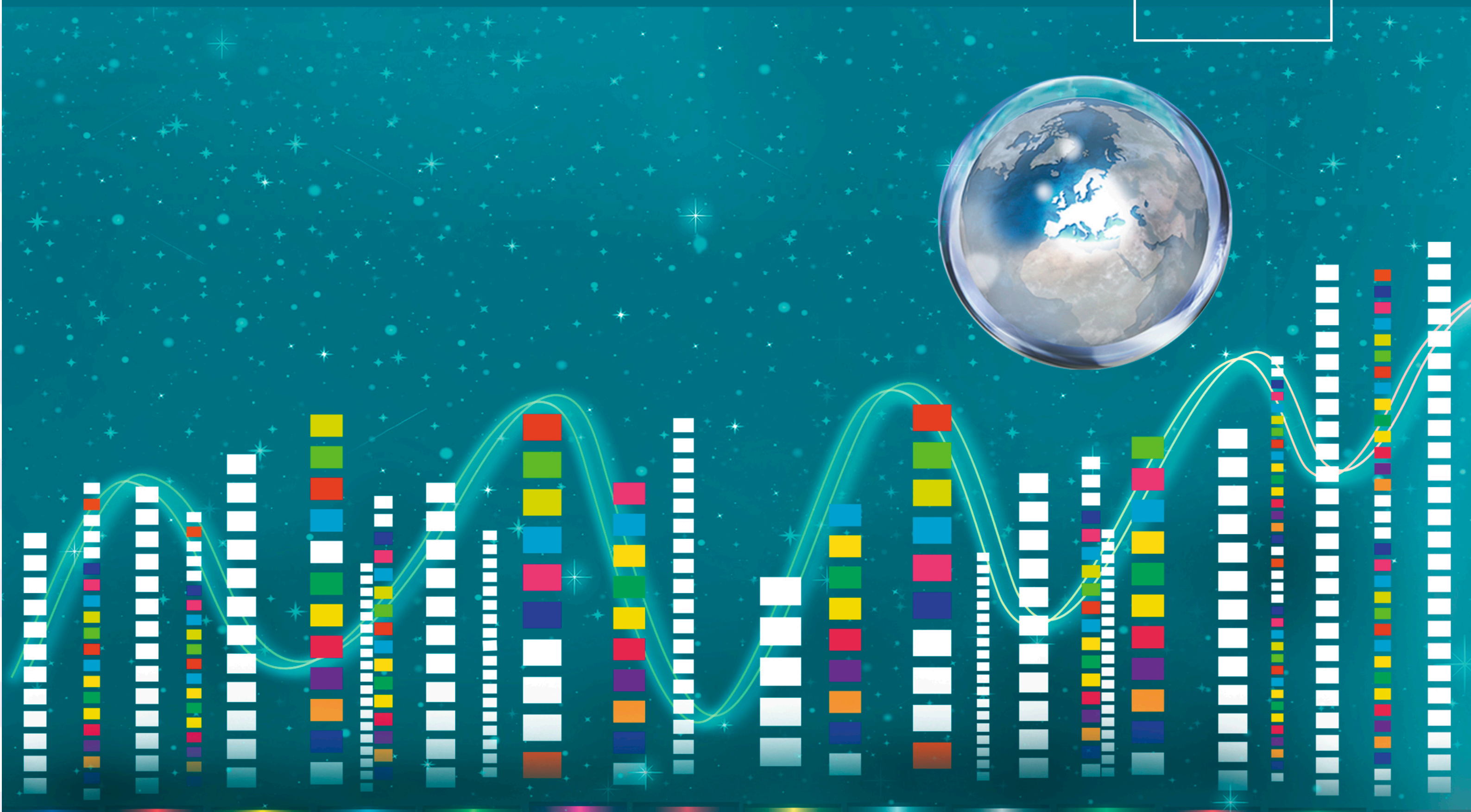
European Commission

Impact Assessment Study for Institutionalised European Partnerships under Horizon Europe

Independent Expert Report



Research and Innovation

Impact Assessment Study for Institutionalised European Partnerships under Horizon Europe

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EUROPEAN COMMISSION

Impact Assessment Study for Institutionalised European Partnerships under Horizon Europe

In collaboration with

2020 Directorate-General for Research and Innovation EN

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Introduction

This Impact Assessment Study had the primary objective to support and provide input to the impact assessments of the first set of 13 European Institutionalised Partnerships based on Articles 185 and 187 of the Treaty on the Functioning of the EU (TFEU) that are envisaged to be funded under the new Framework Programme for Research and Innovation, Horizon Europe.

In addition, the Impact Assessment Study team contributed to future European policymaking on the overall European Partnership landscape by means of a horizontal analysis of the coherence and efficiency in the implementation of European partnerships. The purpose of this analysis was to draw the lessons learned from the implementation of the impact assessment methodology developed for this study and to formulate recommendations for the refinement and operational design of the criteria for the selection, implementation, monitoring, evaluation and phasing-out for the three types of European Partnerships. Finally, an impact modelling exercise was conducted in order to estimate the potential for longer-term future impacts of the candidate Institutionalised European partnerships in the economic and environmental sustainability spheres.

Technopolis Group was responsible for the overall coordination of the 13 specific impact assessment studies, the development of the common methodological framework, and the delivery of the horizontal analysis. It also conducted specific analyses that were common to all studies, acting as a 'horizontal' team, in collaboration with CEPS, IPM, Nomisma, and Optimat Ltd. For the implementation of the individual impact assessment studies, Technopolis Group collaborated with organisations that are key experts in specific fields covered by the candidate Institutionalised European Partnerships. These partner organisations were Aecom, Idate, Steer, Think, and Trinomics. Cambridge Econometrics took charge of the impact modelling exercise.

The Impact Assessment Study was conducted between July 2019 and January 2020. The 13 Impact Assessment Studies were conducted simultaneously, based upon a common methodological framework in order to maximise consistency and efficiency. The meta-framework reflected the Better Regulation Guidelines and operationalised the selection criteria for European Partnerships set out in the Horizon Europe Regulation. The 'Horizontal analysis of efficiency and coherence of implementation' was conducted in the same time period, building upon the information available on the 44 envisaged European Partnerships landscape as in May 2019, complemented with information on five envisaged European Partnerships as decided by the European Commission in October and November 2019.

This final report contains the reports of all individual impact assessment studies and the 'horizontal' analyses. It is structured in two parts, reflecting the two strands of analysis:

PART I. Impact Assessment Studies for the Candidate Institutionalised European Partnerships

1. Overarching context to the impact assessment studies

This report sets out the overall policy context and methodological framework underlying the impact assessment studies for the candidate Institutionalised European Partnerships. It describes the changes in approach to the public-private and public-public partnerships under Horizon Europe compared to the previous EU Framework Programmes. An example is the requirement that all envisaged European Partnerships be implemented as either co-programmed, co-funded or institutionalised. The impact assessment studies will consider these three scenarios as the different options to be assessed, in compliance with the Better Regulation guidelines and against the functionalities that the candidate partnerships are expected to fulfil. The report describes the common methodological framework to assess the envisaged initiatives accordingly. The report also presents the landscape of European Partnerships at the level of Horizon Europe Pillar 2 clusters, which lay the grounds for all of the impact assessment studies except the candidate Institutionalised European Partnership for Innovative SMEs.

2. EU-Africa Global Health Candidate Institutionalised European Partnership

This initiative focuses on research and innovation in the area of infectious diseases, with a particular focus on sub-Saharan Africa. It will address the challenges of a sustained high burden of infectious diseases in Africa, as well as the (re)emergence of infectious diseases worldwide. Its objectives will thus be to contribute to a reduction of the burden of infectious diseases in sub-Saharan Africa and to the control of (re)emerging infectious diseases globally. It will do so through investments in relevant research and innovation actions, as well as by supporting the further development of essential research capacity in Africa. The study concluded that an Institutionalised Partnership under Art. 187 of the TFEU is the preferred option for the implementation of this initiative.

3. Candidate Institutionalised European Partnership on Innovative Health

This initiative focuses on supporting innovation for health and care within the EU. It will address the EU-wide challenges raised by inefficient translation of scientific knowledge for use in health and care, insufficient innovative products reaching health and care services and threats to the competitiveness of the health industry. Its main objectives are to create an EU-wide health R&I ecosystem that facilitates translation of scientific knowledge into innovations; foster the development of safe, effective, patient-centred and cost-effective innovations that respond to strategic unmet public health needs currently not served by industry; and drive cross-sectoral health innovation for a globally competitive European health industry. The study concluded that an Institutionalised Partnership based on Article 187 of the Treaty on the Functioning of the EU (TFEU) is the preferred option for the implementation of this initiative.

4. Candidate Institutionalised European Partnership in High Performance Computing

The initiative focuses on coordinating efforts and resources in order to deploy a European HPC infrastructure together with a competitive innovation ecosystem in terms of technologies, applications, and skills. It will address the challenges raised by underinvestment, the lack of coordination between the EU and MS, fragmentation of instruments, technological dependency on non-EU suppliers, unmet scientific demand, and weaknesses in the endogenous HPC supply chain. The initiative has as its main objectives to enhance EU research in terms of HPC and related applications, continued support for the competitiveness EU HPC industry, and fostering digital autonomy in order to ensure long-term support for the European HPC ecosystem as a whole. The study concluded that an Institutionalised Partnership is the preferred option for the implementation of this initiative as it maximises benefits in comparison to the other available policy options.

5. Candidate Institutionalised European Partnership in Key Digital Technologies

This initiative focusses on enhancing the research, innovation and business value creation of European electronics value chains in key strategic market segments in a sustainable manner to achieve technological sovereignty and ultimately make European businesses and citizens best equipped for the digital age. It will address the risks of Europe losing the lead in critical industries and services and emerging KDTs. It will also tackle Europe’s limited control over digital technologies that are critical for EU industry and citizens. It has as main objectives to strengthen KDTs which are critical for the competitive position of key European industries in the global markets, to establish European leadership in emerging technologies with high socioeconomic potential and to secure Europe’s technological sovereignty to maintain a strong and globally competitive presence in KDTs. The study concluded that the Institutionalised Partnership is the preferred option for the implementation of this initiative.

6. Candidate Institutionalised European Partnership in Smart Networks and Services

This initiative focuses on the development of future networks infrastructure and the associated services. This includes bringing communication networks beyond 5G and toward 6G capabilities, but also the development of the Internet of Things and Edge Computing technologies. It will address the challenges raised by Europe delay in the deployment of network infrastructure and failure to fully benefit from the full potential of digitalisation. It has as main objective to ensure European technological sovereignty in future smart networks and digital services, to strengthen the uptake of digital solutions, and to foster the development of digital innovation that answers to European needs and that are well aligned with societal needs. The study concluded that an institutionalised partnership under article 187 is the preferred option for the implementation of this initiative.

7. Candidate Institutionalised European Partnership in Metrology

This initiative focuses on metrology - that is the science of measurement and the provision of the technical infrastructure that underpins accurate and robust measurements throughout society; measurements that underpin all domains of science and technology and enable fair and open trade and support innovations and the design and implementation of policy and regulations. It will address challenges in the fragmentation of national metrology systems across Europe and the need to meet ever-increasing demands on metrology infrastructure to support the measurement needs of emerging technologies and important policy domains in climate, environment, energy and health. The main objective of the initiative is to establish a sustainable coordinated world-class metrology system in Europe that will increase and accelerate the development and deployment of innovations and contribute to the design and implementation of policy, regulation and standards. The study concluded that an A185 Institutionalised Partnership is the preferred option for the implementation of this initiative.

8. Candidate Institutionalised European Partnership on Transforming Europe's Rail System

This initiative focuses on the development of a pan-European approach to research and innovation in the rail sector. It will address the challenges raised by the lack of alignment of research and innovation with the needs of a competitive rail transport industry and the consequent failure of the European rail network to make its full contribution to European societal objectives. It will also strengthen the competitiveness of the European rail supply industry in global markets. Accordingly, the objectives of the initiative are to ensure a more market-focused approach to research and innovation, improving the competitiveness and modal share of the rail industry and enhancing its contribution to environmental sustainability as well as economic and social development across the European Union. The study concluded that an institutionalised partnership under article 187 is the preferred option for the implementation of this initiative.

9. Candidate Institutionalised European Partnership for Integrated Air Traffic Management

This initiative focuses on the modernisation of the Air Traffic Management in Europe - an essential enabler of safe and efficient air transport and a cornerstone of the European Union's society and economy. The proposed initiative will address the challenges raised by an outdated Air Traffic Management system with a non-optimised performance. The current system needs to be transformed to enable exploitation of emerging digital technologies and to accommodate new forms of air vehicle including drones. The objective is therefore to harmonise European Air Traffic Management system based on high levels of digitalisation, automation and connectivity whilst strengthening air transport, drone and ATM markets competitiveness and achieving environmental, performance and mobility goals. This would create €1,800b benefits to the EU economy if the current initiative can be built on and accelerated. The study concluded that an Institutionalised Partnership under Art. 187 TFEU is the preferred option for the implementation of this initiative.

10. Candidate Institutionalised European Partnership on Clean Aviation

This imitative focuses on further aeronautical research and innovation to improve technology leading to more environmentally efficient aviation equipment. It will address the challenges raised by the growing ecological footprint of aviation and the challenges and barriers faced by the aviation industry towards climate neutrality. It will also strengthen the competitiveness of the European aeronautical industry in global markets. Accordingly, the objectives of the initiative are to ensure that aviation reaches climate neutrality and that other environmental impacts are reduced significantly by 2050, maintain the leadership and competitiveness of the European aeronautics industry and ensure safe, secure and efficient air transport of passengers and goods. The Impact Assessment study assessed the options for implementation that would allow for an optimal attainment of these objectives. The study concluded that an institutionalised partnership under Art. 187 TFEU is the preferred option for the implementation of this initiative.

11. Candidate Institutionalised European Partnership on Clean Hydrogen

The report assesses the impact of potential initiatives to support, through research and innovation, the growth and development of clean hydrogen, among which an Institutionalised European Partnership is one of the options assessed. The existing challenges for clean hydrogen include the limited high-level scientific capacity and fragmented research activities, the insufficient deployment of hydrogen applications, and consequently weaker EU scientific and industrial value chains. Environmental, health and mobility pressures are also driving the need for cleaner hydrogen generation, deployment and use. An initiative for clean hydrogen must have as a main objective the strengthening and integration of EU scientific capacities, to support the creation, capitalisation and sharing of knowledge. This is necessary to accelerate the development and improvement of advanced clean hydrogen applications, the market entry of innovative competitive clean solutions, to strengthen the competitiveness of the EU clean hydrogen value chains (and notably the SMEs within them), and to develop the hydrogen-based solutions necessary to reach climate neutrality in the EU by 2050. The study concluded that an Institutionalised Partnership under Art. 187 TFEU is the preferred option for the implementation of this initiative.

12. Candidate Institutionalised European Partnership on Safe and Automated Road Transport

This initiative focuses on Connected, Cooperative and Automated Mobility: the use of connected and automated vehicles to create more user-centred, all-inclusive mobility, while also increasing safety, reducing congestion and contributing to decarbonisation. With current road traffic collisions and negative local and global environmental impacts not reducing quickly enough, it will address the challenges raised by the current fragmentation of research across the field, and the threat to European competitiveness if the research agenda does not advance quickly enough. The initiative will focus on strengthening EU scientific capacity and economic competitiveness in the field of CCAM, whilst contributing to wider societal benefits including improved road safety, less environmental impact, and improved accessibility to mobility. The study concluded that a co-programmed partnership is the preferred option for the implementation of this initiative.

13. Candidate Institutionalised European Partnership for a Circular Bio-based Europe

This initiative focuses on intensifying research and innovation allowing to replace, where possible, non-renewable fossil and mineral resources with biomass and waste for the production of renewable products and nutrients, in order to drive forward sustainable and climate-neutral solutions that accelerate the transition to a healthy planet and respect planetary boundaries. It will address the challenges raised by the fact that the EU economy does not operate within planetary boundaries, is not sufficiently circular and is predominantly fossil based. It will also address the insufficient research and innovation (R&I) capacity and cross-sectoral transfer of knowledge and bio-based solutions, as well as risks posed to the European bio-based industry's global competitiveness. The study concluded that Institutionalised European Partnership based upon Article 187 TFEU is the preferred option for the implementation of this initiative.

14. Candidate Institutionalised European Partnership for Innovative SMEs

The initiative is envisaged as a continuation of the Eurostars 2 programme which is managed by the Eureka network. The initiative focuses on international collaborative R&D of innovative companies, facilitated through a network of national funding organisations as included in the Eureka network. The funded projects are bottom-up and involve small numbers of project partners. The candidate partnership addresses a niche issue namely limited opportunities for international bottom-up collaboration. The partnership provides thus an opportunity for SMEs for international R&D collaboration but does not address specific technological, social, or environmental challenges. Its main objective is to improve the competitiveness of European SMEs through collaborative funding. The study concluded that a co-funded partnership is the preferred option for the implementation of this initiative.

PART II. Horizontal studies

1. Horizontal Analysis of Efficiency and Coherence in Implementation

The focus of this report is on the coherence and efficiency in the current European Partnership landscape under Horizon Europe and the potential to enhance efficiency in the European Partnerships' implementation.

European Partnerships are geared towards playing a pivotal role in tackling the complex economic and societal challenges that constitute the R&I priorities of the Horizon Europe Pillar II and are in a unique position to address transformational failures. Multiple potential interconnections and synergies exist between the candidate European Partnerships within the clusters, but few are visible across the clusters.

As for the improvement of the efficiency in implementation of institutionalised partnerships under Art. 187, potential efficiency and effectiveness gains could be achieved with enhanced collaboration. An option for a common back-office sharing operational implementation activities is worth exploring further through a detailed feasibility study in order to assess whether efficiency gains can be made. Ideally this would be co-designed as a common Partnership approach, leading to a win-win situation for all partners.

2. Impact Modelling of the Candidate Institutionalised European Partnerships

This report presents the results of the use of a macroeconomic model to assess the economic and environmental impacts of the preferred options identified in the individual 13 impact assessment studies. The model used is E3ME. It includes explicit representation for each EU Member State with a detailed sectoral disaggregation.

The impact modelling estimated the impacts of the envisaged initiatives at an aggregated as well as individual level. In total, 14 macroeconomic models have been run, one per reviewed initiative with a time horizon of 2035 and one that combines all initiatives with a time horizon of 2050. The results of each of these models were compared with those of a baseline scenario, which corresponds to a situation where the initiatives would be funded through regular Horizon Europe calls rather than European Partnerships.

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Part I. Impact Assessment Studies for the Candidate Institutionalised European Partnerships

1. Overarching Context to the Impact Assessment Studies

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Introduction

This report sets out the overall policy context of the impact assessment studies for the candidate Institutionalised European Partnerships and the methodological framework that was developed for the impact assessment studies.

It describes the changes in approach to the public-private and public-public partnerships under Horizon Europe compared to the previous EU Framework Programmes. An example is the requirement that all envisaged European Partnerships be implemented as either co-programmed, co-funded or institutionalised. The impact assessment studies will consider these three scenarios as the different options to be assessed, in compliance with the Better Regulation guidelines and against the functionalities that the candidate partnerships are expected to fulfil. The report describes the common methodological framework to assess the envisaged initiatives accordingly.

The report also presents the landscape of European Partnerships at the level of Horizon Europe Pillar 2 clusters, which lay the grounds for all of the impact assessment studies except the candidate Institutionalised European Partnership for Innovative SMEs. This analysis is presented in more depth in the report on the 'Horizontal analysis of efficiency and coherence of implementation' in Part II of the Impact Assessment Study report.

The report is structured around two main headings:

- Chapter 1: Background and context to European Partnerships in Horizon Europe and focus of the impact assessment– What is decided
- Chapter 2: The Candidate European Partnerships under Horizon Europe – What needs to be decided

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1 Background and context to European Partnerships in Horizon Europe and focus of the impact assessment– What is decided

1.1 The political and legal context

1.1.1 Shift in EU priorities and Horizon Europe objectives

Horizon Europe is to be set in the broader context of the pronounced **systemic and holistic approach** taken to the design of the new Framework Programme and the overarching Multi-annual Financial Framework (MFF) 2021-27.

The future long-term budget will be a budget for the Union's priorities. In her Political Guidelines for the next European Commission 2019 – 2024, the new President of the European Commission put forward six overarching priorities for the next five years, which reach well beyond 2024 in scope: A European Green Deal; An economy that works for people; A Europe fit for the Digital Age; Protecting our European way of life; A stronger Europe in the world; and A new push for European democracy. These priorities build upon A New Strategic Agenda for 2019–2024, adopted by the European Council on 20 June 2019, which targets similar overarching objectives. Together with the United Nations Sustainable Development Goals (SDGs), they will shape future EU policy responses to the challenges Europe faces and will steer the ongoing transitions in the European economy and society,

The MFF 2021-27 strives to provide a framework that will ensure a more coherent, focused and transparent response to Europe's challenges. A stronger focus on European added value, a more streamlined and transparent budget, more flexibility in order to respond quickly and effectively to unforeseen demands, and above all, an effective and efficient implementation are among the key principles of the MFF. The objective is to strengthen the alignment with Union policies and priorities and to simplify and reform the system in order to "unlock the full potential of the EU budget" and "turn ambitions into reality". Investment from multiple programmes is intended to combine in order to address key crosscutting priorities such as the digital economy, sustainability, security, migration, human capital and skills, as well as support for small businesses and innovation.[1]

These principles underlying the MFF 2021-27 are translated in the intent for Horizon Europe "to play a vital role, in combination with other interventions, for creating new solutions and fostering innovation, both incremental and disruptive." [2] The new Framework Programme finds its rationale in the daunting challenges that Europe is facing, which call for "a radical new approach to developing and deploying new technologies and innovative solutions for citizens and the planet on a scale and at a speed never achieved before, and to adapting our policy and economic framework to turn global threats into new opportunities for our society and economy, citizens and businesses."

In the Orientations towards the first Strategic Plan for Horizon Europe, the need strategically to prioritise and "direct a substantial part of the funds towards the areas where we believe they will matter the most" is emphasised. The Orientations specify, "Actions under Pillar II of Horizon Europe will target only selected themes of especially high impact that significantly contribute to delivering on the political priorities of the Union."

Figure 1, below, which gives an indicative overview of how the EU political priorities are supported under Horizon Europe, shows the major emphasis placed on contributing to the priority 'A European Green Deal', aimed at making Europe the first climate-neutral

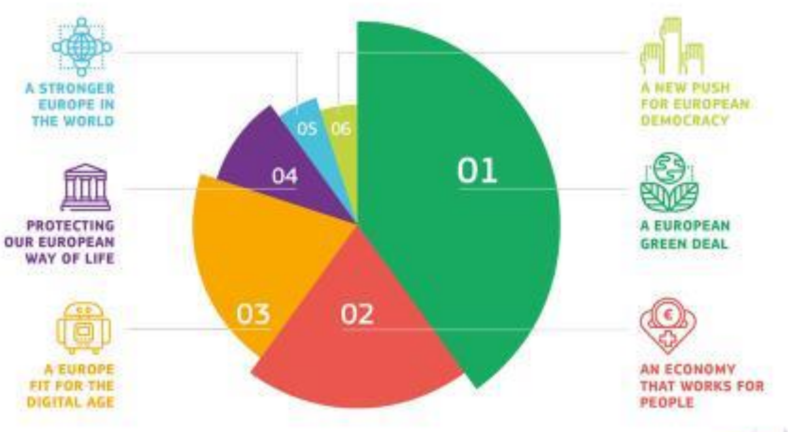
[1] EC (2018) *A Modern Budget for a Union that Protects, Empowers and Defends. The Multiannual Financial Framework for 2021-2027*. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2018) 321 final

[2] EC (2019), *Orientations towards the first Strategic Plan for Horizon Europe*.

continent in the world. At least 35 % of the expenditure from actions under the Horizon Europe Programme will address the Sustainable Development Goal 13: Climate Action.

Especially the R&I activities funded under Pillar II, including seven Partnership Areas (see below), are expected to contribute to the attainment of these objectives in an interconnected manner.

Figure 1: Targeted impacts under Horizon Europe by priority



Note: Preliminary, as described in the General orientations towards the first Strategic Plan implementing Horizon Europe.
Source: European Commission (2019) Orientations towards the first Strategic Plan for Horizon Europe, December 2019.

1.1.2 Renewed ambition for European Partnerships

Reflecting its pronounced systemic nature aimed at 'transformation' of the European R&I system, Horizon Europe intends to make a more effective use of these partnerships with an **ambitious approach** that is impact oriented and ensures complementarity with the Framework Programme. The **rationalisation** of the partnership landscape, both in terms of number of partnership forms and individual initiatives, constituted a first step in the direction of the strategic role that these policy initiatives are expected to play in the context of Horizon Europe. Future partnerships are expected to "provide mechanisms to consistently aggregate research and innovation efforts into more effective responses to the policy needs of the Union".[3] The expectation is that they will act as **dynamic change agents**, strengthening linkages within their respective ecosystems and with other related ecosystems as well as pooling resources and efforts towards the common objectives in the European, national and regional landscape. They are expected to develop *close synergies* with national and regional programmes, bring together a *broad range of actors* to work towards a common goal, translate *common priorities* into concrete roadmaps and coordinated activities, and turn research and innovation into *socio-economic results and impacts*.

The exact budget dedicated to European Partnerships under Horizon Europe will be agreed only upon decisions on the multiannual financial framework (MFF) 2021-2017 and the overall budget for Horizon Europe. In December 2017, the Council nevertheless introduced the principle of a "possible capping of partnership instruments in the FP budget".[4] Accordingly, it reached the common understanding, with the European Parliament, that "the majority of the budget in Pillar II [€52.7bn] shall be allocated to actions outside of

[3] European Commission (2019) *Orientations towards the first Strategic Plan implementing the research and innovation framework programme Horizon Europe*. Co-design via web open consultation. Summer 2019.

[4] Council of the European Union (2017) *From the Interim Evaluation of Horizon 2020 towards the ninth Framework Programme*. Council conclusions 15320/17.

European Partnerships" (Article 8.2(a) of the Common Understanding on the proposal for a regulation establishing Horizon Europe).[5]

1.1.3 Key evolutions as regards the partnership approach

The European R&I partnerships were initially conceived as a means to increase synergies between the European Union and the Member States (Article 181 of the Treaty on the Functioning of the European Union TFEU). Their objectives were to pool the forces of all the relevant actors of R&I systems to achieve breakthrough innovations; strengthen EU competitiveness; and, tackle major societal challenges. The core activities of the European partenrships consist therefore of building critical mass mainly through collaborative projects, jointly developing visions, and setting strategic agendas. They help accelerate the emergence of a programming approach in European R&I with the involvement of all relevant actors and provide flexible structures for partnerships that can be tailored to their goals.[6]

In the consecutive Framework Programmes up to the current Horizon 2020, the partnerships and their forms have mushroomed, leading to an increasing complexity of the partnership landscape. The Horizon 2020 interim evaluation highlighted that the overall landscape of EU R&I funding had become overly complex and fragmented, and a need to improve the partnerships' openness and transparency. The Lamy report suggested that the European Partnerships should focus on those areas with the greatest European Added Value, contribute to EU R&I missions and would need a simplified and flexible co-funding mechanism.

The Competitiveness Council conclusions of December 2017 called on the Commission and the Member States to jointly consider ways to rationalise the EU R&I partnership landscape. In 2018, the ERAC Ad-hoc Working Group on Partnerships concluded, "the rationalisation of the R&I partnership landscape is needed in order to ensure that the portfolio of R&I partnerships makes a significant contribution to improving the coherence, functioning and quality of Europe's R&I system and that the individual initiatives are able to fully achieve their potential in creating positive scientific and socio-economic impacts and/or in addressing societal challenges".

Horizon Europe has taken on board these concerns. The Impact Assessment of Horizon Europe gave a clear analysis of the achievements of Partnerships so far as well as the expectations for the new generation of Partnerships. Greater transparency and openness of the partnerships were considered as essential, as well a clear European added value and long-term commitments of the stakeholders involved.

A list of criteria to decide how European Partnerships will be selected, implemented, monitored, evaluated and phased-out was attached as an Annex III to the proposal to establish Horizon Europe (as revised by the partial political agreement). The rationalisation of the Partnership portfolio in Horizon Europe is expected to allow for a reduction from the current 120 to between 45 and 50 partnerships.

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[5] Council of the European Union (2019) *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing Horizon Europe – the Framework Programme for Research and Innovation, laying down its rule for participation and dissemination*. Common understanding 7942/19.

[6] European Commission (2011) Partnering in Research and Innovation. Communication from the Commission COM(2011) 572 final.

1.1.4 Overview of legal provisions

The Horizon Europe Regulation (common understanding) defines 'European Partnership' as "an initiative where the Union, prepared with early involvement of Member States and/or Associated Countries, together with private and/or public partners (such as industry, universities, research organisations, bodies with a public service mission at local, regional, national or international level or civil society organisations including foundations and NGOs), commit to jointly support the development and implementation of a programme of research and innovation activities, including those related to market, regulatory or policy uptake." It stipulates that "parts of Horizon Europe may be implemented through European Partnerships".

The Horizon Europe Regulation (common understanding) also stipulates that the European Partnerships are expected to adhere to the "principles of Union added value, transparency, openness, impact within and for Europe, strong leverage effect on sufficient scale, long-term commitments of all the involved parties, flexibility in implementation, coherence, coordination and complementarity with Union, local, regional, national and, where relevant, international initiatives or other partnerships and missions." The provisions and criteria set out for the selection and implementation of the European Partnerships reflect these principles.

