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

2024 revision by INFRAG and RIAG

EuroHPC Joint Undertaking

Multi-Annual Strategic Programme (MASP 2021 -2027)

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1. Introduction

1.1 Context

The EuroHPC Joint Undertaking (JU) was established on 28 September 2018 by Council Regulation No 2018/1488, published in the Official Journal of the EU on 8 October 2018, before entering into force on 28 October 2018.

EuroHPC JU became fully operational in 2018, while still under the auspices of the Commission. It adopted and implemented its first work programme and established itself as a successful model of a public-private partnership involving the European Union, twenty-seven Member States, and four associated countries from outside the EU.

The Executive Director was appointed on 15 May 2020 and took up office on 16 September 2020. The Governing Board confirmed the autonomy of the JU on 23 September 2020, having verified that all autonomy criteria had been met.

To date, the EuroHPC JU has already demonstrated that it is the right legal and financial instrument to address the shortcomings of the European HPC landscape and encourage Member States and EU funds to be pooled to create European value for the Union as whole. Indeed, coordination of the HPC strategies of the Union and the Member States by the JU has already led to:

- Pooling of resources and investments;
- Procurement of ten world-class HPC supercomputers addressing user needs and demands;
- A structured and focused research and innovation agenda aligned with the overall ambition of creating a world-class HPC ecosystem;
- Since 2022, two EuroHPC supercomputers ranked in the top 5 of the TOP 500 lists.
- Since 2022, six EuroHPC JU supercomputers are accessible to European scientists.

The approval of a new Council Regulation sets out the updated mission of the EuroHPC JU and adapts the JU’s funding streams to be in line with the new multi-annual financial framework (MFF) of the Union (2021 – 2027). As a result, the JU’s scope and the variety of its activities has been extended.

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

1.2.1 EuroHPC JU's first Multi-Annual Strategic Plan (2021)

This original Plan was developed in 2021 in line with the updated mission set out in the Council Regulation [1] and the Commission Staff Working Document [2] on the new EuroHPC JU.

Input was provided by the JU's Industrial and Scientific Advisory Board, which is made up of the Infrastructure Advisory Group (INFRAG) and the Research and Innovation Advisory Group (RIAG). Both papers are included in the annex to this report.

Input was also provided by the Members of the Governing Board of EuroHPC JU and their experts during discussions organised on the JU's future Strategic Orientations by the staff of the JU between April and June 2021.

The draft Plan was then presented to the EuroHPC JU Governing Board on 3-4 June 2021 for an initial discussion. The consolidated Plan was adopted by the EuroHPC JU Governing Board on 16-17 September 2021.

Once adopted, it formed the basis for the preparation of the updated 2021, 2022 and 2023 Annual Work Programmes.

1.2.2 EuroHPC JU updated Multi-Annual Strategic Programme (2024)

This Multi-Annual Strategic Programme (MASP) has been developed in line with the mission set out in the updated EuroHPC JU Council Regulation.

Legal base

Article 1 (o) of the Statutes (Regulation 2021/1173) states: The Joint Undertaking shall define the multiannual strategic programme, draw up and implement the corresponding annual work programmes for their execution and make any necessary adjustments to the multiannual strategic programme;

Articles 7(4); 7(5); 7 (6); 7(7) of the Statutes (Regulation 2021/1173) states: The Governing Board shall discuss and adopt the multiannual strategic programme as referred to in Article 18(1) of these Statutes

[1] Regulation (EU) 2021/1173.

[2] SWD(2020) 179 final.

Article 18 (1) of the Statutes (Regulation 2021/1173) states: 'The Industrial and Scientific Advisory Board shall consolidate the multiannual strategic programme and submit it to the Executive Director. It shall be the basis for the Executive Director to draft the annual work programme.

Process

In December 2022, the EuroHPC JU Governing Board asked the Infrastructure Advisory Group (INFRAG) and the Research and Innovation Advisory Group (RIAG) to provide input to update the Plan and ensure it will provide elements to future Annual Programmes during the MFF period (2021-2027).

Input was also provided by the Members of the Governing Board of EuroHPC JU and their experts during several discussions organised between December 2022 and June 2023.

The draft Programme was presented to the EuroHPC JU Governing Board on 9-10 March 2023 for an initial discussion. The consolidated Programme was adopted by the Governing Board in 2023.

Once adopted, it will form the basis for the preparation of future Annual Work Programmes during the remainder of the current MFF period (2024-2027).

Considering the recent development within HPC ecosystem, the INFRAG and RIAG expressed their wish to update the MASP accordingly. The process of updating the document started in September 2023.

For consultation purposes on the state of the play and the future needs of the ecosystem, several public consultations were organised between the advisory groups and the different key stakeholders of the HPC ecosystem, including EuroHPC JU private members. After these consultations, several working groups were formed from the members of the advisory groups to work on the text for the different EuroHPC activity pillars. On 16 February 2024, the Advisory Boards presented the finalised version of the current MASP for the adoption by the Governing Board.

When appropriate, and to reflect the evolving HPC context, this document will continue to be updated.

1.3 Mission and Strategy

1.3.1 Mission

Supercomputing, numerical simulation, artificial intelligence (AI) and high-performance data analytics (HPDA) are essential and strategic for European countries to understand and respond to the increasing challenges that their citizens will be faced with in the years to come. These technologies will also continue to play an essential role in ensuring continued leadership of European science, industry (including SMEs), security, and economic development.

The European Union is on the way to completing the challenge which it set itself which is to deploy current HPC technologies and associated (human) expertise, making them accessible to all. The next challenge is to deliver future exascale and post-exascale supercomputing technologies, including AI and the emerging domain of quantum computing, ensuring connectivity and access to the systems

Examples of use cases for HPC include early detection and prevention of diseases, new therapies, understanding the functioning of the human brain, forecasting climate change, and accelerating the design of new materials (in particular energy-efficient ones), medicines, airplanes, and cars.

Mastering these critical technologies, including modelling in combination with data management (DM) and artificial intelligence (AI), is essential for large-scale simulation as well as processing, analysing, and using the quintillions of bytes produced every day. These technologies, for example, are key for ensuring that European researchers from both academia and industry reap the full benefits of data-driven science and forge the path to grand scientific discoveries.

They are also essential for many users from the public and private sectors for serving many social, scientific, and industrial domains. For example, at the beginning of the COVID-19 pandemic, HPC resources helped accelerate the search for new drugs and therapies. Access to HPC resources clearly plays a valuable role in quickly identifying solutions to complex societal emergencies and natural disasters.

European citizens are already benefiting from such applications. Personalised medicine, for example, has already used simulations to understand the nature of diseases, diagnose them rapidly, and develop customised treatments. Supercomputing has also a growing impact on industry by significantly reducing product design and production cycles, accelerating the design of new materials to reach net-zero goals, minimising development and manufacturing costs, minimising critical raw materials thus increasing the robustness of supply chains, and increasing resource efficiency, creating European generative AI models for applications ranging from natural language processing to sophisticated AI-driven simulations and content generation"

By 2027, the EuroHPC JU will establish a world-leading hyper-connected and federated HPC service and data infrastructure ecosystem in the Union. It will ensure that the EU is able to develop innovative and competitive HPC solutions based on European components, technologies, and knowledge. Energy-efficiency and environmental sustainability have become increasingly important and will also be part of this strategy.

In practice, EuroHPC JU should develop, deploy, maintain, and extend a world leading federated, secure and hyper-connected supercomputing, quantum computing service and data infrastructure ecosystem in the Union; support the development and production of innovative and competitive supercomputing systems based on a supply chain that will ensure components, technologies, software, and knowledge limiting the risk of disruptions and the development of a wide range of applications optimised for these systems; widen the use of this supercomputing infrastructure to a large number of public and private users providing adequate training and support, foster education and training of highly skilled people in software and hardware technologies underpinning the infrastructure, and support the twin goals of climate and digital transition as well as the development of key skills for European science and industry.

The JU's approach should be demand-orientated and user-driven where appropriate. For example, the JU is setting up an easy-to-use platform to access the EuroHPC systems and will provide funding to hosting entities to ensure that the compute resources are made available for academic, public sector and industrial users. It should also be technology driven and provide solutions to computational, engineering, or other scientific problems.

The JU will foster its activities in HPC software and hardware R&D. The vision of the EuroHPC technology pillar is to develop European critical energy-efficient exascale and post-exascale technologies, architectures and systems technology and their integration in pilot systems, complemented with the deployment of world-class competitive exascale and post-exascale supercomputers based on this technology. This vision is fully in line with the EuroHPC JU regulation's objective of establishing an effective link between technology supply, co-design with users and software providers, and future actions involving joint procurement of world-class systems, to create a world-class ecosystem in HPC technologies and applications across Europe.

1.3.2 Strategy

The Multi-Annual Strategic Programme (MASP 2021-2027) is based on the strategy set out in the updated Council Regulation 2021/1173. By pooling European and national resources, the EuroHPC Joint Undertaking ensures that the EU and EuroHPC participating states (PS) coordinate their investments with the objective of deploying, in Europe, world-class exascale supercomputers and of supporting world leading high performance computing (HPC). The EuroHPC JU seeks to support sustainable, gender-balanced and inclusive European excellence in computing solutions, improving cooperation in advanced scientific research, boosting industrial competitiveness, and ensuring European technological and digital sovereignty.

In the previous Regulation 2018/1488 on establishing the European High Performance Computing Joint Undertaking, the JU was tasked with supporting two main objectives, which it continued to implement in 2022[3]:

- Developing a world-class supercomputing infrastructure: procuring and deploying in the EU three pre-exascale supercomputers (capable of at least 10^{17} calculations per second) and five petascale supercomputers (capable of at least 10^{15} calculations per second). These supercomputers are located across the European Union and most of them are available to Europe's private and public users, scientific and industrial users throughout Europe; and
- Supporting research and innovation activities: developing and maintaining an innovative European supercomputing ecosystem, stimulating a technology supply industry (from facility infrastructure to low-power processors to software and middleware, and their integration into supercomputing systems), and making supercomputing resources in many application areas available to public and private users, including small and medium-sized enterprises.

In addition, since 2021, in accordance with the new Regulation now in force, the JU has new objectives, as follows:

- To contribute to the implementation of Regulation (EU) 2021/695 (Horizon Europe) and in particular Article 3 thereof, to deliver scientific, economic, environmental, technological and societal impact from the Union's investments in research and innovation, so as to strengthen the scientific and technological bases of the Union, deliver on the Union strategic priorities and contribute to the realization of Union objectives and policies, and to contribute to tackling global challenges, including the Sustainable Development Goals, by following the principles of the United Nations Agenda 2030 and the Paris Agreement adopted under the United Nations Framework Convention on Climate Change;
- To develop close cooperation and ensure coordination with other European Partnerships, including through joint calls, as well as to seek synergies with relevant activities and programmes at Union, national, and regional level, with those supporting the deployment of innovative solutions, education, and regional development, where relevant;

[3] JU Activities as set out in Regulation 2018/1488

- To develop, deploy, extend, and maintain in the Union an integrated, demand-oriented, and user-driven hyper-connected world-class supercomputing and data infrastructure;
- To federate the hyper-connected supercomputing and data infrastructure and interconnect it with the European data spaces and cloud ecosystem for providing computing and data services to a wide range of public and private users in Europe;
- To promote scientific excellence and support the uptake and systematic use of research and innovation results generated in the Union;
- To further develop and support a highly competitive and innovative supercomputing and data ecosystem broadly distributed in Europe contributing to the scientific and digital leadership of the Union, capable of autonomously producing computing technologies, architectures, cooling and energy infrastructures and their integration on leading computing systems, and advanced applications optimized for these systems; and
- To widen the use of supercomputing services and the development of key skills that European science and industry need.
- To train the next generation of scientists and technologist for the efficient use of these technologies to support present and future AI developments.

The Joint Undertaking shall enable the acquisition of world-class supercomputers, while safeguarding the security of the supply chain of procured technologies and systems. It shall contribute to the Union's strategic sovereignty, support the development of technologies and applications reinforcing the European High Performance Computing supply chain, and promote their integration in supercomputing systems that address scientific, societal, environmental, and industrial needs.

To fulfil its mission and achieve its general and specific objectives as set out in the Council Regulation, the EuroHPC JU will adapt its strategy and put forward a range of measures to address risks identified during the implementation of the Work Programmes.

To prepare investment plans for the next evolution of EuroHPC infrastructures and services a SWOT analysis could be conducted as well as bottom-up a roadmap setting out the different Scientific Cases across scientific and industrial user communities.

