:** On the mainly academic research & Development (TRL 1-5)

2.4 State of Play

This section gives a brief summary of the status of different developments in EuroHPC until end 2024, pillar by pillar.

2.4.1 Infrastructure

Since 2021, EuroHPC has procured petascale, pre-exascale HPC systems, and quantum computers, with Europe's first exascale system, JUPITER, to be operational by 2026 [6] while Alice Recoque will start its installation in 2027. The rise of AI Factories (AIFs) in 2025 and their associated AI Antennas (AIFAs) introduced challenges to prepare users for future exascale and AI-optimised systems and services while continuing support for traditional HPC workloads, including fostering hybrid HPC/QC, advancing AI for science, industry, providing public/private cloud access, and supporting large-scale instruments, public services, and urgent computing, while developing skills and defining a European post-exascale vision.

Key actions launched between 2021 and 2025 include:

- **Exascale Systems:** JUPITER call launched in 2021, successfully reached 1 EFlop/s and ranked #4 on the November 2025 edition of Top500 with operations starting in February 2026, while a second exascale system called Alice Recoque, integrating European technologies has been procured by EuroHPC end of 2025 with installation starting end of 2026.
- **Pre-exascale Systems:** LUMI became operational in 2022, Leonardo in 2023, and MareNostrum5 in 2024 [7].
- **Petascale/Mid-range Systems:** MeluXina, Karolina, Discoverer, Vega, and Deucalion continue to be operational. In Q1 2026 EuroHPC will add Daedalus (Greece) and Arrhenius (Sweden) into the list of available mid-range systems. Two new Hosting Agreements have been firmed in Ireland and Hungary for the acquisition of 2 new mid-range HPC supercomputers.

- **Quantum Computing:** Through the HPCQS project two quantum simulators are available since end of 2025 in France and Germany (Jade and Ruby) and six hosting entities have been selected in 2022, with two of these systems already in production in 2025 (PIASQ in Poland and VLQ in Czechia). The other systems will be operational in 2026 [8] while a call in 2024 added Luxembourg [9] and the Netherlands [10], with spin-qubit based system in operations planned for 2027. EuroHPC has also set up a joint project called EuroQHPC-Integration aiming for HPC/QC common integration among Hosting Entities started mid 2025.
- **AI:** To ensure seamless implementation, EuroHPC organises regular meetings with HPC, AI Factories, and QC hosting entities to foster collaboration and share best practices.

2.4.2 AI Factories and AI Antennas

In 2024, a new EuroHPC regulation introduced an AI pillar to deploy AI-oriented supercomputing infrastructure coupled with AI-tailored services and potentially experimental AI facilities, targeting Start-ups and Small and Medium Enterprises (SMEs). September 2024 saw the launch of calls for AI Factories (AIFs). These calls target hosting entities for new AI-optimised or upgraded EuroHPC supercomputers and establish AI Factories.

Linked to the same initiative, the concept of AI Factory Antennas (AIFAs) was introduced in 2025 allowing additional countries to implement AI support services locally while being linked to existing AI Factories for access to larger EuroHPC AI-optimised supercomputers and complementary AI Factory services.

With €1.5 billion in funding, AIF and AIFA calls led to the selection of 19 AI Factories and 13 AIFAs in Europe, designed to support the growth of the AI ecosystem, and accelerate the development and use of trustworthy AI.

First AI Factories started in 2025 in Finland, Germany, Greece, Luxembourg, Spain, and Sweden and several procurements for AI-optimized supercomputers have been launched by EuroHPC with planned operations in 2026 in Finland, Italy, Luxembourg, Germany, Sweden and Spain (upgrade of MareNostrum 5). Such systems will complement the 2 Exascale systems qualified as well as AI supercomputers.

AIFs and AIFAs combine cutting-edge infrastructure with expert support to strengthen the EU's AI industrial and research ecosystem, providing free-use AI-optimized supercomputers, programming and training facilities, with expertise to leverage resources effectively. They enable AI companies, especially SMEs and startups, and researchers to develop advanced AI solutions tailored to industry, public authorities, and scientific disciplines.

EuroHPC has set up tailored access modes to its AI supercomputers with the provision of the Industrial Innovation track which offers three permanent access modes to meet different compute needs – Playground, Fast Lane, and Large-Scale Access.

These modes combine free-of-charge for AI SMEs and startups for innovation purposes with pay-per-use commercial models. Academia and public sector users should target the classical AI for Science and Collaborative EU projects access mode.

In 2025 EuroHPC already made available to users 4 systems for AI-specific access tracks: LUMI-G (accelerated partition), Leonardo, MareNostrum 4 and later JUPITER for all calls as well as MeluXina GPU (for playground and fast lane access), Vega GPU, and Discover GPU (both for playground access).

2.4.3 AI Gigafactories

In April 2025 the European Commission announced the AI Continent strategy based on computing infrastructures (AI Factories, AI Gigafactories, Cloud & AI), access to data (Datalabs, easy access to data), skills development (attract/recruit internationally, AI fellowships & skills development and reskilling through EDIHs), development of algorithms & adoption and EC rules simplification (AI Act).

The AI Gigafactories (AIGFs) are aimed as a 20B€ public/private partnerships for setting up in Europe 4 to 5 massive AI-optimised supercomputers with 100 000 GPUs for supporting training and inference at scale, being competitive with other initiatives overseas like Stargate. AIGFs will be linked with existing AIFs for the provision of tailored AI services in education/training, expertise in HPC, AI and data science as well as access to datasets/models and tools.

AIGFs will be owned and operated by private actors with partial public (EC + interested MS) participation in 2 models: upfront with a contribution on CAPEX or periodic through offtake agreement of public command.

After a successful initial consultation among private actors mid-2025, EuroHPC will adapt its regulation to support such models and will launch an open consultation for selecting 4 to 5 projects based on criteria such as readiness, access to energy, and offtake / business model.

The support of AIGFs by EuroHPC required a modification of the EuroHPC regulation which is expected to be published in January 2026. The roll-out of this initiative via calls for selection of Gigafactories is expected in Q1 2026.

2.4.4 Quantum Technology

Different operational Quantum Deployments are currently taking place, as described in Section 2.4.1. The EuroQHPC-Integration project with the objective to create a common software platform for the 6+2 (eventually 8+2) deployed quantum computers had an informal kick-off during the EuroHPC Summit 2025 in Krakow, and the GA was finally signed by the EC on 7 November 2025. Two QECs have been granted. One kicked-off in October 2025, and one will start in the spring of 2026. A call to develop benchmarks for QC and HPC-QC has also been

released in 2025, which will support future developments, as well as the procurement of systems.

Unfortunately, the middleware call, originally planned in WP 2024, was again delayed. This impacts the development of hybrid applications, increases deployment costs for current and future QC HEs, and risks the lead that Europe has on deploying a hybrid HPC-AI-QC infrastructure.

Another important setback is the uncertainty over the procurement of next generation quantum computers and simulators, which had been planned for 2026-27. If new systems are not procured in this period, it is likely that a gap of several years will exist between the systems currently being deployed and their next generation, leaving European users with an outdated infrastructure.

A good strategic example of creating focus on Quantum Technology and accelerating the developments as first steps, is the launch of the Quantum Grand Challenge call, end of 2025, inviting European quantum computing startups to develop quantum computing solutions with a clear market perspective. This action is implemented in two phases: In the first phase (Phase 1) up to 12 European start-ups (with funding of up to 400k€ during 4 months) will be invited to prepare a technical and financial roadmap that demonstrates the potential of their quantum computing solution and provide physical proofs of principle or preliminary prototypes. At the end of Phase 1 the output of the startups will be evaluated and the startups successfully passing the technical and financial evaluation (6 companies expected with convertible loads of 5 to 8 years for up to 30M€) will be eligible to participate in the second phase (Phase 2, not subject to this call) and submit a proposal to the European Investment Bank (EIB) for financing in connection with the full maturation of the proposed quantum computing solution.

2.4.5 Federation and Hyperconnectivity

A competitive dialogue-based procurement for deploying federation services (authentication and authorisation infrastructure, data transfer, peer review, meta scheduling, etc.) across HPC sites was launched in 2023 with the selection proposal from CSC-IT in December 2024 and a progressive effective launch of the EuroHPC Federation Platform [11] (EFP) and its federation services starting January 2025. Such services took some delays to be launch but end of 2025 a set of 12 Hosting Agreements were concluded with corresponding Hosting Entities. First discussions with EOSC, FENIX and SIMPL took place during September 2025, while March 2026 is the official first release and deployment date.

Furthermore, in 2022, EuroHPC launched a call for tender to establish a study on hyperconnectivity [12] to assess what would be the best solution to interconnect EuroHPC systems and provide the related connectivity services. The study included needs and requirements from computing centres, data infrastructures, end user communities, National Research and Education Networks (NRENs), and GEANT and was presented to the GB in

October 2024 resulting in a procurement of network capacities and services launched end of 2024. This procurement led to the announcement by EuroHPC selection in September 2025 of GEANT (associated to its NREN) with a 60M€ contract over 4 years for building a secure, federated, and future-proof connectivity infrastructure for AI, HPC and Quantum systems across Europe [13]. This infrastructure is planned to serve up to 222 Points of Interest including EuroHPC systems, national or regional HPC systems, domain-science computing centres, large scale instruments and data centres with a bandwidth of up to 1 Tb/s before 2029. In September 2025 a framework Contract was signed for working on the two Specific contracts governing the implementation. In 2026 the priority set of sites will be interconnected.

2.4.6 Technology

EuroHPC has supported European HPC technology development through multiple initiatives, such as the SEA projects [14] or the European Processor Initiative (EPI) [15]. The EPI, a cornerstone project (2018–2025), focuses on European sovereignty in HPC and chip technologies, producing the Rhea General-Purpose Processor (GPP) and proof-of-concept European RISC-V accelerator technology. While the accelerator developments continue in DARE, current funding is lacking for the continuation of the EPI ARM GPP. However, ARM processor development should continue in Europe, given the growing ARM-based ecosystem in the data centre and HPC environment predicted by all market analysts.

In the Technology area, across 2023 -2025 EuroHPC has launched:

- A call focused on developing HPC algorithms for exascale systems [16], to enable the creation of novel algorithms to tackle complex computational challenges and improve time and energy efficiency for critical applications.
- An Innovation Action in low latency and high bandwidth interconnects will support the R&I technology development of innovative and competitive European HPC inter-node interconnection technology [17]. This has been awarded to the NET4EXA project [18].
- An R&I call for HPC Energy efficiency to develop system software technologies that will drastically reduce the energy consumption of future EuroHPC supercomputers through advanced monitoring, data analysis, and scheduling/resource management strategies [19]. This led to the launch of the SEARNERGYS project.

The DARE Framework Partnership Agreement (FPA) on RISC-V aims to establish long-term collaboration with industry, research, and institutions, followed by a call for the first Specific Grant Agreement (SGA) in 2024 [20]. Beginning in 2025, this initiative aims to enhance European-developed Intellectual Propriety (IP), increase value chain potential, and mitigate embargo risks.

However, there has been a notable discontinuation in funding for general HPC-oriented software, including programming models, runtime systems, system software, etc. Europe is strong in this field - notable success include (but are by no means limited to):, developing and influencing standards (such as OpenMP and MPI), implementations (OmpSs and ParaStation

MPI,...), profilers and performance tools (Scalasca, Paraver, Likwid, Maqao,...) or generic workflow systems such as COMPSs and Streamflow. Acknowledging that low-level software for the emerging European sovereign hardware architectures shall be paid special attention should not hinder Europe's strategic investment in more generic HPC middleware, which is in danger due to the marked scarcity of funding in this area in Horizon Europe calls, where research on this type of R&D initiatives is not finding a natural fit. Along the same lines, there is a lack of funding for basic research in the field of HPC software within the European ecosystem.

2.4.7 Applications

For the past decade, the primary funding instrument for applications were the Centres of Excellence (CoEs), fostering collaboration between HPC users and application development experts. CoEs aim to make EuroHPC exascale systems accessible to European researchers and industries while addressing scientific, industrial, and societal challenges, and to deploy prominent codes across EuroHPC supercomputers.

In 2022, ten CoEs were launched in domains like climate, drug development, astrophysics, and plasma science, complemented in 2023 by a second wave of projects covering topics such as personalized medicine, digital twins, energy, neuroscience, and HPC application optimization, and CoEs dedicated to different aspects of Quantum computing [21] [22] [23]. CoEs have significantly influenced European application development and have become a recognizable "brand". In 2024, a new "Application Concept Paper" proposed a revised funding framework for the application pillar, with the CoEs as central elements, dedicated to either a specific application domain or transversal topics. Following the discussions around the concept paper that EuroHPC launched in 2025 a new call in order to strengthen Europe's leadership in HPC by supporting the development of highly scalable, energy-efficient and AI-integrated applications through new Centres of Excellence (community and transversal ones) and Lighthouse Codes. [24]

The field of AI is seeing enormous technical progress and impact and has become strategic for Europe. More AI applications are coming to HPC and HPC applications are increasingly integrating AI components into their workflows. Besides the CoEs focused on HPC/AI, like RAISE [25], or specialised support projects, like MINERVA [26], the AI Factories have become a cornerstone in EuroHPC AI strategy. In total, 19 AI Factory projects have been launched, along with 13 AI Antenna projects, each of which is providing access to AI resources, services and competences at a national level.

2.4.8 Skills & Usage

EuroHPC aims at increasing the HPC expertise through several initiatives, launched since 2022:

- The EuroHPC Master's programme [27] (2021), supports a pan-European MSc in HPC, with first cohort graduated in 2024. The second phase called EUMasters4HPC2 in 2026

will expand coverage to AI and QC and will aim at having 100 students graduated each year from the programme.

- The EuroCC2 grant [28] established a pan-European network of National Competence Centres (NCCs) in 2023. The follow up project EuroCC3 has already been approved and will start May 2026.
- The CASTIEL project [29] (2022) coordinates NCCs and CoE activities, focusing on best practices and training, with a renewal in 2026, together with EuroCC3 the CoEs will not be included in Castiel3 activities as before.
- The EuroHPC professional traineeship [30] (2022) and a EuroHPC virtual training academy [31] (2024) federate existing training activities and create a structure training program with high quality material on HPC/AI/QC. The EuroHPC Virtual Training Academy (EVITA) [31] has been launched in April 2025 to create an interconnected community of learners, educators, and industry professionals who are empowered with cutting-edge HPC knowledge and skills.
- The historical International HPC Summer School initiative (started in 2010) has been renewed end of 2025 with the selection after a call for proposals of the EuroHPCSS project.
- The HPCTRAIN which aims to provide professional traineeships to young professionals in HPC across Europe has been awarded with an effective launch in early 2026. HPCTRAIN will also contribute to enhancing career opportunities, digital skills, bridging the skills gap and industry collaboration.

2.4.9 International Cooperation

An International Cooperation call with Japan was launched in 2022 and the selected HANAMI project [32] started in 2024. In 2024 EuroHPC launched a call for International Cooperation with India [33], and the GANANA proposal was selected, which is planned to start in 2025. New initiatives for other regions, including Latin America are under discussion and postponed in 2026. Linked to HANAMI EuroHPC signed a letter of intent with RCC-Riken in order to give access to European researchers on Japanese HPC systems. In the field of its Global Gateway initiative the European Commission initiated in October 2025 a new collaboration called EU-LAC Supercomputing Network between Europe, Latin America and Caribbean countries that connects existing infrastructures, builds skills, and opens opportunities for joint innovation. The EU-LAC Supercomputing Network will 1) promote shared HPC infrastructures, 2) enhance skills with capacity building and training for researchers 3) boost scientific collaboration by developing joint use-cases such as drug development and climate simulations, 4) demonstrate the capacity of networked infrastructures to work together on developing and deploying AI applications and 5) increase the use of the BELLA cable, the high-speed digital link connecting the two regions.

In the field of quantum computing, following the signature between EU and Japan of a Letter of Intent on 13 May 2025 to strengthen cooperation in quantum science and technology, the

project Q-NEKO (Nippon-Europe Quantum Koraboreshon) has been selected. It represents a collaborative effort involving 16 European and Japanese institutions. Backed by €4 million in EU funding, Q-NEKO the project aims to advance hardware, software, and hybrid high-performance computing-quantum computing environments. This includes applications related to biomedical, material science, seismic/tsunami and/or weather and climate modelling, also leveraging utilisation of quantum-enhanced machine learning and artificial intelligence.

3 Sovereignty

Main Strategy Recommendations for 2026-2027 period:

- Relentlessly fund QC activities which will sustain and extend the current lead of Europe in QC, including quantum simulators/systems, middleware and integration with HPC/AI infrastructures, and applications.
- Fund activities which push the envelope in Generative AI using open source/open model approaches, including development of alternative methods.

Looking beyond 2027:

- Invest in the development of European HW, SW, and applications from low to high TRLs in key fields in a sustainable way. This should be guided by the needs to directly or indirectly guarantee access to the necessary source components and maintain control over European supply chain of technology and data.
- Support established European HPC/AI/QC suppliers and foster the emergence of new ones, by establishing strong partnerships and offering long-term commitments to support their home-grown developments. This should include including European technologies in the deployment of HPC/AI/QC HW and SW infrastructures.
- Leverage open source/open model approaches to maximise European and global uptake and collaboration on key European HPC/QC applications and AI models.

One of the most important mandates of the EuroHPC is to support European sovereignty in HPC, QC, and AI. In our context, sovereignty refers to avoiding control from outside of the EU; achieving freedom from external control [34]

Sovereignty in HPC/AI/QC does not require that the totality of a supply chain is resident to Europe, but rather to protect access to technology and the freedom to use it as the EU sees fit. The following are the associated **objectives of sovereignty**:

1. **Protect against embargo and determine EU export control rules:** Protection against embargo is the guaranteed availability of technology and the freedom to use it, which

requires establishing/strengthening of key elements of the supply chain in Europe. The focus is not on owning the entire supply chain but having sufficient awareness and leverage to assure an adequate flow of supplies. Strategic development of EU technology and production improves our self-sufficiency two-fold: we produce goods that we need, and we have trade leverage to ensure that other countries continue to supply to us. Determination of export control is the power to decide where and under which conditions products can be shipped. Today the export control agenda and rules are managed by the US. Ideally the EU should have its own process (which might or might not align with the US government processes).