1.1.5 Overview of the eight Partnership areas

The Horizon Europe Regulation also identifies the following "Areas for possible institutionalised European Partnerships on the basis of Article 185 TFEU or Article 187 TFEU":

- Partnership Area 1: Faster development and safer use of health innovations for European patients, and global health.
- Partnership Area 2: Advancing key digital and enabling technologies and their use, including but not limited to novel technologies such as Artificial Intelligence, photonics and quantum technologies.
- Partnership Area 3: European leadership in Metrology including an integrated Metrology system.
- Partnership Area 4: Accelerate competitiveness, safety and environmental performance of EU air traffic, aviation and rail.
- Partnership Area 5: Sustainable, inclusive and circular bio-based solutions.
- Partnership Area 6: Hydrogen and sustainable energy storage technologies with lower environmental footprint and less energy-intensive production.
- Partnership Area 7: Clean, connected, cooperative, autonomous and automated solutions for future mobility demands of people and goods.
- Partnership Area 8: Innovative and R&D intensive small and medium-sized enterprises.

Considering the realm of these partnership areas, potential synergies exist with the future **missions**. Horizon European introduced these cross-discipline and cross-sector policy instruments as part of its core objective of stimulating further excellence-based and impact-driven R&I. In contrast with the challenges targeted in Horizon 2020, the missions aim at the achievement of well-defined goals to provide solutions, within a specified timeframe, to scientific, technological, economical and/or societal problems. As part of the preparation of Horizon Europe, the European Commission set up five boards to formulate the future missions in the following areas:

- Adaptation to climate change including societal transformation

- Cancer
- Healthy oceans, seas, coastal and inland waters
- Climate-neutral and smart cities
- Soil health and food

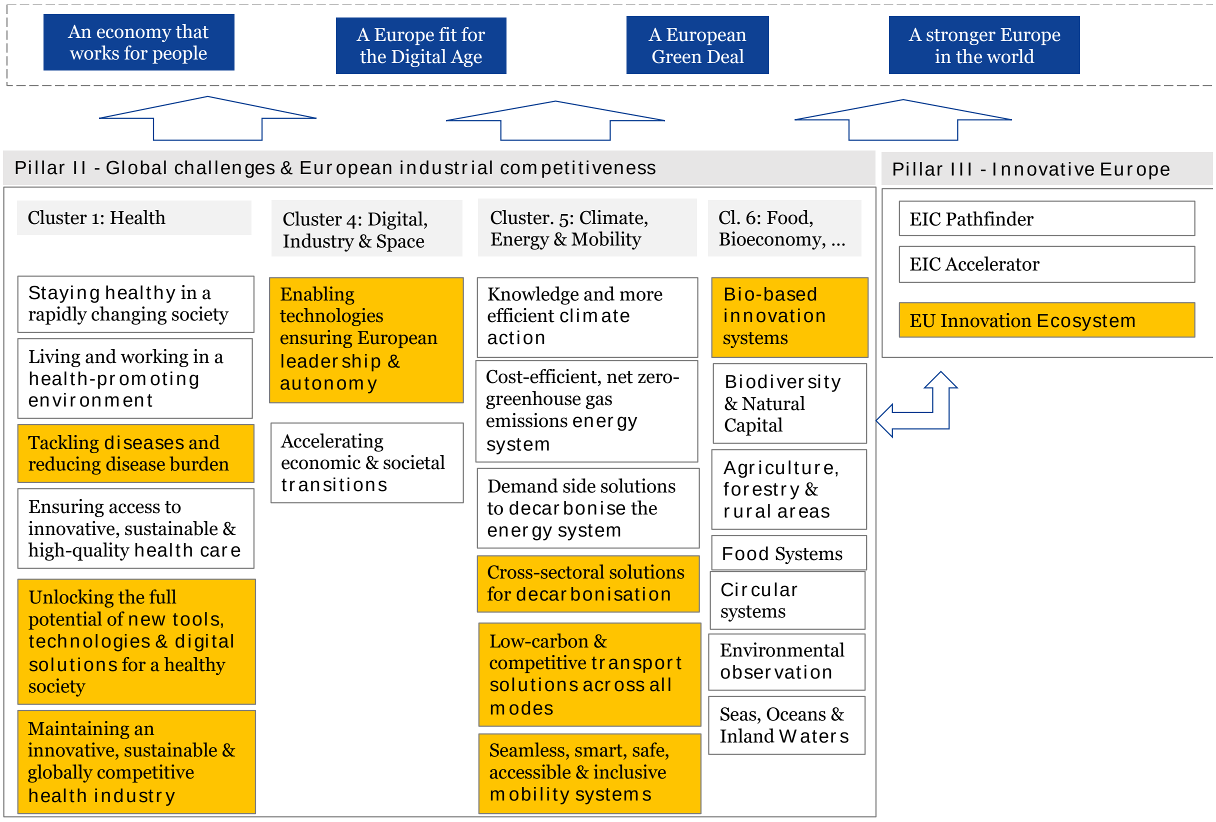
1.2 Typical problems and problem drivers

The European Partnerships are integral part of the framework programme and its three-pillar structure. They are predominantly funded under Pillar 2 "Global Challenges and European industrial competitiveness" and four of its thematic clusters. These clusters cover sectors and technologies, in which research and innovation activities are deemed of crucial importance in solving pressing scientific, societal or economic challenges and ensuring the scientific, technological and industrial leadership of Europe. Only one European Partnership, targeting innovative and R&D intensive SMEs, will instead act under Pillar 3 "Innovative Europe".

The European Partnerships are intended to contribute to the attainment of the pillars' and clusters' **challenges and R&I priorities**. Overarching EU policy priorities addressed are predominantly the European Green Deal, a people-centred economy, the fit for the Digital Age, and a stronger Europe in the world.

In Figure 2, below, the R&I priorities in the Pillars II and III to which the candidate *Institutionalised* Partnerships intend to contribute are highlighted in yellow.

Figure 2: Contribution of Candidate European Institutionalised Partnerships to the Horizon Europe priorities in Pillars II and III



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The European Partnerships under Horizon Europe most often find their rationale in addressing **systemic failures**. Their primary function is to create a platform for a strengthened collaboration and knowledge exchange between various actors in the European R&I system and an enhanced coordination of strategic research agenda and/or R&I funding programmes.

The concentration of efforts and resources and pooling of knowledge, expertise and skills on common priorities in a view of solving complex and multi-faceted societal and economic challenges is at the core of these initiatives. Enhanced cross-disciplinary and cross-sectoral collaboration and an improved integration of value chains and ecosystems are among the key objectives of these policy instruments. In the light of Horizon Europe, the aim often is to drive system transitions and transformations.

Especially in fast-growing technologies and sectors such as ICT, the envisaged European Partnerships also react on emerging opportunities and address systemic failures such as shortage in skills or critical mass or cross-sectoral cooperation along the value chains that would hamper attainment of future European leadership and/or strategic autonomy.

Transformational failures addressed aim at reaching a better alignment of the strategic R&I agenda and policies of public and private R&I funders in order to pool available resources, create critical mass, avoid unnecessary duplication of research and innovation efforts, and leverage sufficiently large investments where needed but hardly achievable by single countries.

Market failures are less commonly addressed and relate predominantly to enhancing industry investments thanks to the sharing of risks.

1.3 Description of the options

The proposal for a regulation establishing Horizon Europe[7] stipulates that parts of the Horizon Europe Framework Programme may be implemented through European Partnerships and establishes three implementation modes: Co-programmed European Partnerships, Co-funded European Partnerships, and Institutionalised Partnerships in accordance with Article 185 TFEU or Article 187 TFEU.

1.3.1 Baseline option – Traditional calls under the Framework Programme

Under this option, strategic programming for research and innovation in the field will be done through the mainstream channels of Horizon Europe. The related priorities will be implemented through traditional calls under the Framework Programme covering a range of activities, but mainly calls for R&I and/or innovation actions. Most actions involve consortia of public and/or private actors in ad hoc combinations, some actions are single actor (mono-beneficiary). There will be no dedicated implementation structures and no further support other than the Horizon Europe actions foreseen in the related Horizon Europe programme or cluster.

Strategic planning mechanisms in the Framework Programmes allow for a high level of flexibility in their ability to respond to particular needs over time, building upon additional input in co-creation from stakeholders and programme committees involving MS. The broad scope of the stakeholders providing their input to the research agenda, however, implies a lower level of directionality than what can be achieved through the partnerships. Often, the long-term perspective of the stakeholder input is limited, which risks reducing strategic capacity in addressing priorities.

The Horizon Europe option also implies a lower level of EU budgetary long-term commitment for the priority. Without a formal EU partnership mechanism, it is also less likely that the stakeholders will develop a joint Strategic Research Agenda and commit to its implementation or agree on mutual financial commitments beyond the single project participation.

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[7] Proposal for a Regulation of the European Parliament and of the Council stablishing Horizon Europe - the Framework Programme for Research and Innovation, laying down its rules for participation and dissemination - Common understanding', March 2019

1.3.2 European Partnership

All European Partnerships will be designed in line with the new policy approach for more objective-driven and impactful partnerships. They are based on the common criteria in Annex III of the Horizon Europe Regulation, with few distinguishing elements for the different forms of implementation. All European Partnerships will be based on an agreed Strategic Research and Innovation Agenda / roadmap agreed among partners and with the Commission. For each of them the objectives, key performance and impact indicators, and outputs to be delivered, as well as the related commitments for financial and/or in-kind contributions of the partners will be defined ex-ante.

Option 1 - Co-programmed European Partnership

This form of European Partnership is based upon a *Memorandum of Understanding* or a *Contractual Arrangement* signed by the European Commission and the private and/or public partners. Private partners are typically represented by one or more industry association, which also functions as a back-office to the partnership. It allows for a *high flexibility* in the profile of organisation involved, objectives pursued, and/or activities implemented.

Co-programmed European Partnerships address *broader communities* across a diverse set of sectors and/or value chains and where the actors have *widely differing capacities and capabilities*. They may encompass one or more associations of organisations from industry, research, NGOs etc as well as foundations and national R&I funding bodies, with no restriction on the involvement of international partners from Associated and non-associated third countries. Different configurations are possible: private actors only, public entities only, or a combination of the two.

The basis, as for all European Partnerships, is the rationale is to create a *platform for 'concertation'*, i.e. in-depth and ongoing consultation of the relevant actors in the European R&I system for the co-development of a strategic research and Innovation agenda, typically covering the period of the next 10 years. The primary ambition is to generate *commitment to a common strategic research and innovation agenda* (SRIA). For the private actors involved, this would allow for a de-risking of their R&I investments and provide predictability of investment paths, for the public actors, it serves as a means to: inform national policy-makers on EU investments and allows for coordination and alignment of their efforts to support R&I in the field at the national level.

The *level of 'additionality is possibly lower than for other partnerships*. There is no expectation of a legally binding commitment from the partners to taking an integrated approach in their individual R&I implementation and it is based on 'best efforts'. However, the Union contribution to the partnership is defined for the full duration and has a comparable level of certainty for the partnerships than in the other forms of implementation. The priorities for the calls, proposed by the partnership members for integration in the Framework Programme Work Programmes, are subject to further input from Member States (comitology) and Commission Services. The full implementation of the Union contribution in the Framework Programme implies that the full array of Horizon Europe funding instruments in the related Pillar can be used, ranging from RIAs to CSAs and including grants, prizes, and procurement.

Option 2 – Co-funded European Partnership

The Co-funded Partnership is based on a Grant Agreement between the Commission and the consortium of partners, resulting from a call for a proposal for a programme co-fund action implementing the European Partnerships in the Horizon Europe Work Programme. Programme co-fund actions provide co-funding to a programme of activities established and/or implemented by entities managing and/or funding research and innovation programmes. Therefore, this form of implementation only allows to address public partners at its core (comparable to the Article 185 initiatives below), while industry can nevertheless be addressed by the activities of the partnerships, but not make formal commitments and contributions to it. The expectation is that these entities would cover most if not all EU Member States (MS). Also 'international' funding bodies can participate as partners, which creates the potential for an efficient interaction with strategic international partners. Legal entities in countries that are not part of the programme co-fund consortium, are usually excluded from funding under the calls launched by the consortium.

The basic rationale for this partnership option is to bring MS together to invest at scale in key R&I issues of general and common interest. The joint programme of activities is agreed by the partners and with the EU and typically focuses on societal grand challenges and specifically, areas of high public good where EU action will add value while reflecting national priorities and/or policies. The ultimate intent is to create the greatest possible impact by pooling and/or coordinating national programmes and policies with EU policies and investments, helping to overcome fragmentation of the public research effort. Member States that are partners in this partnership become the 'owners' of the priority and take sole responsibility for its funding. Commitments of the partners and the European Union are ensured through the Grant Agreement.

Based on national programmes, this partnership option shows a particularly high level of flexibility in terms of activities to be implemented - directly by the national funding bodies (or governmental organisation "owning" institutional programmes), or by third parties receiving financial support (following calls for proposals launched by the consortium). The broad range of possible activities include support for networking and coordination, research, innovation, pilot actions, and innovation and market deployment actions, training and mobility actions, awareness raising and communication, dissemination and exploitation, any relevant financial support, such as grants, prizes, procurement, as well as Horizon Europe blended finance or a combination thereof.

Option 3 – Institutionalised European Partnership

This type of Partnership is the most complex and high-effort arrangement and will be based on a Council Regulation (Article 187) or a Decision by the European Parliament and Council (Art 185) and implemented by dedicated structures created for that purpose. The legal base for this type of partnership limits the flexibility for a change in core objectives, partners, and/or commitments as these would require amending legislation.

The basic rationale for this type of partnership is the need for a strong integration of R&I agenda's in the private and/or public sectors in Europe in order to address a strategic challenge or realise an opportunity. The focus is on major long-term strategic challenges and priorities beyond the framework of a single Framework Programme where collective action – by private and/or public sectors – is necessary to *achieve critical mass* and *address the full extent of the complexities* of the ecosystem concerned.

The long-term commitment expected from the European Union and its partners is therefore much larger than for any of the other options, given the considerably higher investment in the preparation and implementation of the Partnership. As a result, this type of partnership can be selected only if other parts of the Horizon Europe programme, including other forms of European Partnerships, would not achieve the objectives or would not generate the necessary expected impacts. The commitment for contributions by the partnership members is expected to be at least equal to 50% and may reach up to 75% of the aggregated European Partnership budgetary commitments.

The partnership members have a high degree of autonomy in developing the strategic research agenda and annual work programmes and call topics, based on a transparent and accessible process, and subject to the approval of the Commission Services. The choice of topics addressed in the (open) calls are therefore strongly aligned with the needs defined. Normally, the strategic priorities are fully covered by the annual work programmes in the partnership, even though it is in principle possible to keep certain topics for calls in the FP thus complementing the activities in the partnership. The full integration in the Framework Programme implies that the full array of Horizon Europe funding instruments in the related Pillar can be used, ranging from RIAs to CSAs and including grants, prizes, and procurement.

Two forms of Institutionalised Partnerships are of direct relevance to this study, influencing the constellation of partners involved.

Institutionalised Partnerships based upon Art 185 TFEU

Article 185 of the TFEU allows the Union to participate in programmes jointly undertaken by Member States and limits therefore the scope of partners to Member States and Associated Third countries. This type of Institutionalised Partnership aims therefore at reaching the greatest possible impact through the integration of national and EU funding, aligning national strategies in order to optimise the use of public resources and overcome fragmentation of the public research effort.

It brings together R&I governance bodies of most if not all EU Member States (legal requirement: at least 40% of Member States) as well as Associated Third Countries that designate a dedicated legal entity (Dedicated Implementation Structure) for the implementation. By default, membership of non-associated Third Countries is not foreseen. Such membership is possible only if it is foreseen in the basic act and subject to conclusion of an international agreement. Eligibility for participation and funding follows by default the rules of the Framework programme, unless a derogation is introduced in the basic act.

Institutionalised Partnerships under Art. 187 TFEU

This type of Institutionalised Partnership aims at reaching the greatest possible impact by integrating the strategic R&I agendas of private and/or public actors and by leveraging the partners' investments in order to tackle R&I and societal challenges and/or contribute to Europe's wider competitiveness goals.

It brings together a stable set of partners with a strong commitment to taking a more integrated approach and requires the set-up of a dedicated legal entity (Union body, Joint Undertaking) that carries full responsibility for the management of the partnership and implementation of the calls.

Different configurations are possible: partnerships focused on creating strategic industrial partnerships where, most often, the partner organisations are represented by one or more industry associations, or in some cases individual private partners; partnerships coordinating national ministries, public funding agencies, and governmental research organisations in the Member States and Associated Countries; or a combination of the two (the so-called tripartite model). By default, membership of non-associated Third Countries is not foreseen. Such membership is possible only if it is foreseen in the basic act and subject to conclusion of an international agreement. Eligibility for participation and funding follows by default the rules of the Framework programme, unless a derogation is introduced in the basic act.

2 The Candidate European Partnerships under Horizon Europe – What needs to be decided

2.1 Portfolio of candidates for Institutionalised Partnerships under Horizon Europe

2.1.1 The process for identifying the priorities for Institutionalised Partnerships under Horizon Europe

In May 2019, the European Commission consulted the Member States on a list of 44 possible candidates for European Partnership which it had identified as part of the preparation of the first Strategic Planning of Horizon Europe. This list was also part of the

Orientations towards the first Strategic Plan implementing Horizon 2020[8] which served as a basis for an Open Public Consultation from July to October 2019. In October and November 2019, the European Commission and the Member States agreed on increasing the number of candidate European partnerships to 49. Subsequent discussions until the adoption of Horizon Europe will focus on ensuring the overall consistency of the EU partnership landscape and its alignment with the EU overarching priorities and on defining the precise implementation modalities.

In parallel, the European Commission completed inception impact assessments on the candidate institutionalised European partnerships. Stakeholders had the opportunity to provide their feedback on these inception impact assessments in August 2019. A web-based open public consultation to collect opinions on all candidate institutionalised partnerships (but the candidate EuroHPC partnership) was organised between September and October 2019.

2.1.2 Overview of the overall landscape of candidate European Partnerships subject to the impact assessment

Figure 3, below, gives an overview of all European Partnerships that are currently envisaged for funding under Horizon Europe. The candidate Institutionalised Partnerships that are the subject for this impact assessment study are coloured in dark orange.

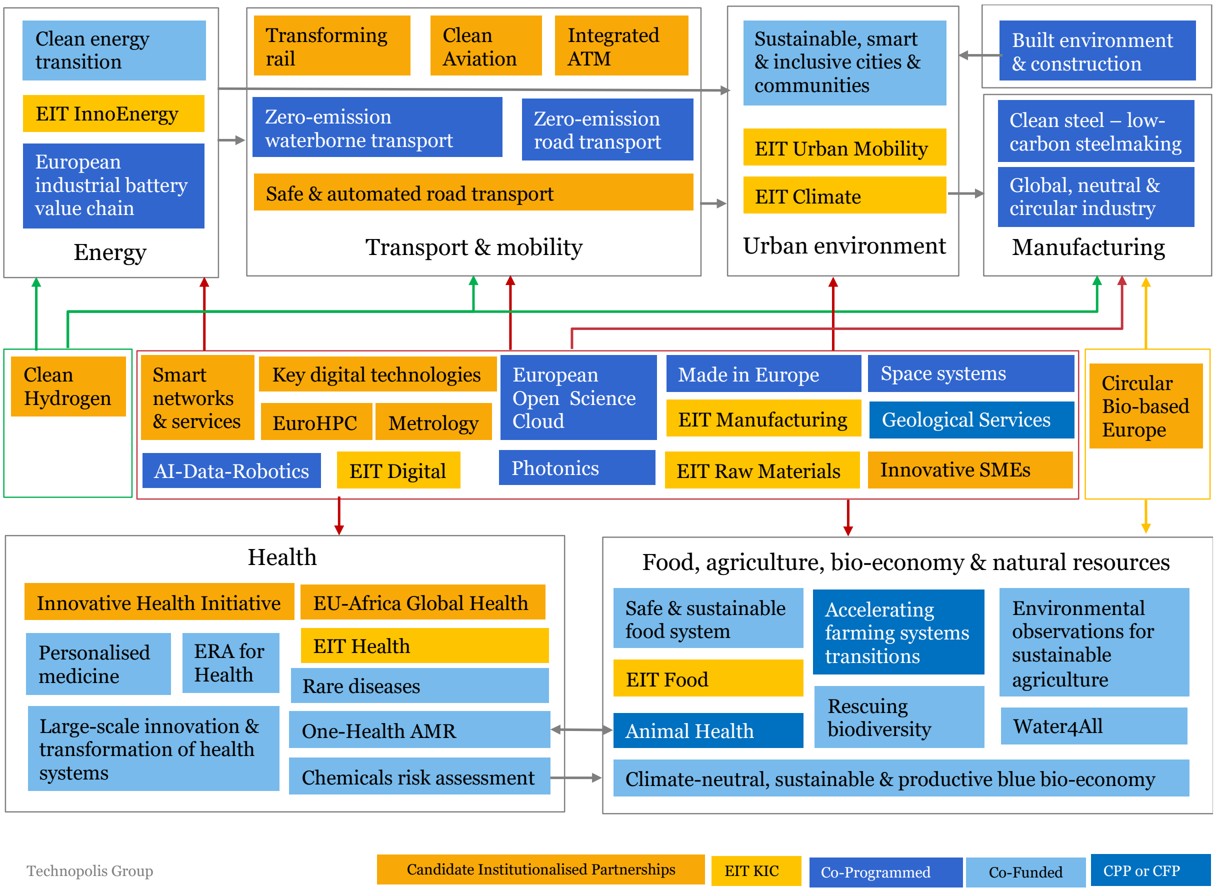
The European Partnerships can be categorised into two major groupings: *'horizontal' partnerships* focused on the development of technologies, methods, infrastructures and resources/materials, and *'vertical' partnerships* focused on the needs and development of a specific application area, be it industrial or societal.

The diagram below shows the central position of the **'horizontal' partnerships** in the overall landscape, developing methodologies, technologies or data management infrastructures for application in the other priority areas. These 'horizontal' partnerships are predominantly proposed as Institutionalised or Co-programmed Partnerships, in addition to a number of EIT KICs. The European Open Science Cloud (EOSC) partnership, for example, will support research partnerships by providing an infrastructure for the storage, management, analysis and re-use of research data.

The upper banner of the diagram groups the **industry-oriented 'vertical' partnerships**. Under Horizon Europe, they have in common a pronounced focus on enhancing sustainability. In this context, the banner includes also one of the most recent agreed-upon partnerships focused on the urban environment. This partnership illustrates the introduction under Horizon Europe of *challenge-oriented* cross-cluster partnerships. Multiple interconnections are envisaged among the 'vertical' partnerships in the different industry sectors covered. In the transport sector, the partnerships are predominantly proposed as Institutionalised Partnerships. In the other sectors, we see a mix of Co-Programmed Partnerships and EIT KICs. There are only two Co-Funded Partnerships.

[8] Orientations towards the first Strategic Plan implementing the research and innovation framework programme Horizon Europe, Co-design via Web Open Consultation (2019), see more here https://ec.europa.eu/research/pdf/horizon-europe/ec_rtd_orientations-towards-the-strategic-planning.pdf

Figure 3: Landscape of European Partnerships under Horizon Europe (2019)



The lower banner includes the **'vertical' partnerships in the societal application areas**. Striking is the dominance of the Co-Funded Partnerships (to be noted that in the Food/agriculture cluster, the partnership type still needs to be decided for several envisaged partnerships). We also note the limited interconnections that are envisaged between the two areas. An exception is the newly envisaged cross-cluster European Partnerships 'One Health AMR'.

2.2 Assessing the necessity of a European Partnership, possible options for implementation and their cost-effectiveness

In this section we set out the methodological framework that underpins the impact assessment studies. In line with the Better Regulation Guidelines, the impact assessment is intervention logic-based and impact-oriented.

The impact assessment allowed also for the conduct of the 'necessity test' for a European Partnership as set out in the Horizon Europe regulation. Pivotal in this context was the identification of the Horizon Europe calls as Option 0 as well as Baseline Option, allowing for a comparative analysis of the three partnership forms (Options 1-3) along all of the assessment dimensions – in relation to each other as well as to the Horizon Europe calls. The options assessment therefore incorporated the required 'necessity test'.

2.2.1 Assessment of the selection criteria

The common methodological framework that we defined for the 13 individual Impact Assessment studies reflects the approach defined in the Better Regulation guidelines. It also integrates the specific criteria for the use of the different types of European Partnerships as they are defined in the Horizon Europe Common Understanding (Article 8 and Annex III). Specifically this regards the **selection criteria** which have to be demonstrated as a minimum in order to justify the necessity of a European Partnership instead of regular Horizon Europe calls only and the implementation criteria in Article 8

1(a), (b) and (c) with certain elements distinguishing the use of the different partnership implementation modes (Table 1).

Table 1: Horizon Europe selection criteria for the European Partnerships

Common selection criteria and principles	Specifications
More effective (Union added value) clear impacts for the EU and its citizens	• delivering on global challenges and research and innovation objectives
	• securing EU competitiveness
	• securing sustainability
	• contributing to the strengthening of the European Research and Innovation Area
	• where relevant, contributing to international commitments
Coherence and synergies	• within the EU research and innovation landscape
	• coordination and complementarity with Union, local, regional, national and, where relevant, international initiatives or other partnerships and missions
Transparency and openness	• identification of priorities and objectives in terms of expected results and impacts
	• involvement of partners and stakeholders from across the entire value chain, from different sectors, backgrounds and disciplines, including international ones when relevant and not interfering with European competitiveness
	• clear modalities for promoting participation of SMEs and for disseminating and exploiting results, notably by SMEs, including through intermediary organisations
Additionality and directionality	• common strategic vision of the purpose of the European Partnership
	• approaches to ensure flexibility of implementation and to adjust to changing policy, societal and/or market needs, or scientific advances, to increase policy coherence between regional, national and EU level
	• demonstration of expected qualitative and significant quantitative leverage effects, including a method for the measurement of key performance indicators
	• exit-strategy and measures for phasing-out from the Programme
Long-term commitment of all the involved parties	• a minimum share of public and/or private investments
	• In the case of institutionalised European Partnerships, established in accordance with article 185 or 187 TFEU, the financial and/or in-kind, contributions from partners other than the Union, will at least be equal to 50% and may reach up to 75% of the aggregated European Partnership budgetary commitments

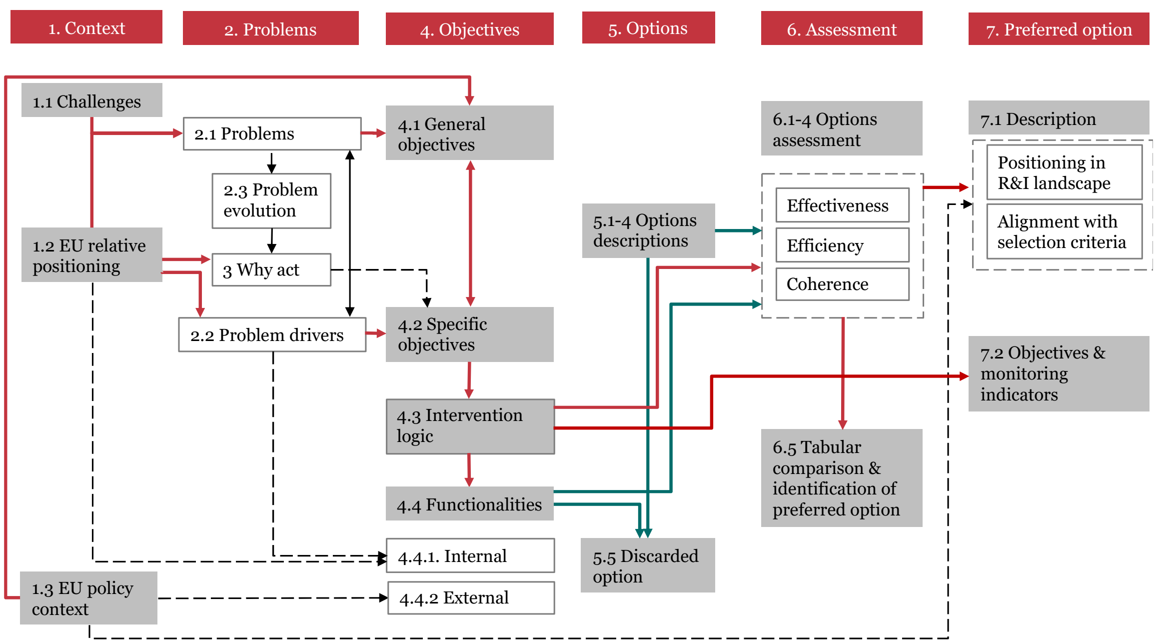
The **Better Regulation guidelines** remained the primary point of reference for the 13 individual Impact Assessment studies. The different steps of the IA process were carried out in a consistent manner in the 13 individual IA studies, supported by horizontal analyses (i.e. common to all studies) such as bibliometrics/patent analysis, social network analysis, the partnership portfolio mapping and analysis, as well as the analysis of the Open Public Consultation data.

The **selection criteria** for the European Partnerships related to effectiveness and coherence fit reasonably well in the Better Regulation impact assessment structure. More problematic was the coverage of the other three criteria groupings, i.e. the criteria of Openness and Transparency, Additionality and Directionality, and the Ex-ante demonstration of commitment.

The solution was the introduction of a section on the **'Functionalities of the initiative'**, in which set out our view on *how* the initiative should *concretely* respond to the selection criteria of 'coherence and synergies', 'openness and transparency' and 'additionality and directionality' in order to reach its objectives. We focused on those aspects that are not covered in other sections of this report, such as coherence and synergies, and covered those elements that from our analysis of the partnership options resulted being **key distinguishing features** of the partnership options, i.e. the composition of the partnership ('openness', including from a geographical perspective), the type of activities implemented ('flexibility'), and the level of directionality and integration of the stakeholders' R&I strategies needed ('directionality and additionality').