- ***Increase emphasis on software, user support and training & education***

Having established a world-class HPC infrastructure in the past years that will continue to be expanded and updated, EuroHPC needs to enter a new phase with increased focus on (application) software, user support, training, and education. *To make efficient use of the* *resources provided by EuroHPC, users need highly optimized and energy aware applications for their domains as well as excellent support and training. Training and education are also essential to create a workforce of highly skilled people capable of advancing the field of HPC & AI, both from a hardware and software perspective. Mobility, diversity, and equity need to be considered at all stages of these activities.* EuroHPC has already initiated a couple of initiatives in this direction, including the HPC Centres of Excellence, the National Competence Centres, various user support and training programmes as well as the European Master in HPC education programme. These need to be continued and expanded following a user-driven approach. The establishment of an independent User Forum providing strategic guidance and advice to the RIAG and INFRAG will be a cornerstone in this strategy.

- **Increase User involvement and feedback**

To empower constructive input with existing and new users, the JU shall establish consultative *groups such as a User Forum or a Scientific Advisory Committee, also considering existing networks and associations.* These groups should be required to facilitate a bottom-up approach and ensure user requirements are considered to support the development of JU activities. These groups should support RIAG and INFRAG and provide reliable, sustainable feedback to the governance bodies of the EuroHPC JU on current and future infrastructure requirements and 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.

- **Foster competition in the calls for proposals and widen participation**

The competitive evaluation of proposals as foreseen in the Horizon Europe and Digital Europe programmes is critical to ensure the best quality and efficiency for the implementation. Calls for proposals should support inclusiveness and effective collaboration while avoiding cartelization. *The JU shall implement appropriate measures such as additional call conditions, limiting the size of consortia, requiring complementary competences and roles of consortium members in grants, defining minimum and maximum contributions and resources for beneficiaries, monitoring participation, and collecting feedback from applicants to promote fair competition, widen participation and improve overall sustainability and impact.*

- **Pursue a strategic and results-focused approach to sustainable R&I**

Strategic R&I requires an approach focused on results, with clear focus, targets, and commitments in the implementation. The practice of identifying a broad challenge in a call for proposals to identify the best solution among proposals submitted by consortia is often not effective in the current European HPC ecosystem and an approach with focused actions of limited scope is required. This is because the ecosystem is relatively small, with a limited number of closely collaborating main actors. As the competence gap, in particular regarding industrial capability and capacity, between different regions of Europe is evident, and the knowledge transfer and harmonisation of HPC development in Europe represents a key priority of the JU, it is critical for the achievement of the JU's strategic objectives, specifically in the area of technology, to ensure that actions involve the most competent actors in Europe and avoid dissipation and fragmentation. Widening participation and knowledge transfer, on the other hand, should be addressed in targeted actions to attract new stakeholders in technology innovation and development, who typically address academic and low TRL research and development.

The JU will provide, in an open, fair, and transparent process, and within the applicable rules of the relevant Framework Programmes, support and guidance to applicants in the preparation of their responses to the JU's open calls. Moreover, the JU will strengthen its role in steering projects towards the agreed objectives, adopt measures such as requesting changes during the grant agreement preparation and project lifecycle to ensure projects are focused on the critical path of development, the introduction of mandatory control points in grant agreements, the termination of unsuccessful development paths within projects and the consolidation of developments to ensure R&I grants focus on the key outcomes of the respective call and that all participants contribute significantly to the results of an action. The JU will further improve the impact and effectiveness of R&I actions by providing more detailed requirements, including on IPR (Intellectual Property Rights) and commercial exploitation, specific mandatory deliverables, milestones, and additional conditions where appropriate. The coherent implementation of actions towards the JU's strategic R&I goals may be supported by additional measures such as payments linked to deliverables and milestones or competitive development streams with subsequent consolidation process, as appropriate.

- **Energy-efficient and environmentally sustainable computing**

To improve the energy efficiency of the entire HPC value chain, user skills, technology and infrastructure need further development.

While HPC centres constitute only a subset of the entire datacentre and cloud facilities, they are growing as well and therefore require careful control of their environmental impact.

HPC operations, manufacturing, integration, and commissioning of equipment do account for a significant part of this impact. Among this are the use of rare materials and important amounts of water for hardware components production, and transportation footprint.

The data centres, which host EuroHPC JU infrastructure, are already mostly liquid cooled, which make it possible to operate a datacentre at an exceptionally low PUE (power utilization efficiency) – a PUE around 1 vs. 2 or more for air cooled solutions. Future EuroHPC Host Entities should whenever it is ecologically worthwhile and economically possible, reuse the waste heat as already done by several EuroHPC systems.

While new EuroHPC JU centres might be built in regions with cooler climates, modern high-temperature cooling techniques allow free cooling also at higher environmental temperatures. An important direction of research is the re-use of heat of waste from cooling. Overall, the use of all renewable or low carbon energy options should be studied and increased.

The commissioning and the decommissioning of equipment and facilities, the reduction of plastics or beyond the environmental impact while building the system, the recycling of electronic or other waste should be considered. A Life Cycle Analysis approach should be used in HPC deployment.

During the active lifetime and operations of a system, the most significant concern is energy optimisation. The best and most energy-efficient technical solution should be sought.

Energy efficient computing aims to maximise energy *efficiency from a systemic point of view (from single components of the supercomputer to infrastructures, end user applications and their impact).* With rising energy prices, energy efficiency gains even more importance and with global warming the environmental impact of large-scale computing must also be considered. The JU aims in cooperation with the hosting entity to develop system level approaches that reduce the cost of exploitation by decreasing power consumption and to optimise the amount of computation achievable under a given energy budget.

Another essential element to achieve a more efficient use of resources is a well-educated and performance-aware and energy-aware user base. This requires appropriate training, but also feedback on performance and energy consumption and effective incentives for a responsible and energy-efficient use of HPC (e. g. the development of measure to link scientific impact to energy consumption in HPC). The JU will work on a qualification framework to establish minimum requirements on the skills of end users of EuroHPC systems while making sure that new user groups get support to be able to gain access to the systems. The JU will also work on development of upstream software development to design such performance/energy measurement tools.

From the processor perspective, the more energy effective CPU or GPU per floating point operation is to be preferred. New features like dynamic GPU frequency control allow a dedicated and optimal running of codes to achieve optimal carbon footprint. Improvements at software level could also be considered to improve energy efficiency. The use of future technologies such as Quantum computing and neuromorphic and in memory computing should be explored including applications and user support, where appropriate for these tasks.

- **Promote standardisation and modular design principles**

Standardisation is widely recognised as a catalyst for industrial innovation, providing a competitive advantage for contributors and reducing the risk for technology lock-in. Standardisation and modular design principles allow the easy replacement, reassembly, or rearrangement of components for flexible solutions, a broad participation of the supply industry including SMEs and an overall more resilient supply chain in a competitive European HPC ecosystem. Modularisation further enables joint developments and the effective pooling of skills and resources to develop common parts of technology and applications. The distributed and diverse HPC ecosystem in Europe, with many public organisations, private companies, national and European initiatives which are often focused on specific aspects of HPC technology, requires common standards for interoperability to establish an internationally competitive and resilient supply chain for European HPC and, when mature, quantum computing technology. Beyond standardisation of technology, common standards, and certifications or accreditations in HPC training and education are required to enable the mobility of talents within Europe and between academia, the public and private sectors. The development and promotion of standardised benchmarks for HPC and quantum computing represents another key area for research and development as well as for potential international cooperations. The importance of standardisation has been acknowledged in the proposal for an EU standardisation strategy and the JU's effort to develop the European HPC ecosystem should be aligned with the overall vision on standardisation in the Union.

The JU will advance pan-European standardisation and modularisation efforts across all relevant pillars of activities. This includes alignment with the activities of established European standardisation bodies, for example the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) and with their relevant working groups, such as the CEN-CENELEC Focus Group *on Quantum Technologies as well as participating in and influencing actual software/middleware standardisation groups such as MPI Forum, OpenMP ARB and AI instances should be fostered either directly or through stakeholders. Similarly, the JU will develop a coherent, trans-national and modular* qualification framework for skills, training, and education in HPC and support the adoption and implementation of common standards by European training providers. To achieve these strategic objectives, the JU will include requirements on standardisation in procurements and calls for proposals where appropriate, to ensure the coherent and effective implementation and to deliver the best possible impact.

European HPC digital sovereignty cannot be done in an isolation from other initiatives. Coordination with other programs such as the EU Chips Act and the KDT Joint Undertaking shall contribute to the overall goals and benefit from technology trickle down.

Building on this, the Infrastructure Advisory Group (INFRAG) and the Research and Innovation Advisory Group (RIAG) have provided updated and renewed input to the strategy.

'EuroHPC should extend its long-term mission and vision for European computing to define a general overarching strategy for all anticipated activities. It should continue to facilitate easy and secure access to an integrated, world-class supercomputing and data infrastructure and to develop and support a highly competitive and innovative high-performance and quantum computing ecosystem encompassing hardware, system and application software, support, and the development of highly qualified personnel. As such, the EuroHPC supercomputing infrastructure should be the strategic instrument for European leadership in the global digital science and economy for the next generation supercomputing and data driven digital era and beyond. The strategy and actions should be based primarily on the requirements of the users. It is important to recognize that the numerous user groups, like academic researchers, scientists working in SMEs or large companies, or researchers in governmental organisations have different requirements with respect to supercomputer hardware, software, support services, and IT security. These divergent needs should be addressed by a federated European supercomputing infrastructure that ensures access to all EuroHPC systems based on the same level of quality. The rapidly increasing demand from data-driven computing applications and technologies including Artificial Intelligence (AI) and Digital Twins requires an agile response from EuroHPC and a sustained engagement with new and emerging communities. The pace and scale of support for HPC and quantum computing education, training and support must be broad and deep to match the investment in hardware and enable a full exploitation of resources. Since the federated supercomputing infrastructure will be essential for the European economy and European industry, science, and society at large, the infrastructure must be resilient, powerful, secure, affordable, and competitive at the international level. EuroHPC should also support potential disruptive innovation supporting global competitiveness in technology development and the retention of skills and expertise in Europe. These are challenges, but also present big opportunities for European suppliers and users who should be empowered to provide appropriate feedback and

strategic advice and expertise. The focus of all EuroHPC activities should be on innovation: in science, in industry and in public services to strengthen the collective European economy and society.

In 2023, RIAG updated its recommendation[4] on the new strategy of the JU:

'In the last two years, 2021 and 2022, the European HPC ecosystem has improved significantly. Still, it is not yet balanced, with significant European leadership limited to the HPC software stack and major but improving deficiencies in contributions to the HPC hardware stack. To achieve European digital sovereignty soon, EuroHPC JU technology initiatives should be focused on providing a boost to the (re)generation of European HPC technology research and industry, especially in HPC-specific areas where there are clear gaps. One of the fastest ways to achieve this goal is to leverage our strengths and extend those capabilities. We see European technology leadership today, based on open platforms like the Linux OS, toolchain, runtimes, frameworks, and libraries, up to the HPC application layer. This enables rapid development and extension of software systems (...). Combining our European strengths with global trends, we can accelerate the path to digital sovereignty by creating the European Open Stack (EOS), establishing, and leveraging an ecosystem based on open source and open standards for computing encompassing both hardware and software and fostering the development of co-designed systems required to advance European and global HPC. This ambitious vision will enable European independence and encourage additional investments. The EOS will produce Intellectual Property (IP) and standards that enable innovation and accelerate the European research and development at all levels in the HPC system stack. To achieve these goals, EOS must include repositories of enabling technologies for the European HPC ecosystem development, from third party hardware IP and tools to system software and applications.'

1.4 Funding EuroHPC JU's activities:

1.4.1 EU Programmes

The Union's contribution to EuroHPC JU is complemented by national and private member contributions.

In line with the new Regulation, the activities of the Joint Undertaking will be structured in one administrative pillar and six technical pillars that will cover activities in the following areas: infrastructure, federation of supercomputing services, technology-related activities,

[4] The full 2023 RIAG Recommendations are available in annex to this document.

supercomputing applications-related activities, broadening usage and skills, and international cooperation. Although activities in each pillar will be described separately, it is clear that each pillar is interlinked with the others and that the whole ecosystem needs to be considered. To do this, special actions will be developed to ensure interlinkage between the pillars.