2. **Ensure that funding for EU research predominantly remains in Europe, and that research results benefit Europe:** this is not about restricting access to EU R&D results from outside or limiting international cooperation, but a focus on preventing transfer of control of IP to entities outside of Europe and ensuring that such results are available for use in the EU. This includes access to research data created within the EU that may be applied for commercial applications. It is recommended that EU research results be accessible to EU users under F/RAND (Fair / Reasonable And Non-Discriminatory) conditions.
3. **Protect and promote European Union values and security standards:** the EU is a leader in world politics, with its own values. Examples include data protection and privacy, fair and trustworthy AI [35], use of open-source licenses and open standards, and digital rights and principles [36]. Protecting and promoting such European values is a key governmental obligation and an important reason for desiring sovereignty. One prerequisite is preventing the introduction of “backdoors” in IT HW/SW products which could compromise the security of EU governments, industry, and end-users. European cybersecurity standards and established security processes must guard against such risks. EU values on data protection and privacy are markedly different than other regions and must be protected and propagated.
4. **Develop and keep high-tech expertise in the EU** (develop ecosystems in HPC/AI/QC for high-quality jobs that ensure creation and retention of key expertise). This refers to fostering education in key fields of science and technology and to creating career opportunities in Europe. The way to achieve this is through economic and career incentives for sought-after experts in conjunction with targeted training & education programs. Collaboration between research and private industry should be promoted to encourage technology transfer to achieve high TRLs and to encourage the growth of the EU private sector, thus developing EU jobs in key technology sectors. This also includes pushing for initiatives such as a European Buy Act to bolster the EU supply chain and promote pride in a robust EU technical ecosystem with emphasis on growing Industry and Production (and thus high-tech jobs).

In this context, EuroHPC shall invest in the development of European hardware, software and applications from low to high TRLs, to guarantee access to the necessary source components

and maintain control over European supply chain of technology and data. Targeting 100% coverage of the HPC/AI/QC field by European solutions is not realistic in the timeframe of this MASP, but EuroHPC should support established European HPC suppliers and foster the emergence of new ones, by establishing strong partnerships with them and offering long-term commitments to support their home-grown developments. Adoption and use of European technologies in the deployment of EuroHPC HPC/AI/QC infrastructures should be more strongly supported, including legal support, so that European suppliers can commit to long-term developments with the prospect of eventual adoption. That being said, Europe must also remain open to international collaborations to avoid falling into isolation. In generative AI, an effective way to achieve adoption and to create a large ecosystem is to promote open-source initiatives and open-weight model releases, as well demonstrated in 2025 through the release of DeepSeek, Qwen, and Kimi open-weight models (among others) by research labs in China, which proved to be highly competitive with closed frontier AI models with a fraction of computing resources and are now widely adopted in industry worldwide.

The EuroHPC calls are important instruments to drive technology development in Europe. As such, the right funding mechanisms should be used in order to secure the commercial viability of European developed technology. Continuous dialogue with the industry and its representatives are required to guarantee this.

Today Europe is strong in the development of Quantum Technology hardware components. But the competition with non-EU27 large tech companies (e.g. NVIDIA, Microsoft, IBM) in this domain is becoming stronger and increasingly addressed on a national strategic security level of a variety of countries. If EuroHPC wants to stay in the forefront of the development of Quantum Technology and its application, we need to accelerate. Because the quantum sector is at an early stage compared to HPC and AI, which have established markets, Europe is in a better position to lead in this domain. If we delay investments (e.g. in QC middleware) we will quickly lose our lead in this fast-moving field.

4 Security

Main Recommendations for 2026-2027 period:

- Cultivate collaboration between the EuroHPC security task force, the European Union Agency for Cybersecurity (ENISA [37]) and national cybersecurity agencies, as well as with relevant research institutions and industry partners.
- Develop, deploy and maintain leading security mechanisms on the federated EuroHPC HPC/AI/QC infrastructures in relation with EFP, align standards with common frameworks, such as Cybersecurity Certification Framework and EU AI Act, and enable greater cohesion in incident response.
- Investigate the potential for geographically distributed (i.e. between different EuroHPC sites) snapshots of critical data, such as AI model repositories, to facilitate resilient recovery and smooth continuation of vital scientific and industrial work on EuroHPC platforms.

Looking beyond 2027, define and maintain common baseline security in cooperation with Security Task Force and establish and foster cooperation with relevant security organisations in European HPC/AI/QC ecosystem.

EuroHPC recognizes that the security of high-performance computing (HPC) infrastructures is inseparable from the trustworthiness (and sovereignty) of the artificial-intelligence (AI), quantum computing and numerical simulations workloads they host. The proposed strategy is therefore built around a holistic, layered approach that safeguards the hardware, software, data, and operational processes that underpin Europe's supercomputing landscape.

At its core, the strategy pursues three intertwined objectives:

1. **preventive resilience**, ensuring that the underlying HPC fabric—interconnects, storage subsystems and compute nodes—is hardened against both conventional cyber-threats and emerging attacks targeting the massive parallelism and low-latency communication that characterise exascale systems;
2. **AI-specific risk mitigation**, which focuses on protecting the integrity, confidentiality and provenance of models, training data sets and inference pipelines, and on defending against adversarial manipulation, model-stealing and data-poisoning campaigns and;
3. **rapid response and recovery**, establishing a Europe-wide incident-handling framework that can detect, isolate and remediate breaches with minimal disruption to scientific and industrial workloads.

To realise these goals, EuroHPC will need to implement a **continuous security-by-design lifecycle across all tiers of the ecosystem**. Architectural blueprints will embed hardware-root-of-trust elements, secure boot mechanisms and attestation protocols that

verify the authenticity of firmware and operating-system images before they are allowed to execute on the supercomputers. Runtime environments will be equipped with mandatory access control, memory-encryption technologies, and fine-grained isolation containers that **separate workloads from one another**, limiting the blast radius of any compromise.

Data protection is addressed through a combination of end-to-end encryption, robust key-management services and provenance-tracking metadata that records the lineage of every dataset and model version. AI-specific safeguards include automated integrity checks on model parameters, runtime monitoring for anomalous inference patterns, and the integration of certified adversarial-defence libraries that can be dynamically injected into training pipelines. Moreover, we will foster the development of privacy-preserving AI techniques—such as federated learning/inference, differential privacy and secure multi-party computation—so that sensitive scientific data can be processed on shared HPC resources without exposing raw inputs.

Governance and collaboration are essential to the strategy’s success. RIAG and INFRAG welcome the creation of a **security task force**, and find it essential to reinforce it with a minimum security and common standards. This task force should coordinate with national and European cybersecurity agencies, such as the Cybersecurity Competence Centre [38], research institutions, and industry partners, aligning standards with the European Cybersecurity Certification Framework and the EU AI Act [39] with relevant, forthcoming regulations. Regular threat-intelligence sharing, joint red-team exercises and a common vulnerability disclosure platform will ensure that the community stays ahead of emerging attack vectors. The security task force shall address incidents, adopt European security technologies like Post-Quantum Cryptography (PQC) and Quantum Key Distribution (QKD), and advise on best practices. AI workloads, often requiring frequent access to external datasets (e.g., RedPajama [40], The Pile [41]), face unique security risks. Opening nodes to external sources without controls can lead to misuse, such as Denial of Service (DoS) attacks [42] or reverse shell exploitation.

Key Challenges and Recommendations to be addressed by the security task force:

- **Data Integration and Ingestion:** Distributed data lakes and machine-to-machine workflows for scientific instruments require secure connections. Common protocols and encryption standards should be enforced, ensuring safe data ingestion and management.
- **Support for Sensitive Data:** Addressing public services and health sectors’ needs requires compliance with national and EU regulations for sensitive data. The task force should explore confidential computing solutions and, in the long term, homomorphic encryption and post-quantum secure cryptographic technologies for data protection during computation (including AI inference, and in a longer term, training). EuroHPC should explore options for funding research and development of such technologies.

- **Post-Quantum Security Preparations:** With the anticipated threat of quantum computers breaking Rivest-Shamir-Adleman (RSA) encryption [43], the task force should evaluate post-quantum Authentication, Authorisation, and Identification (AAI) services based on European technologies to future-proof the infrastructure.
- **Collaborative Cybersecurity Projects:** A proposed cybersecurity/AI project in WP2025 should integrate efforts across federated HPC/AI/QC services. This project would reinforce EuroHPC’s security framework, ensuring compliance and innovation.

Human capital is another pillar: a **dedicated security training programme** will have to be setup in order to up-skill system administrators, developers and scientists in secure coding practices, secure AI model development and incident-response procedures. Certification pathways will be created to recognise expertise in HPC-AI security, thereby cultivating a cadre of professionals capable of maintaining the integrity of Europe’s computational backbone.

Finally, the strategy incorporates a **resilient recovery architecture**. Immutable snapshots of system configurations and model repositories will be stored in geographically distributed, tamper-evident archives, enabling rapid restoration after a breach. A tiered incident-response plan—ranging from automated containment actions within the HPC scheduler to coordinated multi-stakeholder crisis management—will minimise downtime and preserve the continuity of critical scientific missions.

5 Strategy recommendations on Pillars

EuroHPC shall support the development of competitive and sovereign HPC, QC, and AI **solutions** that fulfil user needs and requirements, with training and user support to deliver impact for science and society. **Applications** in HPC, QC, AI, and High-Performance Data Analytics (HPDA) must be exploited on appropriate **infrastructures**, relying on best-breed **technology**. HPC/AI/QC Infrastructure investments should both promote the uptake of research and innovation results generated in Europe, and influence or steer the R&I on missing or critical technology. A recurring R&I cycle should be reflected in EuroHPC's approach: users and market need steer architecture and technology targets, then demonstrators and pilot projects allow integration and validation efforts towards solutions.

The activities of EuroHPC are structured in nine pillars (see Figure 1 in Section 2.2). The following subsections describe the recommended strategy per pillar, with special focus in the time frame 2026-2027. It must be stressed that very tight interrelation between the pillars is necessary to achieve EuroHPC's goals (see Figure 3 in Section 6).

5.1 Infrastructure

Main Strategy Recommendations for 2026-2027 period:

- Support the HPC community by extending the HPC infrastructure with upgrades or renewal of the older mid-range and petascale systems and finalise the deployment of the two exascale systems.
- Finalise the deployment of the 10 QC systems and plan by 2027 for the upgrade/procurement of the next generation of quantum systems, to access the latest QC technologies including those implementing error correction and fault tolerance.
- Tighten the connection between HPC, AI, and QC infrastructures, via federation and middleware solutions. In particular, for the HPC-QC coupling this requires rapid investments on middleware.
- Invest in standardisation, benchmarking, certification, and validation activities for QC, linking to the other digital infrastructure or EU technology developments.
- Prepare the rise of post exascale architectures and services within the next regulation by contributing to a Scientific and Industrial Case with all pertinent stakeholders.

Looking beyond 2027, define and apply metrics reflecting the real-world impact of EuroHPC activities (e.g. via application-based benchmarks, scientific publications, or patents), ensuring that the position of EuroHPC systems on the Top500 or ML_Perf are not the main goal in infrastructure procurements.

In line with the Regulation, EuroHPC shall organise activities for the acquisition, deployment, upgrading and operation of the secure, hyper-connected world-class HPC, QC, AI, and data infrastructure, including the promotion of the uptake and systematic use of research and innovation results generated in Europe. Access to the EuroHPC infrastructure is provided for free to the European user community and is governed by the EuroHPC Access policy [44].

Table 1 is indicative and summarises the acquisition strategy for the 2021-2027. Based on the experience to date, the process of acquiring a EuroHPC supercomputer takes over two years.

Year	HPC/AI Infrastructure						Quantum Infrastructure	
	Midrange	Industrial	Petascale	Pre-exascale	Exascale	AIFs + AIFAs	Digital QPU	Quantum Simulator
2020			5 procured	2 procur.				
2021			4 deployed	1 procur.				
2022	4 HEs selected			1 deploy.	1 HE select.			
2023				1 deploy.			6 HE select.	
2024		1 HE select.	1 deploy.	1 deploy.	1 HE select.	7+ HE for AIFs select.	2 HE select.	1st deploy. (HPCQS)
2025	2 deploy.				1 deploy.	additional AIF select. with first deploy. 13 AIFAs selected	2 first NISQ systems deploy.	2nd deploy. (HPCQS)
2026	2 deploy	1 deploy.				More AIFs deploy.	+4 systems deploy.	
2027					1 deploy.	Last AIFs deploy.	+2 systems deploy. Upgrade or New HE select.	
Total deploy	4	1	5	3	2	19 AIFs and 13 AIFAs	10+	2

Table 1: Indicative overview of HPC and QC system acquisitions (2021-2027). Entries in standard font have been already implemented; entries in italics refer to systems to be deployed before end of the regulation.

5.1.1 HPC infrastructure

Petascale/Mid-range systems: Since 2022, EuroHPC has acquired and deployed petascale and later mid-range supercomputers complementing the top-ranked systems. These supercomputers are co-owned by EuroHPC and Member States, and the Hosting Entities (HE) can choose short running innovation partnerships to acquire systems that are tailored to their needs. EuroHPC should finalise the deployment of the last announced mid-range systems in 2026 (Ireland and Hungary) while thinking before the end of the regulation to upgrade/renew the first wave of mid-range systems installed to keep providing leading edge HPC services to communities across Europe.

Exascale: Starting 2023, EuroHPC has acquired and started to deploy in 2025 with JUPITER two leadership class exascale supercomputing systems. At least one exascale supercomputer will be built with a significant amount of technology based on HPC technology development in Horizon 2020, Horizon Europe, and EuroHPC emerging processor and accelerator

technologies. While the perimeter of such exascale system could encompass also strongly AI, EuroHPC could use such exascale systems to shape and integrate new services that could pave the path to post-exascale. JUPITER (at FZJ in Germany) will be available in February 2026 to European users, already integrating a first partition of European technologies while Alice Recoque (at GENCI/CEA in France) will extend largely this footprint of EU technologies with a 100k cores CPU partition and the networking technology. Beyond 2027 after the availability of Alice Recoque, EuroHPC should reconsider how it will continue to support leading edge HPC projects, probably using converged AI/HPC supercomputers providing the proper user-support and tooling for fostering the use of GPUs and mixed precision / emulation schemes for numerical simulation workloads.

AI-Factories: From 2025, EuroHPC shall acquire and own several new AI-optimised supercomputers within the progressive deployment of 19 AIFs (see Section 5.2) associated with 13 AI Factories Antennas (AIFAs) across Europe, while the acquisition of an additional high-end supercomputer (post exascale) has been cancelled. Purchase criteria for the AI-optimised supercomputers will include fitness for the intended set of HPC and AI applications, variety of solutions, phased installation to take benefit of yearly improvement of the GPU on the side of AI features, delivered performance for these, and energy/carbon efficiency. Beyond 2027 EuroHPC should consider maintaining AI-Factories in their AI services dimension while relying for massive AI configurations on AI Gigafactories for the infrastructure dimension. In that sense a long-term vision articulating AI Factories and AI Gigafactories should be proposed with a proper public/private co-funding.

Industrial HPC systems: Subject to support industries and SMEs, EuroHPC is also supporting the acquisition and deployment of industrial supercomputing systems for industrial users in cooperation with and co-funded by private members of EuroHPC, adhering to industry specific requirements for increased security, data protection and availability. This initiative is aimed to foster collaboration between research and industry in both open and confidential research. In 2024 EuroHPC selected a consortium led by CINECA for deploying a first industrial grade mid-range supercomputer expected in 2026. The vision for industrial HPC systems will also evolve with the rise of AI Gigafactories led by industry and tailored to address both research and production/commercial activities.

The Top500 as well as ML_Perf lists should not be the only benchmarks and motivations for deploying HPC/AI compute infrastructures. Together with the User Forum EuroHPC could also work on a **new set of KPIs for highlighting the scientific and industrial impact** provided using its facilities and services on Europe Science and Innovation.

In that domain INFRAG and RIAG welcome the launch end of 2025 by EuroHPC of calls for proposals toward the establishment of European benchmarks in HPC, AI and QC but **recommend that once developed such benchmark receive long term support from EuroHPC for their maintenance.**

5.1.2 Quantum Computing Infrastructure

Quantum computers vs. simulators: In digital quantum computers, applications are described by a sequence of discrete operations while in analogue quantum simulators applications are characterised by the continuous evolution of the system's state. These computer systems, including analogue-digital hybrid systems, have recently evolved significantly and started to show large potential (in terms of performance and energy) for competing with the best classical supercomputers on specific tasks. While first systems are commercially available, definite multifunctional advantage is not expected to be achieved in the next few years.

HPC-QC integration: Integrating quantum systems into HPC environments brings new opportunities and challenges. It is necessary to further co-design and develop new algorithms, applications, software abstractions and software practices, which requires the HPC and QC communities to work together and share knowledge and experience (see Sections 5.6.2.1 and 5.7.3). To achieve this, researchers and industry must have access to state-of-the-art quantum systems by equipping EuroHPC HEs with some of the best available quantum computers and simulators together with enabling technologies, as well as fostering training and developing use cases. While EuroHPC has now deployed an unprecedented set of 2 quantum simulators and soon 4 quantum computers by early 2026 it is important to notice that a delay has been taken on the HPC/QC integration side which could slow down the rise of hybrid workloads and more globally the uptake of the community. A first project called EuroQHPC-Integration federating the 2+6 first hosting entities, gathering their planned ecosystem and integration activities, has been initiated in 2025 but a stronger effort in terms of co design of the associated software stack is missing.

Recommendations: It is recommended to reduce the gaps in the HPC-QC ecosystem via:

- **Use cases** involving industry, start-ups/scale-ups, academia, Research and Technology Organisations (RTOs) and government – as successfully done in different national initiatives [45].
- **Testbeds:** Set up QC testbeds and field labs as part of the EuroHPC infrastructure.
- **Integration and use:** Stimulate the development of quantum software, algorithms, applications and integration layers on top of the HPC-QC Operational Infrastructure. This includes the development of quantum software engineering practices and tools designed to accelerate the QC uptake in research and business.

Fault tolerance (FTQC): The development towards scalable fault-tolerant QC (including quantum memories and coherently interlinked Quantum Processing Units (QPUs)) has been intense over the past years, with the European and global industry aiming to have such systems available by the end of the decade. Several Member States recognised this and

included concrete goals in the national initiatives². EuroHPC should plan for the next generation of quantum systems by upgrading and procuring state-of-the-art systems, integrating fault-tolerant QC technologies to stay at the forefront of QC and support EU startups. This should be defined by the improved capacity to develop more complex use cases and by new capability to explore and implement quantum error corrected algorithms. Error correction is a co-design effort involving both hardware and quantum error correction experts that need to develop algorithms depending on the hardware capabilities, and software developers who incorporate the quantum error correction algorithms and evaluate their benefits.