The logical process is summarised in Figure 4, below. The diagram shows how the 'functionality' sections constituted an important passage from the objectives and intervention logic sections to the options assessment. Building upon information collected in the previous sections (context, problem and objectives analysis) and in combination with the description of the available options, the description of the desirable 'functionalities' allowed for, on the one hand, the identification of the discarded option(s) and, on the other hand, the options assessment against coherence and against the selection criteria of 'Openness and Transparency' and 'Additionality and Directionality'. In the final chapter of the Impact Assessment report, the alignment of the preferred option with the criteria for the selection of European Partnerships was described, emphasising the outcomes of the 'necessity test'.

Figure 4: Flow of the analysis



Notes: the numbers indicate the related chapters or sections in the Impact Assessment reports

2.2.2 Methodological approach

Overview of the methodologies employed

The understanding of the overall context of the candidate institutionalised European Partnerships relies on a desk research partly covering the main impacts and lessons learned from their predecessor partnerships (if any). This was complemented with a set of quantitative analyses of the Horizon 2020-funded partnerships, or in case these did not exist, the H2020-funded projects in the field. The analyses included a portfolio analysis, a stakeholder and social network analysis in order to profile the actors involved as well as their co-operation patterns, and an assessment of the partnerships' outputs (bibliometrics and patent analysis). A cost modelling exercise was performed in order to feed into the efficiency assessments of the partnership options (see below).

Public consultations (open and targeted) supported the comparative assessment of the policy options. Each study interviewed up to 50 relevant stakeholders (policymakers, business including SMEs and business associations, research institutes and universities, and civil organisations, among others). They also used the results from the Open Public Consultation organised by the European Commission (Sep – Nov 2019) and the feedback on the Inception Impact Assessments of the 13 candidate institutionalised European Partnerships that the European Commission received in September 2019.

The timing of the Impact Assessment studies, in parallel to the negotiations between the European Commission and the existing Joint Undertakings on the specific implementation of the rules for the future European Partnership, as well as the ongoing discussions within the existing partnership on their future research directions, has set potential limits to the validity of the input and feedback collected from the stakeholders during the consultations.

A more detailed description of the methodology is provided in the Annexes C of each impact assessment report.

Method for identifying the preferred choice

The four policy options were compared along a range of key parameters. The comparison along these parameters was carried out in an evidence-based manner. A range of quantitative and qualitative evidence was used, including ex-post evaluations; foresight studies; statistical analyses of Framework Programmes application and participation data and Community Innovation Survey data; analyses of science, technology and innovation indicators; econometric modelling exercises producing quantitative evidence in the form of monetised impacts; reviews of academic literature on market and systemic failures and the impact of research and innovation, and of public funding for research and innovation; sectoral competitiveness studies; expert hearings; etc.

Options assessment related to effectiveness and coherence

On the basis of the evidence collected and gathered, the Impact Assessment study teams assessed the effectiveness of the retained policy options along three dimensions corresponding to the different categories of likely impacts: scientific, economic and technologies, and societal (including environmental) impacts. The Impact Assessment study teams considered to which extent the retained policy options fulfilled the desirable 'functionalities' and were therefore likely to produce the targeted impacts. This analysis resulted in a scoring of the policy options along a three-point scale.[9] Instead of a compound score, the assessment of the effectiveness of the policy options concluded on as many scores as there are expected impacts.

Likewise, the impact assessment study teams attributed scores (using the same approach as above) reflecting the potential of each retained policy option for ensuring coherence with programmes and initiatives within (internal coherence) and beyond (external coherence) Horizon Europe.

[9] Scores vary from + to +++, where + refers to low potential for presenting a low potential for reaching the likely impacts, ++ to a good potential, and +++ to a high potential.

Scores were justified in a consistent and detailed manner in order to avoid arbitrariness and spurious accuracy. A qualitative or even quantitative explanation was provided of why certain scores were given to specific impacts.

When assessing the respective efficiency of the retained policy options, the Impact Assessment study teams considered the scores related to effectiveness and the identified costs to conduct a "value for money" (or cost-effectiveness) analysis. They accordingly attributed a comparative score to each of the options ranging from 1 (option with the highest costs) to 3 (options with the lowest costs).

Options assessment related to efficiency

A standard cost model

The 'horizontal' team has reviewed the cost categories and costs for each of the four policy options, at some length. Our first model used published data from past partnerships and Horizon 2020 calls working with the Commission's standard accounting codes (Title 1, Title 2, Title 3). The analysis revealed wide-ranging differences in costs across partnerships and functions, which was thought to be too complex to be helpful to the current exercise. As a result, we created a static, common model using average costs as a means by which to indicate the order of magnitude of effort and thereby reveal the principal differences between each of the policy options.

The model was developed jointly with the European Commission services and is presented in the study Data report (D1.2), along with an explanation of the data sources used and the assumptions made.

It is important to note that the costs identified are theoretical and do not reflect the actual costs of any existing individual partnership. In light of this fact, and to avoid any risk of misunderstanding, we have transposed the financial estimates into a qualitative presentation using + / - system in order to compare the various cost elements for each policy option with the equivalent costs for the baseline policy options (see Table 2).

The principal differences in costs as compared with regular Horizon Europe calls relate to the European Partnerships' one-off costs (e.g. developing the proposal and Strategic Research and Innovation Agenda), additional supervision by the European Commission and any additional programme management effort. The main difference between the three types of European Partnership are twofold: (i) the extent to which a partnership will need to run a limited or comprehensive programme management unit and (ii) the extent to which a new partnership may benefit from a pre-existing programme management unit that will greatly reduce or eliminate the set-up costs that would apply to a wholly new partnership.

Table 2: Intensity of additional costs compared with HEU Calls (for Partners, stakeholders, public and EC)

Cost items	Option 0	Option 1	Option 2	Option 3 -Art. 185	Option 3 -Art. 187
Preparation and set-up costs					
Preparation of a partnership proposal (partners and EC)	0	++	++	++	++
Set-up of a dedicated implementation structure	0	0	0	Existing: + New: ++	Existing: ++ New: +++
Preparation of the SRIA / roadmap	0	++	++	++	++

Cost items	Option 0	Option 1	Option 2	Option 3 -Art. 185	Option 3 -Art. 187
Ex-ante Impact Assessment for partnership	0	0	0	+++	+++
Preparation of EC proposal and negotiation	0	0	0	+++	+++
Running costs (Annual cycle of implementation)					
Annual Work Programme preparation	0	+	0	+	+
Call and project implementation	0	0 In case of MS contributions: +	+	+	+
Cost to applicants	Comparable, unless there are strong arguments of major differences in oversubscription				
Partners costs not covered by the above	0	+	0	+	+
Additional EC costs (e.g. supervision)	0	+	+	+	++
Winding down costs					
EC	0	0	0	0	+++
Partners	0	+	0	+	+

Notes: 0: no additional costs, as compared with the baseline; +: minor additional costs, as compared with the baseline; ++: medium additional costs, as compared with the baseline; +++: higher costs, as compared with the baseline

Rationale for the comparative scoring on 'overall costs' and 'cost-efficiency' in the scorecard

In the scorecard analysis, the scores related to the set-up and implementation costs will allow the study teams to consider the scale of the expected benefits and thereby allow a simple "value for money" analysis (cost-effectiveness).

Table 3 shows how we translated the cost analysis into a series of numerical scores.

Table 3: Cost-efficiency matrix

	Option 0: Horizon Europe calls	Option 1: Co-programmed	Option 2: Co-funded	Option 3: Institutionalised
Overall cost	3	2	1	1
Cost-efficiency	3	3	2	2

For the 'overall cost' dimension, we assigned a score 1 to the option with the highest additional costs and a score 3 to the option with the lowest additional costs compared to the baseline. This was based on the following considerations:

- **Horizon Europe regular calls** will have the lowest overall cost among the policy options and have therefore been **scored 3** on this criterion, using a scale of 1-3 where 3 is best (lowest additional costs). This adjudged score is based on two facts: firstly, that Horizon Europe will not entail any additional one-off costs to set up or discontinue the programme, where each of the other policy options will require at least some additional set-up costs; and secondly, that Horizon Europe will not require any additional running costs, where each of the other policy options will involve additional efforts by the Commission and partners in the carrying out of necessary additional tasks (e.g. preparing annual work programmes).

- A **co-programmed partnership** (Option 1 - CPP) will entail slightly higher overall costs as compared with the baseline policy option and has therefore been given a **score of 2**, using a scale of 1-3 where 3 is best (lowest additional costs). There will be some additional set-up costs linked for example with the creation of a strategic research and innovation agenda (SRIA) and additional running costs linked with the partners role in the creation of the annual work programmes and the Commission's additional supervisory responsibilities. A CPP will have lower overall costs than each of the other types of European Partnership, as it will function with a smaller governance and implementation structure than will be required for a Co-Funded Partnership or an Institutionalised Partnership and – related to this – its calls will be operated through the existing HEU agencies and RDI infrastructure and systems.
- The **Co-Funded Partnership (**Option 2 – CFP) has been **scored 1** on overall cost, using a scale of 1-3 where 3 is best (lowest additional costs). This reflects the additional set-up costs of this policy option and the substantial additional running costs for partners, and the Commission, of the distributed, multi-agency implementation model.
- The **Institutionalised Partnership** (Option 3 - IP) has been **scored 1** on overall cost, using a scale of 1-3 where 3 is best (lowest additional costs). This reflects the substantial additional set-up costs of this policy option – and in particular the high costs associated with preparing the Commission proposal and negotiating that through to a legal document – and the substantial additional running costs for the Commission associated with the supervision of this dedicated implementation model.

In relation to **cost-efficiency**, we considered that while there is a clear gradation in the overall costs of the policy options, the cost differentials are less marked when we take into account financial leverage (co-financing rates) and the total budget available for each of the policy options, assuming a common Union contribution. From this perspective, there are only one or two percentage points that split the most cost-efficient policy options – the baseline and CPP policy options – and the least cost-efficient – the CFP and IP. We have therefore assigned a score of 3 to the baseline Option 0 and CPP options for cost-efficiency (no or minor additional costs, as compared with the baseline) and a score of 2 for the CFP and IP policy options (medium additional costs, as compared with the baseline).

Scorecard analysis for the final options assessment

The scorecard analysis built a hierarchy of the options by individual criterion and overall. The scorecard exercise supported the systematic appraisal of alternative policy options across multiple types of monetary, non-monetary and qualitative dimensions. It also allowed for easy visualisation of the pros and cons of alternative options.

Each option was attributed a value of 1 to 3, scoring the adjudged performance against each criterion with the three broad appraisal dimensions of effectiveness, efficiency and coherence.

Scores were justified in a consistent and detailed manner in order to avoid arbitrariness and spurious accuracy. A qualitative or even quantitative explanation was provided of why certain scores were given to specific impacts, and why one option scores better or worse than others.

The scorecard analysis allowed for the identification of a single preferred policy option or in case of an inconclusive comparison of options, a number of 'retained' options or hybrid. The final selection is a policy decision.

2.3 Cross-partnership challenges in Horizon Europe clusters

In this section we set the envisaged and candidate partnerships in the context of the Horizon Europe clusters and the related higher-level EU policy objectives and priorities. We focus on the evolution of the policy context including the new European Green Deal/climate neutrality objectives, the Horizon Europe Framework relevant to this cluster, and the link to the relevant Sustainable Development Goals. Seeing the focus on the Pillar II clusters, this section excludes the candidate *Institutionalised Partnership for Innovative SMEs*.

2.3.1 Cluster 1 – Health

Research and innovation (R&I) actions under this cluster will aim at addressing the major socio-economic and societal burden that diseases and disabilities pose on citizens and health systems of the EU and worldwide.

The R&I activities funded under the Pillar II Cluster Health aim at contributing to the achievement of the Sustainable Development Goal 'Ensuring healthy lives and promoting well-being for all at all ages' resulting from investments in research and innovation focused on three overarching EU policy objectives: 'An economy that works for people', 'A Europe fit for the Digital Age', and 'A European Green Deal' (see Figure 5, below). The Horizon Europe proposal for a regulation defined the areas for possible institutionalised European partnerships on the basis of Article 185 TFEU or Article 187 TFEU as "*Partnership Area 1: Faster development and safer use of health innovations for European patients, and global health".*

At the core in this cluster are the R&I orientations that aim at ensuring that citizens *stay healthier throughout their lives* due to improved health promotion and disease prevention and the adoption of healthier behaviours and lifestyles, the development of *effective health services* to tackle diseases and reduce their burden, and an improved access to *innovative, sustainable and high-quality health care*. These objectives require an unlocking of the full potential of *new tools, technologies and digital solutions* and ensuring a *sustainable and globally competitive health-related industry* in the EU, allowing for the delivery of, e.g. personalised healthcare services. Last but not least, the citizens' health and well-being need to be *protected from environmental degradation and pollution*, addressing a.o. climate-related challenges to human health and health systems.

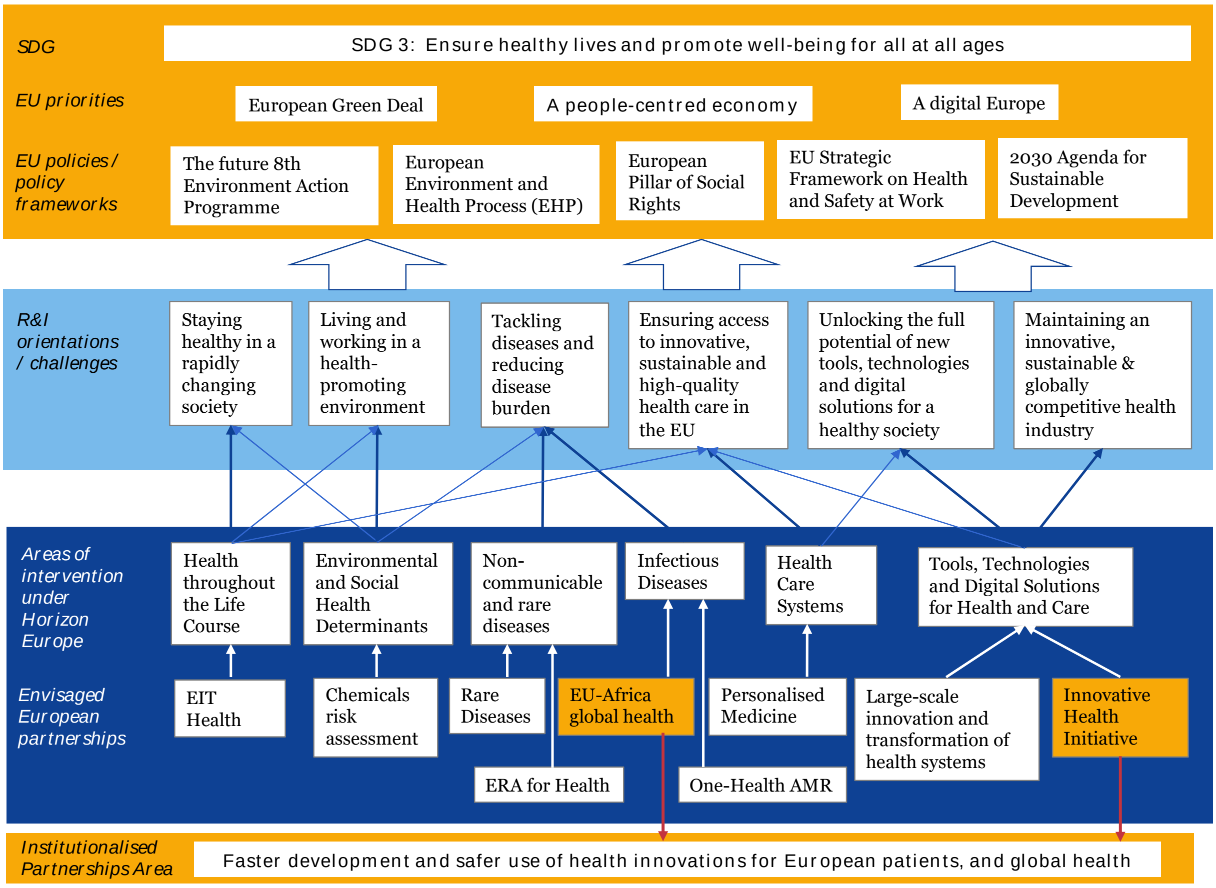
Figure 5, below, shows that the portfolio of envisaged European Partnerships in this cluster[10] aims to contribute to all of the R&I orientations in this cluster. However, there is a pronounced focus on the 'tackling diseases and reducing the disease burden' objective, addressed by five out of the ten partnerships (amongst which there is one candidate Institutionalised Partnership). The objectives focused on an improved exploitation of digital solutions and competitiveness of the EU health-related industry are addressed by two partnerships amongst which one is a candidate Institutionalised Partnership.

In this context, it should be noted that the portfolio of European Partnerships in this cluster predominantly encompasses Co-funded Partnerships, focused on joining the R&I programmes and investments at the national level. There is therefore overall a limited level of involvement of the private sector in the development of the SRIAs (i.e. as partners of the envisaged partnerships), be it from the supply or user side in the value chains. The only exceptions are the Innovative Health Initiative and the EIT KIC Health. European Partnerships also provide limited support for the assessment of environmental and social health determinants, uniquely addressed from a chemical risks perspective.

[10] As proposed in the Horizon Europe 'Orientations towards the first Strategic Plans', dd. December 2019

The description of the interconnections between the partnerships in this cluster and the ones funded in the context of other clusters, provided in the reports of the individual impact assessment studies, sheds more light on this topic.

Figure 5: R&I priorities and higher-level objectives of the Horizon Europe Cluster 1 – Health



Technopolis Group

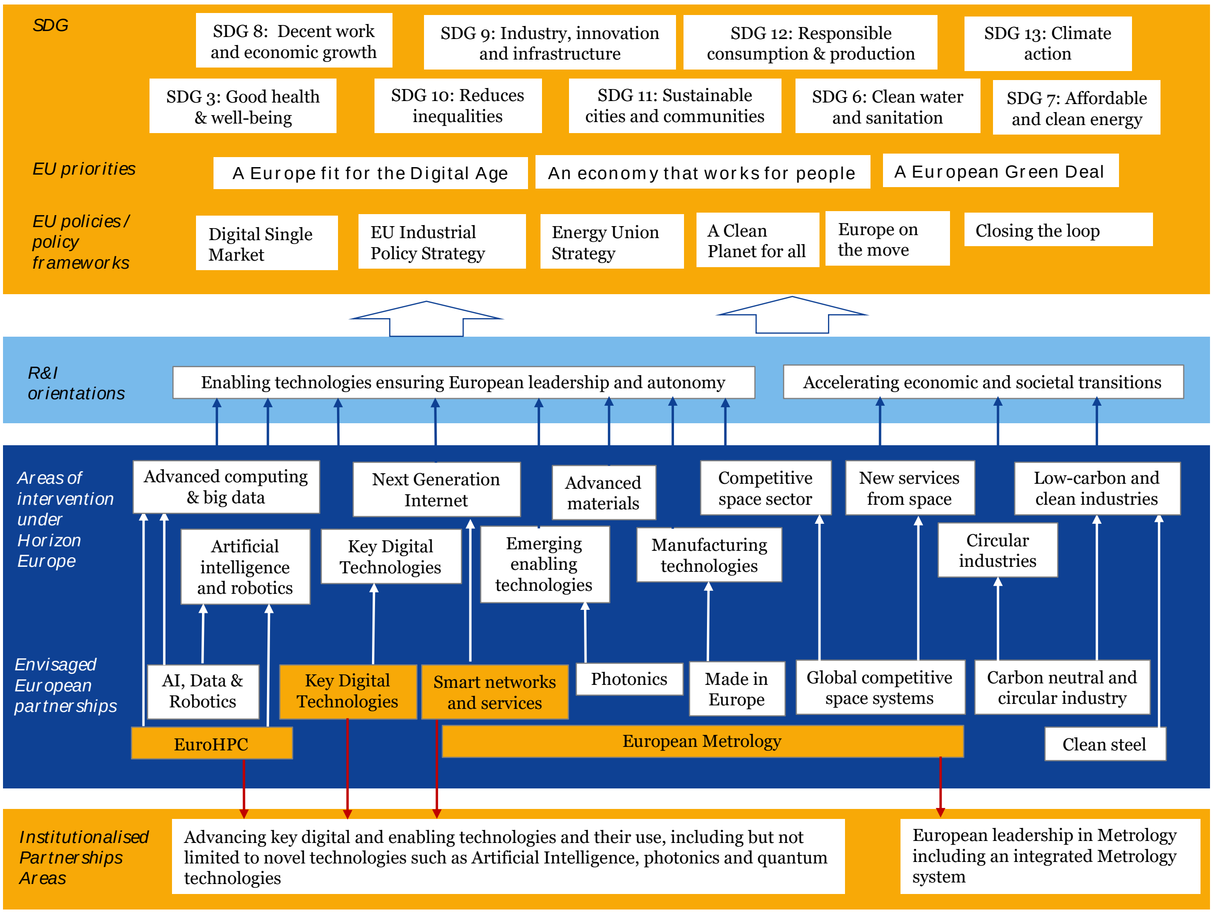
2.3.1 Cluster 4 – Digital, Industry and Space

In this cluster the focus is on the digitisation of European industry and on advancing key enabling, digital and space technologies which will underpin the transformation of our economy and society at large. The overarching vision for R&I investments in this cluster is "a European industry with global leadership in key areas, fully respecting planetary boundaries, and resonant with societal needs – in line with the renewed EU Industrial Policy Strategy." The expected effects on the European economy and society imply that the R&I activities under this cluster will contribute to various Sustainable Development Goals and respond to three key EU policy priorities: 'A European Green deal', 'A Europe fit for the digital age', and 'An economy that works for people' (Figure 6).

The cluster pursues three objectives: 1) ensuring the competitive edge and sovereignty of EU industry; 2) fostering climate-neutral, circular and clean industry respecting planetary boundaries; and 3) fostering social inclusiveness in the form of high-quality jobs and societal engagement in the use of technologies. A human-centred approach will be taken, i.e. technology development going hand in hand with European social and ethical values.

The key R&I priorities are grouped in two general categories: (I) Enabling technologies ensuring European leadership and autonomy; and (II) Accelerating economic and societal transitions (these will be complemented by priorities of other clusters). European Partnerships envisaged to support the R&I in the specific intervention areas are mainly co-programmed partnerships. Exceptions are the three candidate Institutionalised Partnerships in the digital field and the candidate Institutionalised Partnership in metrology, reflecting their related Partnership Areas.

Figure 6: R&I priorities and higher-level objectives of the Horizon Europe Cluster 4 – Digital, Industry and Space



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Multiple convergences exist between the technologies that are covered in the first strand of the priorities in this cluster, i.e. "enabling technologies ensuring European leadership and autonomy". In their function of 'enabling' technologies, they will also make critical contributions to the attainment of the desired 'transitions' in the 'vertical' industry sectors targeted in the second strand of priorities in this cluster as well as in the other clusters. A major contribution from this perspective can be expected from the four candidate Institutionalised Partnerships as well as from the 'Made in Europe' partnership, focused on manufacturing technologies.

2.3.2 Cluster 5 – Climate, Energy and Mobility

The main objectives of this cluster are to fight climate change, improve the competitiveness of the energy and transport industry as well as the quality of the services that these sectors bring to society. This is supportive of several Sustainable Development Goals including affordable and clean energy (SDG7); industry, innovation & infrastructure (SDG9); sustainable cities & communities (SDG11); sustainable consumption & production (SDG12); and climate action (SDG13). The cluster is most closely aligned to the EU priority for 'A European Green Deal' but also has synergy with two of the other five priorities; 'An economy that works for people' and 'A Europe fit for the Digital Age'. This extends across various policies including a Clean Planet for all, the Energy Union strategy, Single European Railway Area, European ATM Master Plan, Single European Sky, and Europe on the Move (Figure 7).

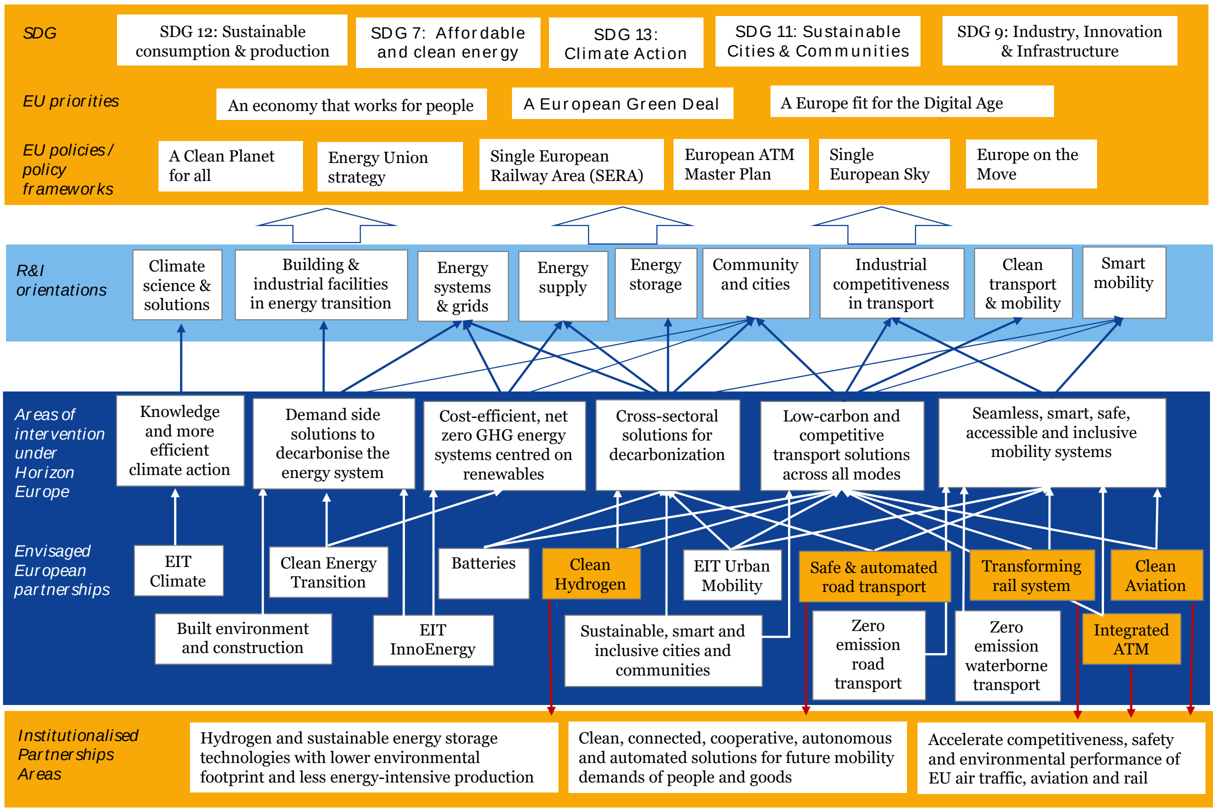
The cluster is directly relevant to several of the areas for possible institutionalised European partnerships on the basis of Article 185 TFEU or Article 187 TFEU, namely:

- Partnership Area 4: Accelerate competitiveness, safety and environmental performance of EU air traffic, aviation and rail

- Partnership Area 6: Hydrogen and sustainable energy storage technologies with lower environmental footprint and less energy-intensive production
- Partnership Area 7: Clean, connected, cooperative, autonomous and automated solutions for future mobility demands of people and goods

Cluster 5 is structured under six areas of intervention under Horizon Europe and nine R&I orientations. Figure 7, below, shows the portfolio of envisaged European Partnerships that are relevant to this cluster and their link to the areas of intervention.

Figure 7: R&I priorities and higher-level objectives of the Horizon Europe cluster Climate, Energy and Mobility



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There are 14 candidate Partnerships that align with this cluster of which eight are possible Institutionalised Partnerships, including five Article 187 initiatives and three EIT-KICs. There are no candidate Article 185 Partnerships in this cluster. The other partnerships are envisaged as either Co-programmed and/or Co-funded Partnerships.

The diagram above shows the strong orientation of the possible Institutional Partnerships towards the mobility area and more limited direct synergies between the envisaged Partnerships and the 'climate science & solutions' priority. Of course, the climate change challenge underpins the whole of this cluster, except where the focus is on industrial competitiveness, but this will also be at least partially dependent on innovation related to clean energy and mobility products and services.

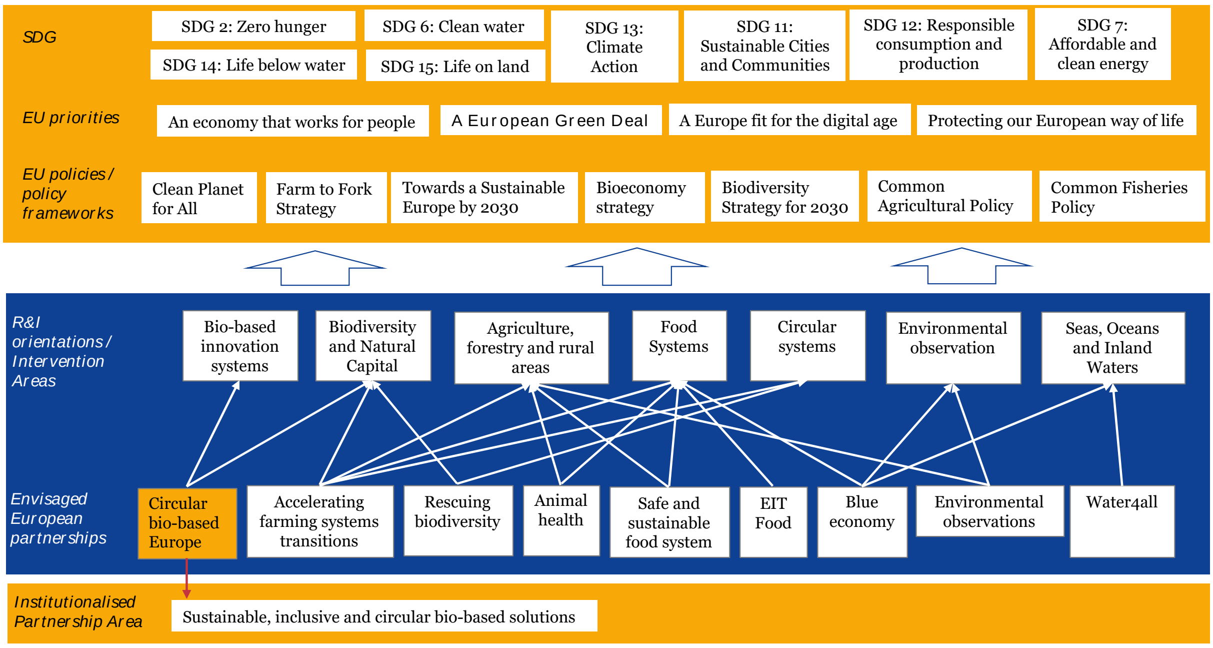
2.3.3 Cluster 6 – Food, Bioeconomy, Natural Resources, Agriculture and Environment

The key objective of Cluster 6, 'Food, Bioeconomy, Natural Resources, Agriculture and Environment' is to advance knowledge, expand capacities and deliver innovative solutions to accelerate the transition towards the sustainable management of natural resources (such as biodiversity, water and soils). The cluster has a large realm and aims to address a wide range of challenges relating to climate change, biodiversity and ecosystems, natural resources, and the production and consumption patterns that may affect them. It encompasses a single area for possible institutionalised European Partnerships aimed at the development of "sustainable, inclusive and circular, bio-based solutions".