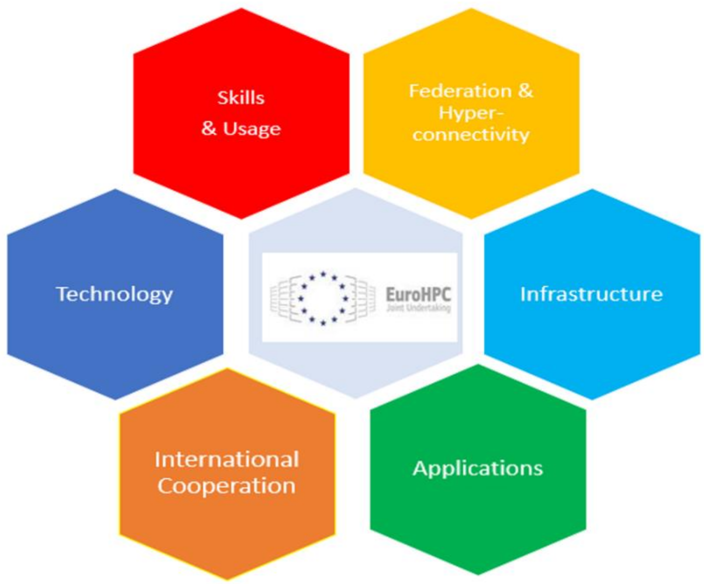

Figure 1: EuroHPC JU action pillars

The current Multi-Annual Financial Framework (2021-2027) has allocated funding to implement this strategy in three specific work programmes, with the following indicative budget allocated to EuroHPC JU activities:

Digital Europe (DIGITAL) Programme : EUR 1.981.300.000[5]

- Infrastructure pillar
- Connecting and federating of supercomputing services pillar
- Widening usage and skills pillar

DIGITAL is a new programme and will allow for co-funding with Participating States who are signatories to DIGITAL to deploy new and upgrading of new supercomputers, ensuring access to

[5] Due to the proposed Chips Act, operational appropriations of EUR 150 million were reallocated within the Digital Europe Programme. As a result, the appropriations from the High-Performance Computing Joint Undertaking (EuroHPC) will be successively reduced during the years 2023 - 2027.

these HPC infrastructure, building on the federation of supercomputing services, and deployment, and usage of the HPC ecosystem. It will also be used to deploy HPC skills and training in the European Union.

DIGITAL will be used to fund the infrastructure pillar, part of the federation of supercomputing services pillar, and the widening usage and skills pillar.

Connecting Europe Facility (CEF): EUR 200.000.000

- Hyper-connectivity
- Data connectivity

The Connecting Europe Facility Programme will be used to fund the remaining activities of the connected and federated supercomputing services pillar, i.e. the high-speed interconnection of high-performance computing, quantum computing and data resources, as well as the interconnection with the Union's common European data spaces and secure cloud infrastructures (e.g. GAIA-X). CEF will support connectivity and, where relevant, cybersecurity activities.

Horizon Europe Programme (HE): EUR 900.000.000

- Technology pillar
- Application pillar
- International Cooperation

HE will continue to focus on R&I activities co-funded with Member States in the areas of technology, applications, and international cooperation. HE will be used to fund the technology pillar, the application pillar, and the international cooperation pillar.

In addition, the newly adopted Recovery and Resilience Facility (RRF) will support the digital transition. Member States are requested by the Commission to ensure a high level of ambition when defining reforms and investments enabling the digital transition as part of their recovery and resilience plans. The Regulation requires that each recovery and resilience plan include a minimum level of 20% of expenditure related to digital. This includes, for instance, investing in the deployment of HPC and connectivity.

1.4.2 National contributions

The Participating States shall make a total contribution that is commensurate to the Union’s contribution. Participating States may complement the Joint Undertaking's contribution in different actions, within the applicable maximum reimbursement rate set out in the HE, DIGITAL, and CEF Regulations. The JU shall provide an online platform to ensure that reporting of national financial contributions and in-kind contributions are reported in a transparent and efficient way, in line with the requirements set out in the new Regulation.

1.4.3 Private member contributions

The Private Members[6] of the Joint Undertaking provide in-kind contributions from operational (JU-funded) projects (IKOP) in the form of unfunded share of costs on JU projects.

To encourage more IKOP contributions, EuroHPC JU has provided support to ensure that reporting of private member in-kind contributions is managed in a transparent and efficient way.

However, as the EuroHPC JU Regulation only allows for IKOP, it will be difficult for Private Members to contribute the target of at least EUR 900 000 000. In consequence, the JU will also explore:

- the use of Innovation Action funding instruments. Innovation Actions will allow for projects to be co-funded with Union, national and private member contributions and will support higher TRL projects in line with the mission of EuroHPC JU.
- the opportunity of procuring an industrial mid-range HPC system in partnership with the private sector (including companies that who have yet to become members of the JU's Private Members associations)
- the possibility for the JU to collect in-kind contributions to additional activities (IKAA) as defined in the HE rules[7].

Significant in-kind contributions from the private side are most likely to be provided in areas where high TRL technologies are developed (7 to 9), and when R&I calls can be aligned with industry product roadmaps and their related internal funding. Related calls could be defined by a joint public-private analysis of R&I roadmaps and projects outcomes production opportunities and use instruments such as Innovation Actions.

[6] In 2023, these are the European Technology Platform for High Performance Computing (ETP4HPC), the Big Data Value Association (BDVA) and the European Quantum Industry Consortium (QuIC).

[7] This is not currently possible under Regulation 2021/1173.

1.5 Milestones and Financial Perspectives

In short, the JU's activities shall be coordinated across the different pillars. Each year, the Governing Board of the EuroHPC JU will approve an annual work programme that will implement identified milestones and actions which will form the different outputs of the strategy.

It is important to ensure that the outputs of each R&I call are deployed and disseminated, and that proper usage and take up of the HPC infrastructure, technologies and applications are monitored. Progress on different projects will be presented through events and other communication activities, the EuroHPC JU website, and the JU's Consolidated Annual Activity Report (CAAR).

Under the current Regulation, EuroHPC JU will operate from 2021 until 31 December 2033 to exercise its responsibilities concerning grant implementation, until the last indirect actions launched have been completed, and to finalise the activities related to the operation of the JU supercomputers.

1.6 State of Play

1.6.1 Infrastructure Procurement

Since 2021, EuroHPC JU has procured several HPC systems which are now operational and accessible to users across Europe. The challenge is to plan for the arrival of future exascale and post-exascale systems and in parallel, to prepare scientists, academics, SMEs, and industry to access them in fast and efficient way.

The other challenge will be to procure quantum computers to provide European scientists the infrastructure to develop new use cases.

In summary, between 2021 and 2023, the following actions were launched by EuroHPC JU:

- The Jupiter exascale system call was launched in 2021, the Hosting Entity Agreement signed in 2022, and the procurement in 2023. The system should be operational by 2024.
- A second HPC exascale system call was published in 2022. The system should be operational by 2025.
- The LUMI pre-exascale procurement took place in 2020 and the system was operational in 2022.
- The Leonardo pre-exascale procurement took place in 2020 and the system will be fully operational in 2023.

- The MareNostrum5 pre-exascale procurement was launched in 2021 and the system will be operational in 2024.
- Four petascale systems (MeluXina, Discoverer, Vega, and Karolina) have been operational since 2021.
- Four mid-range HPC hosting entities were selected in 2022.
- The second mid-range hosting entities call was launched in 2022.
- Two HPC systems (Leonardo and Discoverer) were selected for upgrade in 2022.
- Six quantum computer hosting entities selected in 2022.
- One high level application support call launched in 2022.
- The Discoverer upgrade procurement call was launched in 2023.
- To implement this strategy and support overall coordination in the implementation, the JU organises regular meetings with HPC and Quantum hosting entities, to ensure good cooperation, spread scientific and operational best practice.

1.6.2 Connected and federated Supercomputers

In 2022, the JU launched a call for tender to establish a study to assess what would be the best solution to interconnect EuroHPC systems and provide the related connectivity services. The study will be ready by end of 2023 and a call to procure such a service will be launched in 2024.

Furthermore, a procurement on federation services was launched in 2023.

1.6.3 Technology

To date, 40 projects in R&I in HPC are being managed by the JU.

EuroHPC JU took on projects started by the European Commission which have supported the development of European HPC technologies through many projects, including DEEP-SEA, RED-SEA, and IO-SEA, as well as the European Processor Initiative (EPI) and eProcessor which specifically tackled the need for European processor technology for HPC use

The European Processor Initiative (EPI) is a cornerstone of the EuroHPC JU's activities towards strategic autonomy in HPC, chip technologies and infrastructure. The project has completed its first three-year phase (2018-2021), delivering cutting-edge technologies for European sovereignty such as the Rhea General-Purpose Processor (GPP) and a proof-of-concept implementation of European accelerator technology.

The European Processor Initiative project is ongoing, and the results of this project will soon be available to be deployed in the next generation of HPC systems. The second phase of the project will finalise the development and the bring-up of the first generation of low-power processor units, develop the second generation of the GPP applying technological enhancements targeting the European Exascale machines, develop the second generation of low power accelerator test chips, usable by the HPC community for tests and develop sound and realistic industrialisation & commercialisation paths and enable the long-term economical sustainability with an industrialisation path in the edge computing area, demonstrated in a few well-chosen proofs of concept like autonomous shuttles or video surveillance.

In complement to the EPI action, a call for a Framework Partnership Agreement (FPA) on RISC-V was launched in 2022. The aim is to support a Framework Partnership Agreement (FPA) establishing a stable and structured long term partnership between the EuroHPC JU and a consortium of industry, research organisations and the institutions in High Performance Computing who commit themselves to establishing, coordinating and implementing a strategic and ambitious R&I initiative contributing to the development of innovative HPC hardware and software technology based on the open RISC-V ecosystem, followed by an ambitious action for building and deploying the exascale and post-exascale supercomputers based on this technology.

The growth in the open-source RISC-V market is having an exponential trajectory. This explosive growth is forecasted to continue over the next years. The increasing adoption of open source is disruptive as it drastically lowers the barrier to chip design. China, the US, and India, among others, are already investing heavily in open-source hardware and software to develop a competitive advantage in key sectors. It is only a matter of time to see open-source RISC-V solutions entering the HPC market. The benefits and attraction of adoption of open source depends on the type of actor and their role within the value chain. The Staff Working Document accompanying the recently proposed European Chips Act has identified the following benefits from open-source hardware adoption:

- Creating innovative products with lower costs and access barriers.
- Providing a faster path to innovation and smoother cooperation between actors (academic, research, industry, SME, alliances)
- Influencing technical choices and specifications.
- Allowing customization of open-source IP to user needs, delivering differentiating products.
- Sharing development costs.

- Reducing risks related to third-party IP (unbalanced commercial relationship, end of maintenance/ discontinued products, export control and trade wars).
- Building support and design service businesses based on open-source IP
- Better auditing of security and safety, ensuring that solutions can be fully audited and checked/verified.

The EuroHPC JU will work towards putting in place a stable and structured long-term partnership between the JU and industry, research organisations and the institutions in High Performance Computing who commit themselves to establishing, coordinating, and implementing a strategic and ambitious R&I initiative contributing to the development of innovative HPC hardware and software technology based on the open RISC-V ecosystem. This should be followed by activities to standardize and interoperability RISC-V, find RISC-V solutions for SMEs and of course, by building and deploying the exascale and post-exascale supercomputers based on this technology.

The call on algorithms for HPC applications exploiting the capabilities of exascale systems was launched in 2022 and grant agreements was signed in 2023. This call will develop novel algorithms for the upcoming European exascale supercomputers and the developed proofs of concepts that will demonstrate immense potential to solve currently intractable computational challenges, or to improve time-to-solution and energy-to-solution for important use cases.

In 2023, the JU has launched:

- a Pre-Commercial Procurement (PCP) focused on the development of European technology and their integration in pilot systems that demonstrate a significantly reduced energy footprint for typical expected workloads on EuroHPC systems.
- an 'HPC Energy efficiency R&I Call' to develop new technologies that will drastically reduce the energy consumption of future EuroHPC supercomputers. The activities should address the development of pilot systems that demonstrate significantly reduced energy footprint for typical expected workloads on post-exascale EuroHPC systems.
- 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.

1.6.4 Applications and Data

A call was launched in 2021 to select Centres of Excellence (CoEs) which will support collaboration between HPC users and experts to ensure that future exascale EuroHPC systems are accessible to European researchers and industries and address current scientific, industrial, and societal challenges.

As a result, Grant Agreements were signed in 2022 creating ten Centres of Excellence, leading to the choice of 10 proposals in science and innovation, or working towards exascale, in many domains, including climate and weather, drug development, astrophysics and cosmology, urgent computing, plasma science and engineering. The most prominent codes, or flagship codes, developed by the Centres of Excellence will be deployed on all EuroHPC supercomputers and will be made available for European scientists and the broader European HPC community.