Coordination: Some coordination between EuroHPC and the first quantum computer and quantum simulator hardware deployments has been initiated with the EUROQHPC-I project starting late 2025. This should be strengthened and synchronised with the HPC and QC CoEs, while continuing the build-up of a federated HPC/AI/QC Infrastructure. In that aim a strong collaboration between Quantum Hosting Entities and the Federation platform should be encouraged as well as the urgent launch of the HPC/QC middleware call (earmarked in WP2026) in order to properly couple HPC systems and the 10 procured QC technologies.

As described in Table 1, a new hosting entity was expected to be selected in 2027. Current budget constraints put that deployment at risk. This would lead to a large gap between the deployment of current and next generation QC systems, which are expected to add quantum error correction capabilities. This is a significant risk for the continuous development of a user community, particularly given the fast development of systems as well as a lack of support to the European QC startups engaged in a fierce global competition and will impact negatively the European Quantum Strategy Goals set for 2030.

Community Standards: Standardisation, benchmarking, certification, and validation activities, and linking to the other digital infrastructure or EU technology developments appear mandatory such as EuroQCI [46], the Quantum Internet Alliance (QIA) [47]. In that aim, EuroHPC launched a call toward the establishment of HPC/AI/QC benchmarks in 2025, and several members states are already involved into standardisation activities within European bodies like CEN/CENELEC [48] JTC22. Following this, positive incentives, such as standardisation-related targets for grantees (development, implementation, testing), should be introduced.

The most relevant quantum standardization topics for EuroHPC include interfaces for Hybrid quantum-classical computing systems, Benchmarking methodologies across hardware and application levels, Supply chain analysis for quantum computer development, Hardware Abstraction Layers to improve interoperability, High-level programming languages for accessibility, and Metrology for enabling technologies.

² Like the PROQCIMA LSQ programme in France with 500M€ over 8 years for developing two 128 qubits universal quantum computers using European technologies

It is important that actively participate in these standardization efforts through the CEN-CENELEC working groups JTC22-WG3, JTC3-WG12, and JTC22-WG2 by contributing implementation experience from its hybrid quantum computers and providing test and certification data for enabling technologies.

These efforts are critical for EuroHPC's role in evaluating machine performance, scaling up the quantum computing market, and ensuring proper interoperability and accessibility of its quantum computing infrastructure.

5.2 AI Factories (AIF and AIFA)

Main Recommendations for 2026-2027 period:

- Speed is essential for competitiveness in the AI race: ensure a rapid and coherent implementation of all selected AIFs and AIFAs, while supporting the development and implementation of AI-specific hardware/software platforms and services, adapted to the needs of AI users and their use-cases
- Assess the first set of AIF specific access policies and address the evolving needs of AIF users, allowing differentiated access policies per AIF and matching especially localized industry requirements.
- Encourage deployment of open-source initiatives and open-weight AI models to ensure wide user adoption and continuous improvement by a large AI ecosystem.
- Reinforce AI technology watch, evaluating the rapid changes in the AI ecosystem and ensuring the diffusion of key information throughout AIFs and AIFAs.
- Develop a long-term vision for AIFs, AIFAs and the upcoming AIGFs to provide a holistic public/private set of AI services and infrastructures, ensuring visibility, stability and buy-in for AI users across Europe.

Looking beyond 2027, consider the evolution of the AI Factories into the next EuroHPC phase, with high focus on widespread impact, developing AI-integrating applications and AI skills, taking advantage of the experience of the rollout of AIFs, AIFAs and AIGFs.

AIF(A) activities must be guided and supported to achieve their important targets of driving economic growth and developing AI skills throughout the ecosystem. Guidance based on the successes and challenges encountered by the first AIFs should be propagated to later AIF(A)s through dedicated workshops and the upcoming networking/coordination activities. The latter should also ensure that the AIF(A) services are deeply publicized and evangelized across the EU ecosystem, creating awareness and attracting adopters.

Furthermore, a European AI single marketplace concept should be concretized, taking into account the AIF(A) services, but also those federating and mutualising other AI initiatives and projects, including DeployAI, Dome and MINERVA which are currently addressing sometimes the same services.

The AIF(A)s should be leveraged at EU level to strengthen international collaboration links, for example through the existing partnerships with Japan and India, but also as a basis for new links with countries like Canada, South Korea, Singapore, and others which have strong AI initiatives. Benefits of these collaborations may extend beyond deepening awareness into the evolution of services and (some level of) access to the services themselves. They may provide the mechanism for attracting foreign investment, skills, creation of Europe-based AI R&D labs, and technology transfer. The latter will in turn support a cycle of innovation and evolution of European AI technology.

Europe's technological sovereignty in AI must be based on activities both on advanced hardware and software aspects. Hardware/software co-design and co-evolution activities would support the goal of a robust software ecosystem that fully leverages HPC and AI-optimized infrastructure. The roll-out of AIF(A)s should provide excellent feedback on the modern use and also limits of the built systems, which can guide future hardware/software development activities.

Through the AIF(A)s the diverse (but synergistic) needs of industry and academia should be addressed while ensuring interoperability and security:

- **Industry:** Seeks ready-to-use AI software, models, frameworks, and methods for rapid deployment and integration into existing workflows and business applications. Focus is on ease of use, dynamicity, reliability, security, and cost-efficiency.
- **Academia/Research:** Requires flexibility to develop and test new algorithms, methods, architectures, and foundation/frontier models. Emphasis is on open access, experimentation, and scientific innovation.

Europe has a unique possibility to combine Industry and Research efforts:

1. Layered Software Stack Access

- a. Provide pre-built AI applications and frameworks for industry users.
- b. Offer full-stack, low-level access for academic research and model development.

2. Shared AIF/AIFA/AIGF Infrastructure with Segmented Services, tailored for

- a. Industry: Optimized for business application deployment, inference and fine-tuning at scale.
- b. Research: Robust compute access for large-scale training and frontier AI model development.

3. Public-Private Collaboration

- a. Foster joint projects where industry benefits from cutting-edge research and academia gains access to real-world problems and datasets. This collaborative approach ensures fundamental research gets transferred to real-world applications.

- b. Position AIFs/AIFAs for the provision of AI services (education/training, user support, setting of Datalabs, ...) for engaging and supporting AI users and AI Gigafactories for the provision of AI infrastructure.
- c. This win/win approach will create a unique competitive ecosystem where private European Cloud and Neocloud providers will benefit from public research expertise, allowing them to expose clear differentiators with regards to international competitors. On the other side, public research will benefit from access to large scale hardware configurations and a co-funding of AI factories done by the private side for ensuring their sustainability.
- d. Develop joint services in the field of access to dataspace, models, and tools as well as the development of a European AI open-source software stack.

4. Software Sovereignty Strategy

- a. Invest in European-developed AI frameworks and middleware to reduce dependency on non-EU platforms. This requires urgently the launch of a Sovereign Cloud AI call (earmarked in 2026).
- b. Promote open standards and interoperability across sectors.

Beyond the two-track tailored approach for Industry and Academia/Research, the following recommendations are made.

Assess and optimise EuroHPC access tracks, accounting and compute-time grants: Until AIF large AI-optimised supercomputers become available, prioritise large-scale AI training/fine-tuning on pre-exascale and exascale systems, and development/inference-oriented projects on mid-range (HPC or AI-optimised) supercomputers. Leave the possibility for AI Factories to have reserved access (quotas) on their AI optimised supercomputers to develop their support services. Define evaluation criteria for the selection of flagship projects³, and the rules for them to access resources, guaranteeing availability when needed for time-constrained production and operational workloads. Continue with the fast-track mechanism. Assess and adapt the implementation of new AI access tracks, accounting and budgeting, especially for inference, in view of more AI-centric approaches such as per-service credits, API calls, tokens.

End-to-end capabilities for AI projects: beyond development (training/fine-tuning) of models, enable inference, integration of AI in production services, with use of sovereign Cloud platforms. Support the integration/federation of EuroHPC systems (HPC/AIFs) with EU commercial Cloud providers for a seamless experience for AI developers and end-users. Take a step further and include members of the European Cloud continuum, to include use cases where training/federated learning/continuous learning also happens in European edge nodes. This initiative will be crucial also for preparing the rise of AI Gigafactories, in that aim the

³ Aim of these flagship projects is developing European reference AI models in critical and differentiating domains such as health, weather, climate, manufacturing, robotics, pharmaceuticals and other scientific applications.

launch of the Sovereign Cloud AI call (earmarked in 2026) become a strategic action to support.

Integration of computing and data: Data and AI communities in Europe need to be onboarded quickly, and continuously in the HPC ecosystem to respond to the exponentially growing interest in AI, and to find solutions for integrated HPC-AI approaches. Actions dedicated to integrating the HPC and data-driven communities (e.g., Common European Data Spaces [49]) ecosystem should be considered addressing industrial, governmental, and scientific use cases, including HPDA and AI, as well as training and scaling AI models. Data stewardship policies, procedures and software services will need to be implemented in order to ensure a safe use of data for AI model development.

Security and privacy: Evaluate and deploy mechanisms enabling better data security and privacy in AI-optimised supercomputers: secure processing environments and sandboxes, software-defined data pools for AI with privacy guarantees, end-to-end encryption with user-managed keys. Differentiate dimensions of data privacy and protection, secure processing, cybersecurity (see also Section 4 on Security). Assessing federated learning/inference could be also a way to address security issues on sensitive datasets like health or industrial data.

AI software stack and technology diversification: AIF(A) system's design showcase a significant AI-centric software approach, with new middleware (Kubernetes and other platforms), rich AI frameworks and end-user AI development environments becoming prevalent. Leverage these developments pushed forward by AI interest as a new baseline for modernization of HPC platforms in Europe, facilitating long-term the integration of AI across the application stack. Diverse technologies (HW and SW) should be chosen in future procured systems (as done in QC) to ensure robust and resilient AI-optimised supercomputing environments and foster also the adoption of EU technologies for inference (where already solutions are becoming available) and training of models. Even a fraction of the budget considered for AIGFs would strongly support the European HW/SW industry.

Phased deployments: Support a multi-stage implementation of AIF supercomputers, especially for larger systems, enabling the rapidly evolving technologies to be integrated gradually instead of purchasing monolithic systems that remain unchanged over long periods. Continue this approach with AI Gigafactories, since simultaneously deploying 5 times 100 000 GPUs in Europe will not be appropriated.

Performance and efficiency: HPC/AI providers need to consider carefully optimised platforms for the (still evolving) workloads they will sustain, and that the current trend is foreseeing a continuing increase of power consumption from AI infrastructures, which may require large-scale data centre adaptations and even country-level energy grid changes. Develop methods and tools for deep analysis and optimisation of AI application performance with energy use and carbon footprint considerations. Such tools could be adapted from existing HPC-focused developments and should enable AI-code developers to optimise the AI applications or their

use. Focus on performance profiling and efficiency optimization should not be placed exclusively to existing HPC-oriented developments.

Large-scale foundation and future frontier models: Implement programmes for the development of and making available European large-scale foundation models for GenAI and Frontier AI, building upon and expanding ongoing initiatives (like EuroHPC AI Challenges). It is important to assess and understand the evolution of AI communities in developing/using alternatives to transformer-based models (e.g. recurrent models, Liquid Neural Networks, KAN, to name a few) as well as long context variants (sparse attention and other forms of memory compression) that use highly optimized kernels and could exhibit different infrastructure requirements. Same apply to Frontier AI models in AI for science, massive agentic AI at scale or the development of world models for robotics or autonomous car driving fleets where new approaches could appear. This could be part of a wider initiative consisting of a Scientific and Industrial Case toward post-exascale that EuroHPC could launch concurrently with specific RIA actions. At the same time, EuroHPC should encourage (or require) users to adopt open science practices, such as releasing open models, open data, open source, and release intermediate checkpoints, which can benefit the whole community and increase Europe's competitiveness in AI.

AI-enhanced application development: Support the integration of AI into HPC simulation codes to the widest extent. Establish programmes for modernising old codebases and legacy HPC applications. Find and establish datasets enabling the training of AI models suitable for transitioning HPC codes into HPC/AI coupled applications. Support work on AI runtime infrastructures and adding mixed precision capabilities that take advantage of modern processing capabilities.

5.3 Gigafactories (AIGFs)

Main Recommendations for 2026-2027 period:

- Ensure that the calls for the establishment of AIGFs and the selected applicants consider all aspects – business, use-cases, technology – for a successful and sustainable initiative.
- Secure a strong engagement from EU industry users of the future AIGFs by running a systematic, focused Proof-of-Concept/Proof-of-Value at wide scale on the AIF platforms and with AIF services/support.
- Closely coordinate the deployment of AIGFs where the timeline will be even more critical than for AIFs, as the larger infrastructure will have significant data centre/power grid infrastructure challenges, and also run much larger component availability risks.
- Support and secure sovereign novel AI enabling technologies, from AI infrastructures and accelerator hardware chips to software platforms to mitigate dependency risks on current dominating actors.
- Take advantage of the lessons learned during the implementation of AIFs and AIFAs, from services to platforms, to guide the bring-up of AIGFs.

Looking beyond 2027, ensure that large European companies are effective users of AIGF platforms, that new companies can grow to large scale through their use of AIGFs, and that European technologies (hardware or software) are developed, implemented and used in AIGFs at wide scale.

AIGFs will be implemented after the initial deployment of AIF(A)s, which will be (globally) moderately advanced in their maturity cycle. As precursors to AIGFs, lessons learned during the first years of AIF(A) execution will be important to embed into the implementation of AIGFs.

It will also be important to develop strong synergies between AIFs and AIGFs, as both will serve industry, as well as scientific use-cases, however at different scales and with different targets. In particular AIGFs will be much better suited to ultra-large / flagship / lighthouse undertakings due to their capacity, as 4 to 5 AI supercomputers of up to 100 000 GPUs each (4 times the size of an Exascale system) are envisioned. This platform sizes will allow massive commercial AI inference and AI development at scale which will not be possible on other EuroHPC systems, and also due to regulatory/policy conditions.

To strengthen Europe's innovation ecosystem, the AIGFs must enable European users of all sizes and types, from startups, and SMEs, large industry and the research/public sector to access these platforms, to use and also develop new products and services. It will be essential to prepare the European industry for the arrival of AIGFs through a strong PoC/PoV programme that will use the deployed AIF(A)s as precursor platforms. Securing the deep

engagement of industries of all sizes is critical to ensure both a strong utilisation of AIF(A) facilities and use them as launching pad for AIGFs use.

With the support of proper software Cloud AI tools AIF(A)s and AIGFs could allow to setup an end-to-end sovereign continuum of AI services and infrastructures in Europe allowing the support of training/finetuning services at the level of AIFs and AIGFs (depending the size of models) to inference at scale using AIGFs, with a common layer of AI Services provided by the AIFs.

To maintain global competitiveness and sovereignty in the era of AI, Europe must also accelerate the development of advanced AI infrastructure (both hardware and software). This does not mean that an Europe-only technology pathway must be pursued, but that a diversification strategy should be implemented. It will continue to be important that technology investments in advanced AI chips and software are reinforced. However, attracting leading foreign companies to be established in Europe and become part of the ecosystem (from AI technology manufacturing to use) should be envisioned as well, supporting technology transfer into the European ecosystem, and thus its evolution.

Recent technological developments pushed by reasoning models, long context window or inference-time compute show that AI is massively pushing the boundaries of data centres toward new power levels (up to 1MW per rack), advanced cooling, and design with extreme densification (higher voltage DC power), gigawatt scaling at speed (including on-site clean energy generation and storage), data centre as a unit of compute, and new silicon diversification (GPUs for training and xPU for inference federated by photonics high speed interconnects).

Such trends are offering an unprecedented opportunity for European technological companies to develop the needed hardware and software components to support the pace of AI deployment in Europe and ensure a level of autonomy. In that aim EuroHPC should seek to reserve small fraction of the overall AIGF budget to support such sovereign initiatives.

The AIGF platforms may themselves be used to sustain AI hardware/software technological developments. These efforts should be supported, for example by providing incentives to use AIGF resources in dedicated access tracks for sovereign developments.

5.4 Quantum Technologies

Main Recommendations for 2026-2027 period:

- As stated into the project of new EuroHPC regulation a new advisory group focussed on the integration of the Quantum Flagship activities within EuroHPC will be created alongside with INFRAG and RIAG. Regarding the ongoing synergies setup around HPC, AI and quantum computing between existing bodies, INFRAG and RIAG recommend ensuring that complementarities and synergies will remain to avoid siloing quantum activities.
- Procure next generation quantum computers, focused on systems enabling early-stage error-correction.
- Release the middleware call, originally planned for WP 2024.
- Establish funding mechanisms that support the growth of the European quantum industry.
- Launch calls for high-TRL hybrid application development, ideally involving end-users and the quantum application industry.

Looking beyond 2027, design a suite of calls focused on FTQC, including procurement of quantum computers, the software infrastructure required, and application development. These should drive the establishment of distributed quantum computer infrastructure, profiting from advancements of quantum communications.

In July 2025 the European Commission proposed a combined amendment to the EuroHPC Regulation to support Gigafactories and to include the Quantum Pillar, which is a translation of the Quantum Declaration of 2023 and the Quantum Europe Strategy. The European Commission has adopted this European Quantum Strategy to position Europe as a global leader in quantum by 2030.

When the amendment is accepted by the EuroHPC Governing Board (GB), the activities of the Quantum Flagship will be transferred to EuroHPC. This represents a drastic change - especially the transfer of the Quantum Communication, Quantum Sensing and Basic Science pillars create conditions that are beyond the experience of both EuroHPC and the Quantum Flagship communities. EuroHPC is focussing on making the technology applicable and operational, while the Quantum Flagship community is focusing on Research & Development of Quantum Technology. The new broad focus requires a wide range of skills and expertise.

Moreover, the different basic funding schemes (HE/RIA, 100%; EuroHPC 50-50) will drastically change the ability of many groups to participate in future projects if the JU funding model will be applied broadly. It is therefore essential to understand and formulate the EC-strategy behind this change and document the consequences.

A central issue is whether the Quantum Flagship and its CSA (Coordination and Support Action) shall be properly integrated in EuroHPC, not just embedded. The only viable efficient option is full integration. Therefore, when the amendment is adopted, it is crucial that EuroHPC is allowed to quickly expand the Quantum Technology expertise in the JU in all five domains: Quantum Computing, Quantum Simulation, Quantum Communication, Quantum Sensing, and Basic Science, to achieve good balance between academic research & development expertise versus expertise in the domain of productization, operationalization and adopt end-users and industry.

A major effort will be to integrate the Quantum Flagship in EuroHPC and develop efficient processes at all levels. The Horizon Europe - Work Programme 2026-2027 for Digital, Industry and Space describes the QFLAG calls that must eventually be handled by EuroHPC.