The R&I activities funded under the Pillar II Cluster 6 contribute first and foremost to the 'European Green Deal'. More precisely, they will be instrumental to the announced climate change actions, the Biodiversity Strategy for 2030, the "Farm to Fork Strategy", the zero-pollution ambition, the New Circular Economy Action Plan, and the comprehensive strategy on Africa and trade agreements. However, through cooperation with the other clusters, Cluster 6 may make some contribution to the other EU overarching policy priorities. The R&I activities funded under this cluster therefore aim to contribute to the achievement of several United Nations SDGs including: SDG 2: Zero hunger; SDG 6: Clean water and sanitation; SDG 7: Affordable and clean energy; SDG 11: Sustainable cities and communities; SDG 12: Responsible consumption and production; SDG 13: Climate action; SDF 14: Life below water; and, SDG 15: Life on land.

Cluster 6 is structured around six targeted impacts and seven research and innovation orientations, as shown in Figure 8, below. The R&I activities funded under this cluster aim to (1) develop solutions for mitigation of, and adaptation to, *climate change*; (2) halt the *biodiversity* loss and foster the restoration of *ecosystems*; (3) encourage the sustainable (and circular) management and use of *natural resources*; (4) stimulate inclusive, safe and health *food and bio-based systems*; (5) a better understanding of the determinants of *behavioural, socio-economic and demographic changes* to accelerate system transformation; and, (6) improve solutions for *environmental observations and monitoring systems*.

Figure 8: R&I priorities and higher-level objectives of the Horizon Europe Cluster 6 – Food, Bioeconomy, Natural Resources, Agriculture and Environment



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The European Commission envisages nine partnerships under Cluster 6, two of which would be institutionalised (Circular bio-based Europe and EIT Food), four would be either co-programmed or co-funded (Animal Health; A climate-neutral, sustainable and productive Blue Economy; Safe and Sustainable Food Systems for People, Planet and Climate; Water4All), and three would be co-funded (Accelerating Farming System Transition; Agriculture for Data; Rescuing Biodiversity to safeguard life on Earth).

There is seemingly a good balance between the three types of partnerships. However, industry may have some interest in being involved in the design of the Strategic Research and Innovation Agendas regarding living labs and other research infrastructure ('Towards more sustainable Farming' envisaged partnership) to develop solutions for accelerating the transition of farming systems, and technologies to collect agriculture data.

The proposed portfolio of European Partnerships covers the full range of R&I orientations under Cluster 6.

All but one of the proposed partnerships contribute to orienting R&I activities towards the development of food systems that will ensure both sustainable and healthy diets and food and nutrition security for all. The food system has an impact on several challenges. It directly relates to nutrition and diets, access to food, food security, and has an influence on the use of natural resources, water and soil pollution, climate change. Food waste is a key component of circular systems and biomass has strong potential to offer bio-based energy solutions. Finally, the transformation of food systems should take into consideration demographic changes and the accelerating urbanisation (which reduces lands available for food production but offers opportunities for new types of agriculture such as urban farming).

Two R&I orientations are covered by less than half of the proposed partnerships: Environmental Observations (even though achievement in this area could make significant contribution to the other areas) and Bio-based innovation systems (which is nevertheless at the core of the candidate institutionalised partnership for a circular bio-based Europe).

EUROPEAN COMMISSION

Part I. Impact Assessment Studies for the Candidate Institutionalised European Partnerships

4. Candidate Institutionalised European Partnership in High Performance Computing

Authors

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Abstract

This document is the final report of the Impact Assessment Study for the candidate Institutionalised European Partnership in High Performance Computing under Horizon Europe. The study was conducted by Technopolis Group from July to December 2019. The methodological framework reflects the Better Regulation Guidelines and operationalises the selection criteria for European Partnerships set out in the Horizon Europe Regulation.

The candidate initiative focuses on coordinating efforts and resources in order to deploy a European HPC infrastructure together with a competitive innovation ecosystem in terms of technologies, applications, and skills. It will address the challenges raised by underinvestment, the lack of coordination between the EU and MS, fragmentation of instruments, technological dependency on non-EU suppliers, unmet scientific demand, and weaknesses in the endogenous HPC supply chain. The initiative has as its main objectives to enhance EU research in terms of HPC and related applications, continued support for the competitiveness EU HPC industry, and fostering digital autonomy in order to ensure long-term support for the European HPC ecosystem as a whole.

The study concluded that an Institutionalised Partnership is the preferred option for the implementation of this initiative as it maximises benefits in comparison to the other available policy options.

Executive Summary

This document is the final report of the Impact Assessment Study for the candidate Institutionalised European Partnership in High Performance Computing under Horizon Europe. The study was conducted by Technopolis Group from July to December 2019. The methodological framework for this study, described in the report on the overarching context to the impact assessment studies, reflects the Better Regulation Guidelines and operationalises the selection criteria for European Partnerships set out in the Horizon Europe Regulation. This report contains the findings of this specific study.

In the EC's vision for the period beyond 2020, the candidate HPC initiative falls under the HEU's Digital, Industry and Space cluster and supports the advancement of key digital and enabling technologies. It is important to note that the EU recently approved the creation of the EuroHPC Joint Undertaking (JU) which can be seen as a predecessor to the candidate initiative. The latter will build upon existing support for HPC under H2020, notably the contractual Public Private Partnership and the e-Infrastructures, ICT-LEIT, and FET Work Programmes.

Historically, HPC capability was important to R&D, national security and defence but is increasingly regarded as a general-purpose infrastructure with a broad range of potential applications for any kind of simulation or modelling of physical, economic and social phenomena. Therefore, HPC is crucial to EU strategic autonomy in the digital age.

However, there are several challenges that prevent EU autonomy and leadership in HPC. Firstly, European investments have been insufficient to achieve independence and self-sufficiency. Nationally, both investment and procurement have not been coordinated sufficiently between the EC and MS. Instruments to deliver the Research Agenda were fragmented prior to the EuroHPC JU and the European HPC industry supply chain is relatively weak with limited access to other markets, while demand for scientific HPC continues to outstrip supply.

In order to tackle these issues, three general objectives can be formulated for EU action. The scientific objective is to enhance the EU's capacity for cutting-edge research in both HPC and HPC applications. In economic terms, the objective is to support the competitiveness of the EU HPC industry from both the supply and demand-side. Third, the societal objective is to foster Europe's digital autonomy by ensuring long-term support for the overall European HPC ecosystem as well as improving the wellbeing of citizens.

To deliver on these objectives, the candidate initiative should fulfil several functionalities. Regarding actors, results and impacts can best be achieved if there is an established community of key players across sectors and disciplines within the European HPC research community and supply chain that are involved as members of the partnership. The initiative's activities should be in line with those of the EuroHPC JU. This includes the acquisition and deployment of a supercomputing and data infrastructure, and support for a research and innovation agenda in order to establish an innovation ecosystem supporting both hardware and software supercomputing technologies and their integration.

In terms of directionality and additionality required, the participation of 31 states in the JU signals the support for pooled investment and action in HPC. The JU has already secured €1b for 2019-2026 from H2020, CEF and industry. This will partially fund the procurement of peta- and pre-exascale machines to be hosted in different MS. Regarding synergies with other initiatives, the current JU builds on the model of ECSEL JU and has clear links with the candidate Key Digital Technologies and Smart networks initiatives, all of which are relevant for the candidate initiative.

The relevant policy options for this assessment were Horizon Europe calls, Co-Programmed Partnerships, and Institutionalised Partnerships. Our conclusion is that an Institutionalised Partnership is the preferred option. We considered its large-scale integrated strategy most likely to deliver substantially greater social and economic benefits. We also judged it to be the preferred option in terms of its European added value and its strategic flexibility.

Résumé exécutif

Ce document est le rapport final de l'étude de support à l'analyse d'impact de la proposition de partenariat européen institutionnalisé pour le calcul à haute performance (CHP) dans le cadre d'Horizon Europe. Cette étude a été menée par Technopolis Group entre juillet et décembre 2019. Le cadre méthodologique de cette étude, décrit dans le rapport sur le contexte général des études de support aux analyses d'impact, reflète les lignes directrices pour une meilleure réglementation et opérationnalise les critères de sélection des partenariats européens définis dans le règlement d'Horizon Europe. Le présent rapport contient les résultats spécifiques à cette étude.

Dans la vision de la Commission européenne (CE) pour la période s'étendant au-delà de 2020, l'initiative CHP proposée dépend du cluster « Numérique, industrie et espace » d'Horizon Europe (HEU) et favorise les progrès réalisés dans les technologies numériques clés et habilitantes. Il est important de noter que l'UE a récemment approuvé la création de l'entreprise commune (EC) EuroHPC qui peut être considérée comme le prédécesseur de l'initiative proposée. Cette entreprise commune mettra à profit le soutien existant pour le CHP dans le cadre de H2020, et notamment le Partenariat public-privé contractuel et les programmes de travail infrastructures électroniques, ICT-LEIT et FET.

La capacité CHP a toujours été importante pour la R&D, la sécurité nationale et la défense. Mais elle est toujours plus considérée comme une infrastructure à des fins générales ayant un large spectre d'applications potentielles pour toute sorte de simulation ou de modélisation de phénomènes physiques, économiques et sociaux. C'est la raison pour laquelle un CHP est fondamental pour l'autonomie stratégique de l'UE à l'ère du numérique.

Cependant, plusieurs écueils entravent cette autonomie et le leadership de l'UE en matière de CHP. Tout d'abord, les investissements européens ont été insuffisants pour atteindre l'indépendance et l'auto-suffisance. À l'échelle nationale, tant les investissements que l'approvisionnement n'ont pas été suffisamment coordonnés entre la CE et les États membres. Les outils pour la mise en place de l'Agenda de recherche ont été fragmentés avant l'établissement de l'entreprise commune EuroHPC. Par ailleurs, la chaîne d'approvisionnement du secteur CHP européen est relativement faible, avec un accès limité aux autres marchés, alors que la demande pour un CHP scientifique reste supérieure à l'offre.

Pour y remédier, trois objectifs généraux peuvent être formulés pour l'action de l'UE. L'objectif scientifique est d'améliorer la capacité de l'UE à mener des recherches de pointe, tant dans le CHP que dans les applications qui s'y rapportent. En termes économiques, l'objectif est de soutenir la compétitivité du secteur CHP européen du point de vue de l'approvisionnement et de la demande. Troisièmement, l'objectif sociétal est d'encourager l'autonomie numérique de l'Europe en assurant le soutien à long terme de tout l'écosystème CHP européen et en améliorant le bien-être des citoyens.

Pour réaliser ces objectifs, l'initiative candidate doit remplir plusieurs fonctionnalités. Au niveau des acteurs, les résultats et les impacts seront meilleurs si une communauté d'acteurs de premier plan est établie dans l'ensemble des secteurs et des disciplines au sein de la communauté de recherche et de la chaîne d'approvisionnement CHP européenne. Ces acteurs doivent être impliqués en tant que membres du partenariat. Les activités de l'initiative doivent être conformes à celles de l'entreprise commune EuroHPC. Cela comprend notamment l'acquisition et le déploiement d'un supercalculateur et d'une infrastructure de données, ainsi qu'un soutien pour un programme de recherche et d'innovation afin d'établir un écosystème d'innovation soutenant à la fois les technologies du supercalculateur d'un point de vue matériel et logiciel et leur intégration.

En termes d'orientation et de complémentarité requises, la participation de 31 États à l'entreprise commune signale l'appui d'un investissement et d'une action collectifs au niveau du CHP. L'entreprise commune a déjà récolté 1 milliard € pour 2019-2026 de H2020, du MIE et de l'industrie. Cela permettra de financer partiellement l'approvisionnement de machines péta- et pré-exascales à héberger dans différents États membres. Au niveau des synergies avec d'autres initiatives, l'entreprise commune actuelle repose sur le modèle de l'entreprise commune ECSEL et entretient des liens évidents avec les initiatives proposées pour les Technologies numériques clés et les Réseaux et services intelligents, toutes deux pertinentes pour l'initiative proposée.

Les options stratégiques pertinentes pour cette analyse étaient les appels à projets d'Horizon Europe, les partenariats co-programmés et les partenariats institutionnalisés. Nous avons conclu qu'un partenariat institutionnalisé était la meilleure option. Nous estimons que sa stratégie intégrée à grande échelle est plus susceptible de produire des avantages sociaux et économiques sensiblement plus élevés. Nous avons également jugé qu'il s'agissait de la meilleure option en termes de valeur ajoutée européenne et de flexibilité stratégique.

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Glossary

BDVA	Big Data Value Association
CEF	Connecting Europe Facility
CoE	Centres of Excellence
Cppp	Contractual Public Private Partnership
DEP	Digital Europe Programme
EESI	European Exascale Software Initiative
EIB	European Investment Bank
EOSC	European Open Science Cloud
EPI	European Processor Initiative
ETP4HPC	European Technology Platform for High-Performance Computing
EU	European Union (of 28 Member States)
EU+	European Union (of 28 Member States) plus Norway and Switzerland
Exascale	Computing systems capable of 1018 Floating Point Operations (FLOPs) per Second
EXDCI	European Extreme Data & Computing Initiative
FET	Future and Emerging Technologies
FLOPS	Floating Point Operations per Second
HPC	High Performance (or Throughput) Computing
HPDA	High Performance Data Analytics
ICT	Information and Communication Technology
JU	Joint Undertaking (as defined by Article 187 TFEU)
LEIT	Leadership in Enabling and Industrial Technologies
LIGO	Laser Interferometer Gravitational-Wave Observatory
MFF	Multi-annual Financial Framework
MS	EU Member States
NRENs	National Research and Education Networks
PCP	Pre-Commercial Procurement
PPI	Public Procurement of Innovative solutions
PPP	Public-Private Partnership
PRACE	Partnership for Advanced Computing in Europe
Pre-exascale	Computing power near the exascale performance (i.e. 0.1-0.6 exascale)

SDGs	United Nations Sustainable Development Goals
SHAPE	SME HPC Adoption Programme in Europe
SKA	Square Kilometre Array
SME	Small and Medium-size Enterprise(s)
SRA	Strategic Research Agenda
SRIA	Strategic Research and Innovation Agenda
TFEU	Treaty on the Functioning of the European Union

1 Introduction: Political and legal context

This document presents the impact assessment of the candidate institutionalised partnership in HPC, which is one of the initiatives that will implement the Commission's vision for the period beyond 2020 under the Horizon Europe Pillar II, specifically Cluster 4 – Digital, Industry and Space. It is one of the envisaged European Partnerships in the Partnership Area "PA2: Advancing key digital & enabling technologies & their use".

It is important to note that the HPC impact assessment study differs from the other 12 parallel impact assessment studies, inasmuch as the EU recently approved the creation of the EuroHPC Joint Undertaking "EuroHPC JU".

Through this Joint Undertaking, the EU and participating states coordinate efforts and resources in order to deploy a European HPC infrastructure together with a competitive innovation ecosystem in terms of technologies, applications, and skills. The joint undertaking will be fully operational by 2020 ahead of the next programming period (MFF 2021-27) and will be able to provide the strategic leadership and oversight needed to expand overall investment and produce a step change in Europe's deployment and use of next generation HPC.

1.1 Emerging challenges in the field

High Performance Computers (HPC) are machines that are, at any point in time, leading in terms of speed and performance. HPCs are usually employed for applications where there is a current need for massive computing power, memory, storage, bandwidth requirements or any combination of these, to such a degree that doing an equivalent job in a regular computer or facility would be impossible or unfeasible. In general, the simulation of any physical, economic or social phenomena that can be mathematically modelled could benefit from access to HPC facilities. The first applications of supercomputers for research usually revolved around the areas of weather forecasting and atmosphere research, oil exploration and simulations, genetic engineering, fluid dynamics, aerospace engineering and defence applications. Over the past 5-10 years, however, supercomputers have also been increasingly used in new areas such as digital twins, AI, Machine Learning and other applications requiring Big Data analytics to design and train advanced models.

Traditionally, a strong HPC capability was of strategic importance for R&D, national security and defence. Nowadays, its importance as a general-purpose technology for industry and wider society is being increasingly recognised. As a general-purpose infrastructure, HPC has broad application, and has a role to play in meeting various EU policy goals from global competitiveness to sustainable development (e.g. faster, more accurate climate modelling; green, energy efficient HPC). Table 1 outlines different domains and challenge areas where HPC can make a substantial contribution.

This underlines the importance of HPC as an important element of Strategic Autonomy in the Digital Age: critical digital infrastructures and capabilities, including HPC, are necessary elements of strategic autonomy for the EU.[1] One of EuroHPC's targets is to support the development of European low-power microprocessor technology as a step towards achieving more technological autonomy in terms of a technology that is essential to HPC.

[1] EPSC Strategic Notes (2019). Rethinking Strategic autonomy in the digital age. Available at: https://ec.europa.eu/epsc/sites/epsc/files/epsc_strategic_note_issue30_strategic_autonomy.pdf

Table 1: Overview of the challenges emerging

Social	Demographic change, wellbeing and ageing populations are increasing the demand for new and improved therapies, understanding the nature of diseases, faster and more effective drug discovery and the customisation of therapies to the specific needs of patients (personalised and precision medicine). All these domains rely heavily on HPC being available.[2]
Technical and technological	There is a need for maintaining and increasing industrial leadership and competitiveness in key enabling and digital technologies, and to develop, to promote the uptake of new technologies through technology infrastructures in strategic value chains
Economic	Emerging technologies in digital (big data, AI, robotics), quantum technologies, biotechnologies (genomics, proteomics, and metabolomics), new materials, etc. are expected to contribute to future innovation to support economic growth. HPC paves the way for new business models and innovative applications in such high added-value areas.
Environmental	There is a pressing need for new and improved forms of secure, clean and efficient energy. HPC is a critical tool in the development of new energy technologies such as fusion energy research, the design of high-performance photovoltaic materials and the optimisation of wind turbines for electricity production. The trend towards integrated management of smart city systems will require vast amounts of computing power in order to fulfil the promise of smart, green and integrated transport. The control of large transport infrastructures and other real-time analysis of data is only possible via the use of large-scale computing infrastructure. Climate study and weather forecast prediction. From 1970 through 2012, severe weather cost 149,959 lives and €270 billion in economic damages in Europe[26]. Severe weather forecasting on national and regional scales depends heavily on HPC. Disease control and monitoring of the marine environment and food resources are increasingly needed due to increased population densities and pressure on the environment, leading to a greater need to optimise the production of food and analyse sustainability factors. HPC is a critical element of advanced analysis in these areas.
Political, policy and regulatory framework	The sovereignty and geopolitical argument for indigenous HPC capabilities and supply chain has several ramifications: • There is a need to maintain access and secure first user advantage to state of the art technology, at the same level as European counterparts (US, Japan, China). • There is a need for an improved management of EU borders, better protection of public spaces, improved security and resilience of

[2] For a discussion of the many points of convergence between health and HPC, see the proceedings of the Third International Super Computing (ISC) Workshop on High Performance Computing (HPC) Applications in Precision Medicine, June 20, 2019 Frankfurt, Germany https://ncihub.org/groups/hapm19

infrastructure, and increased cybersecurity based on more effective use of digital technologies.

This is intimately related to the arguments for maintaining strategic autonomy in the EU, and the increasing role that digital and computing technologies have in terms of ability to influence economic, societal and political outcomes.

Stakeholders from industry referred to the innovations in HPC moving towards a digital continuum of Edge computing and IoT as an emerging challenge. Many industrial stakeholders also pointed to the energy consumption of HPC and the growing need for low-power processors as a key area of debate today.

Infrastructure stakeholders also described energy consumption as a key challenge as well as the increasing relevance of HPC in the context of the rise of Big Data.

1.2 EU relative positioning

1.2.1 Competitive positioning of Europe in the field

As Horizon 2020 transitions to Horizon Europe, the scientific and technological focus shifts to supporting a data-driven economy and society, and particularly the development of (commercial) applications of HPC. MS will see the implementation of leading-edge technologies across all aspects of society through the application of AI, Machine Learning, Neural Networks, robotics, predictive analytics to accelerate R&D across science and multiple industry sectors. This implementation is supported by the Digital Europe programme that aims to deploy technology options and solutions for achieving both global challenges and increasing European industrial competitiveness.

The EU has one of the largest GDPs in the world but investments in HPC are much lower than the U.S.A. Market data by Hyperion shows that Europe maintains a relatively constant share of around 26% of the overall spending in all categories of HPC systems.

In the strategically important high-end market of systems over €2.25 million, the current situation is not very satisfactory. The EU has only one supercomputer in the global top 10 and five in the global top 20 (June 2019), dropping from peak 4 and 7 systems respectively in 2012. Spending levels for these high-end supercomputers are an important measure of HPC leadership.

On HPC supply, U.S.A. is the absolute world leader, having the lion's share in all segments of the global HPC systems market. The only sizeable Europe-based vendor, Atos (formerly Bull) accounted for approximately 4.1% of the EU market in 2019 and around 1.1% of the global market in 2018 based on research by Hyperion.

Historically, Europe has been strong in parallel software development and a global leader in exploiting HPC for innovation. The European share of the worldwide commercial HPC software market closely matches its share of global spending in the HPC server market (an estimated 26% in 2018).

Worldwide, the proportion of sites exploiting cloud computing to address parts of their HPC workloads has grown to over 70% in 2019 –helping the "democratisation of HPC", especially as advances in virtualization capabilities becoming more efficient and HPC-friendly.

The convergence of HPC and big data analytics is being driven by HPC users and the growing contingent of commercial firms that are adopting HPC solutions to tackle data analytics. According to Hyperion forecasts, worldwide revenues for HPC systems dedicated to high performance data analysis (HPDA) will grow robustly (15.4% CAGR) in the period

2018–2023 - more than double the forecasted growth rate of the worldwide HPC server market. Moreover, revenues for HPC-based artificial intelligence (AI) are expected to grow more strongly (29.5%) from 2018-2023. Europe's share of these markets is approximately similar to its share of the HPC server system market as a whole (i.e. around one quarter of the global total). To better understand the scientific positioning of the EU in the field of HPC, a scientific and technological analysis based on Horizon 2020 output data (on publications and IPRs) and more general bibliometrics and patent data is provided in Appendix D. The figures up to July 2019 show a total of 433 high-impact publications resulting from HPC-related actions funded through Horizon 2020. Figures by year and call topic from 2017 and 2018 suggest that HPC calls are producing around 150 high impact papers annually. Notwithstanding differences in the volume of funding available for these different call topics, it is clear the vast majority publications resulted from activities with a focus on HPC applications rather than HPC technologies per se, perhaps reflecting the importance of academic contributors to this particular KPI as compared with industrial partners.

The involvement of industry in these publications is low. Only 7% of publications were co-authored with industry, which is lower than the share of industry-academic co-publications for all other candidate partnerships. The data also show rather small numbers of intellectual property rights (IPRs) (fewer than 10 in total) associated with Horizon 2020 HPC projects, which suggests that industrial engagement has not been as central as the participation data would suggest. As a point of reference, a simple search of Espacenet returns around 10,000 records – applications and patents granted – for Europe's leading HPC supplier, Atos Bull (FR), albeit those patents are rather more broadly based than HPC. Similarly, WIPO's recently published patent landscape review of artificial intelligence suggests that around 4,000 patents a year globally relate to applications in computing broadly defined. That is to say, patenting has been an important method of IP protection within this domain historically.

In terms of international benchmarking,[3] publication output globally has increased steadily over the 2010-2018 period, from less than 1,500 publications in 2010 rising to around 2,500 by 2018 (an average annual growth rate of 7.4%). The data show that the US is clearly leading the way, in volumetric terms, with around 6,500 HPC publications having lead authors based at US addresses. Individual EU member states perform reasonably strongly on this measure, in terms of their global ranking, albeit with an output that is around 20% of that of the US. This analysis showed that Horizon 2020's c. 150 HPC publications a year constitute around 5% of the global publication output, which is a similar order of magnitude to the contributions of leading EU member states, like Germany. The most prolific publishers of HPC papers and articles (top 10 by publication output) include two European centres of excellence, specifically the Spanish National Supercomputing Centre and the French INRIA among the top ten.

1.2.2 Support for the field in the previous Framework Programme

The EU has been supporting the development of HPC over several programming periods and has been investing around €150m a year during Horizon 2020, primarily through the contractual Public Private Partnership on HPC (cPPP), before the inauguration of the EuroHPC joint undertaking. H2020 provides significant amounts of dedicated HPC funding through three distinct Work Programmes; **e-infrastructures**, **ICT-Leadership in Enabling and Industrial Technologies (ICT-LEIT)**, and **Future and Emerging**

[3] The analysis was based on data from Scopus and excluded biomedical and health fields.

Technologies (FET). HPC-related calls in **ICT-LEIT** and **FET** for the 2014-2018 period amounted to €258.9m.[4]

In addition to the work delivered by the cPPP, other relevant initiatives like PRACE, GEANT, and the EPI also draw on Union Funds. EuroHPC is a newly created joint undertaking that will operate through to the end of 2026 and already approximates to an institutionalised partnership (a public private partnership with around €1.5bn to invest in an area of strategic importance for the future of the EU), while the cPPP on HPC was a public private partnership between the EC and the ETP4HPC Association. PRACE is an inter-governmental agreement in which the EC is not involved in the governance but rather funds some of the activities. GEANT and EPI are FPAs. EPI will be handled by the EuroHPC in the future, but not GEANT. Appendix D gives further information on the scope and objectives of each of these initiatives, including the recently launched EuroHPC.

The EuroHPC Joint Undertaking will initially operate from 2019 to 2026. The JU foresees an initial co-investment with Member States of about €1b, out of which €486m come from the actions already planned by the Commission in Horizon 2020 and Connecting Europe Facility (CEF) programmes in the current Multiannual Financial Framework (MFF). An additional ~€422m will be contributed to the JU activities by private or industrial players. EuroHPC targets the whole spectrum of HPC technologies, from low-power microprocessors and related middleware technologies to software, programming models and tools, novel architectures and their system integration. The JU is currently in the process of acquiring and providing access to a series of world-class petascale and pre-exascale supercomputing and data facilities for European researchers, industry and public users. In addition, the JU currently supports the process for developing the sector's strategic research and innovation agenda and runs open calls in support of its objectives.

1.3 EU policy context beyond 2021

As set out in report on the overarching context to the impact assessment studies, the R&I activities funded under the Pillar II Cluster Digital, Industry, Space aim at contributing to the attainment of three overarching EU policy objectives: 'A Europe fit for the Digital Age', 'An economy that works for people', and 'A European Green Deal'. Their critical role in facilitating transitions in multiple 'vertical' sectors in our economy and society imply that the R&I actions under this cluster will contribute to addressing several Sustainable Development Goals.

Specifically, in the field of high-performance computing, next-generation HPC systems will significantly strengthen the competitiveness and innovation capacity of European industry within the HPC supply chain, improving economic output and work opportunities in the industry that is supported (*SDG 8 Decent work and economic growth* and *SDG 9 Industry, innovation and infrastructure*).