To fill the gap in some under-served disciplines and services, EuroHPC launched in 2023 an additional call for selecting additional CoEs in the scientific domains of personalized medicine, digital twins, energy, and neuroscience, and performance optimisation of HPC applications.

In addition, in 2023, a call was launched to start developing Quantum Centres of Excellence.

1.6.5 Usage and Skills

A major focus of the JU's activities has been to ensure that the HPC community is ready for the newly available systems.

- A EuroHPC Master's programme call was launched in 2021 and a grant was signed in 2022 to support a pan-European consortium of universities, led by the University of Luxembourg, to provide a MSc programme in HPC.
- A grant for a pan-European network of National Competence Centres (NCC) was signed (EuroCC2) in 2022. The NCCs were launched in 2023.
- A Coordination and Support Action (CSA) on NCCs and CoEs grant agreement was signed (CASTIEL) in 2022. This project coordinates the activities of EuroHPC CoEs and NCCs, particularly in the field of best practice and training.
- A call on HPC Professional Traineeships and a call on to develop a EuroHPC training platform and summer school were launched in 2022.
- A study was launched under procurement to understand the different user requirements in academia, SMEs, and industry in 2023.

1.6.6 International Cooperation

- An International Cooperation call with Japan was launched in 2022
- In 2024 JU will launch an International Cooperation call with India.

2. Pillars of Action

EuroHPC should support the development of competitive and sovereign HPC and AI **solutions** that fulfil user needs and requirements, with training and support to deliver impact for science and society. HPC/AI/HPDA **applications** must be exploited on suited equipment and **infrastructures**, relying on best-breed **technology**.

HPC Infrastructure investments should both promote the uptake of research and innovation results generated in the Union, and influence or steer the R&I on missing or critical technology. A recurring R&I effort should be reflected in the JU's approach: users and market needs steer architecture and technology targets, then demonstrators and pilot projects allow integration and validation efforts towards solutions.

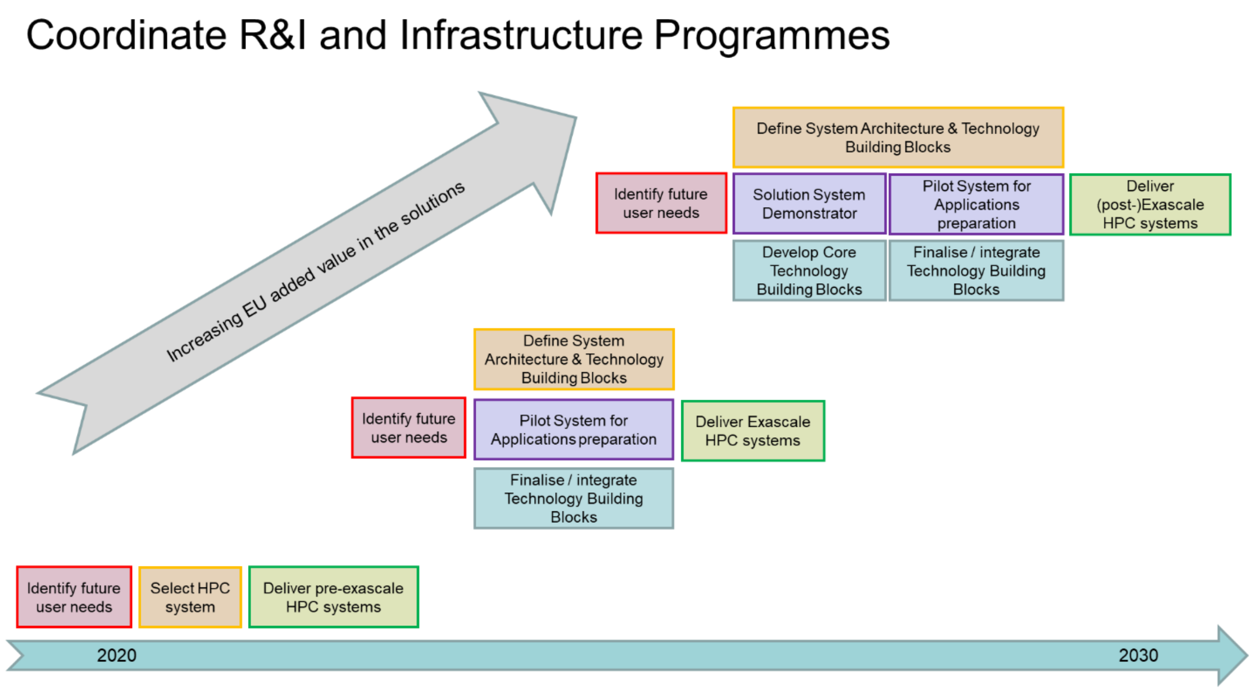

Figure 2: R&I and solution delivery cycles: from users' needs to building blocks, pilots systems then production systems

2.1 Infrastructure procurements

In line with the Regulation, EuroHPC JU shall organise activities for the acquisition, deployment, upgrading and operation of the secure, hyper-connected world-class supercomputing, quantum computing, artificial intelligence, and data infrastructure, including the promotion of the uptake and systematic use of research and innovation results generated in the Union.

Access to the EuroHPC JU infrastructure is provided for free to the European user community and is governed by the EuroHPC Access policy which is available on the EuroHPC JU website.

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

Indicative overview of HPC and quantum system acquisitions (2021-2027)

	2020*	2021*	2022*	2023-2024	2025 - 2027
HPC Infrastructure	5 peta-scale HPCs and 2 pre-exascale HPCs procured	4 petascale deployed 1 pre-exascale HPCs procured	Two pre-exascale HPCs deployed Hosting Entity for one exascale systems (high end) selected Hosting Entity for four midrange HPC systems selected	5th petascale deployed Third pre-exascale HPC deployed Hosting Entity for second exascale systems (high end) selected Hosting Entity for additional midrange HPC system to be selected Hosting Entity for industrial mid-range system to be selected Midrange HPC systems deployed	At least two high-end HPC systems (exascale / post-exascale) deployed A number of industrial mid-range systems deployed A number of mid-range HPCs deployed Hosting Entities for post-exascale systems (high end) selected
Quantum Infrastructure			6 Hosting Entities selected	6 First generation of (experimental) NISQ[8] quantum computers and simulators Selection of additional Hosting Entities	Procurement of next Generation NISQ Quantum Computers (including inter QPU communication technologies) or pre LSQ (Large Scale Quantum) pilots.

Table 1: Indicative overview of HPC and quantum system acquisitions (2021-2027)

(*completed)

[8] NISQ: Noisy Intermediate-Scale Quantum

2.2 HPC and AI infrastructure

Since 2022, the JU has begun to acquire and deploy mid-range supercomputers complementing the top-ranked systems. These supercomputers are co-owned by the EuroHPC JU and Member States. For these supercomputers hosting entities can choose short running innovation partnerships to acquire systems that are tailored to their needs. EuroHPC JU will continue to launch Calls for Expression of Interests to host mid-range supercomputers in each yearly Work Programme.

Starting 2023, the JU started to acquire and deploy two leadership class exascale supercomputing systems owned by the EuroHPC JU. 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.

From 2025, the JU shall acquire one or more high-end supercomputing systems (exascale /post-exascale) owned by the EuroHPC JU and developed with the most advanced technology available, leveraging when possible European technology, and achieving exascale levels of performance. The EuroHPC JU could act as first user and acquire high-end supercomputers that integrate demand-oriented, user- driven, and competitive technologies primarily developed in the Union.

Subject to support industries and SMEs, the JU will also support the acquisition and deployment of industrial supercomputing systems for industrial users in cooperation with and co-funded by private members of EuroHPC JU; adhering to industry specific requirements for increased security, data protection and availability. This initiative should foster collaboration between research and industry in both open and confidential research.

2.3 Quantum computing infrastructure

In quantum computers, applications are described by a sequence of discrete operations while in quantum simulators applications are characterized by the continuous evolution of the system's state. These computer systems have recently evolved significantly and shown **large** potential (in terms of performance and energy) to compete with the best classical supercomputers. However, these demonstrations exist only for a few, very specific scientific tasks. While **first** systems are commercially available already now, definite commercial advantage is not expected to be achieved in the next few years.

Integrating these systems into HPC environments brings new opportunities, but still requires strong efforts on hardware as well as on enabling software and associated interfaces. It is necessary to further co-design and develop new algorithms, applications, and software practices, which requires the HPC and quantum computing communities to work together and share knowledge and experience. To achieve this, it is critical to give researchers and the industry access to state-of-the-art quantum systems, equipping EuroHPC JU Hosting Entities with state-of-the-art quantum computers and simulators together with enabling technologies, as well as fostering training and developing use-cases.

Quantum computing has a high potential for technological sovereignty of the EuroHPC JU Member States. The importance of joint investment, approaches and acceleration for Quantum within Europe was recently prioritized by the launch of the Quantum Declaration / Quantum Pact by the EC and the different EU member-states, which requires attention of the EuroHPC JU strategy and work programmes.

Quantum computing technologies have mostly been developed independently from the HPC community. It is recommended to reduce related gaps in the HPC-QC ecosystem by:

- Building use-cases involving the (entire) ecosystem including industry, start-ups/scale-ups, academia, RTOs, and government – like successfully done via different national initiatives.
- Setting up quantum testbeds and field labs in the HPC domain of the EuroHPC JU infrastructure.
- Setting up knowledge exchange programs, educational programs – classical versus quantum and more –, knowledge databases (wikis), community events, hackathons and other projects that bring these communities to work together.
- Creating a dedicated education program for software engineers in quantum technology.

Preparing the digital infrastructure of the EU for full integration of quantum technology

Existing or near-existing quantum computing devices must be hosted in an existing digital EU infrastructure, while provisioning wider and deeper deployment of quantum technologies, in which Europe has many assets. This includes quantum connectivity and communication, cybersecurity, and cloud infrastructure.

In a forward-looking approach, like what is already done by some Member States, EuroHPC should also start to prepare, in coordination with the Commission's Quantum Flagship and other Commission initiatives on European startups, the use of LSQ (Large Scale Quantum) fault tolerant hardware and software solutions. Upstream R&D funded by Quantum Flagship can be followed by the acquisition and the deployment of first-of-a-kind systems by EuroHPC.

Coordination of quantum activities within the EuroHPC JU

Some coordination started already between the EuroHPC JU and the first 6 awarded Quantum hosting locations and the 2 hosting Entities from the HPQCS project (toward quantum simulators). This should be strengthened and further synchronised with the HPC and QC centres of excellence, while continuing the build-up of a federated HPC-QC Infrastructure.

Additionally, standardization, benchmarking, certification, and validation activities, and linking to the other digital infrastructure or EU technology developments appear mandatory (such as EuroQCI, the Quantum Internet Alliance/QIA

2.4 Connected and Federated Supercomputers

The JU will develop and deploy a federated, secure, and hyper-connected European HPC and data infrastructures that are accessible to researchers from academia, industry (including SMEs), and the public sector.

The infrastructures will be designed based on user requirements in highly flexible configurations tailored to a wide range of services, applications, and user needs. Associated data infrastructures will also be connected, allowing each category of users to manage its own data storage. It will provide a federated and coordinated access to all EuroHPC supercomputers, quantum computers and simulators, data repositories, knowledge and will also be the place where users will get access to the latest future technology to support innovate solutions.

EuroHPC JU aims to build a fully hyperconnected and federated infrastructure, providing end-to-end connectivity, performance, security, and resilience which will underpin the development of a federated ecosystem. As an initial step, EuroHPC JU has commissioned a study on hyperconnectivity which will provide a clear picture of the future requirements of users, systems, and experiments.

By federating the EuroHPC ecosystem, all users, including SMEs, will get appropriate support to access secure services and European HPC expertise, knowledge, and tailored training services provided by Centres of Excellence and National Competence Centres.

The EuroHPC federated ecosystem will also be set up with a view to foster close cooperation with other European activities like EOSC (European Open Science Cloud) for science, GAIA-X, which has a focus on industrial and commercial services, and in order to build links with future common European data spaces. Special attention will be given to industry friendly HPC federation services that stimulate the utilisation of the EuroHPC JU infrastructures by the private sector, especially SMEs.

Regarding AI services EuroHPC, using the ongoing Federation call, could work with European Cloud providers in order to setup up a full end to end sovereign continuum of faculties/ services including the initial training and some fine-tuning workloads. At the same time that EuroHPC will need to adapt its access modes in order to make them more agile to all the HPC communities including new communities such as AI for supporting Open R&D.