5.5 Federation and Hyperconnectivity

Main Recommendations for 2026-2027 period:

- Accelerate the deployment of the EuroHPC federation platform on HPC systems, extend this rapidly to also cover the AIFs, AIFAs and QC systems.
- Connect the federated HPC/AI/QC EuroHPC infrastructure with national HPC/AI/QC infrastructures and EU cloud providers. To support this, the Sovereign AI cloud, bridging public and private resources, should be launched before the launch of AIGFs.
- Connect EuroHPC's HPC/AI/QC infrastructures with the European data spaces, repositories and data lakes in coordination with EOSC, ESFRIs, and scientific institutions and communities (e.g. SKA, CERN, Destination Earth, etc.) and necessary edge data sources using interoperable solutions like SIMPL wherever possible.
- Given increasing data-access-driven requirements in user communities, EuroHPC should monitor for emergence of new connectivity requirements from HE and user communities to see if amendments to existing solution or additional are necessary.

Looking beyond 2027, in view of the critical importance of data access and management for European HPC/AI/QC infrastructures, consider including data management and storage topics into the next regulation of EuroHPC.

The EuroHPC Federation Platform [50] (EFP), and the ultra-high bandwidth interconnect services to be deployed by GEANT [13] are creating the foundation of a fully federated, hyperconnected, and secure HPC/AI/QC ecosystem, providing end-to-end connectivity, performance, and resilience. This federated infrastructure will support academia, industry (including SMEs), and the public sector, offering tailored configurations for diverse applications and user needs. It ensures coordinated access to EuroHPC supercomputers,

quantum systems, and data repositories, fostering innovation through providing convenient, Europe-wide access to cutting-edge technologies and solutions. Early feedback loops with user communities will align the development of this infrastructure with user requirements and enable swift adoption of new technologies.

EuroHPC shall extend its hyperconnected, federated HPC/AI/QC infrastructures to lower-tier national and institutional operators. This will greatly extend the infrastructure footprint and user base, support research and development in Europe not currently reached by EuroHPC, and enhance the understanding of key issues like application performance and energy efficiency, security, and the use of confidential computing to protect data while maintaining efficiency. EuroHPC could also consider establishing close links with European data spaces, repositories and lakes to enable effective and efficient data sharing in a scalable, trusted and reliable way.

5.5.1 Federation of supercomputing resources

Extend federation to cover HPC, AIF, and QC infrastructures: development of the EFP [50] started in 2025 with the primary objective of federating existing EuroHPC HPC facilities; deployment will ramp up in 2026. In the future, the EFP should be extended to cover AI and QC resources, such as the AIFs/AIFAs, providing Europe-wide, secure services for a wide range of public and private users. Some extensions to the EFP may be needed to best support emerging AI and QC use cases, in particular by industrial users. To reach the latter, engaging users early in the design and implementation phases is key. By federating the EuroHPC ecosystem, all users, including SMEs, will get appropriate support to access secure services and European HPC/AI/QC expertise, knowledge, and tailored training and support services from CoEs and NCCs.

Reduce Carbon footprint: Considering the current exponential increase of AI use for machine learning (ML) and Natural Language Processing (NLP), there is an essential requirement to satisfy the needs of new and emerging users whilst also measuring and controlling the carbon footprint caused by the necessary computation and data movement. Federated HPC/AI/QC infrastructures can enable dynamic load balancing and migration, provide fault tolerance, and support energy-efficient operations. In this context, EuroHPC shall investigate carbon footprint reduction by migrating, when possible and advantageous, workloads to sites with higher energy efficiency and/or a more sustainable energy mix.

Connect to European Clouds: Integration with European initiatives like European Open Science Cloud (EOSC) [51], European Strategy Forum on Research Infrastructures (ESFRI [52]), GAIA-X [53] and European private and public Cloud providers will strengthen links with scientific and industrial services, support AIFs/AIFAs, large-scale instruments, and digital twins in data processing and HPC/AI applications. In this manner, a federated AI-oriented platform linking the AIFs/AIFAs with the HPC infrastructure and European Cloud providers shall create a seamless, sovereign continuum for AI applications, including ab initio training, fine-tuning of pre-trained networks, and inference. EuroHPC should also investigate the link to edge, data

spaces/lakes, and cloud infrastructures (computing continuum) to enable seamless access and storage of data. Special focus shall ensure industry-friendly services that encourage private sector and SME engagement with EuroHPC infrastructures.

Such activities could also encompass the coupling between public and private HPC and AI infrastructures, paving the path to the arrival of AI Gigafactories in Europe. In that aim the launch of the Sovereign Cloud AI Call (earmarked in 2026) should be considered before the implementation of the AIGFs.

5.5.2 Hyperconnectivity

In 2023 and 2024 EuroHPC with the EuroHyPerCon [54] external study conducted a wide analysis of current usages, needs and expectations of HPC centres, end users' communities, and NRENs (including GEANT) across Europe. Based on these elements a set of recommendations for increasing progressively the bandwidth of national and transnational networks links to beyond 1.6 Tb/s has been formulated with associated costs and procurement options for EuroHPC. Given increasing data-access-driven requirements in user communities, EuroHPC should monitor for emergence of new connectivity requirements from HE and user communities to see if amendments to existing solution or additional are necessary.

5.5.3 Data Management Services

The scope of EuroHPC investments have mainly been oriented on computational power; however, the success of the next generation of supercomputing (especially AI-optimised ones) depends on highly efficient data orchestration. It is considered critical for the success of EuroHPC that technologies for controlling, managing, and moving massive volumes of data across the HPC/AI/QC continuum are established. As data-intensive applications, such as climate modelling (e.g. Destination Earth), genomics, and AI (e.g. Large Language Model (LLM) training) generate exascale datasets, EuroHPC Hosting Entities (HEs) must facilitate seamless data fluidity among storage tiers, AI training and inference platforms within AI Factories, and edge devices.

This can be achieved currently by EuroHPC tightly collaborating with the responsible EC units or data-focused Joint Undertaking (JU). Looking ahead it is recommended to integrate data management and data centric workflows into the next EuroHPC phases, considering it a key element of the HPC/AI/QC workflows and infrastructure.

Key Challenges and Solutions in the area of data management that EuroHPC should address:

- **Access to European Data Spaces and DataLabs:** EuroHPC systems should develop access to Common European Data Spaces [55] and other EU initiatives, including the Data Spaces Support Centre [56], SIMPL [57], and domain-specific data lakes and repositories (e.g., SKA [58], EMBL [59], CERN [60], ESFRIs) according to FAIR principles.

This ensures access to vast, structured datasets essential for AI and HPC applications. In that aim the DataLabs initiative pushed by the European Commission should be deployed in relation with the Common European Data Spaces. This access should be operationalised through Data Labs, acting as controlled, data-centric environments where datasets from multiple sources can be discovered, curated, harmonised, and prepared for large-scale use. Data Labs will enable the transformation of raw and distributed data into AI-ready assets, ensuring compliance, interoperability, and trust.

- **Data Movement and Bandwidth:** Efficiently transferring vast datasets across HPC systems, AI Factories, clouds, and repositories is critical. Technologies like Globus [61] and Nodeum [62], alongside high-bandwidth networks like the ones to be procured by EuroHPC, are potential solutions. A common approach among EuroHPC sites and Federation services could improve efficiency.
- **Data Formats and Interoperability:** Differences in file systems between HPC (e.g., Lustre [63], IBM Storage Scale [64]) and cloud (e.g., S3 [65]) systems complicate data handling. Standardizing formats like Zarr [66] or HDF5 [67] could reduce overhead. The by now well-established FAIR principles: ensuring data is Findable, Accessible, Interoperable, and Reusable—should also be fostered to enhance compatibility and usability across platforms.
- **Beyond POSIX: Modern Storage Architectures:** To overcome the "I/O wall," EuroHPC should promote technologies that bridge the gap between traditional parallel file systems (Lustre, IBM Storage Scale) and high-performance object storage (DAOS, S3). Standardizing on cloud-native formats is essential for interoperability.
- **Orchestration and Workflow Scheduling:** Workflow management across HPC and cloud platforms faces challenges in task prioritisation and resource utilisation. Hybrid schedulers like PyCOMPSs [68], Dask [69], StreamFlow [70], Nextflow [71], and Kubernetes-based orchestration could provide seamless integration.
- **Automation and Storage:** Enhancing automation and software-defined storage linked to compute workloads would improve system performance.
- **Cloud Integration:** To support cloud-based operations, connector services like S3 should be implemented for collaboration with EU and global cloud providers.
- **Regulatory Compliance:** To serve sensitive sectors like public services and healthcare, in line with the EU AI Act and GDPR, EuroHPC could establish a working group to ensure secure data storage, processing, and transmission in compliance with EU and national regulations.

5.6 Technology

Main Recommendations for 2026-2027 period:

- Support strategic European HW/SW technology developments to build up the European supply chain for HPC and hybrid HPC plus AI and QC products and demand their use in EuroHPC system deployments and project proposals.
- Continue investment to develop European component ecosystems, particularly for: processors including ARM server processors, RISC-V hardware and software ecosystem and special purpose accelerators; advanced semiconductor packaging and chiplet integration; interconnect technology; and memory technologies.
- Continuous and long-term investment in the varied European SW components such as system SW, programming models and software standards, and resumption of funding for higher-level software. Focus on maintenance and sustainability of established SW, not only new, low TRL developments.
- Support software engineering research and foster the application of professional software development techniques, including AI-assisted (vibe coding) approaches, CI/CD, automated testing, software documentation, product releases, etc.
- Integrate security and privacy strategy and implementation across the entire European Technology pillar.

Looking beyond 2027, increase funding on and adoption of European technology, particularly around processors and accelerators based on, e.g., RISC-V and ARM architectures, high speed networks with special emphasis in software support, and to the integration of traditional HPC with QC and AI. Fund basic research. Focus efforts on development of optimized AI models and frameworks, ensuring an efficient use of European resources.

The Technology pillar develops Hardware (HW) and Software (SW) for EuroHPC's future HPC, AI, and QC infrastructures, delivering world-class performance while prioritizing energy and carbon efficiency. Access to cutting-edge, energy-efficient technologies, and stable, interoperable components is vital for EuroHPC's success, making it mandatory to achieve a level of technology sovereignty to guarantee access to the necessary source components⁴ and maintain control over European data. As attempting to reach a target of 100% European solutions is not realistic in the timeframe of this MASP, European added value resides in the design and integration know-how of the subsystems, and on the control over the generated

⁴ The HPC supply chain ranges from core digital technologies and components (processors, memory, interconnect, disks, tapes,...) to racks or any larger scale integration unit (e.g. containers, thermal, electrical, and mechanical equipment for energy supply and cooling), plus software stack (from operating systems to middleware and programming environments tools and applications).

IP. Currently the European HPC supply chain consists of one large system integrator plus SME integrators and technology developers. All rely on components developed and manufactured outside of Europe, adding European components and IP where possible, such as processing elements and advanced cooling technologies. Europe is also the home of ISVs developing critical system and application-level software for HPC. EuroHPC shall support established European HPC suppliers and foster the emergence of new ones.

A representation of the technology stack is shown in Figure 2. System components are at the centre. Going down, we grow out to racks, systems, Data centre Infrastructure, and Federation of systems. Going up from system components, we grow the SW stack from firmware and BIOS to low level SW, Toolchains, languages, System SW... up to application SW.

Pillar	Area	Component	Area	Component
Applications	Applications	Application codes, libraries		
Technology (Software)	Programming Environment	Programming Language and Frameworks	System Management	Runtime System
		Parallel Programming Models		Workflow manager, Resource management/ Job scheduling
	Tools	Compilers		Software deployment tools, SDKs
		Debuggers		File system
		Performance analysis tools		Operating system
Technology (Hardware)	System Components	Processors (CPU, GPUs, other accelerators)		
		Memory and Storage		
		Network		
	Rack integration	Mechanics, Electric, Cooling		
System deployment	Site preparation, Containers			
Infrastructure	Operations	System management, User access		
	Data Centre	Cooling, Heat reuse		
Federation	Connectivity	System connectivity, Uniform user access,		

Figure 2: HPC technology stack

Sovereign supply chain: Supply chain management and make-or-buy policies in deploying future EuroHPC infrastructures will be a primary determinant of Europe’s digital sovereignty. EuroHPC shall contribute to strengthen both the supply and the demand side of HPC/AI/QC technologies, in collaboration and alignment with other initiatives like the Chips JU [72] and the Quantum Declaration / Quantum Pact [73]. On the processing technology side, high-end HPC/AI processor development requires a large amount of initial capital investment, continued for a period of 5-10 years, before becoming commercially self-sustainable. To be successful, a mature SW stack that is accepted by the market is required (discussed more in Section 5.6.2, Software Technologies). For HPC (and also QC) it is critical to secure ownership of technology developed in the region and develop a full (and to the extent possible hardware agnostic) **software stack⁵ based on European solutions** that enable the operation of

⁵ Including frameworks for the implementation of error mitigation and error correction schemes, data, workflow and resource management, I/O protocols, signalling, SW engineering methods and practices tailored for quantum and hybrid computing, and more.

heterogeneous systems including execution and management of jobs. On the SW side, both commercial and open-source pieces are combined, and European added value lies in specific middleware optimisations and integration know-how. To strengthen the supply chain, EuroHPC shall address the recommendations issued in this technology pillar, and consider additional pilot technology demonstrators for HPC solutions, identifying and prioritising critical elements. To benefit from these investments, it is also paramount to prepare the EU workforce for the developed HPC/AI/QC technologies (see Section 5.8).

Co-design: Linking technology development to significant scientific and industrial use cases will ensure broad market relevance and develop digital sovereignty beyond the scientific use cases. Close co-design collaboration between suppliers, customers, HPC centres, and users is crucial to align R&I with end-user needs and would benefit from energy/carbon efficiency and security/privacy targets integrated across all Technology Readiness Levels (TRLs).

Roadmap: A strategic R&I roadmap with clear goals, targets, and Key Performance Indicators (KPIs) will enhance European technology capabilities. Partnerships with industry and research organisations can be married with the use of European R&I results in infrastructure procurements. Technology R&I must strengthen EU sovereignty and leadership [74] by fostering European IP, ensuring supply chain readiness, and meeting Green Deal [75] sustainability goals. Robust networks, storage, and cybersecurity are essential for safeguarding valuable digital data, ensuring secure access, and optimizing system use. Emerging models, such as HPC/AI/QC hybrid computing and European Digital Twin initiatives, must inform technology development, by leveraging complementary R&I activities in big data analytics, AI, neuromorphic computing, and QC. Structured and coherent co-design between technology projects and projects from the application pillar should be established to ensure the suitability and acceptance of the HW solutions.

5.6.1 Hardware Technologies

The competitiveness of the European HPC/AI/QC infrastructure depends on the performance, energy/carbon efficiency and availability of competitive HW technologies. Components require advanced silicon technology nodes to achieve high performance and energy efficiency, with large-scale packaging and highly efficient cooling solutions. Mission critical subsystems or components include memory and storage hierarchies as well as high-speed interconnect networks. At the system level, rack-to-container integration and disaggregated architectures must also be considered. HPC technologies, including General Purpose Processors (GPP), accelerators, and networks/interconnects as well as the requisite system software⁶, which are developed through EuroHPC calls must pursue energy/carbon efficiency goals, be innovative, be able to perform and compete globally, be production ready and, whenever feasible, be deployed in industrial settings.

⁶ Including domain-specific libraries, runtime systems, frameworks and programming environments

As HPC systems become increasingly heterogenous, larger and eventually modular, performance depends on reliability, availability, serviceability, raw compute capability, energy/carbon efficiency, adaptability and security of the underlying technologies; from individual components up to board, modules and system. With growing volumes of digital data and federation of their sources, high performance interconnect hardware, storage and AI engines are becoming increasingly valuable, in many cases eclipsing other components. It is essential to establish software compatibility and integration, and in addition state-of-the-art hardware enabled cyber security technologies that protect data at all layers and provide secure access and use of the systems. EuroHPC will, via its Advisory Groups, monitor the developments in critical hardware areas where European Leadership is currently lacking. This may include asking its Advisory Groups to undertake a full analysis of the situation.

5.6.1.1 HPC/AI processor ecosystem

EuroHPC supports the development of HW technologies such as high performance, energy efficient processors, accelerators, and interconnects. In particular, EuroHPC, in a joint effort with the Chips JU [72], supports the development of low power General Purpose Processor (GPP) and accelerator technologies designed in Europe. The targeted ecosystem for European HPC processors/accelerators will contribute significantly towards European technological sovereignty through a strategic R&I roadmap that strengthens the European capabilities to design, develop and produce the IP related to high-end processors and/or accelerators. This must be driven by relevant key performance indicators, including energy/carbon footprint and efficiency. The development of European processors and/or accelerators should include preparation for future integration in European supercomputers and should be privileged as European technology (as is done in other regions).

General Purpose Processors (GPP): Sometimes referred to as Central Processing Units (CPUs), a range of EU GPPs supporting server applications is becoming viable in HPC and beyond. Classical HPC CPUs must adjust their role as accelerators (Graphic Processing Units (GPUs), neuromorphic engines, Field Programmable Gate Arrays (FPGAs), etc.) are being integrated with production systems. In modern HPC systems, the role of the CPU is migrating from the central compute engine to a dual role: orchestrating accelerators and processing workloads that are not amenable / difficult to adapt to accelerators. The key requirements are acceptable CPU performance (based on measurable KPIs) and a viable SW stack supporting customer production environments.

AI-accelerators: specialised AI accelerators have evolved rapidly and are increasingly included in HPC systems. However, ensuring joint support and optimisation of both HPC and AI workloads on the same system is difficult for several reasons. First, performance does not always rely on the same features, configuration or sizing parameters at processor, memory, and network levels. Additionally, HPC and AI software stacks notably differ. With the acceleration of the AI inference market driven by improved reasoning models, MoE (Mixture of Experts) or the rise of world models requiring low latency answers and low cost per token

there is a complete flip in the architectural choices with an hardware divide between GPU used for training and the prefill phase of inference and latency/memory bandwidth/capacity optimised xPU used for the decode phase of the inference. Such diversification of the hardware for the inference part which represents the dominant market of AI in terms of revenues is a major opportunity for Europe. EuroHPC must invest in appropriate European accelerators and interconnect subsystems for AI (training or inference workloads), ideally also serving the needs of HPC workloads. All processing components in today's HPC infrastructure are non-European; EuroHPC needs to seek alternatives by developing solutions based on ARM, RISC-V, European GPUs or other accelerators, or disruptive solutions (optical accelerators, neuromorphic, dedicated inference engines...).

RISC-V: The RISC-V Instruction Set Architecture (ISA) is an open-standard abstract model for the design and implementation of modern CPUs.