At the applications level, HPC may make a positive contribution on climate change mitigation (*SDG 13 Climate Action*), whether that is through the ability to run more powerful climate change models to inform policy making on mitigation measures or more operational support for weather forecasting and disaster management. It can also contribute to energy-related challenges (*SDG 7 Clean and Affordable Energy*), for example through a routine deployment of HPC in smart grids management or by making component supplier and system integrators more competitive in the area of green HPC through the development of more efficient HPC components, architectures and software. Combined with other technologies such as AI, access to HPC can also make a contribution to other sustainable development goals. For example, HPC can make a positive contribution to an efficient and secure food value chain in Europe and via applications, address food security,

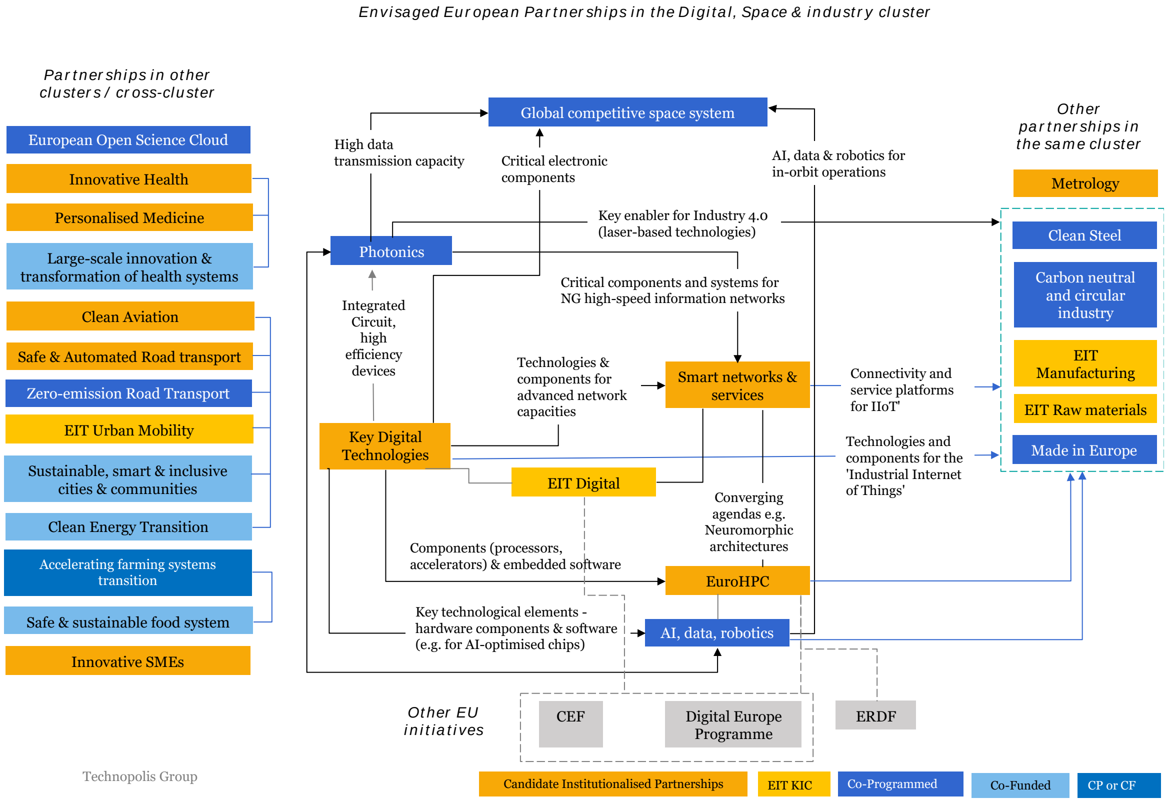
[4] Technopolis analysis based on eCorda data

farming optimisations / sustainable precision agriculture (*SDG 2 End hunger*). A wider use of HPC can also drive advanced diagnostic techniques and personalised medicine, support health research, and accelerate new drug discovery and development (*SDG 3 Good Health and Well-being*) and allow for infrastructure for cyber security applications (*SDG 16 Peace, justice and strong institutions*).

Figure 1, below, maps out the positioning of the candidate Institutionalised Partnership in this field in the landscape of the envisaged partnerships in Cluster 4, with a specific focus on the ones in the digital field. The three candidate Institutionalised Partnerships covering enabling technologies are all related to digital technologies, i.e. electronic components and systems, 5G infrastructure and high-performance computing. Together with photonics, AI, data technologies and robotics, these partnerships are intended to enable digitalisation of vertical industries such as transport, automotive, manufacturing, energy and health, enable new services and ensure the development and deployment of the 'Industrial Internet of Things' (IIoT). The move towards Industry 4.0 (supported by Industrial Internet of things) is crucial for Europe to maintain industrial production in Europe by developing more intelligent systems and machines to increase the value and remain competitive on the high-end markets.

The diagram shows that developments in the field of IIoT will in the first instance be to the benefit of the other envisaged partnerships in this cluster. It also lists the most important initiatives related to the 'vertical' industries in the other Pillar II clusters that can be expected to draw benefit of these developments in the digital sphere, allowing for the development of 'smart health', 'smart mobility', 'smart grids', 'smart cities', precision farming etc. Metrology research will support the initiatives in the digital sphere by providing accurate state-of-the-art measurement capabilities. Better measurement and calibration systems will especially make a direct contribution to the rolling out of 5G applications and to test and validate and design standards for future generation communication technologies and systems.

Figure 1: Interconnections with and among the envisaged partnerships in the Digital, Industry, Space cluster



The mapping of the partnerships landscape in Figure 1 shows a close interconnection between the various initiatives in the digital field, taking a full value chain approach and building upon each other for the attainment of future technological advancements. Technologies like 5G connectivity, cloud computing, and Internet of Things (IoT), which find a point of convergence in the Smart Networks and Services initiative, are key elements leading the technological evolution of digital infrastructures towards 'beyond 5G' and later 6G networks. In order to develop a strong industrial and technological base, it will be necessary to guarantee also cybersecurity for these critical infrastructures. While the Smart Networks and Services initiative is expected to set in place the overall architecture of future networks and services (from component to application level), close collaboration with the Key Digital Technologies initiative that complements the value chain at the device level, creating technological breakthroughs on the individual components, will allow for the creation of the service platforms required for, e.g., the 'Industrial Internet of Things', smart cities or the 5G corridors for Connected and Automated Mobility.

The Cluster 4 envisaged European Partnerships and, especially, those related to digital technologies will benefit from the infrastructure developed in the European Open Science Cloud partnership for the storage, management, analysis and re-use of data. In turn, the technological advancement allowed by the research and innovation activities in Cluster 4 could help further improve the infrastructures and related serviced offered by the European Open Science Cloud.

The Innovative SMEs partnership may also interact closely with the Cluster 4 candidate European Partnerships, as its main beneficiaries (SMEs) compose a large share of the digital companies.

The High-Performance Computing initiative, in close interaction with the AI-data-robotics envisaged partnership, will be pivotal in addressing the need to integrate and analyse information for building smarter applications in emerging Smart Cities and the Internet of Things. Addressing future challenges requires scaling to extreme performance levels by means of HPC solutions as well as bringing compute closer to data sources, i.e. enabling computing at the edge. Connected sensors and IoT devices, smart grid, smart cities, software-defined networks, network function virtualization, data-driven cognitive networking and cyber security utilise edge computing networks to support data transmission over significant distances via distributed and connected communication devices.

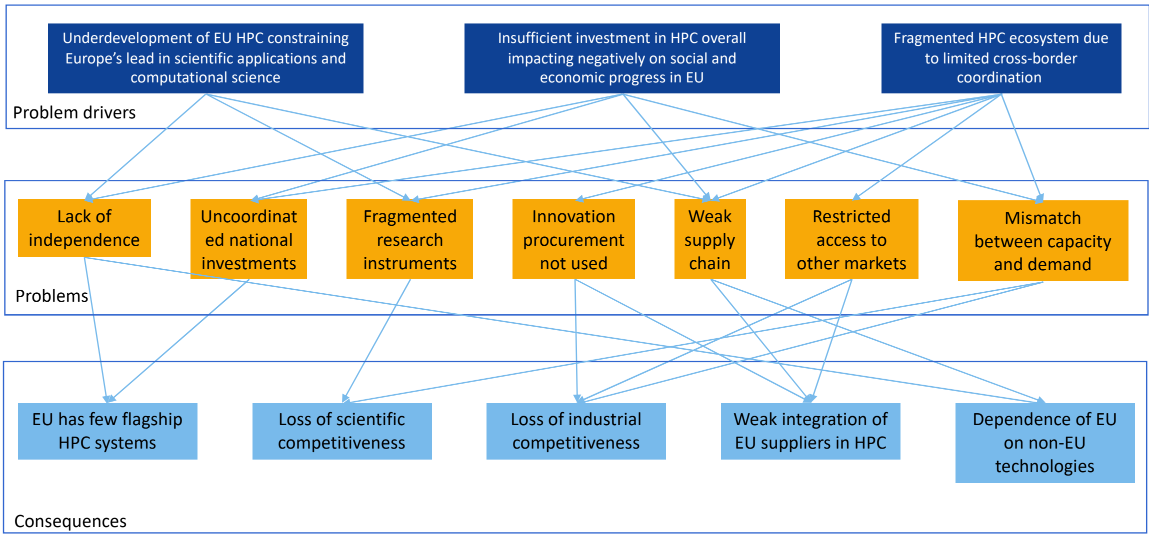
For the candidate European Partnership in HPC, cooperation with the Digital Europe Programme (DEP) and the Connecting Europe Facility (CEF-2) programme would support the initiative in developing and building the HPC infrastructure and ecosystem throughout the EU. The Connecting Europe Facility-2 Programme is expected to ensure terabit connectivity between existing and future supercomputing centres, while the DEP support "will focus on large-scale digital capacity and infrastructure building, aiming at a wide uptake and deployment across Europe of critical existing or tested innovative digital solutions".[5] Furthermore, the EuroHPC JU has also made the argument that additional investments from structural funds (ERDF) may be needed to realise a supercomputing infrastructure as well as the development of applications. Such ERDF contributions would have to be coordinated with deployment and innovation actions funded through DEP in the case of projects with a common European interest or regional relevance.

[5] European Commission (2019) *Partnership for European High-Performance Computing*. Fiche for the consultation with Member States

2 Problem definition

This section provides a discussion of the problems to be addressed in relation to the emerging challenges presented in Section 1.1, drawing on evidence from desk research and the findings of the stakeholder consultation undertaken as part of this study. A problem tree portraying related problems, their drivers and consequences is presented in Figure 2 and described in detail in the following sections.

Figure 2: Problem tree for the initiative on HPC



2.1 *What are the problems?*

2.1.1 European investments in HPC are insufficient to achieve independence / self-sufficiency

The launch of the EuroHPC JU has led to significant improvements in investment. The commitment to build eight new cutting-edge systems will immediately increase computing capacity in Europe by a factor of 10 which will therefore improve access to HPC across the EU, reducing regional inequalities as well as providing a platform for EU suppliers to get involved in the development of those machines. The development effect for Europe's value chains will take time to manifest as the earmarked investment will be used to buy the eight HPC machines and related infrastructure. These investments largely take place in parallel and necessarily make full use of the pre-existing technologies of international vendors. On the positive side, while it is true that Europe does not yet possess the technology for all these systems to be built using endogenous technology, some EU suppliers such as Atos may start introducing R&I developed in previous activities, such as the Mont-Blanc project.[6]

The investment gap will be reduced with the launch of EuroHPC, but the HPC R&D funding shortfall remains significant, the consequences of which could be a further loss of digital autonomy on the one hand and a weakening of industrial competitiveness on the other. The EuroHPC JU is currently partially addressing the issues on the infrastructure-side but additional funds will be needed to specifically address the R&D-related challenges.

2.1.2 National investment and procurement have historically not been sufficiently coordinated between the EC and Member/Participating States

Central coordination or strategy, with regards to European HPC procurement and infrastructure capacity planning, is one of the main features of the EuroHPC JU. In the past, lack of coordination has meant that constant competitiveness, in terms of availability

[6] http://montblanc-project.eu/

of world class HPC facilities, could not be maintained. The lack of coordination saw periods of strong competitiveness followed by periods of relative stagnation in peak performance of European HPC, vis-à-vis other competitors such as the US, China and Japan.

Ensuring Europe maintains sufficient HPC infrastructures to support science and innovation is a priority of the Digital Agenda for Europe. While funds invested do not directly correlate to research outcomes, adequate resources are needed both for investing in R&D and acquiring HPC capabilities.

The EU has a critical role to play in ensuring there are sufficient HPC and high throughput computing systems, data storage, and network capacity available to MS, to deliver against the scientific, technological, economic and societal priorities up to 2027 and until the expected availability of exascale supercomputing systems. MS can also explore opportunities for consolidation and federation of HPC infrastructure. This could be done through co-ordination in procurement of future systems from next generation HPC through to exascale, in order to make a more efficient use of the available resource.[3]

EU-level coordination is a necessity as under-investment remains an issue in comparison to other world regions, which also affects the timeline towards exascale systems. This is reflected in the latest available research by Hyperion Research[7] showing that both China and the U.S. are expected to invest approximately $10b over a period of 7 years (in the range of $1b to $2b per year), while the EU is expected to invest between $5b and $6b in total. Moreover, investments by China and the US will primarily go towards purchases of multiple exascale systems each year whereas the EUs investments would also include pre-exascale in addition to exascale systems. According to Hyperion, Japan’s projected investment levels are somewhat lower in comparison with a planned commitment of over $1b earmarked for the purchase of one exascale system as well as complementary R&D which may be followed-up by several small systems.

2.1.3 A fragmentation of programme instruments to deliver on the needed HPC Research Agenda prior to the launch of EuroHPC

The 2012 Communication and HPC Strategy called on the EC, Member States, PRACE and industry to put several actions in place in order to support European HPC infrastructure and to more efficiently pool investments in HPC. As a consequence, the ETP4HPC contractual PPP was launched, and the EC made a commitment of €700m towards ETP4HPC and funded R&I projects (FET Calls), Centres of Excellence (CoE) to support HPC applications, training and onboarding. In parallel, PRACE continued its activity, with Member States continuing to invest in their national HPC capabilities.

While PRACE provided federated access to computer resources for Top-tier systems, its role was not to articulate a strategic vision that would be followed by MS in their planning and procurement processes. Also, the implementation of the research agenda proposed by ETP4HPC was delivered by the EC through a variety of routes. At a European level, HPC funding is provided through Horizon 2020 as well as through the Connecting Europe Facility (CEF). Additionally, within Horizon 2020 alone, funding is administered through three separate Work Programmes namely, e-infrastructures, LEIT-ICT, and FET.

EuroHPC started to address this fragmentation by channelling the majority of EU research and innovation funding for 2019-2020 through an integrated, strategic agenda that encompasses a portfolio of distinct interventions relating to its specific objectives (e.g. joint procurement of flagship HPC systems; HPC coordination actions; and a programme of HPC research and innovation in key technologies, applications and software). Moreover,

[7] Hyperion Research Update: Research Highlights in HPC, HPDA-AI, Cloud Computing, Quantum Computing, and Innovation Award Winners. Available at: https://hyperionresearch.com/wp-content/uploads/2019/06/Hyperion-Research-ISC19-Breakfast-Briefing-Presentation-June-2019.pdf

EuroHPC is launching R&I actions covering the full HPC ecosystem, including support for national HPC Competence Centres.

2.1.4 There is a weak European HPC industry supply chain and limitations for European HPC suppliers to access other markets

The latest market research from Hyperion[8] shows that the global market for HPC servers grew by 15% from 2017 to 2018, reaching $13.7b in revenues worldwide. North America clearly leads the global market (i.e. purchases of HPC servers) followed by Europe, the Middle East and Africa (EMEA) and Asia/Pacific, with North America and Europe showing particularly strong growth rates in recent years. Within this market, the supercomputer segment grew by 23%.

The European supply chain for HPC is relatively weak as most major manufacturers are headquartered outside the EU. Integration of EU suppliers in the global HPC market is also weak. The following facts illustrate the scale of the problem:

- Out of all HPC systems listed in the TOP500 (November 2019), only 5% (25/500) are supplied by EU manufacturers. Of these 24 systems, 23 were purchased by clients in the EU with just three clients globally, located in Brazil.
- All but 2 of these 25 TOP500 HPC systems supplied by EU manufacturers were supplied by the French Bull-Atos Group. The remaining systems were manufactured by ClusterVision/Hammer (NL/UK) and NEC/MEGWARE (JP/GER).
- Out of the 76 HPC systems in the TOP500 list that are located in the EU, only 26.3% (20/76) were supplied by European manufacturers. This means that 73.7% of the European HPC market is being supplied by non-EU manufacturers.
- Worldwide, EU industry provides 5% of HPC resources while consuming 29% of these resources.[9]
- When global HPC sales are analysed by vendor, only one large European player (Bull Atos) sold more than $100m in 2018, which represents a total market share of around 1.1%, far below the largest US, China and Japan competitors.

A weak European HPC supply chain has potentially negative effects on clients in both government and industry. Industries operating in weaker and less dense supply chains are generally less competitive and are more at risk of being taken advantage of by suppliers and clients, due to market power being concentrated in fewer actors. Companies operating in these environments also have a harder time sourcing and nurturing talent and scaling up their activities.

In addition to the difficulties faced by the HPC industry itself, European industry (HPC users), research and sovereignty are also affected by a weak EU HPC supply chain. With the EU being a buyer of foreign systems in four out of five cases, there is a risk of European clients overpaying or falling behind in the exploitation of HPC as a result of less good access to the latest HPC architectures that are developed, produced and exploited first in the countries where they are developed[13]. Reversing the dependency on non-European HPC supply chains can be partly achieved by entering into strategic joint ventures with manufacturers from other regions, thereby reducing the risks of MS becoming

[8] Hyperion Research Update: Research Highlights in HPC, HPDA-AI, Cloud Computing, Quantum Computing, and Innovation Award Winners. Presented at ISC High Performance 2019, June 18. Presentation retrieved from: https://hyperionresearch.com/wp-content/uploads/2019/06/Hyperion-Research-ISC19-Breakfast-Briefing-Presentation-June-2019.pdf

[9] Impact assessment accompanying the proposal

technologically deprived of strategic know-how for innovation and industrial competitiveness.

The EuroHPC is well-placed to contribute to this specific objective, however, the challenge is substantial given the long-standing and strengthening comparative advantage enjoyed by international HPC vendors. The transition from a weak industry to a globally competitive one will require major additional investment in for example the development and scaling up of new (niche) technologies where Europe has a comparative advantage. This needs to go beyond hardware to encompass HPC software too, where Europe has strengths and there is less of an international monopoly; it is also an aspect where Europe's world-class HPC scientific and institutional users may have a critical role to play in finding breakthroughs that will cope with the massive parallelism of exascale. In addition to exascale, Appendix D provides more up to date baseline information on other related markets such as parallel software, cloud and High-Performance Data Analytics (HPDA).

2.1.5 Innovative procurement instruments to support endogenous growth are not widely used

The EuroHPC IA states that "European suppliers face limitations in acceding to public procurements of HPC in USA, China or Japan." This is in contrast with European public procurement, which is supposed to remain open except for specific cases related to military purpose machines in some Member States.

The public sector dominates the market for cutting-edge HPC systems in Europe operating under the rules of the EU directives on public procurement, which have historically favoured large work packages bought on price. The 2014 revisions (2014/24/EU) did clarify the legitimacy of using different procurement strategies in order to achieve more strategic outcomes (e.g. environmental impact), favour innovative solutions or level the playing field for SMEs.

EuroHPC has been able to persuade member states of the value of a more strategic approach to the procurement of the eight flagship HPC systems, which will provide an important development platform for key European technology suppliers. Current statistics suggest clients continue to favour conventional procurement methodologies with new HPC purchases dominated by systems from other regions. In contrast, the US, China and Japan have traditionally prioritised their indigenous industries.

There is very little evidence so far of public authorities choosing to use the EC's innovation procurement instruments such as Horizon 2020's Pre-Commercial Procurement (PCP) scheme or DG GROW's Public Procurement for Innovation (PPI) pilot. The PPI4HPC project run by BSC, CEA, CINECA, GENCI, and Jülich is one notable exception to this as it was the first multi-national joint procurement for HPC in Europe.[10] However, consultations suggest that the rules associated with these novel instruments are still problematic for the HPC industry in Europe, with requirements for cross-border collaboration among clients and an expectation that multiple suppliers will be invited to develop potential solutions.

Another partial recourse for R&I activities exists in Article 30.3 of the H2020 model grant agreement, which allows the EC to object to the transfer of IP to third countries under certain conditions (if the Agency in question considers that the transfer does not serve EU interests regarding competitiveness, ethical principles or security considerations).

A new and more direct solution to this issue is outlined in the Proposal for the Regulation of the Digital Europe Programme, stating in Article 18.5 that *"The work programme may provide that participation is limited to beneficiaries established in Member States only, or*

[10] For more details see: https://www.ppi4hpc.eu

to beneficiaries established in Member States and specified associated or other third countries for security reasons or actions directly related to EU strategic autonomy."[11]

The main stakeholders affected by these issues are Europe's HPC industry, as this results in smaller addressable markets than those open to their non-EU competitors. In addition, non-EU competitors appear to find it easier to sell in many EU countries where indigenous firms tend to have a more limited marketplace geographically. Furthermore, another key difference between the procurement processes in the EU and those in the US, China, and Japan is that in the latter, procurements for leading edge systems include an industry-driven R&D phase.

2.1.6 Demand for scientific HPC outstrips supply

Currently, the combined capacity of EU HPC resources is not able to meet the demands of scientific users and researchers. For instance, PRACE calls have an average oversubscription ratio of 3:1[12] and there is evidence that a part of the scientific community in Europe, especially in the EU13, does not have access to the level of supercomputing performance that they need for their research purposes.[13]

Evidence on excess demand from industry is more limited. A study conducted by the EIB[14] notes that HPC customers in Europe are primarily public entities in research and academia, accounting for approximately 95% of operating time on Europe's highest performing systems whereas the remaining 6% is installed for private use. Among these, the main commercial users are large corporations while the uptake amongst SMEs is limited, mainly due to a lack of awareness of the benefits of HPC and technical knowledge barriers, as well as the considerable capital costs. There is a trend towards HPC centres gradually opening up to cooperation with industry, and some of the frontrunners have been operating successful industrial outreach programmes to work with the private sector. These centres partly finance themselves via these activities, but the EIB has noted that some public HPC centres lack viable business models due to legal limitations around raising revenues from commercial activities.

On the demand side from the private sector, there are several successful examples of programmes supporting industrial access at European level, such as PRACE Industry Access, PRACE SHAPE, or Fortissimo. However, there is limited evidence of the contribution of these programmes to the satisfaction of growing industrial users' requirements in general and SMEs. In this regard, there may be room for improvement given the potential benefits that HPC can offer to industry.

For instance, HPC enables traditional computationally-intensive sectors to significantly reduce R&D costs and development cycles, and to produce higher quality products and services in manufacturing and engineering industries (e.g. automotive, aerospace), health and pharma (e.g. drug discovery), energy (e.g. discovery of oil and gas resources, renewable energy generation and distribution). HPC also paves the way for new business and innovative applications in high added-value areas (e.g., in personalized medicine, bioengineering, smart cities/autonomous transport, etc.), reinforcing the industrial innovation capabilities, in particular of SMEs.

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[11] COM/2018/434 final/ Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing the Digital Europe programme for the period 2021-2027

[12] See PRACE KPIs at: http://www.prace-ri.eu/prace-kpi/

[13] European Commission. (2018). Impact Assessment accompanying the Proposal for a Council Regulation on establishing the European High Performance Computing Joint Undertaking – Annex 2 part 1.

[14] European Investment Bank. (2018). Financing the future of supercomputing

EuroHPC is already partially addressing the demand for scientific HPC by procuring and acquiring 5 petascale systems hosted in smaller Member States, as a stopgap measure to cope with increased demand and to build capacity in new areas across Europe. Over time, more infrastructure will be required to cope with the demands of computationally intensive sectors and a broader industrial uptake.

Across all stakeholder groups there was a general consensus that European investments in the area of HPC have historically been insufficient

Industry stakeholders felt that more public funding will be needed both from the EU as well as individual MS in order to build up a European HPC ecosystem.

Infrastructure providers mentioned in particular the lack of investments in CoEs which should be delivering considerable impacts in terms of applications. Some interviewees pointed to the lack of critical mass in EU industry and the lack of strengths in terms of technological hardware.

Stakeholders from research confirmed the lack of funding for CoEs as well as the lack of HPC skills across all technical silos as problems.

Member States further reiterated the problem of a skills gap and the fact that Europe is lagging behind in terms of technical competencies and the diffusion of knowledge to industry. In particular, the lack of sustainable career paths in Europe for researchers was seen as a problem by several interviewees.

2.2 What are the problem drivers?

The key problem drivers affecting R&I performance in the European HPC ecosystem are discussed in more detail in the following paragraphs.

2.2.1 Underdevelopment of EU HPC constraining Europe's lead in scientific applications

HPC is now critical for more use cases, complex workloads, and data-intensive computing than ever before. There is a general perception that we are overwhelmed with data, making the ability to store, process, analyse, interpret, consume, and act upon that data a primary concern. For large-scale, multi-national organizations and those in heavily regulated industries— such as finance, healthcare, or those covering multiple industry verticals — the situation becomes ever more complex and challenging.

By the end of this decade, the world's store of digital data is projected to reach 40 zettabytes (10^{21} bytes), while the number of network-connected devices (sensors, actuators, instruments, computers, and data stores) is expected to reach 20 billion.[15]

Escalating data concerns are widespread in what is termed the 4th Industrial Revolution, where demands are exceeding the capacity of traditional computing and requires HPC infrastructure to manage this exponential growth in data. This is driven by Cloud directives, together with new and evermore complex workflows, workloads and algorithms. Taken collectively, they represent a vast "digital continuum" of computing power and prolific data generators that scientific, economic, social and governmental concerns of all kinds will want and need to use. The volume and speed of data growth has introduced several challenges: -

- HPC system management and growing cluster complexity

[15] ETP4HPC & EXDCI. (2019). A blueprint for the new Strategic Research Agenda for High Performance Computing. April 2019.

- Data centre power, cooling, and floor space limitations (incentivising research into green HPC architectures)
- Storage, data movement, and management complexity
- Lack of support for heterogeneous environment and accelerators
- Significant shortage of skills to integrate and manage the HPC ecosystem
- Cyber-security risk management

The deployment of HPC is undergoing significant change, and the term no longer applies to only supercomputers in large datacentres but also to converged computer infrastructures supporting simulation, modelling and data analysis in a digital computing continuum.

Researchers and research output on both HPC applications as well as on HPC technology will expand from the current fields deploying HPC solutions to adjacent fields to address AI, Data Analytics, Edge, Fog, and IoT-related challenges. This will influence the selection and definition of future research and development and innovation priorities. Awareness of the strategic role HPC plays in science, industry and in our everyday lives has increased dramatically over the past 10 years and investments by MS in that period demonstrates that HPC is no longer a niche sector in the technology ecosystem.

In this context, European supercomputing infrastructures represent a strategic resource for understanding and responding to the increasing challenges EU citizens will face in the years to come, as well as for the future of European industry, SMEs, and the creation of new jobs. They are also key to ensuring European scientists reap the full benefit of data-driven science. For instance, scientific research on the functioning of the human brain, the development of the Earth’s climate, drug discovery, and targeted medical therapies as well as modelling in quantum and classical physics increasingly rely on supercomputing and big data analysis.

For this reason, underdevelopment in any of the technologies underpinning HPC in Europe will harm European scientific leadership in applications bound to reap the benefits of access to flagship computing facilities. Europe needs an integrated world-class HPC and data infrastructure with exascale and post exascale computing performance that can compete worldwide. This would reduce Europe's dependence on facilities in third countries and encourage innovation to stay in Europe. While funds invested do not directly correlate to research outcomes, adequate resources are needed both for investing in R&D and acquiring HPC capabilities.

For this reason, the EU has recognised its critical role in helping to ensure there are sufficient HPC and high throughput computing systems available, data storage and network capacity available to MS, to deliver against the scientific, technological, economic and societal priorities up to 2027 and until the expected availability of exascale supercomputing systems. Additionally, MS could also explore opportunities for consolidation and federation of HPC infrastructure, through co-ordination in procurement of future systems from next generation HPC through to exascale, in order to make a more efficient use of the available resource.[3]

2.2.2 Insufficient investment in HPC overall

European investment in HPC infrastructure and research and development remains significantly and consistently less than the US, China, Canada and Japan. Current R&D investment levels – even with the addition of the EuroHPC funds – will not be sufficient to allow Europe to achieve independence in this critical technology.

The funding gap has been estimated at €500m-€750m per annum compared to the US, China, and Japan,[16] which is problematic if the EU wishes to create a lead market in cutting-edge technology to address the problems in European HPC. Linked to this, the potential risk to EU competitiveness in the technology industry is estimated to be a projected, quantitative negative impact of EUR 1 trillion by 2027.[17] Looking forward, the differences in projected exascale investment levels are also reflected in the projected exascale system dates. While the EU will initially be purchasing pre-exascale systems between 2020 and 2022, China and the US are expected to achieve peak exascale in 2020 and 2021 respectively, and would be supplied by domestic vendors. Similarly, Japan is set to attain exascale around 2021-2022, based on Hyperion Research[18] projections, and would be relying on local suppliers and processor technology. In the EU's roadmap, on the other hand, exascale systems do not come into play until 2023-2024 and would still be based on a mix of US and European vendors and processors. EuroHPC is actively addressing these issues by supporting more endogenous technology development and uptake in new European HPC facilities. Appendix D provides more information on projected levels of R&D investment for exascale systems.

Another way of illustrating the insufficiency of investment is via the number of systems in the Top-10 and TOP500 in each of the world regions. This is a widely accepted headline indicator of regional competitiveness in HPC, revealing a country or region's access to the most powerful machines in existence. The EU went from 4 systems in the global HPC Top-10 in 2012 to 1 in 2019 (see Appendix D). Just installed in June 2019, the 'SuperMUC-NG' at the Leibniz Supercomputing Centre in Germany is currently in 9th place in the global Top-10 ranking (as of November 2019). In terms of the top 20 HPC systems, the EU's position remained unchanged, with 5 systems in June 2017 as well as November 2019.[19] In terms of the TOP500 (November 2019) systems, less than 80 such systems exist in EU Member states, compared with 117 in the US and 228 in China.

This gap in the number of accessible Tier-0 and Tier-1 systems affects a wide range of stakeholders. Flagship systems are needed for frontier scientific discovery and their procurement and installation/maintenance processes bring together the industrial supply chain and result in new architecture developments and spillovers to smaller HPC systems.

Additionally, the availability of Tier-1 and Tier-2 systems in the TOP500 is very important for scaling up codes to run on flagship HPC and to support industry and wider research communities. While the purchase of Tier-1 and Tier-2 systems may be a matter for individual member states and larger enterprises, there remains an important EU perspective with regard to the digital divide (access to HPC infrastructure is uneven across EU MS, with new member states being less well served than their larger counterparts in the EU15).

EuroHPC has already contributed to the acquisition of 5 petascale machines, in addition to 3 pre-exascale, in line with its stated specific objectives.[20] Europe's HPC technology and

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[16] European Commission. (2018). Impact Assessment accompanying the Proposal for a Council Regulation on establishing the EuroHPC Joint Undertaking.