This could be possible as an extension federation of services/supercomputers.

2.4.1 Hyperconnectivity

In 2023, the JU has procure an independent study on hyper-connectivity for HPC resources. The result of the study should provide an exhaustive analysis of the communication and/or connectivity needs for the EuroHPC HPC (including quantum machines) and other relevant European and national supercomputing and data infrastructures (e.g. European common data spaces), available technology and service providers, and user landscape. It should facilitate an informed view of the implementation options, including the description of services to be provided, network architecture, implementation instruments, and budgeting. Finally, the study should provide the detailed specifications for the provisioning of the hyper-connectivity services to be provided to the EuroHPC JU and investigate to which extent this may be achieved by extending of the already existing infrastructures, such as GEANT and NRENs.

Based on the outcomes of the study, in particular the implementation roadmap and specifications, the JU will procure the deployment of the hyper-connectivity service from 2024 onwards.

2.4.2 Federation of supercomputing resources

EuroHPC JU shall focus on the deployment and operation of a platform for federating HPC and quantum infrastructure and resources providing Union-wide, secure services for a wide range of public and private users across Europe. Also, considering the current exponential increase of HPC use for AI, ML and NLP methods, this is an essential requirement to be able to satisfy the needs of new and emerging users whilst also ensuring ways to reduce the expected growth in the carbon footprint.

The JU could also consider the link with data spaces, as the right environments to enable data sharing in a scalable, governed, trusted and reliable way. It could also look into the link to edge and cloud infrastructures (computing continuum) to enable seamless access and storage of data.

In order to achieve a self-consistent European federated and secure HPC service infrastructure ecosystem, EuroHPC JU shall initiate market assessments within European ecosystem which shall include identifying existing or developing solutions which are aligned to the needs of scientific communities in Europe.

The outcomes of these assessments will be analysed in detailed and from 2023, procurements will be launched. These procurements will take into consideration not only the technical implementation of the federated and hyperconnected solutions (including both HPC and Quantum systems) but these will also include requirements for:

- common policies to use and interact in the infrastructure,
- security standards,

- organisation of coordination activities,
- long term support and services of the federated and hyperconnected solutions
- long term interoperability and sustainability aspect.

The federation of EuroHPC resources envisage to deliver the following services:

- Security and access control: A service that provides secure and controlled access to resources, including user authentication, authorization, and encryption following EU and national regulations.
- Discovery and access: A service that allows researchers to easily discover and access computing resources and data from multiple locations, including metadata search and retrieval;
- Transfer and movement: A service that enables fast and reliable transfer of data between supercomputing resources and data sources/lakes, including data staging, transfer protocols, and data synchronization.
- Carbon footprint: A service that tracks the resulting carbon footprint of these solutions

The JU shall promote these hyperconnected and federated infrastructures to the lower tiers of the national and institutional HPC operators. It shall also consider additional actions that could be performed in order to have more in depth knowledge about which performance, energy use and security of applications running on the systems and explore the use of confidential computing services in order to protect data and applications (while preserving performance).

Within the context of federation, the JU should consider engaging in collaborations with entities like EOSC, ESFRIs or European Cloud providers in order to federate public /private compute and data resources to implement an end-to-end sovereign and secured continuum of resources and services for the AI community (in the field of the new AI Factories vision) or for serving the needs of large-scale instruments or digital twins in the ingestion/processing of instrumental data.

2.5 Technology

Technology encompasses all hardware and software elements contributing to the setup of solutions fit for HPC, AI and QC applications inside proper infrastructures with related support and service.

The competitiveness of the Europe's HPC infrastructure depends on the performance and availability of the most modern technologies. The overall performance of the European HPC infrastructure depends not only on the performance of the supercomputers, but also on the stability and interoperability of each individual component. With large increases in digital networking, data and information are becoming increasingly valuable, in many cases eclipsing raw computing power. It is essential that state-of-the-art cyber-security technologies and protocols protect data at all layers and provide secure access and use of the systems[9].

Technological research and innovation must be state-of-the-art and reinforce strategic sovereignty (as indicated in Council Regulation (2021/1173). Furthermore, the research and innovation must guarantee early access to European technologies and lead in development of European IP.

Several assumptions were made regarding the research and innovation of the HPC technologies that the JU shall invest in:

- The approach must be based on establishing what end-users need.
- Technology development should include, where appropriate, the principle of co-design.
- Technology development must support EU digital sovereignty.
- The approach must consider a resilient supply chain in a competitive European HPC and Quantum Computing ecosystem (supply-chain-readiness-level).

The process for R&I should include actions to:

- *Foster a clear focus, targets, and commitments in the implementation; define TRL targets (which are aligned to the relevant funding programmes) for hardware and software technology.*
- *Work towards putting in place a stable and structured long-term partnership between the JU and industry, research organisations and the institutions in High Performance Computing who commit themselves to establishing, coordinating, and implementing a strategic and ambitious R&I initiative contributing to the development of innovative HPC hardware and software.*
- *Assess the different Technology Readiness Level (TRL) of existing solutions in order to assess which technologies to invest in; monitor the developments in critical hardware where European Leadership is lacking in the development of solutions (hardware, software, applications).*
- *Establish, maintain, and implement a strategic R&I roadmap that fosters the European capabilities to design, develop and produce the IP related to technologies by relevant key performance indicators; monitor the EU R&I projects progress and adjust the roadmap accordingly.*

- *Align execution time frames of the EuroHPC JU proposals and funded projects with market development so as to maximize long-term sustainability of the developed technology and hardware and software assets.*
- *Promote the uptake and systematic use of research and innovation results generated in the Union in infrastructure procurements Intellectual Property Rights.*

IPR arrangements for the technological assets developed using the EuroHPC funding should respect EU funding rules, including giving IP rights to the JU, to control the specific technological developments, while preserving the privacy and interests of the beneficiaries. In particular, provisions could be made in grant agreements for technology projects to guarantee first exploitation in Europe, the transfer of ownership of results, and if relevant, the granting licenses or sub-licenses.

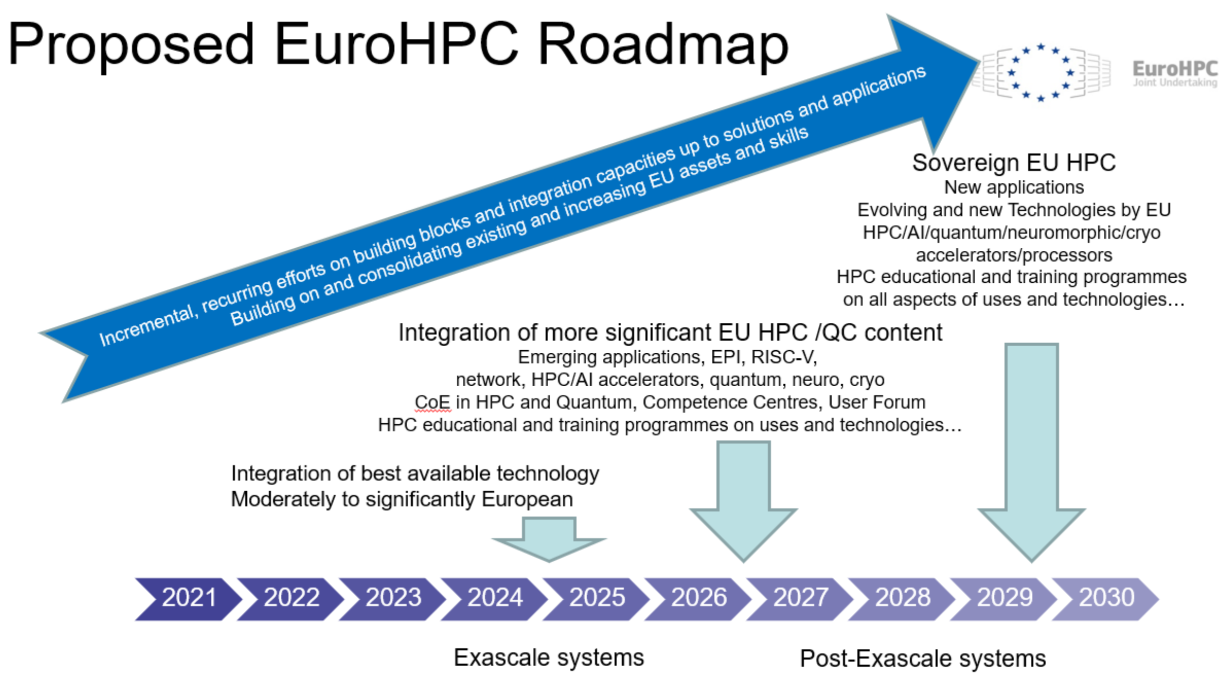

Figure 3: Technologies for HPC/-AI solutions: progression is foreseen from "Best available technology" to "Integration of more significant European content" to be integrated into solutions procured by EuroHPC

HPC technologies, including General Purpose Processors, accelerators, and networks/interconnects, which are developed through EuroHPC JU calls must pursue energy efficiency goals, be innovative, be able to perform and compete globally, be production ready and whenever feasible be ready to be deployed in industrial settings. RISC-V based solutions are a key element in the way forward.

These technologies need to take into account new usage models such as hybrid computing and the European Digital Twin initiatives. Technologies should also take into account other R&I activities ongoing in the European ecosystem such as those in big data analytics, AI, and neuromorphic and quantum computing.

A building block approach (see table in Introduction of this Chapter 2) to the whole Research & Development cycle is envisaged. While it is important to leave the door open to non-European suppliers in this process to foster competition and a diverse set of possible solutions, intellectual property (IP) gained in that process must remain in Europe.

EuroHPC JU started an iterative and modular approach where calls should be continuously launched to define building blocks and their interfaces, to develop these building blocks (hardware and software), and to integrate them into innovative HPC architectures for exascale and post-exascale.

The European Open Stack (EOS) is an open ecosystem for computing encompassing both hardware and software and fostering the development of co-designed systems required to advance European and global HPC.

EOS can be represented by a collection of hardware elements or specifications and software pieces such as development tools, system software, middleware, libraries – open source or not. EuroHPC JU calls in 2019, followed by pilot projects call in 2020 led to projects developing some of these elements.

The technology development shall be tied to large scientific and industrial use cases to make sure the development addresses the broader European market and contributes to the digital sovereignty beyond scientific HPC. Close co-design of suppliers with potential customers, as well as the HPC centres acquiring systems and the users of such systems should be encouraged and use-cases should be vertical to the EOS. Further details can be found below in the EOS section.

2.5.1 European HPC and Quantum Computing Supply Chain

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

Attempting to reach a target of 100% European solutions is not realistic, if only regarding some parts or subcomponents, like memories, are not designed nor manufactured in Europe. Production facilities of other electronic or mechanical parts can sometimes be found in Europe or their production can be relocated to Europe. The final EU-added value eventually resides in the design and integration know-how of the subsystems, like for cooling, provided by either a supercomputer vendor itself, or by a specialised company providing the technology to a vendor/integrator.

In order to establish an innovative and competitive European HPC value chain, both the supply and the demand side of HPC, including quantum computing technologies, must be strengthened. The strategic EuroHPC JU R&I programme supports the development of HPC hardware such as microprocessors, similar to the European Commission's Quantum Flagship for quantum technologies. As a significant public procurer of HPC and quantum computing infrastructure, the EuroHPC JU will also support a development path up to TRL 8/9 including the deployment of indigenous technology developed in preceding European R&I projects. The coordinated investment in public R&I and public procurement provides an effective driving force towards a vibrant HPC and quantum ecosystem in Europe.

In order to implement this mid-term vision of fostering European technologies, EuroHPC could collaborate with other initiatives like Quantum Flagship to use the so-called 'innovation procurement initiative'. A European strategy for sovereignty in quantum technologies is important for ***a resilient industrial supply chain*** *and to secure ownership of technology developed in the region. To enhance European HPC capabilities through quantum acceleration, it is critical to develop full software stack based on European solutions that enable the operation of these heterogeneous systems and the execution and management of jobs.*

This includes data, workflow and resource management, I/O protocols, signalling, software engineering methods and practices tailored for quantum and hybrid computing, and more. To benefit from these investments, it is also paramount to prepare the EU workforce for quantum technologies. This full software stack should include frameworks for the implementation of error mitigation and error correction schemes. The objective is not to develop these error handling techniques, but the frameworks for their easy adoption and use. The developed stack should also target being hardware agnostic whenever technically possible.
In order to address the above, the EuroHPC JU should consider these activities in future work programmes.