Recommendations on RISC-V: For the RISC-V ISA to succeed in the HPC space three concerns must be addressed:

- **SW ecosystem development and proliferation:** important for accelerators but decisive for server CPUs.
- **Indemnity:** as soon as a company achieves financial success, patent trolls arrive. With professional IP companies, management of this risk is included in the purchase price. For open standards, the end user is responsible. This may be addressable by a cooperative action with a central fund but needs to be well thought out.
- **Fragmentation** (split in SW trees, often due to variations in HW developments) is managed in single companies by limiting the supported features and thorough testing. Fragmentation is exacerbated by geopolitics and by the variability in designs, particularly for open, extendable instruction sets. One risk is that Independent Software Vendors (ISVs) will not port and support the ISA with all its diverse features due to the limited ROI for each fragment. It is recommended that Europe Align and help to drive existing standards, and where possible involve ISVs, in lieu of developing an independent SW and trying to convince ISVs to adapt to it after the fact. And, wherever possible, push for open SW.

Disruptive processing technologies: with the cadence of performance and energy efficiency improvements driven by the slowing of Moore's law, and with the emergence of novel applications scenarios (like the integration of HPC and AI), disruptive processing technologies can be attractive approaches to improve compute performance and energy efficiency. Areas in which Europe is well positioned and should continue strongly investing in research and development are quantum, neuromorphic, and cryogenic computing, to name just a few. Such disruptive developments offer a unique opportunity for Europe to leapfrog international competition, steer future roadmaps and control IP and commercialisation. For this to succeed, a sustained effort is needed to increase the maturity of the solutions to higher TRLs and readiness for production. Therefore, EuroHPC should invest in facilitating their path to

commercialisation by increasing maturity, integrating them into pilot systems, and exploring applicability for HPC/AI/QC use cases and applications. Close involvement of users in a co-design effort will be important to align technology development to user needs and grow a market that is able to sustain further technology evolution. To capitalise across EU investments, closer integration between calls from Chips JU and calls from EuroHPC is advised for a full view/continuum of co design actions.

Chiplet solutions and packaging: high-end processors are reaching reticle limits, becoming too large and expensive⁷ to produce as one single block of silicon. Instead, processors are manufactured aggregating various smaller chiplets ([76]) with different functionalities (e.g. core processing, memory, I/O). This trend goes towards higher package heterogeneity, mixing CPU with acceleration chiplets ([77]) and opening the opportunity to tailored processor designs for specific markets and needs (e.g. AI-oriented applications, inference, tensor operations, etc.) Europe is supporting chiplet based development through the EPI, DARE and Automotive initiatives (CHASSIS, etc.). To facilitate the success and further European processor IP, EuroHPC should put dedicated effort in developing packaging technology supporting standard interfaces, in particular Universal Chiplet Interconnect Express (UCIe), to allow the integration of various chiplets (e.g. ARM, RISC-V, or accelerators for tensors/stencils).

5.6.1.2 Network and interconnect technologies

High-speed interconnect networks are critical for both monolithic architectures and the fastest possible integration of disaggregated HPC/AI/QC/Neuromorphic resources and storage/memory systems. Furthermore, high-speed interconnect components represent a significant part of the acquisition cost of state-of-the-art supercomputers and are essential for strategic supremacy in HPC/AI/QC; in particular they are growing in importance as current transformer-based AI reasoning or world models with close to real-time inference benefit from heavily provisioned interconnect (1 link/GPU). EuroHPC should invest rapidly in R&I on photonics used from intra-chip communication (photonics-based chip-to-chip optical connectivity) to rack-to-rack interconnect. The global market for HPC interconnect is currently dominated by a single non-European player (NVIDIA), and it is often leveraged as a bundled sale with GPU and CPU. There is therefore a real opportunity for European industry to both protect itself against single vendor bundling and gain market share outside Europe if a competitive solution can be developed. For these reasons, EuroHPC has implemented several projects funding significant European research which led to the deployment by Eviden of European-based high-speed interconnect into the 2nd EuroHPC Exascale system (Alice Recoque). This major area should continue to be supported and developed. In particular, EuroHPC should connect with and support the activities of the Ultra Ethernet Consortium [78], with the aim of implementing new interconnects that are both feature-rich and high-performance in future EuroHPC infrastructure. The UEC aims to deliver feature-rich, scalable,

⁷ The production yield is quadratically inversely proportional to the size of the chip.

and energy-efficient interconnect solutions that incorporate advanced capabilities such as workload-aware optimization, congestion control, and enhanced Quality of Service. European participation in the UEC standardization process would strengthen interoperability with global systems, reduce technological dependency on non-European suppliers, and stimulate industrial innovation in advanced networking technologies. It would also contribute to the development of a robust and competitive European ecosystem in high-performance interconnects, with potential spillover effects into AI, cloud, and edge computing domains. EuroHPC should therefore promote pilot projects and testbeds based on Ultra Ethernet technologies, and facilitate collaboration between European research institutions, industrial stakeholders, and standardization bodies.

Emerging paradigms such as SmartNICs (or network co-processors) to assist with communications, on-the-fly compression/encryption of data and related small compute portions in workloads such as AI are worth special consideration. These efforts, though, require a strong co-design with the appropriate software support to favour programmability.

Scaling QC's Quantum Interconnects will be critical for transfer of Quantum information, including entanglement, between separate quantum processors or nodes. These are essential for enabling scalable quantum computing as well as general quantum networking, which need to preserve the very fragile quantum states and entanglement across different parts of a system or between physically separated systems, which can be different modalities.

Separately, EuroHPC and projects such as EuroQCI [79] and the Quantum Internet Alliance (QIA) [47] should continue development of Wide Area Networks for the benefit of the future HPC+QC infrastructure.

5.6.1.3 Supercomputer and data centre integration

Supercomputers and the data centres operating them rely on the interplay of many different components, including compute nodes, interconnects, storage subsystems, electrical power supplies and distribution, monitoring systems and cooling systems. Robust integration approaches across the full range of components are required to assure reliability, performance and energy efficiency of supercomputers and data centres.

As the complexity and scale of HPC systems continue to grow, modular construction approaches are gaining traction. In particular, the use of containerised systems—physical modular units that encapsulate HPC rack- or multirack-level components—is emerging as a key option for building large-scale, flexible, and rapidly deployable supercomputing infrastructures. These systems offer advantages in terms of scalability, maintainability, and energy management, and can facilitate the deployment of HPC capabilities in diverse operational environments.

The current pace of deployment of AI data centres integrating latest GPU technologies is now pushing the boundaries of modern data centres with megawatt rack scale design, extreme densification (including higher voltage DC power architectures) and cooling

technologies, new silicon diversification with disaggregation between training and inference workloads (and even inside inference), deployment of photonics everywhere as well as major issues of accessing, storing and delivering the needed power (in the range of hundreds of megawatt to gigawatt scale).

These trends represent opportunities as sources for technological development in European research and innovation projects.

5.6.1.4 Memory Technology

Memory Technology is principally controlled by 3 major WW vendors: Samsung (South Korea), SK Hynix (South Korea), and Micron (USA). Memory standards are developed and managed by JEDEC (Joint Electron Device Engineering Council). Datasets are continuing to grow, and data storage and movement are increasing in importance to compute. As such, Europe should invest both in memory technology and in research in Processing In memory (PIM) and Processing Near Memory (PNM). These approaches offer significant potential to minimize data movement, enhance energy efficiency, and enable new architectural models tailored to AI, HPC, and scientific workloads. A coordinated European effort should focus on supporting research and innovation activities that explore novel memory architectures, including photonic interfaces, non-volatile memory integration, and memory-centric computing. Engagement with international standardization bodies such as JEDEC is essential to ensure that European technological developments are adequately represented, and that interoperability with global systems is maintained. Furthermore, the development of pilot demonstrators and testbeds based on PIM and PNM technologies would facilitate the validation and integration of these solutions into European HPC infrastructures. The transition from academic research to industrial application must be supported through targeted funding mechanisms and technology transfer initiatives, particularly in sectors where memory performance is a strategic enabler, such as automotive, aerospace, and biomedical computing. Public procurement instruments, including pre-commercial procurement and innovation partnerships, can play a decisive role in stimulating demand for European-developed memory technologies and in accelerating their adoption within public and research infrastructures. By aligning strategic investments, standardization efforts, and industrial collaboration, Europe can establish a competitive and sovereign ecosystem in advanced memory technologies, capable of addressing future computational challenges and contributing to technological autonomy in critical digital domains.

Similarly, the development of the AI inference market faces hardware limitations. Real time inference with low cost per token (measured by time to first token or tokens per second) are limited due to bottlenecks in memory bandwidth and memory capacity, especially for the decode phase of inference. Extrapolating from the rapid development of DRAM/HBM due to massive deployment of AI datacentres, there is a clear opportunity for new memory technologies like high bandwidth flash (HBF) or for redesign of architectures integrating 3D stacked SRAM in next gen inference-based AI systems. This type of disruption offers an

opportunity for Europe to enter the memory space. Beyond traditional technologies for memory and storage, prospective actions need to be launched in the field of longer term disruptive technologies like storage in real or synthetic DNA that could bring breakthroughs in terms of density (up to 1 EBytes in 4U) and reliability (simplify data duplication across sites).

5.6.2 Software Technologies

The development of software technologies for HPC, AI and QC will address a European system SW stack which connects low-level interfaces at the operating system level with user and application programming interfaces. While the important role of open source and public domain software is acknowledged, the impact of open-source software on a sovereign European value chain is often limited due to the lack of specific knowledge, capacity and control of the development. The competences for the independent development, build and deployment, maintenance, and support of many **critical software components for the operation of supercomputing environments** are currently not usually available in Europe.

European Software Stack (ESS): EuroHPC shall work with stakeholders to coordinate co-design in the R&I of hardware and software activities and ensure those activities meet user requirements and that developed technologies are deployed. Calls shall be launched, which will take each building block in HPC, AI and QC from innovation to deployment, targeting different TRLs as required by the status of HW developments. **This activity shall be closely coordinated with ongoing development of software integration layers (middleware) and applications that are targeting current and upcoming European supercomputing technology.** Admittedly, not every SW component of a European supercomputer shall be developed in Europe (see Section 3 on European Sovereignty); instead, EuroHPC shall support European scientific institutions joining international bodies (e.g., OpenMP, MPI, PCIe, CXL, to name a few), to influence their evolutions toward EuroHPC's interests, hence minimizing the effort of adaptations in the rest of the involved software components. Instead, API-level compatibility and development of specific back-ends shall be favoured where possible. To eventually attain high TRLs, the **ESS must adhere to well-established SW development procedures for production software**, including requirements for measures to assess and secure the quality, reliability, and security of the developed software as an integral part of the development cycle.

SW Modularity: The promotion of common interfaces on the basis of open community standards is critical to develop an innovative, competitive, resilient and more autonomous HPC ecosystem. It will enable developers to select and implement potentially competing alternative solutions, the seamless substitution of software components and the rapid composition of new solutions. This shall not preclude, however, the existence of non-standard(-isable) Application Programming Interfaces (APIs) for reasons such as providing high-level abstractions, intermediate or domain-specific libraries, or forerunners of standardisation attempts. In addition, *de facto* and community standards have demonstrated to play a very important role in the world of HPC and should be actively sponsored.

SW Diversity: Activities to support the development of a system software stack shall account for the diversity of the European software ecosystem, which involves many contributors from multiple institutions. By pursuing a modular approach with focused grants for specific software developments with limited scope, EuroHPC shall address the challenges of the evolving European HPC ecosystem, while maintaining inclusive and balanced support and funding. Given the relatively low cost of these SW components with respect to HW efforts, EuroHPC shall favour healthy and collaborative competitiveness and diversity. Allowing more than one SW component to implement the same functionality following different approaches will bring the benefits of competitiveness plus increase the chances of success and long-term sustainability. Using open-source licenses shall ensure cross-pollination and wide acceptance of the most successful approaches. Enforcing interoperability and promoting the creation, adoption and contribution to open standards are key elements for the implementation by EuroHPC.

Challenges: HPC/AI/QC applications face a broad set of interrelated challenges, requiring system software and programming environments that can support high performance, scalability, flexibility, and portability across increasingly heterogeneous architectures, while also ensuring performance and energy efficiency portability. Productivity remains critical, as developers need tools that reduce development time while effectively exploiting advanced hardware. Growing data complexity demands robust data management across multi-tier memory, storage systems, accelerators, and networks. Software must also be widely available and well-integrated across EuroHPC systems, while remaining usable for both new and experienced users through better analysis, feedback, and optimization support. Resilience and security are increasingly important in the face of hardware failures, network issues, renewable energy variability, and emerging threats such as adversarial attacks. Integration of AI software with HPC environments remains difficult due to fragmented frameworks and tools, while energy efficiency has become a priority on par with raw performance, including the ability to leverage time-varying renewable energy. Additional challenges include limited expertise and support resources, the need for sustained funding to maintain software and retain skilled personnel, barriers to production adoption under strict operational constraints, and the immaturity of operational software for quantum computing, which restricts effective QC-HPC integration.

Priority domains for SW technologies that address the aforementioned challenges include:

- **Strategy for adoption:** develop a structured strategy for high TRL software solutions to be adopted in the EuroHPC production environments. This shall start with a direct dialogue between software developers, system vendors, and operational teams to address the strict requirements (e.g., security, performance, reliability) and SLAs of the EuroHPC infrastructures. This also **requires a new level of balance between requirements for hardware and software investment within the future EuroHPC system procurements and project proposals**. The definition of a European software stack will greatly favour adoption across EuroHPC stakeholders.

- **Generative AI:** Leveraging generative AI within the life cycle of European software components and applications as a new methodology for developing, deploying, optimizing and maintaining software components. Conversely, EuroHPC shall not let through the opportunity for optimisation of Generative AI through the HPC software stack, which is prone to yield countless benefits.
- **CI/CD:** An effective common development and deployment mechanism for end-user software such as a Continuous Integration/Continuous Deployment (CI/CD) platform and software container technologies; optimised container images can underpin the open science approach (e.g. interoperability, portability, and reproducibility) and are an option for the support for legacy code. The container mechanisms used must allow highly efficient use of the hardware capabilities across all relevant platforms (in terms of performance and energy).
- **Workflow managers** supporting scientific and AI pipelines across modular HPC supercomputers, federated HPC, cloud-HPC, and QC-HPC. The focus should be on workflow managers that support the integration of HPC, AI and data analytics in the same application workflow within a supercomputer. In addition, since many workflow solutions are available, efforts towards their integration should be sought.
- **Scheduling and resource management software** (including dynamic elastic resource allocation and management mechanisms) for highly heterogeneous supercomputers, and mixed HPC/AI/QC environments. Note that the heterogeneity mentioned here refers to the hardware heterogeneity within one system and is not addressed by the federation platform. This includes not only global resource management systems but also runtime systems and system software handling resource heterogeneity, which shall evolve to efficiently handle upcoming hardware and system configurations. Where applicable, such SW shall optimise the global energy use of HPC/AI/QC systems and sites, be able to match resources with the evolving needs of malleable applications and adapt to varying availability of green energy. The overarching objective is to co-optimize achieved throughput and energy/carbon footprint.
- **Performance analysis and debugging:** In the era of vast heterogeneity in hardware but also in term of programming models, performance analysis and debugging is key to programming productivity. EuroHPC requires in its procurements effective tools tailored for its hardware and software stack to help developers finalise production-ready code that is effective and efficient in terms of time-to-solution and energy-to-solution.
- **Cloud-accesses:** Middleware for Cloud-HPC and Cloud-QC integration to make supercomputers easy to use for non-traditional HPC users, e.g. SMEs working with data analysis, generative AI, or data streams from the compute continuum.
- **Monitoring:** Fine-grain, non-intrusive and holistic monitoring and analysing of performance and energy data down to the application/job/workflow level, and advanced data analysis to determine performance, energy, and resource consumption

patterns and create actionable recommendations for application developers, end-users and system operators.

- **Security:** Software monitoring and protecting the security of systems and detecting and responding to incidents and intrusions related to the EuroHPC infrastructure.
- **Support European processors:** Complete and highly optimised (in terms of performance and energy use) software stack for European processors, including compilers and libraries, application and system runtimes, application frameworks and programming environments.
- **Standards:** Activities to achieve and maintain a leading influence in standards for frameworks and programming models and their implementations for HPC, AI and QC.

5.6.2.1 *Quantum Computing Software Technologies*

As quantum computers are added to the EuroHPC infrastructure, a comprehensive SW stack must accompany these computers to enable also non-expert application developers. User interfaces, libraries, debuggers and validation tools, high-level programming models and languages are needed, as well as compilers that translate high level languages to QC circuits for a specific QPU-technology, and transpilers⁸ that optimise already compiled circuits for that same dedicated QPU technology. Although some of these tools already exist, their maturity level (TRL) is relatively low, and additional developments will be needed when larger quantum computers become available.

Hardware abstraction: The plethora of QC solutions requires many of the SW tools to be designed targeting specific modalities. However, it is important to abstract HW-specific parts of the SW away from the end user. These abstractions are fundamental for the uptake of the QC technology. The complete toolchain described above, with clear interfaces, paired with the appropriate level of abstraction, will also allow experts to develop SW components for where their expertise lies, be it in the quantum, computer science, or application domain.

Scheduling software: The system-related SW is closely related to the QC hardware and to the fine management of the compute resource provided by the QPUs. This leads to a classical schema where a computational task must be submitted to a limited and expensive computing resource. The HPC world addresses this kind of situation with efficient scheduling mechanisms, which handle waiting queues fairly and optimise the usage of resources. In hybrid HPC/QC environments, multi-level schedulers need to take care of the different time restrictions that occur in a hybrid Quantum Computer Science (QCS) program (e.g. between shots, iterations, offloaded tasks). To this end, the definition of a standardised approach, which considers the different characteristics of each type of QC hardware, such as the sampling rate, qubit connectivity and qubit number, among others, is required.

Quantum emulators: In recent years different emulators have emerged: SW-based, GPU-based, and FPGA-based. SW-based emulators use methods like decision diagram-based

⁸ Transpiler is another name for source-to-source compilers.

simulators to reduce memory needs by finding patterns in state vectors and quantum gates. GPU-based emulators use Single-Instruction-Multiple-Data (SIMD) to increase parallel processing in matrix operations necessary for quantum circuit simulation. FPGA-based emulators also use SIMD techniques and special designs to make the most of the sparse nature of gate matrices, cutting down on unnecessary operations and processing time. Even with these improvements, scalability is still limited by memory and execution time. To simulate large quantum systems, the use of modern and powerful HPC systems is necessary in order to mitigate the exponential cost of these simulations⁹. In the future, emulators will remain important for refining quantum computing models. Unlike real QCs, emulators allow step-by-step analysis of quantum algorithms with high accuracy, including phase information. Emulators with noise models are also valuable for engineering new quantum technologies, as they provide performance insights by varying physical parameters. Moreover, emulators enable tracing the state of the circuit at any point for debugging, which is not possible on actual QPUs. Most available emulators, although being open source, are developed by QC manufacturers and often lack support for HPC implementations like distributed computing and GPU acceleration. EuroHPC should support the development of a fully parallel, accelerated (open source) emulator, needed for the rapid adoption of quantum technologies. Such an emulator should be able to address challenges imposed by major qubit modalities, for instance through compatibility with several different noise models.