[17] Explanatory Memorandum on the proposal for a Council Regulation establishing the EuroHPC Joint Undertaking, January 2018

[18] Hyperion Research Update: Research Highlights in HPC, HPDA-AI, Cloud Computing, Quantum Computing, and Innovation Award Winners. Available at: https://hyperionresearch.com/wp-content/uploads/2019/06/Hyperion-Research-ISC19-Breakfast-Briefing-Presentation-June-2019.pdf

[19] European Commission. (2018). Impact Assessment accompanying the Proposal for a Council Regulation on establishing the European High Performance Computing Joint Undertaking.

[20] The authors refer in this paragraph to the widely accepted classification of Tier-0 (flagship), Tier-1 (national), Tier-2 (regional, institutional) HPC

software companies will also benefit from their involvement with the procurement of these systems, which they can then use to win access to global value chains supplying mid-tier systems within Europe and internationally.

2.2.3 Fragmented HPC ecosystem due to limited historical cross-border coordination

The scale and scope of the EU HPC ecosystem is such that there are likely to be ongoing difficulties with fragmentation, notwithstanding the efforts of EuroHPC. This is another area where the problems are so deep seated that EuroHPC will need additional support.

Inefficiencies and fragmentation in the delivery of strategic research agendas in HPC can affect several stakeholders. In the first instance, the most affected are researchers in HPC and next generation architectures, who confront many different funds and calls for proposals offering sub-critical investment for less-than-ambitious development work that adds little novelty over previous and parallel studies. As noted above, the fragmented funding landscape will also impact 'scientific' productivity whereby large numbers of calls support small numbers of discrete actions and fail to deliver the scale and intensity of effort required to achieve a breakthrough (a problem of critical mass and indivisibility). These inefficiencies and confusions can reduce the volume and quality of the overall research output in HPC, which will frustrate the achievement of the outcomes envisaged in the research agendas. Ultimately, this kind of suboptimal landscape will continue to weaken European competitiveness in advanced HPC systems (science and industry), which will in turn have negative consequences for European science and industry (HPC users) more generally in the longer term.

Industrial stakeholders felt there was a shortage in the European skills base in terms of know-how to use and program large computers and develop applications for them. Furthermore, the lack of diversity in the relevant industrial base and SMEs was also seen as a problem driver.

Interviewees from infrastructure providers referred to the fragmentation of the European ecosystem as an issue and .

Stakeholders from research were of the opinion that European developments in processor architecture were not advancing fast enough to be able to keep up with international competitors.

2.3 How will the problem(s) evolve?

The EuroHPC Joint Undertaking has launched multiple activities addressing the documented problems. However, while it is expected to make good progress in several areas, particularly around coordination and procurement, several of the problems are so entrenched and of such strategic significance for Europe that they warrant further attention. In absence to further coordinated action in HPC, the issues described would continue to deepen.

Europe's value chains will be limited in as much of the earmarked investment will be used to buy the eight HPC machines and related infrastructure, with those investments taking place largely in parallel and necessarily making full use of the pre-existing technologies of international vendors.

While the investment gap will be reduced with the launch of EuroHPC, the HPC R&D funding shortfall remains significant, the consequences of which could be a further loss of digital autonomy on the one hand and a weakening of industrial competitiveness on the other. The EuroHPC JU is currently partially addressing the issues on the infrastructure-side but additional funds will be needed to specifically address the R&D-related challenges. There is a considerable risk in the longer term to Europe's scientific community, should access to state-of-the-art systems become more problematic: Currently, Europe's computational scientists are doing world-class research on predominantly internationally sourced systems, and this will increasingly be the case unless action is taken to increase HPC capacity in Europe. This would increase risks not only for competitiveness, but also for brain drain of top talent in HPC.

3 Why should the EU act?

A similar argument for EU action in supporting the European HPC ecosystem was made in the EuroHPC Impact Assessment of 2018 and subsequent regulation establishing the EuroHPC JU. In it, the EU considered it must act to eliminate the fragmentation of investments in HPC by MS, which requires coordinated action in support of the European HPC ecosystem, as stated by the European Parliament in 2017, in response to the lack of HPC capacity in Europe.[21] This argument remains valid. The following sections provide further justification to the subsidiarity and added value questions.

3.1 Subsidiarity: Necessity of EU action

The nature and scale of the issues affecting the HPC sector in Europe, including the provision of competitive HPC access to the scientific and industrial community, imply that single actors and even consortia of actors and Member States cannot solve them on their own in the framework of national markets and legal systems. Below are some of the issues that signal this necessity for EU intervention.

Global Dimension of the challenge: The race towards exascale HPC systems is understood to be an international endeavour similar in scale to other flagship scientific infrastructure such as next-generation synchrotrons, telescopes and similar ultra-large-scale facilities. Moreover, many of these scientific facilities are increasingly dependent upon the early realisation of next generation computer and storage technology in order to achieve their own scientific objectives.

Europe runs the risk of lacking the necessary competences to design and operate exascale machines and offer support services to the most demanding applications. European suppliers with the competences and financial resources to provide the European market with next generation and exascale systems may not wish to invest in these architectures without public intervention at a centralised level.

Need for pooling / leverage of investments: A joint procurement and management process of several pieces of major flagship infrastructure requires not only efficient pooling of investments between the EC and Member States, but also appropriate leverage from the private sector and additional funding sources.

The EU needs to address the private sector expectation that supercomputing systems should be treated as strategic assets, and as such it is reasonable for the EU and MS to accept a proportion of the innovation and investment risk in order to bring these systems into production, in what will be at very small scale across the region.

Need for standardisation and interoperability: Norms are powerful sources of synergies, and for HPC this is no different. Standardisation around procurement and maintenance processes, technical architectures, access criteria, and service offerings in HPC can reduce barriers to entry for new and existing users. In turn, interoperability of systems and processes and can contribute to making the most of the available resources and HPC capacity. This coordination around standards and interoperability is needed to speed up the pace of development of new HPC solutions and HPC use cases in Europe.

[21] Briefing on EU Legislation in Progress – EuroHPC Joint Undertaking, June 2018

3.2 Subsidiarity: Added value of EU action

A coordinated initiative in HPC would underline different aspects of Horizon Europe's stated EU Added Value.[22]

- The creation of critical mass in European HPC to address global challenges
- Increased coordination across public and private actors and across Member States
- Increasing the EU's competitive advantage in HPC vis-a-vis major competitors
- The creation of new market opportunities through collaborative multi-disciplinary teams and dissemination of results
- Leveraging private investment

A coordinated initiative in in HPC would underline the stated added value of the wider Digital Europe Programme,[23] focusing on areas where necessary funding is so significant that no Member State can do it alone; areas where there is a need to aggregate resources that are scattered throughout Europe; and areas where interoperability is important.

Issues around ownership, access, governance of the infrastructure, division of responsibilities, and exploitation of results need to be clear from the outset for all partners to confidently commit their time and resources to the initiative.

Additionally, there is also a clear political will today to cooperatively address what were previously domestic concerns, and this is in part due to the EU sovereignty and geopolitical arguments. These arguments have a good deal in common with those used in other EU flagships such as Galileo. As HPC is increasingly being considered a strategic technology it makes sense for the EU to ensure that Europe has both scientific and industrial capabilities at least on par with other world regions. It also makes sense for the EU to ensure that current capabilities are not degraded beyond the point where it would be difficult to regain competitiveness. The urgency and sovereignty arguments add to the strong case for added value of the intervention at EU level.

Industry saw EU action as a necessity in order to catch-up in field where Europe has been lagging behind, processors in particular before major scientific or technological breakthroughs can be seen. Interviewees saw it as unlikely that the private sector in Europe would lead the way in terms of developing HPC technologies and applying these in the context of Edge computing, AI, or machine learning.

Research stakeholders felt European efforts to develop processor technologies have to be accelerated. Otherwise, next generation HPC systems would not be built around said technologies in Europe.

4 Objectives: What is to be achieved?

4.1 General objectives

In order to tackle the problems identified in Section 2, it is important to clarify the objectives of EU action in the field of research and innovation. We have identified three general objectives corresponding to the main problems discussed in Section 2.1. The general objectives also align with those of the wider cluster of initiatives where this candidate initiative is set out.

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[22] Horizon Europe Impact Assessment. A New Horizon for Europe. DG RTD (2018)

[23] DE Regulation COM(2018) 434 final

- **Scientific:** Enhance EU capacity for cutting-edge research in HPC and HPC applications
- **Economic:** Support EU HPC industry competitiveness: supply and demand
- **Societal:** Foster digital autonomy of Europe by ensuring long-term support for the European HPC ecosystem and improving the wellbeing of citizens

Collectively, these general objectives underline the necessity of a joint effort to addressing the issues, given the scale of investment required to realise pre-exascale and exascale machines, networking and upgrading mid-range systems, and meeting deployment and capacity building needs.[24] Table 2 presents the alignment between the candidate initiative's proposed objectives and Horizon Europe's impact pathways, suggesting there is a high degree of consistency between them.

Table 2: Consistency with Horizon Europe's impact pathways

Science	Description
Pathway 1 – Creating new, high quality knowledge	The realisation of exascale and post exascale computing demands a number of major technological advances, including for example in energy efficiency, hierarchical memory and storage and reliability, each of which will have to be built on cutting-edge science. Moreover, next generation HPC systems will provide the scientific community with the ability to advance the state of the art in a wide range of application fields pushing harder at answers to key questions in areas such as material science, combustion modelling and precision medicine
Pathway 2 – Strengthening human capital in R&I	The development of exascale systems has the potential to create a European community of several thousands of scientists and engineers with the skills and insights to continue to push next generation computing (software and hardware). Moreover, as with any ultra-large-scale research infrastructure, the new facilities and their scientists and software engineers will help to train and upskill tens of thousands of scientists and engineers
Pathway 3 – Fostering diffusion of knowledge	There may be some indirect benefits as regards the diffusion of knowledge that results from a more geographically equitable partnership with contributions to the creation and use of exascale computers across the full EU
Society	**Description**
Pathway 4 – Addressing EU challenges and global challenges	Some of the most pressing global challenges - such as climate change - are already heavily dependent on HPC and some aspects of these classical simulation and modelling problems are currently out of reach with existing computer and storage systems. Other challenges – such as health and well-being are becoming more critically dependent upon HPC in order to make the most of new advanced therapies
Pathway 6 – Strengthening the uptake of innovation in society	There may be some indirect benefits from the development of exascale systems in Europe as public agencies and even citizens have more or better access to these state-of-the-art facilities, in ways that may improve decision making in areas ranging from security to land-use planning and weather forecasting
Economy	**Description**
Pathway 7 – Creating more and better jobs	Next generation HPC technologies will enable classical simulation and modelling applications to tackle known problems that are currently out of reach, for reasons of cost-effectiveness (e.g. total in-silica design of jet engines and airframes)

[24] European Commission. (2018). Impact Assessment accompanying the Proposal for a Regulation of the European Parliament and of the Council establishing the Digital Europe programme for the period 2021-2027. SWD(2018) 305 final

Science	Description
	It will also support the creation of new types of applications that exploit the massive parallelism of exascale systems and allow machine learning and large-scale data analytics on a scale as yet unseen The creation of more programming models / software and more advanced simulation and data-analytics should generate many new, high value jobs, albeit there will need to be substantial levels of automation (e.g. of code generation, systems maintenance), so the number of new jobs created may lag the value of economic output. There is also a likelihood that many of the R&D and industrial processes one might digitise will result is at least some job losses
Pathway 8 – Generating innovation-based growth	Next generation HPC technologies should have substantial spillover benefits across Europe's computer and software industries, providing a platform to secure and improve their global competitiveness. The demand for such products and services is expected to grow rapidly in Europe and internationally, and leading European innovators should be able to exploit this buoyant marketplace delivering strong economic growth and exports
Pathway 9 – Leveraging investment in research and innovation	EU member states have been willing to co-invest in HPC alongside the EU, however, the limited scale of the EU HPC industry does limit options for financial leverage. Global manufacturers have been prepared to co-finance government exascale development initiatives and procurement, which may help in some degree

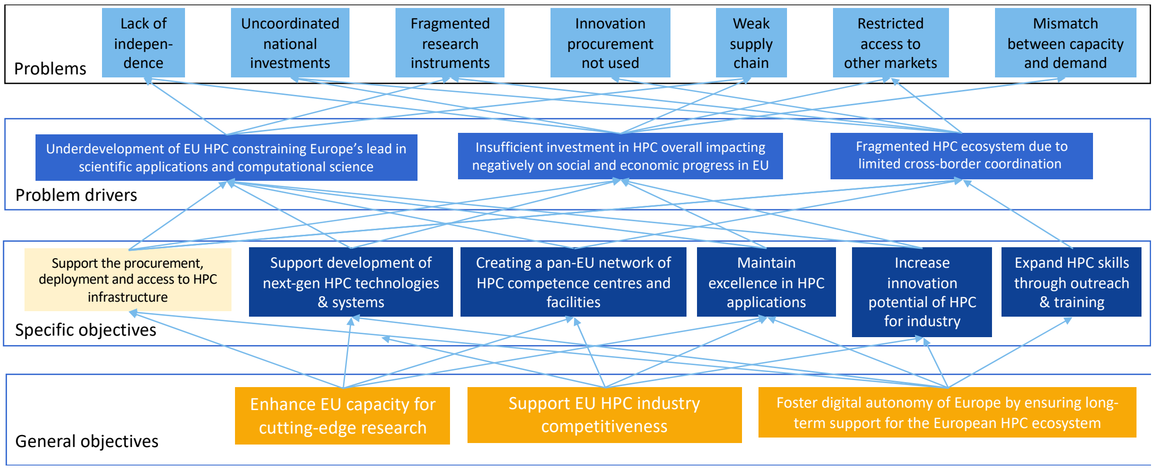
In the same manner, the proposed general objectives are also aligned to make a positive contribution towards specific sustainable development targets in different domains, either directly or indirectly via impacts through improved access to HPC capacity and applications.[25] The relevance of the SDGs for this exercise was introduced in Section 1.3 and is developed further in Section 4.3.3, as part of the likely societal impacts from the candidate HPC initiative.

4.2 Specific objectives

In order to achieve the general objectives, six specific objectives are defined. These specific objectives respond to the problem drivers discussed in Section 2.2. The relationship between the general and specific objectives is shown in Figure 3.

[25] Using AI to help achieve Sustainable Development Goals https://www.undp.org/content/undp/en/home/blog/2019/Using_AI_to_help_achieve_Sustainable_Development_Goals.html

Figure 3: Objectives tree for the initiative on HPC



4.2.1 Scientific objectives

The proposed initiative should support the development of the next generation of key HPC technologies and systems towards exascale, addressing the whole European technology spectrum from low-power microprocessors and related technologies to software, algorithms, programming models and tools, to novel architectures and their system integration through a co-design approach.

This would be carried out mainly via the "support of an ambitious research and innovation agenda to develop and maintain in the Union a world-class High Performance Computing R& I and ecosystem, exascale and beyond, covering all scientific and industrial value chain segments, including low power processor and middleware technologies, algorithms and code design, applications and systems, services and engineering, interconnections, know-how and skills, for the next generation supercomputing era.". EuroHPC's most recent multiannual Strategic Research and Innovation Agenda[26] already identifies the following priorities:

- **Development of extreme-scale computing technologies and system architectures**, programming models, mathematical methods and algorithms in an increasingly complex environment of heterogeneous computing with memory and storage hierarchies.
- **Development of energy-efficient HPC solutions (Green HPC),** supporting the adoption of applications with industrial and societal relevance on evolving HPC hardware and system software/programming environments
- **Improvements in software and codes for industrial users to fully exploit the new capabilities of extreme performance HPC** environments

Historically, Europe's strengths have been in the domain of scientific applications and systems integration rather than in production.[27] Moving applications to exascale will require significant changes to support these new technologies. In some cases, legacy applications cannot run on exascale systems without complete rewrites. Additionally, there are many other important R&I challenges that need to be addressed in the transition to exascale, beyond just improving processing technologies. These challenges and others need to be solved in order to properly tackle areas such as hybrid HPC, Quantum, and Neuromorphic architectures. For example:

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[26] EuroHPC JU. (2019). Strategic Research and Innovation Agenda 2019

[27] Feedback from a member of the Expert Panel for this IA Study

- **Advances in Scalability**: An exascale system will require in the order of one billion processing elements. An imbalance in the time taken for different threads of execution to complete can have a significant detrimental effect on overall application performance. This implies a different and more complex approach to the architecture of parallel applications for exascale systems.
- **Advances in Resilience**: An exascale system will be so large it is to be expected that during normal operation it will contain several failed components (such as processors, network interconnect, etc.). Today's applications are built in the expectation that systems are fully functional. Traditional approaches such as checkpoint/restart may not operate efficiently at exascale, so fault tolerance and redundancy approaches need to be studied and implemented at multiple levels (e.g. hardware, OS, software (OS, runtime), middleware and applications).
- **Heterogeneity of HPC systems**: Many HPC systems today already are heterogeneous. For example, some nodes may include specialised accelerators or large amounts of memory while others do not. Heterogeneity will be much more common in exascale systems as compute accelerators will be ubiquitous, in order to meet the challenges of power consumption.

The proposed programme of work would target at least both short and mid-term time horizons, 2022-23 with first generation exascale facilities, and the rest of the decade. The first exascale systems will likely be based on a combination of CPUs and GPUs. After 2026-27, when the refresh of such systems is due, it is likely that some new innovative technologies (hybrid and Quantum computing, neuromorphic architectures, very low power CPUs, FPGAs, etc.) will be ready for inclusion in the next generation of exascale. Such a trend is also underpinned by the vast shift towards applications needing extreme scale computing, influenced by AI and Data centric workflows. The proposed initiative on HPC partnership should be well placed to contribute decisively in this mid-term timeframe, as the results of its SRIA start bearing fruit.

4.2.2 Economic/technological objectives

Specific economic and technological objectives relate to infrastructure development, acquisition and operation, providing the research and scientific community, as well as the industry including SMEs, and the public sector with flagship facilities and a level playing field for accessing them across the Union. The latest EuroHPC workplan has already proposed focusing on the following:

- **Providing competitive HPC and data infrastructures and support** to the development of EU-based technologies and applications across a wide range of fields.
- **Procurement and deployment of world-class HPC and data infrastructures** for European use, providing a new framework for the acquisition of an integrated, demand-oriented and user-driven world-class petascale and pre-exascale supercomputing and data infrastructure in the Union.
- **Developing access provisions** to HPC infrastructures and services for scientific and industrial users including SMEs, and the public sector.
- Create a pan-EU network of HPC competence centres and facilities, by promoting activities to **develop and connect regional, national and European HPC resources**, such as Centres of Excellence and the HPC national competence centres.

4.2.3 Societal objectives (including environmental and social objectives)

Societal objectives should support the expansion of HPC skills, with a view on maintaining Europe's longstanding excellence in HPC applications and the ability to use HPC to address EU and global challenges for societal good:

- **Applications and skills development** to promote the benefits and a wider uptake of HPC for European needs and to tackle EU and global challenges. Delivering **outreach and training** actions for attracting human resources to HPC and increasing skills and engineering know-how in the European HPC ecosystem. Both HPC and advanced digital skills (i.e. specialised skills in HPC, artificial intelligence and cybersecurity) are key objective areas within the Digital Europe Programme (DEP), with skills being a key contributor to wider uptake and digitisation of industry. DEP will implement skills activities primarily through the Digital Innovation Hubs and relevant competence centres.[28]
- **Maintain excellence in HPC applications,** combining HPC with other technologies like edge and cloud computing, to tackle complex workflows and urgent computing needed to respond to innovative industrial applications as well as societal challenges. Work carried out in the HPC initiative would be serving more than 800 scientific and industrial applications in domains ranging from climate change to personalised medicine, new materials, bioengineering, new drug discoveries, and even social sciences (e.g. migration prediction).
- **Increase the innovation potential of industry**, and in particular of SMEs by promoting the development, uptake and systematic use of research and innovation results generated by using HPC, with special emphasis to those that afford an increased capability of European stakeholders to tackle EU and global challenges.

In terms of objectives of the future initiative, there was a strong consensus across stakeholder groups that the development of HPC applications were an absolute priority. It was felt that it was crucial for applications to be developed in parallel to architectures so that there can be a strong level of integration between the two, maintaining Europe's leadership in this regard. In a similar fashion, it was deemed a necessity for architectures to be co-developed with specific applications and workloads in mind.

Stakeholders from industry further pointed to the importance of prioritising energy efficient HPC and novel cooling technologies as well as including SMEs more closely.

Researchers also indicated that there is no need for EuroHPC to reinvent the wheel in terms of OS but to use off the shelf solutions. Linux in particular was cited by interviewees across all stakeholder groups as a preferred option.

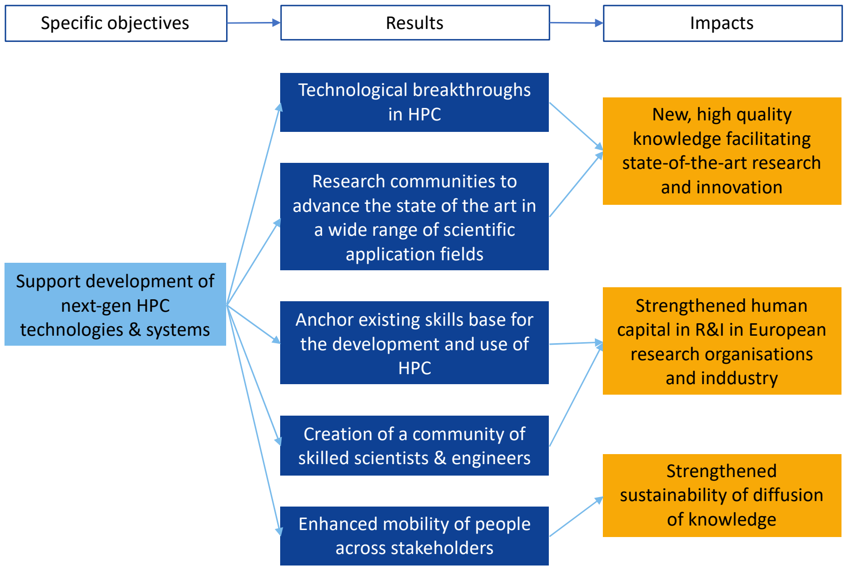
4.3 Intervention logic and targeted impacts of the initiative

4.3.1 Likely scientific impacts

The initiative is likely to lead to three key scientific impacts, as illustrated in Figure 4 and further described below.

[28] COM(2018) 434 final

Figure 4: Impact pathway leading to scientific impacts



Pathway 1 – Creating new, high quality knowledge (High likelihood)

In terms of the creation of new knowledge, the HPC initiative is likely to contribute to significant technological and scientific breakthroughs within HPC in general. In terms of HPC technology, impacts can be expected both on the hardware and software side. In terms of hardware, breakthroughs will occur in terms of architecture, GPUs and low-power processors,[29] and crucially, system integration. In terms of software, significant progress can be expected in the development of codes and algorithms, and operating systems for future architectures, which is equally important as hardware developments but often underestimated.[30] The initiative will also help advance a wide range of scientific application fields. These range from genomic analysis, high energy physics, marine and climate modelling, quantum-chemical calculations, as well as artificial intelligence (AI), deep and machine learning (DL & ML), and high-performance data analysis (HPDA). It is also expected that industry participation in the initiative and in shaping the R&I agenda will result in increased relevance, and therefore increased uptake of the results by industry.

Pathway 2 – Strengthening human capital in R&I (High likelihood)

The initiative's impacts also include anchoring the European skills base that already exist in national computing centres and in the research communities that use HPC as well as building up human capital in data science and management, research software engineering, system administration and DevOps, and processor design in both user communities. This can then lead to secondary impacts on industry where these skills are relevant to various simulation-based applications and can result in spillovers to skilled engineers and technicians in industry For the research community, the initiative may also help prevent a brain drain of skilled research from Europe to the US, China, or Japan by providing flagship supercomputers.

Pathway 3 – Fostering diffusion of knowledge (Medium likelihood)

The current EuroHPC JU is already supporting the diffusion of results to industry and wider user communities and the future initiative will be able to push this further. Diffusion in the European HPC ecosystem currently occurs through the mobility of people from public sector

[29] These developments would take place in conjunction with the activities of the EPI

[30] Software can go a long way in terms of maximising the performance that can be obtained from an algorithm on an HPC machine. Well-designed codes may therefore be more impactful than faster hardware alone.

facilities to new employers, sectors and countries, often in private businesses. The European RTD Framework Programme has also been contributing steadily to the rapidly growing body of HPC knowledge globally, as revealed by our bibliometric analyses.

All stakeholder groups agreed that a key scientific impact would be to drive the development of new system architectures, codes and algorithms, and applications, especially in the context of the convergence of data analytics with AI, ML and HPDA. There was also widespread agreement that positive contributions would be made to human capital developments in terms of technical architects, hardware designers, software developers, etc. across the HPC stack. The majority of interviewees also highlighted the cross-cutting nature of the benefits flowing from these skill enhancements in a wide range of sectors and scientific fields.

Member States felt that building up human capital would also offer more sustainable career prospects to researchers and that it may help prevent the brain drain of HPC related expertise out of Europe.

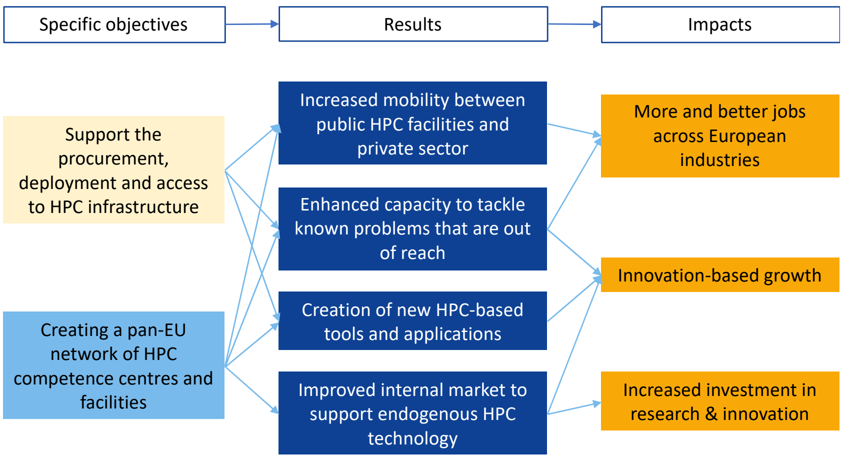
Opinions on the impact of EPI were somewhat mixed with most industrial and infrastructure stakeholders agreeing it had the potential of developing a successful low-power processor while researchers, member states, and intermediaries where more sceptical of its future success with some expressing concerns that its first generation processor was likely to be sub-optimal.

Positive impacts were generally expected in terms of the diffusion of knowledge, in particular through the mobility of labour as well as publications and demonstrations.

4.3.2 Likely economic/technological impacts

The likely key economic/technological impacts of the initiative are mapped inFigure 5.

Figure 5: Impact pathway leading to economic/technological impacts



Pathway 7 – Creating more and better jobs (high likelihood)

The proliferation of HPC in sectors from financial services (currency trading) to precision medicine and data analytics means there is likely to be a growing number of job opportunities across most sectors. Moreover, ubiquitous HPC computing together with AI is expected to drive substantial levels of automation in both the public and private sectors over the next 10 years, so there is also a likelihood that automation will result in at least some job losses that will be offset by job creation elsewhere in the economy.

Pathway 8 – Generating innovation-based growth (high likelihood)

Next generation HPC technologies will enable classical simulation and modelling applications to tackle known problems that are currently out of reach, for reasons of cost-effectiveness (e.g. total in-silica design of jet engines and airframes). The main impacts in terms of innovation-based growth are expected in other industrial sectors beyond IT (aeronautic, automotive, chemistry, pharmaceutics, energy, etc.). An HPC partnership will also support the creation of new types of applications that exploit the massive parallelism of exascale systems allowing for machine learning, AI, and large-scale data analytics on a scale as yet unseen. There is a clear demand for HPC in industry in different sectors. However, in terms of performance ~30% of total HPC performance is in industry with the remaining being in academic / public sector facilities. Industry is interested in HPC, but it is not the largest user or the main user of the largest facilities. At a macroeconomic level, returns on investment in HPC are high. Hyperion data from 2018 shows that in Europe every dollar invested in HPC has generated close to $290 in revenues for businesses and $48 in profits.[31] With these types of returns, any industry participation in an HPC partnership would be generating substantial innovation-based economic growth in Europe.

Pathway 9 – Leveraging investment in research and innovation (High likelihood)

The current EuroHPC JU acts to leverage public investment in HPC R&D. While private companies are not involved directly, private engagement is articulated via the industry associations that contribute to the Strategic Research Agendas. It is likely that an increase in private R&D relating to next generation HPC will be triggered indirectly, through participation in individual actions and possibly emulation of strategic priorities. The initiative can pool the investment needed to make sure that European suppliers can access an internal market that, even if not protected and still competitive, is sufficiently large to support the endogenous development of HPC technologies in Europe. Therefore, an increase in private R&D could be a more long-term effect of the partnership, supported further by initiatives such as the EPI.

Overall, stakeholders were in agreement that a major economic impact would be the development of a European HPC ecosystem. Furthermore, most stakeholders expected to see impacts on both the hardware and software side of the HPC value chain. Infrastructure providers and members states largely took the view that the more significant impacts were to be expected in terms of software rather than in hardware industries.

In terms of broader industries that stand to benefit from European HPC, a wide variety was listed by the interviewees. The main industries that were frequently cited across the different groups were automotive, aerospace, oil & gas, engineering, energy, and pharmaceuticals.