Software has still another status, in the sense it often combines openly available open source (possibly vendor-improved; possibly supported by a third party i.e. not for free) and proprietary pieces. Here again the EU added value lies a lot in specific optimisations of middleware and in software stack integration know-how.

The European HPC supply chain currently consists of one large integrator, plus a number of SME integrators. They all rely on components developed and manufactured outside of Europe; however, they all add various levels of European components and intellectual properties to their solutions. Several of them, are particularly strong on advanced cooling technologies. Europe is also the home of a number of independent software vendors (ISVs) developing software for HPC.

The European Commission followed by EuroHPC JU have supported the development of European HPC technologies through a large number of projects, including DEEP-SEA, RED-SEA, and IO-SEA, as well as the European Processor Initiative (EPI) and eProcessor which specifically tackled the need for European processor technology for HPC use. The EPI project has resulted in the development of an ARM-based low power General Purpose Processor (GPP), which is currently coming to market and which EuroHPC JU expects it will be a key component in future EuroHPC systems.

The EPI project has provided the European HPC ecosystem with valuable experience in designing a General-Purpose Processor. The JU will build on this experience when embarking on projects to use the RISC-V ISA as the instruction set for HPC processors.

Since HPC and quantum technology are both key technologies for Europe, developments around tech sovereignty, supply chain management and make-or-buy will have impact on the deployment of HPC, quantum computers and simulators the EU. It will be key to bring this in balance, create and execute a long term joint European strategy that support these developments.

In order to strengthen the supply chain, EuroHPC JU shall consider providing holistic integration calls for support in the form of pilot technology demonstrators for HPC solutions. Since the elements are not clear at the moment, the strategy is to identify critical elements for the future in a first step and formulate a priority list for strengthening the supply chain in an updated version of the MASP.

2.5.2 European Open Stack: a concept for European HPC solutions building blocks (EOS)

EuroHPC JU will work with stakeholders to coordinate codesign in the R&I hardware and software activities and ensure that activities meet user requirements and deployment of these technologies. Calls shall be launched which will take each building block in HPC and Quantum Computing hardware and software from innovation to deployment. This activity shall be closely coordinated with ongoing development of software integration layers (middleware) and applications.

EuroHPC JU shall also assess the different Technology Readiness Level (TRL) in order to assess which technologies to invest *in hardware and software - such as processors, interconnects,* *operating systems, compilers, runtimes, workflow frameworks, for HPC, AI and quantum, performance/energy analysis tools, numerical and I/O libraries. EuroHPC should define requirements for the building blocks to be collected as European Open Stack (EOS) elements - which can be open source or not – in terms of readiness and quality, documentation, and public interfaces.*

The European Open Stack (EOS) should include:

- Ecosystem for European HPC processors including low-power processors, accelerators, interconnects shall be supported. In particular, the JU in a joint effort with the Key Digital Technologies Joint Undertaking shall support the development of low power General Purpose Processor (GPP) and accelerator technologies. These developments do not only target the state-driven supercomputer-market but primarily broader, industry-driven markets. Processor development shall be driven by industry use cases in cloud and server markets.
- Software Stack components and tools from operating systems to libraries as well as AI frameworks so as to foster the ease of use and compatibility of the EuroHPC machines from the user perspective.
- Compliance, design, and organisation of these building blocks that facilitates further integration, based on modular principles, coordinating resource management across layers of the Software Stack into novel HPC architectures Technologies and systems for the interconnection of classical supercomputing systems with other, often complementary computing technologies, such as neuromorphic or quantum computing technologies.
- Technologies for operation and security of HPC systems that take industrial needs into account.
- Emerging computing paradigms and their integration into leading supercomputing systems, including High Performance Computing, AI, and quantum computing systems.
- Tools for deployment of industrial-oriented HPC infrastructure and associated software environments and service platforms for industrial innovation.
- Tools and procedures forming a minimal common layer of security services that could be a European standard to be implemented by all Hosting Entities.

EuroHPC JU may support a full service for industrialising, managing, and supporting in a long-term period the EOS software deployed on EuroHPC computers. Additionally, EuroHPC may consider imposing the support of EOS software to the vendors of the future procured systems.

2.5.3 Hardware Technologies

The competitiveness of the European HPC infrastructure depends on the performance and availability of the most modern Hardware technologies. HPC demands hardware compute component designs built in the best silicon technology nodes to provide the highest energy efficiency and best performance. However, technology intersects many other facets of HPC, from packaging up to large-scale cooling solutions. Mission critical subsystems or components are storage hierarchies as well as high-speed interconnect networks. There are also new upcoming integration paths such as rack-to-container integration.

As HPC systems become more and more heterogenous, larger scale and eventually modular, it is important to focus on related underlying technologies' reliability, availability, serviceability, performance, security and observability. All these underlying technologies are critical for state of the art modular massively parallel systems. The infrastructure's overall performance no longer depends on the performance of just a single supercomputer, but also on the stability, availability, performance, and interoperability of each individual component from board to modules to the entire system. With large increases in digital networking, data and AI engines are becoming increasingly valuable, in many cases eclipsing raw computing power. It is also essential to establish software compatibility and that state-of-the-art hardware enabled cyber security technologies protect data at all layers and provide secure access and use of the systems. The JU will, via its Advisory Groups, monitor the developments in critical hardware where European Leadership is lacking. This may include asking its Advisory Groups to undertake a full analysis of the situation.

Specialised AI hardware has evolved rapidly and can equip HPC systems (such as more and more widespread GPUs). However, ensuring joint support and optimisation of both HPC and AI workloads on the same system is difficult because performance does not always rely on the same features and sizing parameters - at processor, memory, and network levels - and because the HPC and AI software stacks notably differ.

EuroHPC needs plans to invest in appropriate accelerators and interconnect subsystems for AI (training or inference workloads). Where GPUs are currently used. Europe needs to seek alternatives to non-European GPUs by developing solutions based on ARM, RISC-V, European GPUs, or disruptive solutions.

- **Ecosystem for European HPC processors**

Hardware technologies such as low-power processors, accelerators, interconnects will be supported by the JU. In particular, the JU in a joint effort with the Key Digital Technologies Joint Undertaking will support the development of low power General Purpose Processor (GPP) and accelerator technologies designed in Europe and taking into account RISC-V based solutions.

These developments do not only target the state-driven supercomputer-market but also broader, industry-driven markets.

The development of an ecosystem for European HPC processors will contribute towards European technological sovereignty, by establishing, maintaining, and implementing a strategic R&I roadmap that fosters the European capabilities to design, develop and produce the IP related to high-end processors and/or accelerators driven by relevant key performance indicators. The development of European processors and/or accelerators should prepare the technology for its future integration in post-exascale supercomputers to be acquired at a later stage by the EuroHPC JU targeting systems incorporating European technologies.

The RISC-V Instruction Set Architecture (ISA) is an open standard, an abstract model for the design of integrated circuits that defines how a microprocessor is implemented. By adhering to the standard, different implementations provide some degree of software binary compatibility. The ISA specification with a free licensing model forms the basis for future processor developments, such that effort invested in building the software ecosystem is sustainable.

The RISC-V ISA has reached a level of maturity to demonstrate its viability as the de facto open ISA for future microprocessors and paves the ways for a new software/hardware ecosystem. The development of open hardware requires an ecosystem that supports the development of ideas through implementation in silicon and towards systems made up of different chips. The establishment of such an ecosystem requires careful guidance.

The RISC-V ISA presents two major opportunities for European R&I, both benefit from first-mover advantages. The first is to actively participate in the ISA definition, especially in HPC where there is less focus because there is less RISC-V traction. Second, European R&I can facilitate the development of HPC components and systems based on RISC-V implementations and the associated software ecosystem. Finally, the JU can define projects that facilitate paths from prototype to production and enable a new ecosystem to form and thrive, creating a central repository with well-defined IP rights and a common, business-friendly licensing model that provides a catalyst for European R&I in industry, especially for SMEs.

- **Network and interconnect technologies**

High-speed interconnect networks become of highest importance not only for monolithic architectures but in particular for the fastest possible integration of segregated resources and storage systems, as well as disruptive computing technologies like quantum computers and neuromorphic computers. Such technologies require sustained development and integration effort. High-speed interconnect components represent a significant part of the acquisition costs of state-of-the art supercomputers and are essential for strategic sovereignty in HPC.

EuroHPC JU has run multiple projects funding significant European research into this important field and the JU will continue to support and develop this further.

The world-wide market for HPC interconnect technology is currently dominated by a single non-European actor. There is therefore a real opportunity for European industry to gain market shares, also outside of Europe, if a competitive solution can be developed.

- ***Integration platforms up to container technologies***

Robust and efficient integration platforms are needed as intermediate building blocks for supercomputers, ensuring in particular the crucial electrical supply and cooling functions, and some interconnection logistics. Containers as modular physical units of HPC systems delivery are becoming an option even for the composition of large HPC systems. The development and optimisation of such flexible and modular platforms need recurring support. Software Technologies

2.5.4 Software Technologies

The development of software technologies for HPC and AI, including for quantum computing, will address a system software stack which connects low-level interfaces at the operating system level with HPC 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 available in Europe.

A number of challenges arise when it comes to HPC, AI and QC software stacks and the related applications from development and compile- to run-time:

- *Availability: how to deploy the software so that it is available on all EuroHPC machines.*
- *Performance: optimisation of applications, their dependencies with respect to parallel systems and network design for data-intensive workloads.*
- *Scalability: applications must be easily scalable in order to use resources efficiently.*
- *Portability: heterogeneous and diverse architectures (hardware and software environment); this is particularly problematic for older applications.*
- *Data management: there is an increasing number of data-intensive applications.*
- *Usability: it is difficult for new HPC users to find the optimal setup.*
- *Resilience: hardware failures, network overloads, system failures, lead to data loss, delays, or system downtime, resulting in financial losses, productivity losses, security risks, etc.*
- *Lack of expertise: high level support, and developer and user training must be recurring.*

- *Security: protection of the applications from errors, bugs, or vulnerabilities, such as data poisoning, model stealing, or adversarial examples.*
- *Software integration and AI**:** AI applications often use different frameworks, libraries, and tools, which can create compatibility and usability issues. For example, AI frameworks may not support HPC communication protocols, or HPC schedulers may not handle AI workloads efficiently. Software integration and orchestration can also be challenging for hybrid environment. Compiling AI software can be difficult (incompatible and undocumented versions of dependent software).*
- *Power consumption: energy efficiency, eventually, is becoming an overarching concern and priority, rather than raw performance; this efficiency can benefit from many improvements in the software stack but is eventually a global notion for an application or even the global use of an HPC system.*
- *Lack of resources for promoting and providing user support on the various software installed on EuroHPC supercomputers.*

In line with the general R&I strategy of the EuroHPC JU, developments on a European HPC software stack for HPC will be guided by the principles of modularity, interoperability, and open standards. The promotion of common interfaces on the basis of open standards is critical to develop an innovative, competitive, resilient and more autonomous HPC ecosystem. It will enable developers to select and implement possibly competing alternative solutions, the seamless substitution of software components and the rapid composition of new solutions.

Activities to support the development of a system software stack will account for the diversity of the European software ecosystem which involves many contributors from academic institutions, public organisations, independent software vendors, hardware suppliers and integrators. By pursuing a modular approach with focused grants on specific software developments with limited scope, the JU will build on preceding work and address the challenges of the evolving European HPC ecosystem, while maintaining inclusive and balanced funding support. Enforcing interoperability and promoting the adoption and contribution to open standards represent key elements for the implementation by the JU. Accordingly, the JU will structure calls for proposals to ensure individual grants will respect a well-defined scope with clear boundaries to other software components.

The uptake of best practices for professional software development is a cornerstone for the implementation of JU's strategy on software technologies; Within JU funded actions, this will include requirements on the adoption of effective project monitoring and management, the automation of development and deployment, as well as the establishment of feedback loops with application developers and users including continuous training. Activities supported by the JU should also include requirements for measures to increase the quality, reliability, and security of the developed software as an integral part of the development cycle, and include well-defined, quantitative, and measurable KPIs, milestones and deliverables which allow swift and effective adjustments during the project lifecycle.

Priority domains for software technologies include the development and deployment of:

- Dynamic elastic resource allocation mechanisms and effective resource management software for future exascale and hybrid HPC and quantum computing environments.
- *Workflow managers supporting scientific and AI pipelines across modular HPC supercomputers, federated HPC, cloud-HPC, and QC-HPC.*
- *Software for fine-grain and non-intrusive monitoring and analysing usage performance monitoring, energy, and resource consumption patterns.*
- *Middleware for cloud-HPC integration to make supercomputers easy to use for non-traditional HPC users, e.g. SME working with data analysis, generative AI, data streams from the compute continuum.*
- *Relevant common benchmarks (application based and synthetic) beyond outdated HPL.*
- System software components contributing to the federation of the European HPC infrastructure.
- Software for security related monitoring, protection, incident detection and response for the EuroHPC JU's infrastructure.
- An effective common development and deployment mechanism for end-user software such as a central continuous integration/continuous deployment platform and software container technologies; *optimised container images enforce the open science approach (e.g. interoperability, portability, and reproducibility) and are an option for the support for legacy cod*e.)