Middleware: QC middleware should leverage the experience that already exists in HPC and should make sure that it can be easily integrated in this previously existing framework. The dichotomy between user-related and system-related middleware makes it necessary to explicitly define the interface. De-facto standards are currently emerging, such as OpenQASM [80] and QIR [81], but there is no consensus at the time of writing. QC middleware should also expose solutions to emulate on HPC systems the behaviour of quantum applications running on various QPUs. This use of emulators is helpful for: 1) application development, 2) validation of applications before running on QC HW, 3) debug and profile a quantum job, and 4) validate the correct execution of a quantum program by comparing emulated and HW results.

Middleware and runtime systems: the successful HPC/AI/QC integration depends on middleware that can account for the different QC modalities, as well as integrate to existing HPC frameworks. Runtime systems available today are often rudimentary, and specific to QPU modalities. The development of middleware and runtime systems need to look for common interfaces that can be used across modalities as much as possible. However, all interfaces need to be flexible enough not to have unwanted and unnecessary negative impact on the performance of any QPU modality. Recently several regions in the world started to invest in middleware development, as well as global enterprises. For Europe to remain in the lead on hybrid HPC/AI/QC computing, it is imperative that investments in the middleware are

⁹ The largest simulation of a quantum circuit used 0.5 PB of memory to simulate 45 Qbits, see [85]

prioritized. The development should leverage the experience of the HPC community and target a solution compatible with QEC and FTQC.

Error mitigation and correction: EuroHPC shall consider providing holistic integration calls with the mission to build generic as well as HW-specific SW stacks, including state-of-the-art Quantum Error Mitigation (QEM) and Quantum Error Correction (QEC). The goal is to establish efficient co-design of applications within the framework of a co-evolving HPC/AI/QC community, and requires tight collaboration between European HPC centres, academia, institutes, QC HW and SW startups, and SMEs. The overall aim is to build European HW/SW-collaborations that can compete at the forefront of the global state of the art of large-scale demonstrators and make deeply educated decisions regarding future quantum-system procurements.

Standards: International standard bodies are currently working to define standards for quantum technologies. In order to safeguard European developments, EuroHPC should engage and/or support European QC communities and private bodies (QuiC) with these efforts to ensure proper representation in these discussions alongside with several members states that are already involved into standardisation activities within European bodies like CEN/CENELEC. It should be noted that eventual standards will also play a role in the technical definitions of export controls, which already significantly affect the QC market.

5.7 Applications

Main Recommendations for 2026-2027 period:

- Strengthen the funding of the application pillar by rebalancing the funds with respect to the infrastructure procurements as to make best use of the procured infrastructures.
- Support the communities in their effort for developing, porting and optimizing their applications to the currently predominant HPC system architectures with tools, libraries and methods that will ease adaptations in the future.
- Support the integration of HPC experts into the scientific communities, allowing thus for a strong interaction between application domain, software and architecture experts, which is crucial for the development of exa-scale ready applications.
- Support the optimisation of foundational models on HPC platforms and support the integration of AI approaches in HPC applications (e.g. AI-hybridization, fine-tuned the generated foundational models, ...).
- Support the growth on QC applications, both in stand-alone and hybrid HPC/AI/QC contexts.

Looking beyond 2027, develop and promote frameworks based on separation of concerns between scientific coding and technical computing implementation, to facilitate the sustainable development and automated porting of domain applications in the ever-more heterogeneous infrastructure world of future, including its AI and QC capabilities, EuroHPC platforms and their efficient exploitation.

The success of any technological infrastructure is determined by its impact on science, industry, and society. To date, Europe has a strong record in application development and is world-leading in many academic and industrial domains. To maintain this position, constant efforts are needed as applications must adapt to new HW technologies, incorporate new algorithms, libraries, and scientific methods, and improve their efficiency. While the question of the right balance between exploring/developing new technologies and critical performance for traditional applications should be raised with societal value as a guiding principle, supporting scientific and industrial communities to ensure that they can run and optimize their applications on EuroHPC platforms remains crucial.

Community heterogeneity: The European HPC user community is not a homogeneous body; it spans a broad spectrum of skills, knowledge, and experience in developing and using HPC, AI and QC applications. The scientific communities work with legacy codes, which brings challenges and limitations. HPC for numerical simulation, unlike the younger AI area, has a strong and complex application and software basis. The challenges to be addressed now are

preparing existing codes and applications (academic and commercial) for the current and future HPC/AI/QC architectures deployed by EuroHPC, and designing new algorithms and methods that run and scale on future platforms and that are fit to tackle upcoming scientific challenges. This effort should be based on scientific and industrial cases giving a prospective on the scientific and industrial questions targeted by the user communities. The goal is to have a rich set of commonly used applications in key scientific and industrial domains relevant for the European industry, supporting existing users as well as emerging ones, readily available on EuroHPC systems and using these efficiently.

Continuous dialogue with application communities: A continuous interaction and link with the user community and EuroHPC is crucial to ensure adequate support for Europe's evolving and rich application ecosystem. This also allows to align the R&D strategies with the user's needs, and swift and prompt uptake of new technologies and services (AI, QC neuromorphic computing, ...). This dialogue should also cover topics such as federated services and improved interconnect between EuroHPC sites. The User Forum and its Coordination Group represent a key player in this dialogue and need to be better connected with existing projects involving users. It is also important to connect and better coordinate the different initiatives and communication channels (e.g., NCCs, CoEs, Lighthouse projects, User Forum, user support projects etc.), taking into account the various players (e.g. users vs. application developers, HPC vs. AI focus, etc.).

Funding instruments: In 2024, the set of funding instruments for the application pillar has been updated. The main funding instrument of the application pillar remains the Centres of Excellence (CoEs) in different flavours, complemented by the Lighthouse Codes. Additional calls, for example for innovative algorithms and for transversal libraries, are planned in the coming years. This effort must be even increased to rebalance the funding toward applications. Only by doing so we can, on the long run, ensure an effective use of the EuroHPC platforms by the real applications and therefore a positive and significant impact on society.

Embracement of novel computing hardware: Stimulate the usage of novel (and possibly disruptive) computing hardware, such as quantum devices, neuromorphic computing or other accelerators for specific AI tasks, as well as their integration into the HPC software and application stack.

5.7.1 HPC Applications

The lifetime of applications can easily span decades. Therefore, all development activities require long-term planning and a sustained effort beyond the typical duration of 3-4 years for EuroHPC projects. This is even more important now, as acceleration, improved performance and energy efficiency depends on better and faster systems, as well as on optimised applications.

Recommendations: To address the challenges associated with the increasing complexity of software development on heterogeneous HPC architectures, the general shortage of skilled developers and the general objective of achieving more modular, reusable, reliable, and higher quality software, EuroHPC shall:

- **Portability and scaling:** support HPC codes, applications, and tools in all phases needed to achieve highest computing and data processing performance, and energy efficiency up to extreme scales (i.e. co-design, development, incorporation of new methods, exploiting low/mixed precision, porting, re-structuring, optimisation, upscaling, interoperability, re-engineering, etc.). More funding must be provided to ensure that applications reap the full benefit of new computing platforms, considering the constraints of the communities' legacy codes, but also to retain personnel qualified to deploy these applications on these platforms on the long-term.
- **Code modernization and separation of concerns:** provide help to restructure the codes, where possible. The vision is to have science coded by scientists, using an abstract high-level language, in mini kernels that would be assembled by a software framework handling the technical part of the code (e.g. parallelization, I/O, data structure, ...). Then, the porting to new architectures could be realized by “only” adapting the implementation of the software framework. This approach would favour the “separation of concerns”, with the scientists focusing on science and the infrastructure being developed and ported by computing scientists. New, more modern alternatives from Fortran, such as Julia, C++, Python, Rust should be considered, although with caution. AI should also be exploited at different degrees (AI-HPC coupling, AI used for code generation, AI used as black-box neural networks, ...) for improved quality, portability, and efficiency of the codes.
- **Software engineering standards:** support the user communities in their effort to apply common software engineering standards and best practices with respect to code development, modularization, integration, and deployment including automated testing. Such standards must emphasise software quality in terms of delivered performance and energy use and build upon the tools and procedures that have already proven useful in the different communities.
- **Increased interactions between experts:** favour the cooperation between the different levels of experts from hardware experts to application experts via system software experts. This requires increased porosities and cross-training between the different communities and would, in particular, favour sharing of best practices.
- **Data management:** favour a better integration of application domain specific data lakes with the applications in the EuroHPC computing ecosystem, and transparent connection with different sources of data. Informed data management is also essential to cope with the deluge of data in all parts of the workflow. This requires new tools and mechanisms for simplified, yet efficient and performant, interfaces to access and manipulate data.

- **Novel algorithms and applications:** support the development of novel algorithms and applications, especially in areas where HPC has not been yet exploited and where there is an opportunity to enlarge the portfolio of European applications and algorithms. A sample area is electric power systems (EPS) where (HPC) is not a standard part of the toolboxes employed.
- **Workflows:** promote new frameworks for the development of complex scientific workflows that combine different application components, possibly of different nature (HPC, AI, HPDA) to be executed inside large allocations in a single supercomputer. Those frameworks should address challenges related to the efficient use of the new heterogeneous and complex HPC systems, with malleable, elastic execution and dynamic allocation considering performance as well as energy cost. Support new usage methodologies for interactive execution based on workloads, especially for AI workloads or converged HPC+AI ones.
- **Benchmarks:** consider new methods of benchmarking relevant for actual HPC/AI/QC use cases. Today, the evaluation of our HPC systems performance is mainly based on indicators, such as theoretical floating point operation performance or synthetic benchmarks (e.g. HPL). New benchmarking criteria measuring the results of real use cases, based on realistic workloads (for instance including I/O) and considering also the carbon footprint should be developed. Application communities should spend effort developing domain-specific benchmarks, including full use cases but also mini-apps for rapid measuring of memory bandwidth, I/O throughput, time-to-solution and energy-to-solution on different architectures. These benchmarks would favour co-design across the whole stack of players from hardware vendors to domain experts, so that new architectures and software genuinely benefit European flagship applications. INFRAG and RIAG welcome the launch by EuroHPC end of 2025 of a benchmark initiative for HPC/AI/QC but recommend a long-term support for the maintenance of the set of applications/mini-apps being selected as European benchmark.
- **Transversal libraries:** Fund and promote the development and porting of transversal libraries with higher TRL for applications to accelerate readiness for new architectures and address cross-cutting elements, such as energy efficiency. Examples are libraries for emulation of high precision using low precision arithmetic, code verification, automatic optimization of code deployment, or data compression, but also system libraries e.g. communication or workflow engines libraries. Special care should be taken to ensure the composability of the different libraries; indeed, too often each library assume a complete control of the application deployment and the combination of multiple libraries introduces hard usage conflicts. Mechanism for supporting and evaluating the uptake of these transversal libraries by the user communities are to be considered too.
- **Energy efficiency:** Support application developers and end-users in achieving meaningful reduction of energy use through new methods and tools applicable by the

targeted users, and not just a top cadre of specialists. Effective training should play a large role here, too.

- **Security:** Support the user communities in improving application security and preventing misuse and cyberattacks. This can be achieved for example by stronger access control, isolation of workloads, code signature, encrypted containerisation, or safe distribution of certified software and applications. Paradigms such as “confidential computing” shall be more widely supported.

In addition to these recommendations, we see some specific challenges related to the increased importance of AI and of Quantum Computing in HPC.

5.7.2 AI Applications

EuroHPC aims to achieve excellence and maintain European world-leadership in HPC/AI/QC applications that are key for European science, industry, and the public sector. In particular, these applications need to integrate the worlds of simulation and AI to facilitate hybrid workloads, such as AI-complemented simulations or larger workflows consisting of alternating AI/ML and HPC steps.

Recommendations: The following objectives need to be pursued:

- **Foundation and Frontier AI models:** Support the development multimodal, reasoning, and agentic foundation models made in Europe. These models should be applicable to a variety of domains (science, healthcare, education, public administration, among others) and have strong performance across European languages. This can be pursued either through a “universal” single model (à la the Trillion Parameter Consortium, TPC) or via several models depending on relevant domains and underlying scientific principles. These models are the cornerstone of specific AI applications and will thus provide a solid, trustworthy and sovereign basis for a wide variety of European AI tools at large.
- **Specialisation and optimisation of models:** ensure the maintenance and continuous improvement of the frontier models above and strongly support the specialisation of such models in science and industry (finetuning, post-training, and test-time scaling) for increasing applicability in real-world problems. Develop replicable recipes for post-training and optimizing these models so that they can be integrated across a wide range of use-cases and application areas. The optimisation aspect is particularly important such that European infrastructure investments are utilized to their full potential.
- **New domains:** Identify application areas that need additional AI-support, to enhance or develop new applications, meeting diverse European user community needs.
- **Interoperability:** Develop common APIs that allow interoperability of Big Data and AI workloads, which are typically deployed in public clouds and European Data Spaces [55], with HPC/AI infrastructures.

- **AI-assisted code development:** Develop AI tools to accelerate application development using agentic AI or vibe coding tools. Ensure the wide adoption of AI-assisted (sometimes called AI Co-Scientist) tools to enhance productivity and accelerate scientific discovery and research.
- **Agentic AI for Science:** support the development of agentic AI targeted to help solve scientific and engineering problems, and encompassing agents focusing on pure HPC simulations, pure deep learning, or hybrid approaches (blending domain knowledge with simulations).

5.7.3 QC Applications

More and better quantum applications and use cases are needed for a wider adoption of the deployed EuroHPC quantum computers. European Quantum Excellence Centres (QCoEs) [82] shall bring users of quantum technologies together and train a growing skilled workforce able to develop new applications for QC, applying SW engineering principles, and foster knowledge and uptake of QC. These QCoEs should develop quantum applications that can solve real-world problems. This could involve collaboration between QCoEs, HEs, and industry partners to identify challenges that can be addressed using QC and then developing applications that can solve those challenges. Quantum programming facilities and application libraries, especially if released open source, help developers to create new quantum applications. The EuroHPC QC platforms acts as testbeds for quantum technologies and serve as software development platforms for both middleware and applications.

Application development should focus on use cases providing the most foreseeable advantage in a relatively short term, as well as studies of new qubit technologies.

Quantum Computing applications: The mathematical areas for QC applications are in the realm of the simulation of quantum systems (e.g. quantum chemistry and materials science) and in optimization (e.g. of quantum systems such as spin glass but also for e.g. logistics problems.) Quantum Machine Learning (QML) is another active field of research, although at somewhat lower TRLs than the other possible applications. Several leading QC system vendors, define AI/QML applications as a priority. To keep alignment with this development, it would be important to launch R&I calls for developing QML, optimization and quantum material applications, also with the prospect of running on fault tolerant QC that could arrive at the end of the decade.

AI for quantum computing: It should also be noted that classical AI can be very useful for designing QC hardware and processes (qubit frequencies allocations, optimising qubit control, etc.). AI techniques are also used on the software side, supporting the initial preparation of variational quantum algorithm ansatz, quantum gates synthesis, code transpilation, and optimization prior to computation. Moreover, after the QC computation AI can be used to perform quantum error mitigation and detection, variational algorithm ansatz tuning, or quantum sampling. A call addressing AI for QC and QC for AI should allow to explore different couplings of these two groundbreaking technologies.

Recommendations:

- **Hybrid HPC/AI/QC:** EuroHPC should support experts from HPC/AI/QC startups, academia, and end users (including SMEs and large companies) in developing proofs of concept for novel hybrid HPC/QC applications. Quantum-inspired algorithms enable using powerful quantum information processing techniques on classical HPC hardware. Therefore, quantum-inspired approaches for HPC and AI must also be supported, as they lead to improved solutions for classical problems and to more efficient classical simulation of QC.
- **QC benchmarks:** Progress in application development and experimentation should be the basis for defining a broad set of application-centric benchmarks in close cooperation with the application communities, avoiding to prematurely lock into a particular technology or algorithm. Benchmarks are used in HW-SW co-design, essential for the success of both QC devices and applications. They are also needed to establish a widely acknowledged ranking system, mature and flexible enough to accommodate future technological developments.
- **Quantum Applications:** Setup mechanism to foster and accelerate the development of End-User applications in the Quantum Centres of Excellence / Quantum Competence centres, by grand Quantum Application Software challenges and other incentives.
- **Quantum Middleware:** Define this Software as a strategic gap in the European ecosystem and build a grand challenge to migrate these topics from the academic domain to a productized industry / startup-domain. We have learned for the cloud vendor lock ins, that this software layer is crucial in the interaction between Hardware (QC + HPC) and application layer, and if we don't have this expertise in Europe we end up in a similar situation as the cloud platforms are today.

5.8 Usage and Skills

Main Recommendations for 2026–2027 period:

- Provide specific training and education to grow the pool of hardware, system software developers, and HPC, AI, and QC system administrators, building upon IT and STEM curricula. Federate European and national training and education for HPC, AI, and QC to exploit synergies between different initiatives.
- Initiate, in 2026, a structured bottom-up consultation process to prepare for the post-exascale era, with the objective of identifying strategic use cases across scientific, industrial, and public-sector communities, and consolidating application and service requirements in HPC, HPDA, AI and QC.
- Support the hybrid HPC, AI, and QC environment via projects that pull together QC Hosting Entities, AI Factories and NCCs to foster collaboration between HPC/AI and QC. Extend more largely European HPC masters with QC and AI topics and provide training and education instruments for HPC and AI specialists to learn how to use QC systems.
- Provide specific training and education instruments for AI specialists to learn how to efficiently use HPC resources extracting maximum performance to lowest energy consumption and carbon footprint.
- Ensure continuous investment in support structures for HPC, AI, and QC users, making it clearer which projects and initiatives exist and what their respective responsibilities are.

Looking beyond 2027, intensify the investment in a growing and diverse pool of HPC, AI, and QC experts, particularly by developing attractive career paths and long term-perspectives that motivate young talents to enter and stay in the field. Establish a long-term collaboration between AI Factories and AI Gigafactories in the provision of AI services, including user support and training.