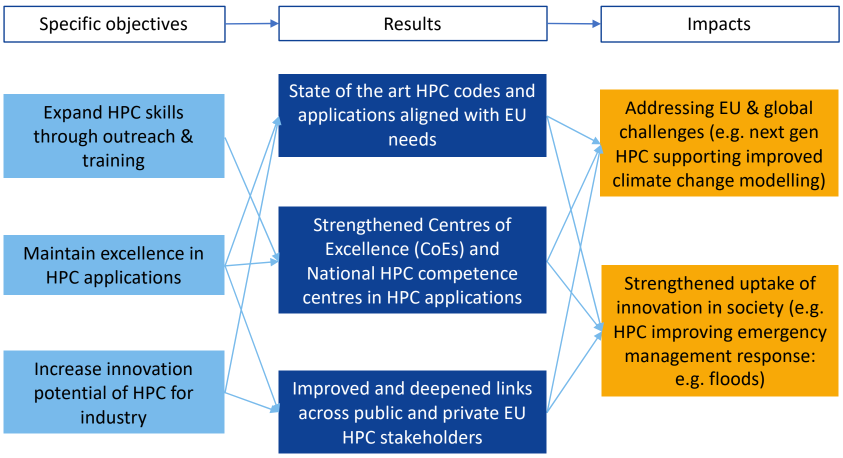
Member states and intermediaries also indicated that European sovereignty might be an outcome provided EPI is successful across the European value chain and is complemented by the necessary software developments. Interviewees from these two groups also agreed that there can be an opportunity for SMEs to benefit but issues of access and wider usability of HPC resources remains a challenge.

4.3.3 Likely societal impacts

The scientific and economic/technological impacts discussed above will also support the attainment of societal impacts as shown in Figure 6.

[31] HPC User Forum – Economic Models Linking HPC and ROI. Retrieved from: https://www.hpcuserforum.com/ROI/

Figure 6: Impact pathway leading to societal impacts



Likely environmental impacts

For climate research, a large part of the work undertaken by the IPCC[32] is underpinned by simulations done using HPC. Therefore, a direct link between the facilities provided by an HPC initiative and climate research is foreseeable which would in turn generate policy impacts. In the area of fusion energy, HPC is also key for all the work done in ITER and any further steps in fusion demonstrators will need simulations in next generation HPC. At a more macro-level, there are potential spillovers from development work on GreenHPC and on energy consumption in computing more generally.

Pathway 4 – Addressing EU challenges and global challenges (High likelihood)

A key impact of the initiative will be an increase in European digital sovereignty. This entails an increase in the availability of European suppliers for servers, networks, processors, etc. and a decrease of the degree to which European system integrators depend on non-EU critical components. Access to HPC combined with other technologies can also make a contribution to several sustainable development goals such as SDG 2 goal (ending hunger) via applications to address food security, farming optimisations and sustainable precision agriculture.[33] SDG 3 (Good Health and Well-being) can benefit from a wider use of HPC to for example drive advanced diagnostic techniques, personalised medicine, conduct health research and accelerate new drug discovery and development, and SDG 16 (Peace, justice and strong institutions) can benefit from the use of HPC and AI as infrastructure for cyber security applications

Pathway 6 – Strengthening the uptake of innovation in society (medium)

The initiative would be expected to directly strengthen innovation capability of participating industries, both in the supply and demand for HPC technologies. Additionally, a variety of impacts from the wider development of HPC in Europe would be expected to trickle down to technologies with society-wide uptake. New HPC technologies feed directly into the broader €1t ICT market, which in turn allows for further innovations in areas such as smart phones and devices, the internet of things, the use of data centres that power consumer-facing applications hosted in clouds, and other future products enabled by new paradigms such as Edge computing (e.g. for autonomous driving).

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[32] Intergovernmental panel on climate change

[33] European Association of Remote Sensing Companies. Sentinel Benefits Study: A Case Study of Farm Management Support in Poland. July, 2019.

PwC. Copernicus Market report – February 2019.

Finally, HPC is relevant and is expected to contribute as the key enabler and backbone for application areas with a wide societal reach, such as AI, Big Data and cybersecurity. HPC is instrumental as a contributor to the industrial transformation of the EU economy, in particular with a view of integrating AI features across a wide range of industrial sectors.

There may also be some indirect benefits from the development of exascale systems in Europe as public agencies and even citizens have more or better access to these state-of-the-art facilities, in ways that may improve decision making in areas ranging from security to land-use planning and weather forecasting.

Likely social impacts

Potential policy impacts are expected from the work undertaken in the HPC initiative, primarily in public procurement processes that prioritise endogenous supply chains and that can be replicated in other areas.

Based on the application that will be developed while using HPC, we expect that some of these impacts will materialise via HPC contribution to Earth-observation services, Weather forecasting, Disaster prevention and Crisis management systems such as those from Copernicus (e.g. Copernicus emergency monitoring service, Copernicus Land Monitoring Service, and others). Furthermore, HPC can also lead to increased rapid response capabilities. For example, EuroHPC is already discussing special access criteria for emergency access to EuroHPC machines, to deal with disaster situations requiring computing power at a short notice (floods, earthquakes, pollution, disease propagation, etc.).[34]

Table 3 lists the eight (of 17) SDGs where the research has suggested that next-generation HPC systems ought to make a meaningful contribution, alongside an informed judgement as to the extent of the potential contribution to each SDG.

Table 3 Extent of the potential contribution to SDGs

SDG	Extent of the contribution
SDG 2 End hunger	Via applications of HPC (medium)
SDG3 Good Health and Well-being	Via applications of HPC (high)
SDG4 Quality Education	Societal-level (medium)
SDG7 Affordable and Clean Energy	Via applications of HPC (high)
SDG8 Decent Work and Economic Growth	Direct contribution (high)
SDG9 Industry, Innovation, and Infrastructure	Direct contribution (high)
SDG13 Climate Action	Via applications of HPC (high)
SDG16 Peace, Justice, and Strong Institutions	Via applications of HPC (medium)

4.3.4 Likely impacts on simplification and/or administrative burden

The initiative is unlikely to create impacts in terms of simplification or administrative burden of the R&I activities supported under Horizon Europe.

[34] Workshop on EuroHPC Systems Access Policy. 21 October 2019. Presentation by Sergi Girona. Available at: https://www.youtube.com/watch?v=DIQthdbBl_Y

4.3.5 Likely impacts on fundamental rights

The HPC initiative is unlikely to have direct impacts on fundamental rights or social cohesion. However, widening access to HPC computing in Europe and doing so in a coordinated way with all Member States can help contribute to reduce a potential divide between Member States and access of researchers to flagship infrastructure. Indeed, the petascale machines already procured by EuroHPC are to be hosted in small Member States that would not have been able to procure these facilities on their own, as a way to increase domestic access and capability.

The interviewees were generally of the opinion that EuroHPC has the potential to contribute towards addressing EU and global challenges. More specifically, HPC was frequently described as a key enabling technology that would permit simulations, predictions, and modelling that allows us to address previously unattainable problems. In particular, interviewees had high expectations of the role of HPC in acceleration science and research into areas including weather and climate, healthcare and medicine, energy, agriculture, cybersecurity, and disaster management. Out of these climate and weather research was the single most frequently cited area of impact across all interviewees.

In addition, member states and intermediaries were somewhat sceptical as to the likelihood that individual citizens would directly interact with HPC in the future. Rather, the expectation is that these will benefit in a much more indirect way.

Finally, the ECMWF, DG GROW and DG Connect have all expressed an interest in principle in developing a digital twin earth model, which would link all aspects of earth systems (oceans, atmosphere, weather, etc.) in a far more comprehensive model that would deliver reliable forecasts for a variety of phenomena. The scale and complexity of the model – and its data inputs – would be critically dependent upon advances in next-generation HPC architectures and software in order to cope with the number of variables and still achieve reasonable run times, and earth systems scientists would like to see these concepts being developed in tandem with post-exascale systems.

4.4 Functionalities of the initiative

This section outlines the functionalities that need to be considered when assessing the policy options in Section 6, reflecting the selection criteria for European Partnerships defined in the Commission proposal for the Horizon Europe Regulation.[35] In the following paragraphs, we discuss the implications of the criteria relating to the type and composition of the actors involved, the range of activities to be undertaken and the directionality required if the initiative is to deliver the objectives discussed above. We also consider the complementarities and synergies with other, related initiatives under Horizon Europe and beyond.

4.4.1 Internal factors

Type and composition of the actors involved

This functionality relates to the criterion "Involvement of partners and stakeholders from across the entire value chain, from different sectors, backgrounds and disciplines, including international ones when relevant and not interfering with European competitiveness". It

[35] European Commission (2018), Proposal for a Regulation of the European Parliament and of the Council establishing Horizon Europe – the Framework Programme for Research and Innovation, laying down its rules for participation and dissemination, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018PC0435&from=EN

concerns the need to involve the full range of stakeholders that can usefully contribute to delivering the future R&I agenda.

Based on the analysis conducted and views of the stakeholders, the results and impacts of the initiative can best be achieved if there is an established community of key players across sectors and disciplines within the European HPC supply chain that are involved as members of the partnership. These would also need to cover research communities in specific S&T fields as well as the Private sector (including SMEs) across the HPC supply chain.

Based on a study on financing the future of supercomputing conducted by the EIB in 2018,[36] the industrial stakeholders of the HPC value chain in Europe can be broken down as follows:

- **Chip manufacturers and suppliers of critical components**: These include the producers of core HPC hardware components as well as specialised manufacturers. Overall, this segment of the value chain is not featured prominently in Europe. Companies: Intel, NVIDIA and IBM
- **System integrators, storage specialists, and network providers**: These integrate components thereby providing the HPC hardware infrastructure. These are also particularly relevant to the European Science Cloud. Companies include MEGWARE and Bull
- **Independent software vendors (ISVs)**: ISVs develop software solutions designed for HPC applications. Companies: KE-works, Noesis, rbf-morph, ParTec[37]
- **HPC supercomputing centres**: Offer HPC capacity on pre-installed, ready-to-use hardware as well as various HPC services, typically on a semi-profit driven business model. Centres: GOMPUTE, HLRS, CPU 24/7, CINECA
- **HPC intermediaries**: provide support to industry and SMEs in HPC applications and link together HPC service providers with customers. Organisations: CEA, SICOS, Fraunhofer (SCAI & ITWM), ENSOC
- **HPC customers**: Those that eventually make use of the provided HPC services in order to develop and provide enhanced products or services. For instance; Albatern, CybeleTech, Daimler, Algo'Tech

The members of the industry associations ETP4HPC and BDVA cover several if not all of the segments described above.[38] ETP4HPC and BDVA are private members of EuroHPC and actively participate in EuroHPC's Research and Innovation Advisory Group to advise on the HPC work programmes. In order to obtain an overview of the major HPC stakeholders in Europe in the R&I context, in addition to the aforementioned value chain, a composition analysis of H2020 cPPP grants was conducted, based on the eCorda database. The results (in more detail in Appendix D) allow us to analyse who was already heavily involved in HPC-related activities under H2020 and the cPPPs, from the perspective of the largest recipients of Horizon 2020 funding. The top 10 recipients of funding during H2020 are the following organisations, which are primarily public HPC centres and universities:

- Barcelona Supercomputing Centre

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[36] European Investment Bank. (2018). Financing the future of supercomputing: How to increase investments in high performance computing in Europe.

[37] ParTec is mainly active in HPC system software rather than applications

[38] For an overview of ETP4HPC members see: https://www.etp4hpc.eu/membership.html, for all BDVA members see: http://www.bdva.eu/full-members

- The University of Manchester
- Jülich Research Centre
- Alternative Energies and Atomic Energy Commission (CEA)
- Bull/Atos
- The University of Edinburgh (EPCC)
- KTH Royal Institute of Technology
- Iceotope Research & Development
- European Centre for Medium-Range Weather Forecasts (ECMWF)
- Foundation for Research & Technology – Hellas (FORTH)

In addition to Bull/Atos, the following companies are heavily engaged in H2020 HPC-related contract awards. The major recipients are either located in the UK or in Germany. In several cases, the companies are European branches of non-EU companies such as Arm (now owned by the Japanese Softbank Group), Fujitsu and Intel:

- Iceotope Research & Development
- Seagate Systems
- MEGWARE
- Arm
- Fujitsu
- Intel
- Maxeler Technologies
- Pro Design Electronic
- EXTOLL

The great majority of these public and private sector organisations are currently involved in the EuroHPC JU, either directly or indirectly as active members of their respective HPC industry associations. Some of the organisations listed are not involved in the EuroHPC JU but are involved in related initiatives such as the Fortissimo project (including KE-works, Noesis, rbf-morph, and Algo'Tech) or the European Processor Initiative (such as EXTOLL). Organisations with no formal involvement in the EuroHPC JU or other initiatives are independent HPC providers such as GOMPUTE and CPU 24/7 or individual users such as the Energy Solution Centre (ENSOC), Albatern, and Daimler.

Based on our review of the HPC landscape, we identified six stakeholder groups that need to be involved in any future partnership on HPC. These are currently involved in the EuroHPC Joint Undertaking and align with the groups consulted for this Impact Assessment study:

- European associations involved in furthering research agendas
- Industrial stakeholders developing HPC technologies
- Infrastructure providers
- Intermediary organisations providing access to a range of users
- Member States (MS) and the European Commission (EC)

- End-users using HPC resources, in research and industrial application domains

Industry participation is essential to drive the application development agenda and to stimulate large private investments in the area. However, the coordination model needs to put the appropriate checks and balances in place to mitigate eventual conflicts of interest, in terms of potential interference of private sector participants in public procurement processes run by the undertaking. In terms of industrial usage of EuroHPC machines, there is a need to promote industrial users even further.

Stakeholders involved need to commit to working jointly together for a period of time that can range between 4 and 8 years, considering the length of large collaborative R&D projects and the useful lifespan of HPC facilities (before these have to be upgraded to remain competitive).

Type and range of activities

This functionality relates to the criterion "Approaches to ensure flexibility of implementation and to adjust to changing policy, societal and/or market needs, or scientific advances". It concerns the types of activity that the initiative is intended to encourage, such that it is able to respond effectively to the challenges and problems described in Section 2.

The EuroHPC JU currently has three main pillars of activity.[39] In the case of a renewed HPC initiative these areas of activity would likely continue to exist.

- The acquisition, deployment, interconnection, operation, and access time management of world class supercomputing and data infrastructures. This refers primarily to the acquisition of HPC machines. These acquisitions are underpinned by calls for the selection of hosting entities as well as calls for tender of supercomputers.[40]
- Support for a research and innovation agenda for establishing an innovation ecosystem addressing hardware and software supercomputing technologies and their integration into exascale supercomputing systems, advanced applications, services and tools, skills and know-how. This also includes support for the development of the first generation of European low-power microprocessor technology as well as European exascale machines.[41]
- General administrative activities for the operation and management of the initiative

With regards to funding calls, the EuroHPC Research and Innovation Advisory Group (RIAG) has submitted recommendations and identified areas of priority that have been taken into account for the development of the EuroHPC workplan. These focus on developing exascale technologies, the software stack, applications for future systems, and skills development.[42] These recommendations form the basis for two main calls and associated topics, launched in the EuroHPC work programme:

- Call towards extreme scale technologies and applications
  - Extreme scale computing and data driven technologies
  - HPC and data centric environments and application platforms

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[39] Council Regulation (EU) 2018/1488 of 28 September 2018 establishing the European High Performance Computing Joint Undertaking

[40] EuroHPC JU Work Plan.

[41] Ibid.

[42] EuroHPC Research and Innovation Advisory Group (RIAG), Strategic Research and Innovation Agenda, 2019

  - Industrial software codes for extreme scale computing environments and applications
- Innovation and widening HPC use and skills base
  - HPC Competence Centres
  - Stimulating the innovation potential of SMEs

These calls focus on technologies at relatively higher levels of maturity. Industry-driven work programmes ensure that the range of activities implemented is relevant, actionable, and follows the needs of the stakeholder communities being supported.

For industrial users, there is a need to balance all the positive spillovers that industry can reap from using the facilities with the fact that these are public infrastructures partially funded with public money. For this reason, there is currently a cap of 20% on the capacity of EuroHPC machines being offered to commercial firms at market rates, for research that does not need to be published. In order to use the capacity that is free at the point of use, private companies need to publish the results of the research and go through the competitive process of resource allocation. This model safeguards all the different interests in what is essentially a shared, pan-EU infrastructure.

Directionality and additionality required

This functionality relates to the criteria "Common strategic vision of the purpose of the European Partnership" and "Creation of qualitative and significant quantitative leverage effects". The former highlights the importance of ensuring that all participating stakeholders have a common understanding of the purpose of the policy intervention and the direction of the R&I activity it is intended to encourage. The leverage effects relate to the creation of spillover effects of the knowledge gained in the broader community as well as the crowding-in effects on private investments in R&I – both among participating stakeholders and in the broader community, and/or the pooling of resources from EU Member States.

The structured consultation of the EU Member States allowed for a **first view on the interest among the EU Member States (MS)**[43] for participation in the HPC Partnership. Initially 82% of countries showed an interest in participating in the HPC partnership and 93% showed an interest in having access to results. Initially, 4 countries (CY, NL, UK, RO) were undecided, however of those 4 countries NL, RO and CY have already become members of EuroHPC.

Currently, 31 participating states are involved in EuroHPC, which shows the solid support behind the idea of pooled investments and action in HPC.

Estimates used by DG Connect show that the scale of additional investments needed for Europe to stay competitive and achieve a position of leadership in the HPC race are on the order of €750m per year up to 2022, in order to match the developments of Europe's main competitors for HPC leadership . This concerns both the development of new technology as well as the deployment of new flagship HPC infrastructure in Europe. Previous and related initiatives give an idea of the scale of investments needed to maintain competitiveness in flagship HPC:

- On the HPC procurement side, for the PRACE 1.0 period (2010 – mid 2015), the four hosting members—Spain (BCS), Germany (GCS), France (GENCI) and Italy (CINECA) each pledged to contribute €100m, for a total pledge of €400m. The PRACE project partners received in FP7 EC funding under the PRACE Preparatory and Implementation

[43] The information is based on the feedback of 30 countries to the questionnaire sent by EC services to all 28 EU Member States as well as Iceland and Norway. The feedback was provided at an early stage of the preparation of the partnerships (June 2019), thus the MS' commitments might change.

Phase Projects 1IP to 3IP (2010-2014) totalling €67m, complemented by €43m from the consortium budget. Over the past 9 years (2010-2019), the total funding of the PRACE Projects amounts to €162m of which €121m have been provided by the EC.

- For the development of an industry driven HPC R&D programme, we can take for reference the amounts deployed via the H2020 cPPPs. HPC-related calls in **ICT-LEIT** and **FET** for the 2014-2018 period amounted to €258.9m.[44]

The EuroHPC Joint Undertaking has already secured funding for the period 2019 to 2026, with an initial co-investment with Member States of about €1b, out of which €486m come from the actions already planned by the Commission in Horizon 2020 and Connecting Europe Facility (CEF) programmes in the current Multiannual Financial Framework (MFF). An additional €422m will be contributed by private or industrial players in the form of in-kind contributions to the JU activities.

Petascale and pre-exascale machines procured by the EuroHPC JU foresee joint funding, with up to 50% of the costs and an equal percent of the access time for European users, and the remainder paid for by the hosting states for their own usage. For pre-exascale systems, the EU will fund up to half of both the acquisition and operating costs. Petascale machines in smaller member states to raise HPC capabilities will be funded by the JU with up to 35% of the costs and the same percentage of access time on the facilities. The next financial framework to start in 2021 is expected to cover the exascale HPC procurements and development work for post-exascale technologies.[45]

Five of the Member States involved in EuroHPC have already been selected as sites for the first 5 EuroHPC-owned petascale Computers. These are Euro-IT4I (Czech Republic), Meluxina (Luxembourg), Deucalion (Portugal), Vega ESR (Slovenia), and PetaSC-BG (Bulgaria). Another three facilities and member states have been retained as hosts for the pre-exascale facilities. These are Lumi (Finland), BSC (Spain) and Leonardo in (Italy).

It is worth noting that the five sites selected for EuroHPC petascale computers (with the exception of the Czech Republic) do not particularly align with strong countries from the perspective of having a track record of hosting TOP500 HPC facilities.[46] *This underlines the value proposition of participation in the partnership for smaller Member States. Via EuroHPC, this cohort can reap the benefits of hosting facilities that they would otherwise not have been likely to procure outside of the partnership.*

The contributions to the EuroHPC JU budget itself are pooled as follows: the European Union covers administrative and operational costs, with Participating States making a contribution to the administrative and operational costs that is commensurate to the Union's financial contribution set out in Article 4(1) of the JU establishing Regulation. Private Members of the JU make or arrange for their constituent entities and affiliated entities to make contributions to the JU's administrative costs. Provided that the Union budget is adopted by the budgetary authority without changes, it will constitute a ceiling for the actual Union contribution.[47]

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[44] Technopolis analysis based on eCorda data

[45] INTERVIEW: EuroHPC Director Kalbe on Plans to Ramp Up Europe's HPC Infrastructure. HPCwire January 29, 2019

[46] Based on an analysis of TOP500 data.

[47] Decision of the governing board of the EuroHPC JU No 8/2018. Adopting the Joint Undertaking's Budget for 2019

4.4.2 External factors

The proposed Regulation for Horizon Europe identifies the need to consider "Coordination and complementarity with Union, local, regional, national and, where relevant, international initiatives or other partnerships and missions" when assessing the case for a partnership. It concerns the potential for linkages with other relevant R&I initiatives proposed or planned for the forthcoming Framework Programme, at the EU level in the context of the MFF 2021-27, and beyond.

The current EuroHPC Joint Undertaking builds on the successful model of the ECSEL JU in leveraging investment in the area of semiconductors and electronic components, and articulating the sector in Europe around a common SRA. Currently the JU has clear links (i.e. converging research agendas) with the Key Digital Technologies and Smart networks candidate initiatives, for example in areas such as neuromorphic architectures. There is currently a less evident link with the other initiatives mentioned in Section 1.3.

One of the important functional requirements of an HPC partnership is the federation of budgets from different sources (EC, MS and the private sector) for investment at scale in an integrated, strategic research and innovation agenda. In particular, the partnership needs to address the pooling of public and private funding both in the area of R&I programme funding as well as in running joint procurement exercises while operating under EU-law (e.g. VAT exemption, procurement rules, etc.). The EU, represented by the Commission, should be allowed to be a part of the partnership's governance, in order to safeguard the Union's interests.

Even if the main stakeholders at European level are involved, it is important that the partnership remains open to new actors, both domestically (e.g. new-to-HPC economic sectors, new HPC actors including SMEs) and internationally (e.g. leading scientific collaborations and private industry, possibly including UK firms post-Brexit). This raises additional important points with regard to external factors:

- With regard to **Brexit**, after the UK's withdrawal from the EU, the rules of access to EU procurement procedures of economic operators established in third countries will apply to candidates or tenderers from the UK depending on the outcome of the negotiations. Therefore, treatment of UK organisations in case of Brexit should be subject to conditions of a framework agreement once such would enter into force.
- One of the main interests of EU investing in strategic areas supported by target actions in the form of the proposed initiatives shall be the interest of the European economy and broader impacts from an EU-perspective. Therefore, the principle of **reciprocity** in terms of reciprocal market access for private companies, also in the context of value chains, would need to be fully respected and would need to be monitored by the proposed initiative.
- **Access to raw materials** is important for the correct functioning and resilience of the EU economy. While Europe is a large producer of essential industrial minerals it is also an importer of most of them. This dependence on imports, together with export restrictions from resource-rich countries and volatility in the commodity markets make access and supply of raw materials an important topic at European level. The process of technological discovery also impacts the need for new and rarer raw materials, for example with increased demand for different of metals and rare earths needed for new microprocessors and other electronic components. Therefore, access to raw materials is an external constraint that needs to be taken into consideration when drafting the SRIA, as an element contributing to sovereignty not only of the technology but also in terms of independence of supply.

5 What are the available policy options?

In this section, we provide an overview of the key characteristics of the policy options for this initiative. The Horizon Europe regulations put forward three forms of European Partnerships that constitute the policy options for this initiative; standard Horizon Europe calls are a fourth option while acting also as a baseline against which the three partnership options will be compared.

To ensure a correct assessment of the different options and their effectiveness, it is crucial to take into consideration both the objectives and the functional requirements outlined in Section 4.4. The descriptions of the options in the sections below therefore focus on the implications of the options' characteristics related to these functionalities. They are based on the options' characteristics specifically related to the functionalities listed in Section 4.4. A full description of the options is provided in the report on the overarching context to the impact assessment studies.

5.1 Option 0: Horizon Europe calls (baseline)

Under this option, strategic programming for research and innovation in the field will be done through the mainstream channels of Horizon Europe. Related priorities will be implemented through traditional calls under the Framework Programme covering a range of activities, but mainly calls for R&I and/or innovation actions.Table 4, below shows the key characteristics of Option 0 as it would apply to the HPC initiative.

Table 4: Key characteristics of Option 0

	Implications of option
Enabling appropriate profile of participation (*actors involved*)	• HPC-related academic research groups and centres of excellence anywhere in the EU would be able to bid to relevant calls for proposals in any of the three Horizon Europe pillars (Science, Global Challenges and Competitiveness, Innovation), in order to compete for individual grant awards. Individual HPC centres of excellence can also bid for support through the Research Infrastructures programme and may be attractive partners for consortia preparing proposals for any or all of the five mission areas. • Academics might also bid for individual research or mobility grants through various ERC schemes or Marie Sklodowska Curie Actions, with a view to carrying out fundamental research of relevance to next generation HPC, from condensed matter physics (e.g. spintronics) to computer science (e.g. AI) or building their skills and networks through placements in world-class centres of excellence. • Individual businesses – small and large – will be able to join with public sector researchers in bidding for collaborative research grants within calls issued through Pillar 2 (e.g. Advanced computing calls within Cluster 3: Digital and Industry) and will also be able to compete for grants and finance from the new European Innovation Council (EIC) in either of its principal strands: future and emerging technologies or innovation awards (for SMEs). It is likely that networks of HPC businesses – from across the value chain – will be able to bid together with a view to winning grants to cover the costs of their networking or coordination activities, and possibly more, as was the case under Horizon 2020 (e.g. the European Technology Platform for High Performance Computing: ETP4HPC).

	Implications of option
	• Existing HPC networks and partnerships would be able to bid to relevant calls for proposals in a wide range of calls for proposals, in order to compete for individual RIA / IA grant awards or larger research infrastructure awards (e.g. for the creation or extension of pan-European digital infrastructures related to HPC or for the opening up of existing HPC infrastructures to wider user communities across Europe in order to improve access across the EU).
Supporting implementation of R&I agenda (*activities*)	• In previous Framework Programmes, individual European member states have been able to come together to bid for Union support for transnational research and innovation networks and programmes, where these have been judged to be of high European Added Value. This has allowed member states to define common research agendas in areas of mutual interest – to the EU and individual countries – and thereby expand national efforts in key topics including HPC. This funding option may not be available through Horizon Europe outside the Co-Fund Partnerships, which are described below. On the other hand, several key issues around procurement and ownership of new HPC infrastructure can't be implemented under this option as some of the objectives envisaged would fall outside of Horizon Europe's remits. • EU member states would also be able to bid to Horizon Europe for support with the procurement of innovative HPC systems (e.g. PCP and PPI calls for proposals), which would be relevant to address the specific objective of improving access to HPC across the EU and reducing the digital divide. • Researchers and businesses located outside the EU should be able to join their EU counterparts in bidding into a majority of Horizon Europe calls, however, in most cases those international partners will need to pay their own costs of participation. There are exceptions where the EU has an established co-funding agreement with a third country and specific provisions exist for making funding available for their participants in Horizon. Several of these EU partner countries have substantial HPC-related capabilities, such as China, Korea and Japan, which could be a relevant source of insight and expertise in the development of exascale computing.
Ensuring alignment with R&I agenda (*directionality*)	• The baseline option would provide the HPC community with a wide range of opportunities to bid for financial support to underwrite the costs of some or all of the types of activities that will be required in order for Europe to make progress against each of the HPC objectives defined in the preceding chapters. • The European HPC community – both the public and private sectors – will be able to contribute to the development of Horizon Europe work programmes in response to the public consultations organised by the Commission and through the established comitology process, where member state representatives are able to challenge or champion particular topics or priorities within the respective programme committees.

	Implications of option
Securing leveraging effects (*additionality*)	• Without formal EU partnership mechanism, it is unlikely that HPC stakeholders will develop a joint Strategic Research Agenda and will commit to its implementation while agreeing on financial commitments beyond participation in single project participation. • Leveraging effects will be limited to what can be achieved via Horizon Europe's funding intensity rules for different types of stakeholders. This option would also have limited possibilities for co-investment by other partners and issues around ownership and usage of ESIF funds would not be addressed by this option.

5.2 *Option 1: Co-programmed European Partnership*

All European Partnership will be based on the common criteria in Annex III of the Horizon Europe Regulation, with few distinguishing elements for the different forms of implementation. A co-programmed European Partnership is based upon a *Memorandum of Understanding* or a *Contractual Arrangement* signed by the European Commission and the private and/or public partners. Private partners are typically represented by one or more industry association, which also functions as a back-office to the partnership. Industry associations usually drive the development of the Strategic Research and Innovation Agenda, with agreement among partners and with the Commission. Table 5, below shows the key characteristics of Option 1 as it would apply to the HPC initiative.