2.6 Applications and Data

The success of any technological infrastructure is determined by its impact on science, industry, and society. Performance indicators such as theoretical flop performance, synthetic benchmarks (like HPL) or scaling behaviour of individual jobs to an entire HPC system may help to guide developments but do not reflect the impact of these investments*. The current hardware trends show that HPL is now an outdated benchmark for procurement, instead EuroHPC should prefer figures of merit related to actual use, with which the* impact is measured by the outputs and results of innovative, efficient applications that fully exploit available HPC technology for real use cases. To date, Europe has an enviable record in application development and is world-leading in many academic and industrial domains. To maintain these leading positions constant efforts are needed as applications need to adapt to new hardware technologies, incorporate new algorithms and methods, adaptable codes, and scientific methods, and improve their efficiency and scaling on existing and future systems. *These activities require a long-term planning to avoid funding gaps and to retain qualified personnel.*

The hardware trend shows a possible reduction of the FP64 (64 bits) performance on GPUs and even CPUs. It makes mandatory for EuroHPC to support HPC user communities in better understanding the numerical sensibility of their application and moving, when possible, to either mixed precision or hybridizing with AI models. Such actions encompass R&D activities to develop tools, increased user support and training. In addition, scientific workflows often require combining different applications and associated data flows which is a great challenge for the implementation of effective resource allocation mechanisms on supercomputers and the optimal use of available resources.

European HPC users are not a homogeneous body, but span a broad spectrum of skills, knowledge, and experience in developing and using HPC and quantum applications. The challenges now faced are centred around preparing existing applications (academic and commercial) for the known EuroHPC architectures and designing new algorithms, methods, and applications that run and scale to match future hardware developments and are fit to tackle upcoming scientific challenges. Application software development is a long-term effort, and constant improvements are needed to maintain the relevance of applications. *The goal of these activities is to have a rich set of commonly used applications in key scientific domains, spanning existing users as well as emerging ones, readily and efficiently available on EuroHPC systems.*

The JU has already funded several Centres of Excellence (CoEs) for HPC Applications and launched a call to support algorithm development to prepare for the post-exascale era. *The JU should continue to provide support for the coherent, domain-focused expertise for user training and support and for the user-driven development and optimization of next-generation algorithms and applications.*

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, sustainable, reusable, reliable, secure, and higher quality software, the JU shall:

- Provide continuous support to the development and improvement of important applications in a wide range of scientific and industrial areas.
- Promote modularisation of applications by identifying common software building blocks and supporting their redesign using specialised software libraries to exploit synergies between applications and simplify the development of new applications.

- Prioritise the development of software libraries for applications to accelerate application readiness for new architecture and address horizonal and cross-cutting elements, such as artificial intelligence and energy efficiency.
- Support new usage methodologies for interactive execution and elastic scheduling for dynamic allocation of resources based on workloads, in particular for AI workloads.
- Support the harmonisation of programming models and concepts, quality standards as well as best practices in software engineering.
- *Address the challenges and limitations arising from legacy code present in many applications. HPC for numerical simulation, unlike younger AI area, has a strong and complex applications and software basis. Tools and support have to be put in place for their porting, adaptation and re-engineering, and whenever possible further optimisation – not all codes and components can be fully rewritten.*
- *Improve application security. enforce access control, isolation of workloads, code signature, containerisation, safe distribution of certified software and applications.*

2.6.1 HPC and AI Applications

Through this pillar of activity, EuroHPC JU aims at achieving excellence and maintain European world-leadership in HPC, AI and quantum applications that are key for European science, industry, and the public sector. Scientific and industrial HPC codes, applications, and software packages in key areas for Europe shall be codesigned, developed, ported, and optimised to fully exploit the performance of current and future computing systems. *Also, novel scientific methods will need to be integrated*. They will also need to integrate the worlds of simulation and AI to facilitate hybrid workloads, such as AI-enabled simulations or larger workflows consisting of alternating AI/ML and HPC steps

The following objectives need to be pursued:

- Support for HPC-powered codes, applications, and tools in all phases (such as in co-design, development, incorporation of new methods, porting, re-structuring, optimisation, up scaling, interoperability, re-engineering, etc.) in critical domains for extreme scale computing and data performance.
- *Support to HPC users' communities with tools/wizards and training in moving their applications to low/mixed precision or hybridizing with AI in order to continue to benefit from the increased performance of future GPUs and even CPUs.*
- *Development of European Foundation multimodal model(s) for science.*
- *Improvement of the diversity of applications and software including beyond the scope of the existing initiatives. New methods and tools for porting, building, and running software*

environments and applications on different systems and architectures, facilitating, and widening the access while ensuring performance of the applications, and energy efficiency.
- Novel approaches combining HPC, AI and HPDA for cybersecurity applications, for example preventing or responding in real-time to cyberattacks.
- Development of quantum computing testbeds and platforms for quantum applications and services. The availability of quantum computer emulators on top of the existing HPC infrastructure could help to accelerate the development of applications for quantum computers.
- Identification of applications areas that need additional support to meet the diverse European user community needs.
- Development of common APIs that allow the interoperability of Big Data and AI workloads, which are typically deployed in public clouds and European Data Spaces (e.g. GAIA-X), with HPC infrastructures.

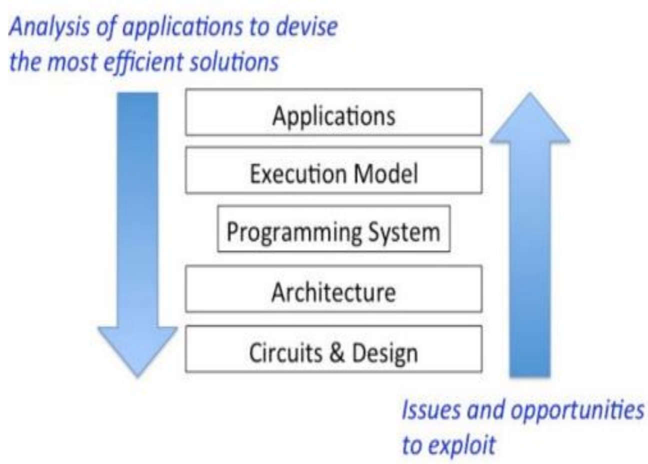

Figure 4: Applications development circle

The JU shall continue the development of HPC and quantum applications, exploit synergies and, develop novel algorithms, codes and tools optimised for future generations of supercomputers. Further development and sharing of methodologies for analysis and parallelisation should constitute a transversal spine to sustain a holistic multi-domain applications scope.

2.6.2 Growing the quantum applications ecosystem

To unlock the potential of quantum computing, there is a strong need not only to develop advanced quantum hardware but also to bring European users of quantum technologies together and facilitate the development of quantum applications and use cases. Industry calls for the development of applications and European Quantum Excellence Centres (QECs) shall play a key role in this. They shall foster the development of an ecosystem of quantum programming facilities, application libraries, and a skilled workforce, the discovery of new applications for quantum computers and software engineering principles, fostering knowledge and uptake for these technologies.

Connecting the domains of Quantum Computing and conventional modelling and simulation, quantum-inspired approaches must also be supported, leading to improved solutions for classical problems and to more efficient classical simulation of quantum systems. Quantum inspired algorithms provide the possibility to take advantage of powerful quantum information processing techniques without depending on a quantum computer.

These Quantum Centres of Excellence should develop quantum applications that can solve real-world problems. This could involve collaboration between Quantum Excellence Centres***, Hosting Entities,*** and industry partners to identify challenges that can be addressed using quantum computing and then developing applications that can solve those challenges. Developing quantum programming facilities and application libraries that can support the development of quantum applications, involving the establishment of open-source libraries and platforms that can be used by developers to build quantum applications. The EuroHPC quantum hardware can support the development of quantum applications and software for integration (middleware), as well as the establishment of testbeds for quantum technologies.

To foster collaboration between HPC and Quantum communities toward hybrid HPC/QC, the JU should explore the development of novel hybrid quantum algorithms and setup tailored programmes to engage and support end-user communities through concrete PoCs (proof-of-concepts) gathering experts from QC startups, academia, and end users (including SMEs and large-companies).

Due to the still uncertain time for realisation and demonstration of quantum computing advantage and production-ready quantum devices, it is important to focus a part of application development on use cases with the most foreseeable advantage in a relatively short term.

2.6.3 Artificial Intelligence and Data

Data and Artificial Intelligence (AI) communities in Europe also need to be included quickly in the HPC ecosystem to respond to the exponential increase in HPC usage of AI. Actions dedicated to integrating the HPC and Data Space ecosystems should be considered addressing industrial and scientific use cases, including HPDA and AI use cases. Furthermore, actions dedicated to the scaling out of AI models (e.g. in natural language processing, vision or toward multi modal approaches), should be considered, fostering the use of leading edge HPC facilities and access to large datasets, and optimised frameworks and support services. At the time of writing, it is broadly known that new requirements of efficiently using AI on HPC systems are not to be underestimated. The JU will work with its Advisory Committee to establish the areas of actions that could be considered. It is clear that cutting-edge Machine Learning (ML), Deep Learning (DL), and the use of Large Language Models (LLM) can significantly benefit from HPC systems. Actions dedicated to integrating the HPC and data-driven communities (e.g., Common European Data Spaces[10]) ecosystem could be considered addressing industrial, governmental, and scientific use cases, including HPDA and AI use cases. The following key actions will need to be taken into consideration to ensure a broader uptake of HPC/AI methods across a wide range of communities:

- Access to EuroHPC systems with specific HPC/AI tooling
- Deploy and advance HPC workflow tools for AI and HPDA, including MLOps
- Provide advanced expertise in using efficient HPC/AI methods at scale
- Sharing AI/HPC methods scalability findings in the light of energy constraints in Europe. Specific actions dedicated to the scaling out of AI models (e.g. in natural language processing, vision, sequence, or toward multi-modal approaches), should be considered, fostering the use of leading edge HPC facilities and access to large datasets, and optimised frameworks and support services.

The JU could also develop an understanding of new HPC/AI requirements needs to engage in Digital Twins and other AI models that support different applications in the field of sustainable energy production (e.g.: wind farms), healthcare, climate research, etc. It is important to note the increased importance of digital twins in research and industry. Thus, this is another area where the development of applications should be supported for these end users' communities. Priority should be given to the following topics:

- Tools enabling HPC workflows for AI and large data analytics workloads, e.g., with software containers.
- Techniques for supporting the interactive access to large datasets and their management in HPC systems.
- Reusable methodologies and tools for the development of a wide range of digital twins involving the coupling of traditional HPC simulation and modelling with computationally intensive artificial intelligence training processes and access to large datasets. While this is the case for digital twins, the use of coupling is also considered in other traditional HPC communities (e.g., computational fluids dynamics).

[10] Common European Data Spaces, Online: http://dataspaces.info/common-european-data-spaces

- *Programmes for the development and the availability of European Foundation models for science and collaboration with international initiatives in that field. The rise of Large Language Models (LLMs) has transformed the landscape of artificial intelligence, driving innovations across numerous sectors, from natural language processing to generative AI. EuroHPC plays a critical role in ensuring Europe's excellence and competitive position in this rapidly evolving field. By providing access to state-of-the-art high-performance computing resources, EuroHPC should enable European researchers and companies to train and refine complex LLMs, fostering advancements in AI that are essential for economic growth, technological sovereignty, and addressing societal challenges.*

2.7 Usage and Skills

To enhance Europe's competitiveness, boost its technological and data sovereignty, and strengthen European innovation, the European HPC ecosystem made up of the JU, Member States, HPC research institutes, HPC users, the Centres of Excellences (CoEs) and the National Competence Centres (NCCs) need to work together to a generate a highly knowledgeable, world-leading scientific and industrial *community capable of advancing hardware and software technologies and provide training and support at different maturity levels.*

EuroHPC JU has launched two calls in support these objectives: the EuroHPC Professional Traineeships and EuroHPC Training Platform and Summer School. In addition, the EUMaster4HPC project is ongoing to educate the next generation of HPC experts.

EuroHPC JU 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.