To enhance Europe’s competitiveness, boost its technological and data sovereignty, and strengthen European innovation, the European HPC ecosystem made up of EuroHPC, Member States, HPC research institutes, HPC users, CoEs, AIFs/AIFAs and NCCs must work together to generate a highly knowledgeable, world-leading scientific and industrial community capable of advancing HW, SW and applications, and provide training and support at different maturity levels. In particular, EuroHPC shall support the development of digital skills, professional training, and education, attracting engineering knowledge and human resources to HPC in Europe and increasing Europe’s workforce skills.

Consultative groups: To increase involvement of existing and new users, EuroHPC established in 2024 a new consultative group consisting of a User Forum. This group supports RIAG, INFRAG and future QTAG, and provides reliable, sustainable feedback to the governance bodies of EuroHPC on current and future infrastructure and software requirements and give

strategic advice for the development of targeted use cases and a renewed scientific and industrial case. They will also serve to disseminate the range and availability of EuroHPC infrastructure, training, and skills to new and existing user communities. In that aim with the rise of QTAG it will be crucial to avoid siloing quantum technologies inside a standalone advisory group but much more like for HPC and AI into INFRA and RIAG to establish bridges between the three consultative groups of EuroHPC. Same concerns could be raised for AI where one day a possible AIAG on Artificial Intelligence could appear with the rise of AI Gigafactories.

Key use Cases: As EuroHPC will end its second period with the deployment of two exascale systems, several first quantum computers and a set of AI-optimised supercomputers in the field of AI Factories, the next regulation could aim to deploy so-called post-exascale systems across Europe. While post exascale concept is not fully defined yet it could be important for EuroHPC alongside with R&I projects on new technologies to launch a wide consultation, for gathering key use cases among scientific, industrial and public services end users communities in order to gather their needs and expectations in terms of HW/SW technologies and services. This could lead to a European definition of the post-exascale concept consisting not only of more powerful or more architectural-diverse/tailored systems but also on a new generation of services provided to end user communities.

5.8.1 National Competence Centres (NCCs)

Motivation: It is essential to extend the use of supercomputing to a wider range of scientific and industrial users, for instance by helping SMEs develop innovative business cases using supercomputers and providing them with training opportunities and critical HPC/AI/QC skills they need. Investment in HPC NCCs is promoting a wide coverage of HPC/QC activities and expertise in the EU and is providing specific services and resources for industrial innovation (including SMEs). With the advent of AI Factories, the NCCs are no longer responsible for the dissemination and enabling of AI technologies. Special attention is needed to prevent too many one-stop shops from emerging in Europe in the areas of HPC, AI, QC, etc., where end users ultimately lose their way.

History and role: The NCCs were created by the EC in 2020 and were strengthened in 2022 to prioritise and support exchange of best practices, to foster the uptake of HPC solutions by startups, SMEs and large companies, the sharing of existing libraries of HPC codes, and access to upgraded HPC application codes. They facilitate access to the best HPC/AI/QC codes and tools and innovative scientific and industrial applications in collaboration with CoEs and the European Digital Innovation Hubs (EDIHs) [83]. This includes federating capabilities, exploiting available competences, providing user input into the development of HPC technologies and applications, and ensuring that application knowledge and expertise have the widest geographical coverage in Europe. HPC Competence Centres and HPC Hosting Entities work together to facilitate access to large-scale HPC enabled pilot demonstrators and testbeds for big data applications and services in a wide range of scientific and industrial sectors. More

recently AI Factories have been entitled to perform the same mission as the NCCs but for AI domain, alongside to the EDIHs doing also enabling and community support.

Recommendation: To foster the convergence between HPC, AI, and QC, it's important to rationalise and simplify the number of one-stop shops and marketplaces setup in Europe. European users have the feeling of being lost by so many uncoordinated initiatives. In that aim, EC should rethink its strategy between all involved parties (NCCs, CoEs, AIFs, EDIHs or projects like Deploy AI or Dome) to provide ideally a unique one-stop shop or EU gateway to HPC/AI/QC services in Europe.

5.8.2 HPC skills

Motivation: The development of a skilled workforce is one of the most sustainable investments in HPC/AI/QC with the potential for long lasting impact in a rapidly changing environment. Europe needs skills in highly specialised HW and SW development to support HPC/AI/QC infrastructures, federated resources and services, technologies, and applications. Europe needs an increase in HPC skilled workforce that is diverse, and gender balanced. This workforce is critical to support the design of emerging European HPC technologies, to stimulate interaction with application communities and ensure optimal use of HPC/AI/QC systems on EuroHPC platforms, and to provide adequate support to users.

Build upon IT and STEM: Training, skills, and support is a cross-cutting topic relevant to HW and SW technologies, applications, including areas such as AI, data, cybersecurity, or QC, and not forgetting large system administration and computing centres operations. Proximity with more general Information Technology (IT) or Science, Technology, Engineering and Mathematics (STEM) areas should be leveraged, e.g. by connecting with existing curricula in broader IT or STEM areas that could offer HPC extra specialisations to complement EuroHPC efforts. Lifelong perspectives must also be considered, facilitating periodic re-training or on the job training, and circulation between academic and industrial sectors.

Status Quo: EuroHPC has launched three calls in support of these objectives: the EuroHPC Professional Traineeships and EuroHPC Training Platform and Summer School [30], and the EVITA EuroHPC Virtual Training Academy [31]. On top of these, the CoEs offer specialised training for HPC specialists as well as IT and data professionals, application developers, and advanced users of HPC applications. At this stage as these initiatives have been launched recently INFRAG and RIAG do not have additional recommendation to provide.

Training material repository: To exploit all the above sources and leverage the HPC training materials developed in the European projects (e.g. R&I project, CoEs, AIFs and NCCs), a portfolio of common European HPC training material should be established. EuroHPC shall create, implement, and maintain a reliable and long-term repository to safely store all the existing and future training materials and make them available to the European citizens. This facility could also accommodate HPC training material provided by the Participating States.

Master Program: The **EUMaster4HPC** [27] is educating the next generation of HPC experts and already celebrated the graduation of its inaugural cohort in 2024. EuroHPC launched a new call for the following phase of its Master Program with a new proposal EUMaster4HPC2 being selected. INFRAG and RIAG believe it is important to extend their scope beyond HPC to include AI and QC, which are now part of their field of activity, and to be more ambitious on the number of students trained per year (targeting ideally more than 200 students graduated per year). This is vital for ensuring that a regular flow of skills will feed the activities of the infrastructure and of the European HPC ecosystem at large, ensuring gender equality and inclusiveness of all countries. This ambition comes also with mandatory efforts of raising awareness about such a pan-European program and appropriate career plans among academia and industry.

Talent creation and retention: in a field of a fierce global competition on skills, more actions shall be considered to attract, develop, and retain a European talent pool in HPC and AI and develop viable and rewarding career paths for Research Software Engineers (RSE) and other key roles. These new career paths could encompass both public and private assignation to make such careers more attractive, especially in the field of the upcoming relations between AI Factories and AI Gigafactories.

In addition, appropriate support (on different maturity levels) in using the EuroHPC infrastructure and applications needs to be provided. Support to increase EuroHPC competences will also come with the NCCs and will support the European ecosystem of users and developers. These efforts need to be paired with pan-European activities to coordinate user support, from a beginner to advanced levels, provided by HPC centres (both EuroHPC and national/institutional) and technology and application projects.

Recommendations: EuroHPC shall consider actions in the following domains:

- **Specialised training for HPC specialists** should be continuously offered, from technology developers to computing centres staff (HPC sysadmins, HPC engineers), to software and application developers, and to advanced users of HPC/AI/QC applications and related topics.
- **Performance and energy efficiency:** Skills to support development of performant, energy efficient and sustainable solutions in HPC technology and application design must be promoted, in the interest of reducing the energy and Carbon footprint of the HPC/AI/QC infrastructure. Actions should make developers of applications and workflows as well as end-users aware about the energy used by their applications or their use of these, educate them on methods to optimise these aspects through changes in application codes or application usage, and provide incentives for investing effort in reducing the energy/carbon footprint of their HPC/AI/QC-related activities. Such training must emphasise the importance of efficiently using available infrastructure resources, in the interest of achieving high performance and at the same time reducing energy use.

- **Industry-specific training:** Short-term, industry-specific training schemes, for example combined with consultancy and trial use of HPC infrastructures through hosting entities and competence centres. SME-tailored courses and support offerings like staff exchange programmes with research and academia could be offered. For end-user SMEs, this could include hands-on training and solving real use cases, developed in cooperation with the competence centres and the European Digital Innovation Hubs.
- **Mobility:** Encourage mobility and supporting training projects that also include the opportunity to study/train in another European Participating State. Opening such programs internationally to talented people would be beneficial. Such mobility programmes could also encompass mobility between public and private entities.
- **Skills for emerging and hybrid approaches:** Skills for emerging technologies such as quantum computing should be considered, as well as those combining HPC and other related technologies (AI, QC, data, cybersecurity, etc.). Such new tracks could include knowledge exchange programs, educational programs (e.g., [84]), knowledge databases (wikis) and other projects that bring these communities to work together. Create either a dedicated education program for SW engineers in quantum technology or extending the EUMaster4HPC programme with QC content.
- **Sustainable career paths** with reasonable and competitive conditions. The development of a European talent pool must be a permanent and overarching objective in HPC, AI and QC. The creation of a European job market for HPC professionals shall be considered, with rewarding career paths for research software engineers and other key roles.
- **Recognition of (open source) software** development/publication with the same weight as scientific writing/publishing. Unfortunately, in academia, financial resources are often available for researchers but not for software engineers. The academic career path of RSEs is also more limited than that of researchers.

5.8.3 HPC training for AI users

New cases relevant to the AI and data communities, and for which HPC resources and methods are relevant and will grow tremendously. This can include training of large language models, model development, cross-training of data sets and models, bias detection and quality assessment of trained models, monitoring and early detection in federated models, validation, and test of accuracy against simulations and complex digital twins. It is essential to provide broad diffusion of how HPC competences and approaches can augment and accelerate existing ambitions or provide new sources of revenue.

Regarding AI uptake the challenge of using HPC infrastructures by the AI community will rely on three key factors: 1) the availability of converged HPC/AI supercomputers, 2) revised access modes for the AI community, and 3) HPC experts able to support the AI research groups in optimising and scaling out their models. Of these three aspects, the third (support of AI research by HPC experts) can be the strength of EuroHPC.

Recommendations:

- **Upskilling programmes** for existing profiles from AI model developers, AI quality managers, Database engineers, Data Scientists, etc. AI model developers, AI governance and compliance professionals, and in particular large dataset architects, should have access to HPC education and training. Different modalities from initial training to on-the-job training are to be considered, to match the different stakeholders needs, from deep technical specialisation to agile training for swift uptake by private companies. Support must come at national and European level for the full ecosystem of users and developers.
- **HPC material for academic AI curricula:** Develop off-the-shelf content and structures to include HPC teaching within existing academic programmes at undergraduate and post-graduate courses related to AI and Data for mass uptake across education establishments in all Member States.
- **Energy/Carbon efficiency:** Ensure that efficient use of resources and minimisation of energy/carbon footprint is considered by HPC and AI professionals as an important factor. These AI-training activities should also teach application developers and end-users how to select methods to tackle a given problem with efficient use of resources and energy in mind¹⁰. In a similar vein, energy used for ab-initio or recurring training must be amortised across many uses of a trained model, and such analysis should impact the selection of AI approaches and training schemes.
- EuroHPC shall also consider a **training certification scheme**, which could be adopted by all European actors and should be embedded with the digital identity of the user giving possibility to access the European HPC systems based on the level of knowledge the person obtained. In the case of AI and data arena, it is recommended to develop a certification alongside such upskilling programmes for AI and Data professionals as part of Continuous Professional Development.

All the above activities, while focused on European participation, need to implement the state-of-the-art in learning methodologies, including alternative forms of learning (e.g. student-centred instruction, participatory learning, hands-on learning, open learning) should be implemented.

5.8.4 Users

User support: Users of the EuroHPC infrastructure require support, tailored to their knowledge and problems at hand. This includes first and second level support to be provided by the infrastructure providers as well third level support, currently partially provided by the NCCs and projects like the CoEs. EuroHPC develops a structure covering all levels of user support and shall fill the existing gaps with appropriate actions. This has started with projects

¹⁰ Traditional ML techniques like regression or clustering can address certain data analysis problems with less energy use than more powerful, yet also power-hungry DL-based approaches.

like EPICURE [24] (up to level 3 support) and the MINERVA support centre for AI launched in 2024. Given the growing number of instruments for user support, EuroHPC should clarify the role of different support services provided locally by the HEs and AIFs, versus those provided at pan-European level, as well as to rationalise and pool certain actions between the NCCs, EPICURE, MINERVA, and CoEs.

Co-design and technology adoption: a fluent communication should exist between the application communities (both users and application developers), and the user support teams in HPC sites, as well as with hardware and software developers. This would help developers of European software and hardware solutions (see Technology Pillar in Section 5.6) to understand the end-user requirements, and vice-versa facilitate the adoption of the developed solutions by application communities. Currently this communication role is being played by, e.g., the CoEs, and it should be ensured that such communication channels continue existing in the future.

Energy efficiency: End-users play a significant role in limiting or even reducing the energy/carbon footprint of the EuroHPC infrastructure. They must employ it in a responsible way, e.g. by avoiding jobs/workflows configurations that lead to inefficient use of resources and energy waste. To achieve this, training in best-known-methods for HPC/AI/QC system use, tools providing actionable feedback, and user incentives (e.g. [85]) are necessary.

User Forum: the EuroHPC User Forum was launched in 2024 to promote knowledge exchange, professional development, and collaboration within the European HPC/AI/QC communities. It is constituted by users from academia, industry, and public sectors, as an open institution, inclusive, independent, transparent, and responsive to the needs of its members. The EuroHPC User Forum is led by a coordination group of 12 members representing various communities from academia and industry, numerical simulation and AI, traditional end user communities to new ones including humanities and social sciences. Activities started during EuroHPC User Days in October 2024, and several actions have been initiated (e.g. to encourage efficient use of HPC resources, and to gather HPC/AI user and application needs). Regular meetings with INFRAG+RIAG (and future QTAG) ensure a proper feedback loop with inputs and user surveys that are used for MASP updates or advice to EuroHPC Work Programs.

Special care must be taken in supporting User Forum activities and increasing representation of industry and new communities like public services or QC, e.g. with support from ETP4HPC, BDVA, and QuiC.

5.9 International Cooperation

Main Recommendations for 2026-2027 period:

- Following respective agreements with EC extend international cooperation to the regions of Latin America, South Korea, Singapore, Africa and Canada, covering HPC, AI and QC, and ensure not only strong scientific/technical collaborations but also political support.
- Launch in 2026 a program call for supporting additional global initiatives with existing AI Factories.
- Support collaboration with international initiatives in a manner coordinated at European level, particularly in the area of AI (e.g. TPC [86]) to secure positioning and ensure visibility of European developments and interest.

Looking beyond 2027, implement means to exchange compute cycles with international collaboration partners, allowing users from outside Europe accessing the EuroHPC infrastructure and, reciprocally, European HPC users to access infrastructures abroad.

In line with the EU's external policy objectives and international commitments, EuroHPC should define, implement, and participate in international collaborations on supercomputing to foster research addressing global scientific and societal challenges, while promoting the competitiveness of the European HPC supply of technologies and user ecosystem.

EuroHPC should support international cooperation in supercomputing between European and non-European partners in the following topics: scientific cooperation, EuroHPC R&I projects, reciprocal exchange of access time between HPC systems, exchange of young HPC professionals, and EuroHPC system procurements. It will also closely monitor activities related to the HPC sector as well as evolving user needs outside the EU.

Scientific cooperation: EuroHPC supports the continuation of the long-established tradition of full openness. This contributes to competence and technology building and addresses the European need for skilled staff at all levels from PhD students to senior engineers and scientists. Europe should strengthen its existing scientific partnerships (e.g., with Japan, India and in 2025 with Latin America and Caribbean countries in AI) and initiate broader scientific collaboration with aspiring HPC/AI regions (e.g., South Korea, Singapore, Africa in the field of the "Global Gateway" EU initiative or Canada) toward HPC global grand challenges or Frontier AI. Cooperation with countries that are part of Horizon Europe and/or EuroHPC (e.g. Canada) should be even more intensive. An important goal is to make the European HPC ecosystem as attractive as possible to worldwide talents in a context of a fierce competition to skills. This includes opening parts of the infrastructure to qualified international users, exchange of students/staff, and offering European training and education programs to qualified individuals irrespective of their nationality (but possibly linked to affiliations within member countries).

While first initiatives like the HANAMI project [32] with Japan established strong technical collaborations between partners it appears that on the political side where EuroHPC and the European Commission are supposed to engage in discussions with their Japanese counterparts (MEXT, METI) about sustainability and cross access to HPC resources, the situation was fully blocked. In 2025 RCC-Riken in Japan allowed European researchers to access to its supercomputing resources in the field of the HANAMI project while EuroHPC still does not allow it as just retour on its own resources. This should be corrected and better addressed in future calls.

Hybrid HPC/AI/QC: Cooperation activities shall now encompass HPC, AI, and QC. Building upon existing cooperations with Japan and India, EuroHPC should also, in a moving geopolitical context, develop international cooperations with countries like Canada, Singapore, or South Korea with strong national policies especially in AI and QC.

Technology development: While EuroHPC R&I projects should support the European digital sovereignty, it remains important to continue collaborating with international companies that actively contribute to the relevant fields of HPC/AI/QC, hence helping European HPC users and scientists to achieve the best results. Furthermore, one should keep the obligation for both European and international participants in European projects to disseminate the results and foster efforts to implement them into their products. EuroHPC should take a global lead in the international development and continuous support of open source software critical for the HPC/AI/QC stack and the establishment of community standards supporting the uptake.

HPC infrastructure procurements: for mid-range systems and exascale supercomputers, one can observe an imbalance in that Europe is a fully open HPC market, while the US, Japan and China remain firmly closed to non-domestic companies. While a reciprocal approach of EuroHPC in its procurements might at first seem natural, this is not deemed productive in the longer run. Instead, Europe should act in two ways: first, put pressure on the international actors to open their closed markets, and second, oblige international participants to provide added value to the European HPC ecosystem by explicitly collaborating with European companies and research institutions, in particular with European SMEs.

QC infrastructure procurements: For the procurement of quantum computers and simulators, it should be recognised that the EuroHPC region is leading the path to integrating these systems into HPC. As such, it is important to use this opportunity to benefit European businesses developing quantum technologies and procure these systems from companies based in the EuroHPC Participating States. A different approach is suggested for like-minded countries with a more nascent quantum industry, where quantum technology from EuroHPC states can provide strategic mutual benefit. In these cases, EuroHPC should consider working on activities with the objective of early adoption of cross-border technology by Participating States and partnering countries.