More actions shall be considered to develop and retain a European talent pool in HPC and develop viable and rewarding career paths for research software engineers and other key roles. *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 Competence Centres nationally 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.*

To increase involvement of existing and new users, the JU shall establish consultative groups such as a User Forum or a Scientific Advisory Committee. These groups shall support RIAG and INFRAG and provide reliable, sustainable feedback to the governance bodies of the EuroHPC JU on current and future infrastructure and software requirements and 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.

2.7.1 National Competence Centres (NCCs)

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 skills they need. Investment in HPC National Competence Centres is promoting a wide coverage of HPC activities and expertise in the EU and is providing specific services and resources for industrial innovation (including SMEs);

The HPC National Competence Centres were created by the Commission in 2020 and were strengthened in 2022 to prioritise and support exchange of best practices, the sharing of existing libraries of HPC codes and access to upgraded HPC application codes.

The National Competence Centres facilitate access to the best HPC and data intensive codes and tools and innovative scientific and industrial applications in collaboration with Centres of Excellence and Digital Innovation Hubs. This includes federating capabilities, exploiting available competences, and ensuring that application knowledge and expertise has the widest geographical coverage in the Union. HPC Competence Centres and HPC Hosting Entities work together to facilitate access to large-scale High-Performance Computing enabled pilot demonstrators and testbeds for big data applications and services in a wide range of scientific and industrial sectors.

In addition, ongoing collaboration with HPC National Competence Centres work and HPC Centres of Excellence is providing user input into the development of HPC technologies and applications.

Furthermore, in order to strengthen the ongoing deployment of first quantum simulators and computers by EuroHPC, JU could setup projects that would pull together QC Hosting Entities and National Competence Centres with the objective of fostering collaboration between HPC and Quantum communities toward hybrid HPC/QC.

2.7.2 HPC Skills

The development of a skilled workforce is one of the most sustainable investments in HPC with the potential for long lasting impact in a rapidly changing environment. Europe needs skills in highly specialised hardware and software development in order to support HPC infrastructure, 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 and applications, the running of existing HPC and quantum systems and the provision of support to users. *In addition to training our own* *workforce, efforts should be made to attract and retain the best HPC professionals world-wide to join the European HPC activities.*

Training, skills, and support is a cross-cutting topic relevant to technologies, applications, and chip design, including areas such as AI, data, cybersecurity, or quantum computing, and not forgetting large system administration and computing centres operations. Potential or actual competence shortage is already a concern in different specialties needed for HPC. HPC training and education can leverage and specialise more mainstream IT skills by offering relevant specialisations. Attractiveness of the broader HPC sector must be fostered, as well as the proximity with more general IT or STEM areas leveraged. For instance, connecting with existing curricula in broader IT or STEM areas that could offer HPC extra specialisations can complement EuroHPC efforts, which cannot cover all the education needs in all technical and scientific areas of interest.

Lifelong perspectives must also be considered, facilitating periodic re-training or on the job training, and circulation between academic and industrial sectors. EuroHPC JU shall consider actions in the following domains:

- *Specialised training for HPC specialists should be offered, from technology developers to computing centres staff (HPC sysadmins, HPC engineers), to software and application developers, and to advanced users of HPC and AI applications and related topics.*
- 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. 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.
- 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.*
- *Skills for emerging technologies such as quantum computing should be considered.*
- *Skills combining HPC and other related technologies (AI, data, cybersecurity, etc.).*
- *Skills to support development or energy efficient and sustainable solutions in HPC technology and application design.*
- *Sustainable career paths with reasonable and competitive conditions.*

The development of a European talent pool must be a permanent and overarching objective.in HPC. 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.

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. AI model developers, AI governance and compliance professionals, large dataset architects, in particular, 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 teams.

Support must come at national and European level for the full ecosystem of users and developers.

EuroHPC JU has launched three calls in support of these objectives: the EuroHPC Professional Traineeships, EuroHPC Training Platform and Summer School and the EuroHPC Virtual Training Academy. In addition, the EUMaster4HPC project is ongoing, with the goal of educating the next generation of HPC experts. Furthermore, the CoEs shall offer specialised training for HPC specialists as well as IT and data professionals, application developers, and advanced users of HPC applications.

While the success of the first promotion of EUMaster4HPC seems to be strong, EuroHPC should make rapidly an assessment of the needs (especially in AI and quantum) in order to increase the funding to EUMaster4HPC and fully revise its ambitions.

In 2023, the EuroHPC Virtual Academy Call shall be launched. It shall seek to develop a European HPC training framework which shall set out a common HPC skills-tree where all levels of users and skills need to be carefully defined and classified. The Virtual Academy shall also develop a catalogue of training programmes and courses which are made available in Europe through EuroHPC Hosting Entities, CoEs, Competence Centres and EDIHs, industry and SME partners, PRACE and other recognised HPC training organisations.

The EuroHPC Virtual Academy learning framework shall identify different ‘learning tracks’ depending on whether the person is seeking to be trained to be a ‘designer of HPC Technology, ‘a user’ ‘or ‘a provider of HPC Services’, and whether they need specific skills specific to a type of HPC or Quantum Technology, AI, data, application, or use case.

A first step shall be to build an inventory of existing training portfolios across Europe. Existing HPC training courses shall be classified and modified in accordance with the established framework standardised skills tree.

In parallel to these activities, a portfolio of common European HPC training material should be established and a EuroHPC portal developed where the currently existing HPC training material as well as future new material for teaching the advances of the future technology developments that do not exist now can be accommodated.

In order to exploit and leverage the European HPC training materials developed in the EU projects, a suitable repository is needed. As a result, a EuroHPC shall create, implement, and maintain a reliable and long-term EU repository that can safely store all the training materials developed within the EU projects (e.g. all the EU CoEs and NCCs) and then make it available through internet to the EU Citizens. This facility could also serve as repository for the HPC training material provided by the Participating States.

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

- *Provide upskilling programmes for existing profiles from AI model developers, AI quality managers, Database engineers, Data Scientists, etc.*

- *Develop off-the-shelf content and structures for inclusion of 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.*

EuroHPC JU 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 would be recommendable 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 EU participation, need to implement the State-of-the-Art of Learning Methodologies, including alternative forms of learning methodologies — such as student-centred instruction, participatory learning, hands-on learning, open learning etc. - should be implemented.

2.7.3 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.*

The JU shall develop a structure covering all levels of user support and fill the existing gaps with appropriate actions. This action has been started with projects like EPICURE or the newly call launched on AI support, but the ambition has to be revised.

User Forum: A EuroHPC User Forum will be further developed in 2024 by the EuroHPC JU. It shall promote knowledge exchange, professional development, and collaboration within the European HPC and Quantum communities. It shall be open, inclusive, independent, transparent, and responsive to the needs of its members. The Forum shall be made up of users from academic, industrial, and public sector sectors. It is an open group where discussions cover updates from EuroHPC, current developments in the European HPC community, collection of user requirements, and report on difficulties and issues they face using the EuroHPC JU infrastructure. It is not however a forum for vendors.

The creation of the EuroHPC User Forum shall have the following aim, support, and governance:

- The aim of the User Forum is to foster structured, coherent, and regular communication and exchange with all user communities and stakeholders;
- The mission and goals of the User Forum should be clear, concise, and relevant;
- The User Forum shall facilitate open consultation with user and scientific communities that also serves to highlight the EuroHPC vision;
- The User Forum shall have dedicated administrative support from the JU to ensure its sustainability and effectiveness;
- The JU shall establish a governance structure responsible for overseeing the Forum's activities and to collate and communicate feedback on user requirements to the Advisory Groups of EuroHPC as necessary;

Scientific Advisory Committee: the EuroHPC JU also needs the coherent, independent expertise and strategic vision of a world leading high-level scientific advisory committee. Indeed, a large amount of the available compute resources in Europe are requested and used by scientific groups from universities and public research centres on daily basis.

As far as research and innovation is concerned, these academic users are an indispensable source of guidance. They work on a wide range of different scientific disciplines (astrophysics, particle physics, climate, weather, earth science, life science, energy, or engineering[11]) and also from scientific fields not traditionally acquainted with HPC (e.g., social sciences, digital humanities). These academic users could provide advice to INFRAG, RIAG and EuroHPC JU and be part of the User Forum.

[11] see PRACE scientific case 2018-2026 ISBN: 9789082169492)

The JU shall consider the creation of a specific Scientific Advisory Committee (SAC) with a consultative role, which would be composed of recognised world high-level experts from across domains to provide coherent, independent expertise and strategic vision to EuroHPC. The Committee should, for example, propose scientific cases for post-exascale supercomputing.

2.8 International Cooperation

In line with the external policy objectives and international commitments of the Union, Europe should define, implement, and participate in international collaboration on supercomputing to foster research which addresses global scientific and societal challenges, while promoting competitiveness of the European HPC supply of technologies and user ecosystem.

The EuroHPC JU shall support international cooperation in supercomputing between European and Non-European partners in the following topics: scientific cooperation, EuroHPC JU Research and Development projects, reciprocal exchange of access time between EU and non-EU systems, exchange of young HPC professionals and EuroHPC JU supercomputer procurements. It will also monitor closely activities related to the HPC sector as well as evolving user needs outside the European Union.

In the field of scientific cooperation, the JU supports the continuation of the long-established tradition of full openness. This contributes not only to competence and technology building, but also to answering 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 the USA and Japan) and initiate broader scientific collaboration with aspiring HPC countries (*e.g.* India, ASEAN, Latin America). An important goal is to make the European HPC ecosystem as attractive as possible to talents world-wide. This includes to open parts of the infrastructure to qualified users worldwide, exchange of students/staff, and offer European training and education programmes to qualified people irrespective of their nationality (but possibly linked to affiliations within the member countries).

While EuroHPC JU Research and Development projects should support the digital sovereignty of the EU by expecting European participants and European technologies to play a central role in the European funded R&D projects, it remains important to continue collaborating with international companies that actively contribute to the relevant fields of HPC R&D, hence help achieve the best results for European HPC users and scientists. Furthermore, it would be extremely helpful to oblige both European and international participants in European projects to disseminate the results and undertake dedicated efforts to implement them into their products.

In the field of EuroHPC JU 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

JU in its procurements might at first seem natural, this is not deemed productive in the longer run. Instead, the EU has to act in two ways: first to convince the international actors to open their closed markets, and second to oblige international participants to provide “added value” to the European HPC ecosystem by explicitly collaborating with European companies and research institutions, and especially European SMEs. For the procurement of quantum computers and simulators, it should be recognized that the EuroHPC region is leading the path to integrating these systems to 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, the EuroHPC JU should consider working on activities with the objective of early adoption of cross-border technology by both EuroHPC States and the partnering countries.*

In the field of AI, Europe and EuroHPC should integrate international consortiums on the development of massive multimodal foundation models for science not only by bringing data but also contributing to the development, the training / fine tuning and an inference offer of our own European open-source models.

The JU shall ensure that JU infrastructure and activities (e.g. training) are easily accessible for suitable international collaboration partners of JU. Formal collaborations with foreign end-users should also include projects involving European software firms, thus fostering the development of European software solutions as well as their international uptake. These projects can aim at the development of software tools and applications for HPC, quantum computers and simulators or hybrid classical-quantum systems.

3. Activities with other Joint Undertakings and EU activities

EuroHPC JU shall work very closely with the European Commission to ensure that its activities are undertaken in close cooperation and coordination of other activities organised by the Commission including the EU Chip Act, the EU Quantum Flagship and shall monitor development in EOSC, GAIA-X, etc.

Furthermore, EuroHPC JU shall work closely with our sister JU, the newly created ‘Chips’ JU (formerly Key Digital Technologies JU) and the newly created Cybersecurity Competence Centre.

Finally, EuroHPC JU could consider working more closely with EOSC and ESFRIs 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 associated data services.

With GAIA-X and interested European private Cloud providers EuroHPC could collaborate in establishing a full end-to-end sovereign federated offer supporting Open R&D, confidential R&D and commercial activities for industry.

4. Annexes

Regulation 2021/1173

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1173&from=EN

Infrastructure Advisory Group (INFRAG) Input (2019)

EuroHPC INFRAG - Multiannual Strategic

INFRAG MASP: Updated Topics and Recommendations (February 2023)

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Research and Innovation Advisory Group (RIAG) Input (2020)

EuroHPC JU RIAG MSRIA 2021-2022 v11

RIAG proposal for MASP 2023-2027 (February 2023)

RIAG Proposal for MASP 2023-2027.pdf

Commission Staff Working Document (attached to Regulation 2021/1173)

4Annex2part2pdf (4) Staff.pdf