AI model development: EuroHPC should integrate international consortia on the development of massive multimodal foundation models for science, not only by bringing data

but also contributing to the development, training/fine-tuning, and inference of our own European open-source models. EuroHPC should also engage in a coordinated effort into international collaborations like the TPC [86], while preserving the interests of Europe in terms of the development of European models and the protection of data.

Training: With a requirement of reciprocity and *juste-retour*, EuroHPC shall ensure that its training activities are easily accessible for suitable international collaboration partners. Formal collaborations with foreign end-users should also include projects involving European HW and SW companies, thus fostering the development of European HW/SW solutions for HPC, AI, and QC (individually or as hybrid solutions), as well as their international uptake.

6 Topics cutting across pillars

Section 5 addressed each of the EuroHPC pillars separately, but these are tightly interconnected by a number of cross-sectional topics that run across several pillars (see Figure 3). This causes a level of repetition of terms and discussions in the text on these pillars. The following subsections shortly address the main cross cutting topics and should help to navigate the EuroHPC activities and pillars.

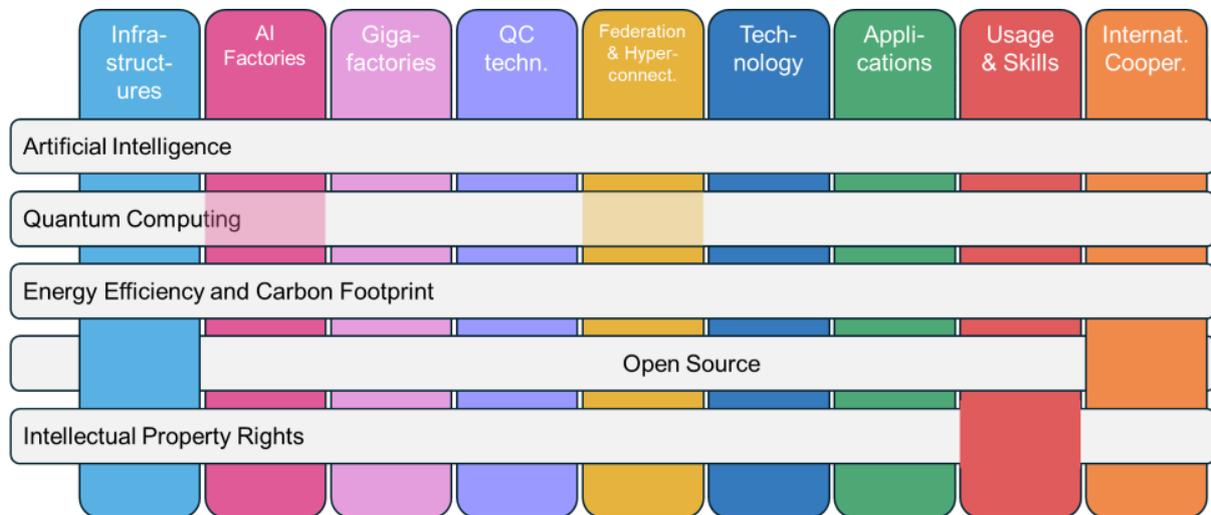


Figure 3: Pillars (vertical) and transversal topics cutting across them (horizontal). The pillars are discussed in Section 5, while the ‘transversal topics’ are summarized in Section 6. In this figure, a topic laying over a pillar (e.g. Artificial Intelligence over AI-Factories) is part of it. When the overlap is faded (e.g. Quantum Computing over the AI-Factories), it means that the overlap does not exist or is very weak right now, but that it should be intensified in the future. For topics laying behind the pillars (e.g. Open Source behind Infrastructures), the overlap is considered insignificant.

6.1 Artificial Intelligence

AI is strongly entangled with HPC at the infrastructure, technology, and application level, and for this reason is present and relevant to all pillars of EuroHPC:

- **Infrastructures:** HPC systems serve AI users, however the latter come with strong requirements regarding access policies and software environment, which are challenging for traditional HPC operators who need to evolve and upskill rapidly.
- **AIFs, AIFAs:** specific computing infrastructure and services for the AI community, with focus on industrial and SME needs but leveraging joint partnerships with academia and research centres to ensure true innovation.
- **AIGFs:** ultra-large-scale computing infrastructure developed for Europe’s most challenging AI ambitions.
- **QC:** AI workloads will be accelerated by QC infrastructures when these will become production-ready, but also AI may help QC platforms through AI-powered noise reduction and correction.
- **Federation and hyperconnectivity:** AI users need to run codes and have data on HPC, AIFs, private Cloud services, and even the edge. They require therefore unified user

access, access to common repositories of datasets/models and tools, and fast data transfers across platforms.

- **Technology development:** specific HW and SW solutions are developed for the AI-market, which may also benefit from the use of HPC methodologies and tools for optimisation, and make efficient use of energy and hardware resources
- **Applications:** AI has transformative potential for many application areas, both by using AI to modernize legacy applications with historical technical debt, and in accelerating applications by combining simulation (e.g. physics-based methods) with large-scale AI approaches towards the development of world agentic models and embodied AI.
- **Users & Skills:** to ensure adoption of AI, platforms must be both user-friendly and robust. Access to experts is critical for adoption of the provided AI platforms and AI software.
- **International cooperation:** is mandatory to keep up with the extremely fast evolution of AI applications and methods.

6.2 Quantum Computing

QC is an emerging technology that shall become intrinsic parts of HPC infrastructures, both as QC-centric machines and as accelerators for parts of HPC/AI applications. For this reason, same as for AI, QC is present in all HPC pillars:

- **Infrastructures:** QC systems are deployed across Europe, aiming at creating efficient state-of-the-art hybrid HPC/QC infrastructures.
- **AIFs:** QC aims at becoming also a computing infrastructure for AI, which means that it would be part of future AIFs.
- **Quantum technology:** the foreseen integration of the Quantum Flagship in EuroHPC, it will have to be well planned and integrated with the existing infrastructure and research activities around QC in EuroHPC, avoiding to create silos.
- **Federation and hyperconnectivity:** hybrid HPC/AI/QC infrastructures require unified user access and tight network connections (Quantum Interconnect) to facilitate offloading code from HPC to QC devices.
- **Technology development:** There is need for specific HW and SW solutions in QC, from prototyping of different quantum technologies up to developing quantum middleware to facilitate system operation and the deployment of applications. The term quantum middleware refers to the software layer responsible for the interaction between the QC and HPC, as well as between the hardware layer and the application layer.
- **Applications:** as a technology in early development stages, strong investments are needed in the development of QC applications. In the near future, several application areas such as Quantum Machine Learning, optimization and the simulation of quantum systems are expected to achieve results beyond the capabilities of classical

computers, thus enabling complex problems to be solved faster and more efficiently. A federated setup of HPC with QC will accelerate the possibilities.,

- **AI for QC:** Already in the short term, great potential lies in using ML and generative AI for optimising quantum circuits and algorithms to approach fault tolerance and quantum advantage (ML for QC).
- **Users & Skills:** specific training for the use of QC and hybrid HPC/AI/QC solutions is needed, both for system operators, HW/SW engineers, and application developers.
- **International cooperation:** is needed to make European QC developments visible worldwide and increase their chances to succeed in the global market.

6.3 Energy Efficiency and Carbon footprint

Given the significant energy consumption and carbon footprint of HPC/AI/QC infrastructures and its high growth rate, in particular in the AI sector, the environmental impact of these infrastructures is substantial. Therefore, efficient use of energy and minimisation of the carbon footprint clearly are supremely important objectives. It is critical to reduce total energy use and carbon footprint of the complete infrastructures across their full lifecycle and avoid the *rebound effect*¹¹. For this reason, energy efficiency must be addressed by all pillars:

- **Infrastructures:** HPC/AI/QC systems should be purchased with energy/Carbon efficiency in mind and must be operated in the most energy/Carbon efficient manner, co-optimising use of resources, energy consumption and the workload throughput. Use of Carbon-neutral or green energy sources should be maximised, where necessary supported by efficient energy storage solutions.
- **AI Factories and Gigafactories:** Supercomputer infrastructures for use with AI applications must be energy and Carbon efficient, and AIF/Gigafactory end-users must be trained to consider energy consumption and enabled to employ the compute resources responsibly.
- **QC Technology:** while quantum computers promise very significant reductions in energy used for computations compared to conventional HPC/AI systems, it will be important to assess and minimise the energy use and carbon footprint of the complete QC infrastructures, including the systems required for integration in the EuroHPC HPC/AI infrastructures and the facilities required for running the QCs, over their complete lifetime.
- **Federation and hyperconnectivity:** unified user APIs providing energy consumption and resource usage metrics to the users in an understandable and actionable way

¹¹ The rebound effect refers to a phenomena observed in many different contexts, namely, that an improvement on efficiency does not automatically lead to a lower energy consumption or carbon footprint, because the efficiency gains are overcompensated by performing more work. In the HPC context this means that efficiency improvements are often overcompensated by performing more application runs, or even installing larger HPC systems for the same costs, so that the overall environmental impact is not reduced.

should be provided. Also, mechanisms provided by a federated infrastructure like the EFP should provide the opportunity to transparently move load to sites with availability of green energy to lower the overall energy costs and CO₂ footprint.

- **Technology development:** HW and SW solutions must target a near-optimal compromise of (high) performance and (low) energy consumption and Carbon footprint. Investments on low-power processing, memory/storage and networking technologies, which might take the form of CPUs, accelerators, and novel or disruptive technologies are needed, and adoption of such technologies in systems available on the market must be strongly supported. System software and programming models, on the other hand, must ensure that the hardware resources are utilised in a near optimal way, avoiding waste and optimising the combination of energy and throughput. Where necessary, hardware technologies and system architectures should become able to gracefully adapt to variations in available/affordable energy.
- **Applications** codes should be written so that they co-optimize performance and energy consumption and carbon footprint when solving a given numerical or AI-based problem. This can be driven by relevant efficiency metrics (which measure results over energy used to create them), which might be domain or even use-case dependent and would have to be established. Applications should also be enabled to gracefully adapt to changes in the volume or nature of available resources as may be required by availability or optimisation of energy consumed by the HPC/AI/QC infrastructures. On the AI side in relation with the EFP Federation platform new services like federated learning could allow to mutualise the computing power and avoid massive exchanges of data while preserving security.
- **Users & Skills:** HPC/AI/QC code developers and users both must be trained on specific strategies to optimise and employ applications in a way that minimises the energy and carbon footprint of their codes.
- **International cooperation:** best practices in energy efficient operation and use of HPC/AI/QC infrastructures should be shared widely to profit from the international experience and minimise the overall environmental impact of the rapidly growing HPC/AI/QC infrastructure landscape. Cooperation with commercial data centres should be established to share design patterns and best-practices and amplify the effect of optimisations achieved in each of the two sectors.

6.4 Open Source and Open-Weight AI Models

There are many reasons why open source is important, including supporting wide-spread collaboration, improving accessibility, providing transparency and enabling use and improvements by third parties or user communities. Open-source licensing promises to enable widespread take-up of technology, to accelerate its further development and to lower the costs of using and maintaining such technology. This is particularly relevant in HPC/AI/QC to avoid vendor lock-in via proprietary system interfaces, middleware and programming

models. In the context of EuroHPC, open source relates to data, software and hardware. Since activities funded by the EuroHPC use public money, project results should be released as open source to the extent this is feasible. As previously mentioned, this is relevant also in areas such as AI, for example for making European large-scale foundation models for generative AI and data used to train them available, or in emerging areas such as tools for the development of quantum computing applications. In the context of AI, there are several degrees of “openness”: fully open (where source, data, checkpoints, and model weights are all open) and open-weights (where only the model weights are open).

Although open source is in principle preferable, there are scenarios in which releasing technology under open-source licenses is not the best approach. For instance, industrial partners participating in EuroHPC projects should be able to protect their technology development under other license types that enable its commercialisation and support further development and maintenance. In these cases, dual-licensing approaches can be recommended, or directly releasing closed source software under licenses that effectively enable widespread use in Europe such as CC_BY and derivatives. Such considerations often apply to hardware, which today regularly tends to embody a significant amount of third-party IP which is not or sometimes even cannot be licensed as open source. A

In addition, ongoing and sustainable development, support and maintenance for open-source technology is of critical importance to support its take-up and long-term use. In addition to relying on pro-bono work by open-source contributors, this should be backed by specific support projects, or by paid support/maintenance schemes and potentially further development by commercial parties. Requiring provision and support of open interfaces and open-source SW stacks in future EuroHPC procurements would also strengthen sustainable use of HPC/AI/QC and maximise opportunities for the European scientific and commercial areas to participate and profit from the growth in HPC, AI and QC.

6.5 Intellectual Property Rights

It is important to leave the door open to non-European suppliers in the HPC and AI space to foster healthy competition and diversity of solutions, but control of intellectual property created by EuroHPC funded R&D must remain in Europe. Intellectual property rights for the technological assets developed using EuroHPC funding must respect the applicable EU funding rules. This includes in extreme cases giving IPR to the funding authorities, to ensure availability of related intellectual property in Europe, and protect legitimate interests of academic and industrial beneficiaries. Provisions should be made in grant agreements for R&D projects to safeguard exploitation in Europe, allow the granting of suitable technology licenses or sub-licenses, or if necessary, the transfer of ownership of results.

7 Coordination with other JUs and EU activities

EuroHPC shall work very closely with the EC to ensure that its activities are undertaken in close cooperation and coordination of those organised by the EC (e.g. Chips JU). Good progress has been made in this direction to consolidate Quantum Computing initiatives, with the transfer of the EU Quantum Flagship to EuroHPC in 2026. EuroHPC shall monitor developments in EOSC [51], GAIA-X, etc. In particular, tight collaboration is recommended with:

- **Chips JU:** EuroHPC shall work closely with the created Chips JU (formerly Key Digital Technologies JU) to leverage synergies in processor technology development.
- **EU AI initiatives:** many projects and initiatives are running or upcoming in the area or AI in the EU, and a good coordination between EuroHPC and those is important.
- **Cybersecurity Competence Centre:** to establish secure HPC/AI/QC infrastructures.
- **Data Infrastructures:** EuroHPC could consider working more closely with EOSC and ESFRIs, as well as projects like SPECTRUM [87] or SIMPL in order to position EuroHPC as the prime HPC infrastructure for data connectivity to large scale instruments like CERN, SKA, Einstein telescope, and many others, with a clear mutual agreement on the governance and on who will perform/fund the associated data services.
- **Cloud:** with GAIA-X and interested European private Cloud providers, EuroHPC could collaborate in establishing an end-to-end and sovereign federated offer supporting open R&I, confidential R&I, and commercial activities for industry and SMEs.
- **Quantum:** on top of the achieved consolidation of the Quantum Flagship within EuroHPC, alignment and strong collaboration should be established with other EU programs like EuroQCI and the Quantum Internet Alliance (QIA) to upgrade the connectivity with Quantum connectivity, the Chips JU to produce Quantum chips, and CEN-CENELEC (JTC for Quantum Standardisation. The adoption of the amendment for Gigafactories and Quantum will have impact in how to cooperate within the JU and with other EC activities.

8 List of Acronyms

AAI: Authorisation, and Identification	HPL: High Performance Linpack
AI: Artificial Intelligence	HW: Hardware
AIF: Artificial Intelligence Factory	IKOP: In-Kind financial contributions from Operational Projects
AIFA: AI-Factory Antenna	IOT: Internet of Things
AIF(A): when refereeing to both AIFs and AIFAs	IP: Intellectual Propriety
AIGF: AI-Gigafactory	ISA: Instruction Set Architecture
API: Application Programming Interfaces	ISV: Independent Software Vendor
BDVA: Big Data Value Association	IT: Information Technology
CAPEX: capital expenditure	JEDEC: Joint Electron Device Engineering Council
CEF: Connecting Europe Facility	JU: Joint Undertaking
CI/CD: Continuous Integration/Continuous Deployment	KPI: Key Performance Indicators
CoE: Centre of Excellence	MASP: Multi-Annual Strategic Programme
CPU: Central Processing Unit	ML: Machine Learning
DEP: Digital Europe (DIGITAL) Programme	MLOps: Machine Learning based System Operations
DL: Deep Learning	MoE: Mixture of Experts
DoS: Denial of Service	NCC: National Competence Centre
EC: European Commission	NLP: Natural Language Processing
EDIH: European Digital Innovation Hub	NREN: National Research and Education Network
EOSC: European Open Science Cloud	PQC: Post-Quantum Cryptography
EOSS: European Open Software Stack	PS: Participating State
EPI: European Processor Initiative	QC: Quantum Computing
ESFRI: European Strategy Forum on Research Infrastructures	QCoE: Quantum Centre of Excellence, aka Quantum Excellence Centre
ESS: European Software Stack	QCS: Quantum Computer Science
ETP4HPC: European Technology Platform for High Performance Computing	QEC: Quantum Error Correction
EU: European Union	QEM: Quantum Error Mitigation
EuroHPC: EuroHPC Joint Undertaking	QIA: Quantum Internet Alliance
EuroQCI: EU Quantum communication infra. strategy.	QKD: Quantum Key Distribution
FoM: Figure of Merit	QML: Quantum Machine Learning
FPA: Framework Partnership Agreement	QPU: Quantum Processing Unit
FPGA: Field Programmable Gate Array	QuIC: European Quantum Industry Consortium
GB: EuroHPC Governing Board	R&I: Research and Innovation
GenAI: Generative AI	ROI: Return on Investment
GPP: General Purpose Processor	RRF: Recovery and Resiliency Facility
GPU: Graphic Processing Unit	RSE: Research Software Engineers
HE: Hosting Entity	RTO: Research and Technology Organisations
HEP: Horizon Europe Programme	SGA: Specific Grant Agreement
HPC: High Performance Computing	SIMD: Single-Instruction-Multiple-Data
HPC/AI/QC: mixed environment of HPC, AI, and QC. In this document we use the term loosely to refer to one or more of the three areas, the combination of two or three of these approaches in infrastructure, technologies and applications, and also about supporting a growing environment that potentially combines them (in pairs or all three together).	SLA: Service Level Agreement
HPDA: High Performance Data Analytics	SME: Small and Medium Enterprises
	STEM: Science, Technology, Engineering and Mathematics
	SW: Software
	SWOT: Strength, Weakness, Opportunity, Threat
	TPC: Trillion Parameter Consortium
	TRL: Technology Readiness Level
	UCIe: Universal Chiplet Interconnect Express

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