Table 5: Key characteristics of Option 1

	Implications of option
Enabling appropriate profile of participation (*actors involved*)	• The HPC Co-Programmed Partnership will be led by private partners (industry associations) with interested EU member states supporting the partnership through their participation in the governance and advisory bodies, where they will be an important source of advice around the development of the SRIA and the associated work programmes. • The HPC CPP calls will be open to all actors – public and private – throughout the EU, including existing HPC centres of excellence, platforms and networks. The CPP SRIA will also trigger HEU calls that allow EU stakeholders to work with international actors, where that is value-adding.
Supporting implementation of R&I agenda (*activities*)	• The HPC Co-Programmed Partnership's research and innovation agenda will be implemented through Horizon Europe, and as such the strategy will be able to make use of any or all parts of the framework programme that are relevant to it. • The HPC CPP will make use of the full extent of Horizon Europe, as described in the presentation of the baseline option in the preceding sub-section. There will be some limitations where an industry-led partnership may not be eligible (e.g. the ERC), however, any such issues will be resolved in the discussions between the partnership and the Commission in the finalization of its proposal.
Ensuring alignment with R&I agenda (*directionality*)	• A Co-Programmed Partnership (CPP) will provide the platform for the European HPC community to implement a strategic research

	Implications of option
	and innovation agenda that directly addresses each of the specific objectives listed above. • The CPP HPC strategy will be developed in consultation with all relevant stakeholders from across the HPC value chain and throughout the EU. It will encompass the views of the research community and HPC industry as well as lead users in a wide range of application areas. The CPP will also be able to formulate a strategy that encompasses a broad range of RDI activities (e.g. research, innovation, innovation procurement) along with an associated budget and a set of KPIs. • The HPC CPP will work with the Commission to determine where best to include its priorities within the appropriate HEU work programmes, subject to the further input of member states through the comitology process on for example the relative importance of HPC topics vis a vis other priorities and the resultant phasing of HPC calls for proposals.
Securing leveraging effects (*additionality*)	• While co-programmed efforts are a way to ensure *'concertation'* of the research agenda in agreement with HPC stakeholders, the level of additionality would be possible lower than with other forms of partnership. • The Union contribution to the partnership is defined for the full duration and has a comparable level of certainty for the partnerships than in the other forms of implementation, however there is no expectation of a legally binding commitment from other partners with regards to their contribution.

5.3 *Option 2: Co-funded European Partnership*

The Co-funded Partnerships provide co-funding to a programme of activities established and/or implemented by entities managing and/or funding research and innovation programmes. Therefore, this form of implementation only allows to address public partners at its core (comparable to the Article 185 initiatives below), while industry can nevertheless be addressed by the activities of the partnerships, but not make formal commitments and contributions to it. Table 6 below shows the key characteristics of Option 1 as it would apply to the HPC initiative.

Table 6: Key characteristics of Option 2

	Implications of option
Enabling appropriate profile of participation (*actors involved*)	• The HPC Co-Funded Partnership will be led by EU member states with leading academic research groups and industry players supporting the partnership through their participation in the governance and advisory bodies, where they will be an important source of advice around the development of the SRIA and the associated work programmes. • The HPC CFP transnational calls will be open to all actors resident in participating states, albeit with a majority of calls being directed to public actors (research institutes and university centres of excellence) rather than private actors. • The HPC CFP's use of HEU calls will be open to actors throughout the EU and will also allow EU stakeholders to work with international actors where that is value-adding. The focus on

	Implications of option
	coordination activities and infrastructure will be most relevant to existing HPC networks and centres of excellence.
Supporting implementation of R&I agenda (*activities*)	• The HPC Co-Funded Partnership's research and innovation agenda will be implemented through a combination of transnational calls and Horizon Europe calls, and as such the strategy will make use of national RDI instruments and those parts of the framework programme that are especially relevant and where member states have no or fewer types of support measures available (e.g. strategic, cross-border procurement of large-scale HPC systems).
Ensuring alignment with R&I agenda (*directionality*)	• A Co-Funded Partnership (CFP) will provide the platform for the European HPC community to implement a strategic research and innovation agenda that directly addresses each of the specific objectives listed in Section 4. • The CFP HPC strategy will be led by EU member states developed in consultation with stakeholders from across the HPC value chain and throughout the EU. The CFP will formulate a strategy that emphasises the concertation of publicly funded RDI activities at both the national and European levels (e.g. research, innovation, innovation procurement) along with an associated budget suitable for tackling the coordination and access issues on the one hand and the anticipated technology paradigm shift on the other. • The HPC CFP will work with its participating states and the Commission to determine the best balance between the co-funding of national RDI programmes and the use of the appropriate HEU work programmes, from the perspective of the SRIA. For example, the partnership may prefer to use HEU research infrastructure actions and innovation procurement to address the need to improve access and reduce the digital divide, while using a co-funding mechanism to support a transnational research programme on more fundamental questions like quantum computing.
Securing leveraging effects (*additionality*)	• The co-funded option would manage to bring MS together to invest at scale in HPC, pooling and coordinating national programmes and policies with EU policies and investments, helping to overcome fragmentation of the public research effort. However, this option does not ensure a sustained commitment from strategic industrial partners.

5.4 Option 3: Institutionalised European Partnership

This type of Partnership is based on a Council Regulation (Article 187) or a Decision by the European Parliament and Council (Art 185) and implemented by dedicated structures created for that purpose.

5.4.1 Institutionalised Partnerships under Art 185 TFEU

Article 185 of the TFEU allows the Union to participate in programmes jointly undertaken by Member States and limits therefore the scope of partners to Member States and Associated Third countries. This type of Institutionalised Partnership aims therefore at reaching the greatest possible impact through the integration of national and EU funding, aligning national strategies in order to optimise the use of public resources and overcome fragmentation of the public research effort. For the particular case of an HPC initiative, given that all predecessor activities have focused on bringing industry and the public sector together, an Art 185 IP is not from the outset a feasible policy option.

5.4.2 Institutionalised Partnerships under Art. 187 TFEU

This type of Institutionalised Partnership aims at reaching the greatest possible impact by integrating the strategic R&I agendas of private and/or public actors and by leveraging the partners' investments in order to tackle R&I and societal challenges and/or contribute to Europe's wider competitiveness goals. The basic rationale for this type of partnership is the need for a strong integration of R&I agenda's in the private and public sectors in Europe in order to address a strategic challenge or realise an opportunity. The focus is on major long-term strategic challenges and priorities beyond the framework of a single Framework Programme where collective action – by private and public sectors – is necessary to *achieve critical mass* and *address the full extent of the complexities* of the ecosystem concerned.Table 7, below shows the key characteristics of Option 1 as it would apply to the HPC initiative.

Table 7: Key characteristics of Option 3: Institutionalised Partnership Art 187

	Implications of option
Enabling appropriate profile of participation (*actors involved*)	• This policy option supports the involvement of all the types of stakeholders identified in Section 4.4.1 • The HPC IP will work with its private members, participating states and the Commission to determine the best RDI implementation strategy, with its calls for proposals drawing on the full HEU toolbox as regards RDI instruments (e.g. research and innovation actions).
Supporting implementation of R&I agenda (*activities*)	• An HPC Institutionalised Partnership (CFP) will provide the platform for the European HPC community to design and implement a strategic research and innovation agenda that directly addresses each of the specific objectives listed in Section 4. • The IP will manage its own programmes, such that the work programmes and project portfolios can be closely matched to the SRIA, however, it will rely to a large extent on HEU instruments and will therefore follow the standard arrangements and observe HEU terms and conditions on eligibility, funding and open access. Its calls will therefore be open to applicants based anywhere in the EU and possibly centres of excellence from third countries where appropriate. • The HPC IP will also make use of the ability of this type of European Partnership to fund so-called 'additional activities,' financed by its private members – without matching Union funds – and involving higher-TRL activities than would be feasible typically for Horizon Europe.
Ensuring alignment with R&I agenda (*directionality*)	• The IP HPC strategy will be led by industry in conjunction with EU member states (a public-private partnership) and will be developed in consultation with stakeholders from across the HPC value chain across Europe and internationally. It will also be aligned with Participant States' R&I and investment priorities (e.g. exascale, hybrid, etc.).

	Implications of option
	• It will encompass the views of the HPC industry and research community and as well as lead users in a wide range of application areas, from climate modelling to Industry 4.0. It will provide a comprehensive and integrated view of where and how the EU can respond to the challenges identified, with a medium and longer-term perspective. The IP will also be able to formulate a strategy that encompasses a broad range of RDI activities (e.g. research, innovation, innovation procurement) along with an associated budget and a set of KPIs suitable for tackling the coordination and access issues on the one hand and the anticipated technology paradigm shift on the other (i.e. the shift from petascale to exascale). The move to exascale is not simply a question of quadrupling the numbers of high-performance GPUs that one might find in a current petascale cluster, which will require disruptive technological advances in several areas – including software – where Europe has strengths and there is a window of opportunity globally.
Securing leveraging effects **(*additionality*)**	• The HPC IP will combine large-scale public and private commitments with Union funds and member state resources (tripartite), to arrive at a total budget that is sufficient to ensure progress with each of the specific objectives, within the life of the next multi-annual financial framework (MFF). • While the HPC IP will manage its own budget in pursuit of its specific objectives, the partnership will also be able to input to wider HEU consultations and comitology processes, in order to ensure greater synergies (and possibly increased total expenditure relevant to HPC) with other parts of Horizon Europe, whether that is other European Partnerships or missions (to be determined), science programmes (e.g. ERC) or industry competitiveness calls (e.g. Digital and Industry cluster of Pillar 2).

5.5 Options discarded at an early stage

The EuroHPC joint undertaking is based on Article 187 of the Treaty of the Functioning of the European Union, in recognition of the critical role of Europe's private sector in the realisation of many of its specific objectives, from the delivery and operation of world-class HPC infrastructure through to the development of advanced processors, middleware and other HPC components.

From this perspective, the option of a co-funded European Partnership – with its focus on public-to-public cooperation – would be insufficient as would an institutionalised partnership based on Article 185 of the TFEU. We are not aware of any stakeholder groups that were especially vocal in championing either type of partnership; to that end we have discarded both these options.

Our subsequent comparative analysis will therefore focus on a 3-way comparison between the baseline option, co-programmed European Partnership and an Institutionalised Partnership based on Article 187 of the TFEU.

6 Comparative assessment of the policy options

6.1 Assessment of effectiveness

Based on the intervention logic, the initiative aims to deliver scientific, economic/technological and societal (including environmental) impacts through a set of pathways (Section 4.3), which require a set of critical factors in place to be achieved in the best possible way (Section 4.4).

This section assesses the extent to which each retained policy option has the potential to allow for the attainment of the likely impacts in the scientific, economic/technological and societal sphere, based upon its characteristics (Section 5). At the end of each section we summarise the outcomes of the assessment by assigning a non-numerical score to each option for each impact desired.

The assessments in this section set the basis for the comprehensive *comparative* assessment of all retained options against all dimensions in Section 6.4. Table 8 lists the desired impacts in the three impact areas.

Table 8: Likely impacts of the initiative

Impact area	Likely impacts
Scientific impact	Pathway 1 – Creating new, high quality knowledge
	Pathway 2 – Strengthening human capital in R&I
	Pathway 3 – Fostering diffusion of knowledge
Economic / technological impact	Pathway 7 – Creating more and better jobs
	Pathway 8 – Generating innovation-based growth
	Pathway 9 – Leveraging investment in research and innovation
Societal impact	Pathway 4 – Addressing EU challenges and global challenges
	Pathway 6 – Strengthening the uptake of innovation in society

6.1.1 Scientific impacts

Option 0: Horizon Europe calls (baseline)

Successive European RTD Framework Programmes have invested widely in HPC-related research and innovation, in order to build research capabilities, create important new knowledge and improve coordination among existing centres of excellence.

Given the interest in next-generation HPC systems among EU policy makers and the deep engagement of Europe’s HPC community with successive European RTD Framework Programmes, we would expect the community to have argued successfully for the inclusion of HPC-related work within all three pillars of Horizon Europe and multiple programmes. The total number and value of the Union contribution to HPC-related calls in future Framework Programmes cannot be known at this point in time, however, we have assumed that the social and economic challenges linked with the development of next-generation HPC systems are more important for Europe in 2020 as compared with 2014, and that Horizon Europe will continue to invest heavily in this domain.

Our analysis of Horizon 2020 activities indicates the Union has contracted to invest around €260 million in more than 50 HPC-related actions, as at the end of July 2019. These actions were mainly supported through three programmes: FET, LEIT-ICT and Research Infrastructures. The projects range from individual research and innovation actions (RIAs) such as the €5.8m MANGO[48] project (FET) on novel architectures for next-generation HPC systems through to the €60m e-infrastructure awards to support the implementation of the PRACE network[49] or the dedicated calls to help support the creation of new European centres of excellence in important HPC application areas.[50]

Our composition analysis identified 433 scientific publications from HPC projects in Horizon 2020 or around 1.7 publications for each million euros contributed by the EU. The performance ratio is reduced somewhat by the high levels of investment in the coordination of HPC networks and e-infrastructure, where scientific publications are not a primary purpose for the specific implementation awards. While it was beyond the scope of this impact assessment study to run a separate bibliometric analysis, a majority of the HPC papers are being published in relatively high impact journals (e.g. the top 100 international journals in the computer science field globally),[51] such as Nature Communications (JIF 11.8), the Journal of Chemical Theory and Computation (JIF 5.3) and the IEEE Transactions on Parallel and Distributed Systems (JIF 4.2).

Horizon 2020 investments are also producing an important skills benefit: the PRACE network has delivered 36,400 training days to more than 5,000 people in the period up to the end of 2018. The PRACE network has also improved access to Tier-1 and Tier-0 HPC clusters by scientists across the EU. To that end, we would expect HEU calls to result in a meaningful quantum of scientific benefits for HPC in Europe, including:

- The creation of new, high quality knowledge codified in international scientific publications and conference papers, which should amount to a useful addition to the global HPC output of several thousand papers a year
- Strengthening human capital in the HPC research and innovation space, realised in part through European scientists and engineers participating directly in individual HEU research and innovation actions and in part through the training and education efforts of the HPC projects themselves. The PRACE network is actively involved in training as are the HPC centres of excellence, which will address the skills gap in various targeted domains from environmental science to renewable energy by way of bio-molecular research. The centres of excellence are targeting industry as well as academia, however, the majority of participants are academic computational scientists seeking to upgrade their analytical skills while also enhancing existing tools such that they can take full advantage of next generation HPC systems
- Fostering diffusion of knowledge, through scientific and technical publications and participation in various outreach activities, from classic communication techniques (e.g. project web sites) and social media, through to more deliberative workshops and community-wide conferences (e.g. the Euro HPC Summit Week, which is run annually and attracts 300-500 delegates)

Horizon Europe will also provide opportunities for cutting-edge science relating to important underpinning technologies for HPC, through the ERC, and its bottom-up support for fundamental research in computational science, AI, big data and software. However, this upstream work will happen anyway and will be of benefit to HPC in Europe no matter which policy option is decided upon finally.

[48] https://cordis.europa.eu/project/rcn/197942/factsheet/en

[49] https://cordis.europa.eu/project/rcn/220265/factsheet/en

[50] https://ec.europa.eu/digital-single-market/en/news/ten-new-centres-excellence-hpc-applications

[51] https://www.scimagojr.com/journalrank.php?area=1700&page=2&total_size=5561

Option 1: Co-Programmed

Before presenting the analysis of the expected impacts of an HPC Co-programme Partnership, a number of assumptions were made about the focus on the Strategic Research and Innovation Agenda and how it might differ from the baseline case.

An industry-led HPC co-programmed partnership will focus more heavily on the development of next generation HPC technologies and applications in order to increase the likelihood the European HPC industry can establish a global competitive advantage in key areas of exascale systems and applications. The applications focus is likely to prioritise industry applications over scientific, except where the latter constitute commercially important markets globally.

The CPP SRIA will place relatively less weight on improving access to existing Tier 1 and Tier 0 HPC systems, and will rely on Horizon Europe to continue to provide support to Europe's leading computational scientists, through support for networks such as PRACE or HPC centres of excellence.

The approach of CPP links with EU member states is likely to be more selective than HEU and will occur in the first instance at the level of major HPC facilities, looking to work closely with these world-class centres on a wide array of interconnected R&D projects. Collaborations are likely to extent to other European centres of excellence, including various international scientific organisations like CERN or ECMWF, which have the HPC application environment and strategic ambition to develop the breakthrough technologies needed to implement (pre-commercial) exascale machines within the next several years and to begin shipping commercial systems within the life of the next multi-annual financial framework.

Under these assumptions, an HPC CPP would match or even exceed the number of significant contributions to the status of knowledge delivered through the baseline option, on the assumption that the CPP will prioritise R&D to a greater extent than the HEU calls, which have historically split investments between RIAs (high scientific output) and research infrastructure (direct outputs = coordination, access, skills).

The industry-led CPP will look to develop work programmes that include substantial cutting-edge research, carried out in collaboration with world-class centres of excellence. The research partners will continue to publish in the academic literature – with a very much larger proportion of those articles co-authored with industry – while the industry partners will greatly increase the volume of contributions to the technical literature (e.g. conference papers).

There may be a lower level of investment in the development of HPC-related human capital relevant to computational scientists more generally, with a sharper focus on skills for industrial scientists and engineers.

An HPC CPP would achieve similar levels of knowledge diffusion to the baseline option, but possibly through slightly different channels: for example, through peer-reviewed articles and conference papers, and participation in an increased number of demonstrators and deliberative workshops designed to showcase technological breakthroughs.

The HPC CPP may deliver fewer scientific or technological insights to academics and businesses located away from the HPC hotspots, and in that sense will need to continue to rely on HEU to addresses issues with access and the digital divide.

Option 3: Institutionalised Art 187

Under this scenario, the critical aspects of the strategic research agenda are delivered by the partnership through its own calls. The Participating States will decide, through their engagement in agreeing on a common SRIA with the rest of the partners the topics and call areas that need to be funded. The partnership will work in synergy with Horizon Europe, where a sub-set of more fundamental research questions (those that are highly interesting but rather uncertain in terms of their feasibility or those interesting but less critical) will be funded through HEU calls. This will reduce the risk of the core research questions being mis-specified as a result of the open process for defining calls and should result in an increase in the relevance and quality of the core HPC portfolio, as compared with Policy Option 1. The dual funding route (partnership calls and HEU calls) means the quantum of investment is unchanged as compared with Policy Option 1.

Policy Options 0 and 1 could comparatively result in a more radical set of bids and ultimately a breakthrough in the fields in question if the partnership calls are over-specified, but we consider this to be a very small risk given that the partnership will work in synergy with HEU.

This policy option should result in a doubling of EU investment in HPC, assuming the EC's preparedness to invest in HPC-related research is the same under each Policy Option. In this case, it would be matched by an equivalent investment by member states. It is conceivable that the available budget may be larger than with other options, as there is strong international interest in the issues and the partnership might include third countries that are prepared to co-invest (these are additional funds that the EC would not need to match).

With all funding under the supervision of the partnership, this policy option should result in a more controlled investment than for each of the other Policy Options. That should result in a stronger and more coherent research portfolio. There is also a likelihood that member states' science programmes would be influenced to a greater extent by this Policy Option as compared with Policy Options 0 and 1, with some degree of mirroring and preparatory work resulting in increased national funding and an HPC science spillover.

All things being equal, this would result in a doubling of the number of scientific contributions, with the partnership able to determine the balance of funding across its priorities (in its core funding at least) possibly choosing to invest more heavily in cross-border coordination actions or supply chain initiatives as compared with Policy Option 0 and 1. Notwithstanding this, the increase in investment and national mirroring may generate even more knowledge contributions overall.

There is however a risk that the partnership would choose to focus heavily on higher TRLs and innovation procurement in an effort to make progress quickly on its most pressing problems and related objectives (underinvestment, digital autonomy, digital divide, etc). This would need to be monitored to ensure an adequate balance between the partnership's short- and long-term priorities.

An HPC IP would achieve similar levels of knowledge diffusion to the other policy options. Proper dissemination should be ensured to academics and businesses located away from HPC hotspots. Assuming that the IP operates under the criteria of transparency and openness, this should not present serious issues. The distributed way of handling support to Centres of Excellence and National HPC Competence Centres should ensure effective knowledge diffusion and development of HPC-related human capital across member states.

Interviewees generally favoured the wide dissemination and open publication of results. Industrial stakeholders in particular felt this was an important aspects as the results of the work conducted in the initiative would otherwise be less likely to flow from the research communities to industry.

Summary

Table 9, below, lists the scores we assigned for each of the policy options, based upon the assessments above, as well as taking into account the support expressed by the different stakeholders.

Table 9: Overview of the options' potential for reaching the scientific impacts

	Option 0: Horizon Europe calls	Option 1: Co-programmed	Option 3: Institutionalised Art 187
Pathway 1 – Creating new, high quality knowledge	++	+++	++
Pathway 2 – Strengthening human capital in R&I	+++	++	++
Pathway 3 – Fostering diffusion of knowledge	+	++	+++

Notes: Score +++ : Option presenting a *high* potential; Score ++: Option presenting a *good* potential; Score +: Option presenting a *low* potential

6.1.2 Economic/technological impacts

Option 0: Horizon Europe calls (baseline)

The support for HPC within Horizon Europe would deliver useful technological benefits in the shape of protectable new knowledge, for example, through trademarks for software and designs and patents for hardware-related developments. Our analysis of monitoring data for HPC actions funded under Horizon 2020 suggests that the investments have produced rather more networking and scientific outputs than technologies, with very low numbers of IPRs. This reflects a focus on research infrastructure on the one hand and future and emerging technologies on the other.

On the assumption that Horizon Europe would continue to support HPC in similar ways and through similar actions, as did Horizon 2020, we would also expect to see a greater focus on academic support and a lower level of industry engagement than one might expect to see in other competitiveness areas under Pillar 2: university labs and public research institutes account for the very great majority of HPC participations in Horizon 2020. Pillar 3 (e.g. the SME instrument) may attract interest from Europe's HPC industry, however the provision of support is largely sector-agnostic, so it is hard to determine the extent to which a relatively small, specialist industry might benefit.

Given the historical focus on the development and extension of Europe's HPC research infrastructure (HPC is increasingly a universal scientific tool), we would not expect the HEU investments in HPC-related activities to have a particularly large, direct economic impact. There are important exceptions however, with Atos Bull, Europe's leading HPC vendor having been an active participant in successive EU RTD framework programmes, where it has benefited from many millions of Euros in Union contributions to support its efforts to develop a European Scalable and power efficient HPC platform based on low-power embedded technology, which it has been working on for more than 10 years, in collaboration with ARM and the Barcelona Supercomputing Centre.[52]

The main economic benefit will arise indirectly, through knowledge spillovers – with industry scientists and engineers attending HEU conferences and seminars, reading the technical papers and scientific literature that result from the predominantly academic work – and the development of human capital (the HEU calls will support provision of at least some training for HPC users in industry, through for example the HPC centres of excellence).

This rather measured assessment of economic impact under the baseline policy option is not to suggest that advances in HPC do not promise to deliver major industrial and economic impact, as it is clear from various studies that a growing proportion of the world's industries are increasingly reliant – often critically so – on computing infrastructure for their design and engineering and for their operations and logistics.[53] What is less clear is the extent to which the technological advances contributed by Horizon Europe can make a meaningful contribution to the performance enhancements industry users will derive from the upgrades in compute and storage capacity that are delivered by the likes of AWS and other cloud-based services on a weekly basis. It is reasonable to expect for these to be a small fraction, given the very substantial levels of investment being made around the world, by both the public and private sectors. However, there is not enough data available to have a more precise understanding of the HEU's impact to annual productivity growth of Europe's HPC-using industries.

Option 1: Co-Programmed

An industry-led CPP will look to develop an HPC SRIA and work programmes with a strong technology focus that mobilises interests from across the value chain and across the EU, covering both hardware and software. There are numerous adjacent solutions under development too, which may also be viewed as commercially interesting for EU technology companies (e.g. low latency networks designed to support near real-time access to big and rapidly changing data; or edge computing processing data where the data is generated instead of a centralised data-processing centre or warehouse).

There will be a substantial level of engagement with end users – public and private – that are already working with petascale and pre-exascale technologies, and have their own roadmaps relating to their demand for / development of next generation compute and storage. These users will encompass both established high-technology businesses of strategic importance to the EU economy (e.g. automotive, pharma) and exponents from the new high-value services economy (e.g. digital, financial). The CPP is likely to focus on four of five strategic areas, to ensure the resulting work programmes are coherent and can achieve a level of investment sufficient to make progress. There also needs to be clear commitment of serious resources from these lead users, which will also narrow the field.

This more strategic focus would be expected to produce substantially more technology than the baseline option and an order of magnitude more prototypes, IPRs and start-ups.

The work would produce a substantial commercial benefit to the EU HPC businesses at the centre of the programme. On the other hand, this is a small industry in Europe presently so the absolute scale of the achievements could be limited. There is however a window of

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[52] https://cordis.europa.eu/project/rcn/197943/factsheet/en

[53] See for example, https://ec.europa.eu/digital-single-market/en/news/measuring-economic-impact-cloud-computing-europe or https://stfc.ukri.org/news/high-performance-computing-delivers-economic-benefits/

opportunity with exascale and success for the EU HPC industry in the next five years could transform the sector's growth prospects in the long term.

There will be other economic benefits too. A small number (because of barriers to entry) of EU lead users in the private sector could see an important boost in their global competitiveness, getting to exascale faster than their competitors. The HPC CPP will create important opportunities for limited numbers of small tech companies participating directly in the projects, however, there is unlikely to be a major focus on funding initiatives expressly designed to boost the numbers of HPC start-ups or existing SMEs going to scale. These important challenges will be left to the HEU calls and member states, as they have substantial existing business support measures in place.

Option 3: Institutionalised Art 187

The partnership's direct management of its investments should allow for stronger oversight of its project portfolio than would be possible with any of the other three Policy Options and especially Policy Options 0 and 1 that have to rely on the non-specialists within the Executive Agencies for project support. In this case, the delivery team is able to count on a wider network of experts to engage with all actions (e.g. providing an external check on progress and quality from the perspectives of technologists, users, owners, etc.). This should increase the likelihood of all actions delivering to their full potential.

Given the interest in next-generation HPC systems among EU policy makers and the deep engagement of Europe's HPC community with successive European RTD Framework Programmes, we would expect the community to more strongly support an institutionalized partnership in HPC. As an IP under Article 187, the HPC IP would be based on a dedicated legal entity that carries out full responsibility for the implementation. This would provide a better route to procurement and ownership of the next generation of extreme scale HPC systems and provide the coordination model necessary to fulfil all the stated objectives and community ambitions.

Under an HPC IP, union funding levels can be sufficient to attract high levels of private and national finance, cash and in-kind, with a higher leverage than individual actions, supporting longer term challenges and priorities that tend to go beyond a single MFF. Call topics will, to a large extent, align with a roadmap and priorities that have been significantly influenced by the industrial community. Industrial and especially SME participation will vary across partnerships depending on industry, but the IP will have the latitude to promote participation and private sector uptake in a more bespoke way than the baseline policy option, reaching a higher economic and technological impact than in traditional calls.

Broad membership was largely seen as a desirable aspect of the initiative but only up to a certain point. There was wide consensus that all MS should be involved in the initiative but it was also felt that the involvement of the private sector should not be dominant. Stakeholders from research and member states in particular stated that public control should be maintained as strong involvement of the private sector may constrain the initiative's activities and IP strategy.

Summary

Table 10 below, lists the scores we assigned for each of the policy options, based upon the assessments above, as well as taking into account the support expressed by the different stakeholders.

Table 10: Overview of the options' potential for reaching the likely economic/technological impacts

	Option 0: Horizon Europe calls	Option 1: Co-programmed	Option 3: Institutionalised Art 187
Pathway 7 – Creating more and better jobs	+	++	+++
Pathway 8 – Generating innovation-based growth	+	++	+++
Pathway 9 – Leveraging investment in research and innovation	+	++	+++

Notes: Score +++ : Option presenting a *high* potential; Score ++: Option presenting a *good* potential; Score +: Option presenting a *low* potential

6.1.3 Societal impacts

Option 0: Horizon Europe calls (baseline)

Horizon Europe will likely follow in the footsteps of Horizon 2020 and further increase investment in the HPC centres of excellence, which focus especially on the development of applications in order to maximise the ability of different areas to use next-generation HPC.

Given the new Commission's commitment to sustainability, it is likely that HEU HPC calls will give an additional push for projects to develop novel software environments and application platforms relevant to climate change, energy security and environmental protection.

There have been important contributions in the past, with 7-10% of the HPC publication output being published in international peer reviewed journals that are associated with the energy and environment field. However, we would expect to see the application component of the HEU HPC strategy expanded and pushed more towards environmental applications.

The same may hold with respect to applications in several other critical areas like cyber security, where one might imagine a growing need to protect citizens, key industries and governments while also maintaining an appropriate oversight ethically and thereby strengthening rather than eroding fundamental human rights.

Option 1: Co-Programmed

The HPC CPP is likely to place greater emphasis on green HPC in the broadest sense, as compared with the baseline option, as power consumption (and heat) is one of the major factors holding back exascale machines. The low-power strategy is likely to focus on new architectures (e.g. workflow specific accelerators, such FPGAs or ASICs designed expressly for Machine Learning) rather than taking on world-leading electronics firms like AMD or NVIDIA in trying to develop faster and lower power GPUs. There will also need to be substantial investment in software R&D to take advantage of the new architectures. Given that the number of data centres – and high-end HPC centres – is expected to grow 10-fold in the next five years, these sorts of improvements in energy consumption should translate into both reductions in GHGs and increasing commercial opportunities.

Lastly, the HPC CPP will look to work with lead HPC users within the public sector, both in framing its strategy and in executing collaborative research and innovation activities. It is conceivable there may even been some interest in using HEU's innovation procurement instruments, albeit that may be too niche. These public users will see an accelerated development trajectory – to exascale – that will benefit their own lead customers or users, from policy makers to climate modellers and computational scientists.

These lead users will drive knowledge spillovers from these cutting-edge technology projects through their participation in wider HPC networks, technology development efforts and RI procurement, which should in turn, see other public institutions and computational scientists gaining access to more powerful HPC systems with all that entails for digital inclusion.

The HPC CPP will increase the likelihood that Europe can become a bigger player internationally – a stronger competitor for China and the US – which should help to ensure the leading companies and countries globally continue to trade with EU-based clients on an openly commercial basis. This should also help to reduce any trends towards technological dependence and a loss of digital autonomy.

Option 3: Institutionalised Art 187

The IP allows bringing all relevant actors together to fund/execute all actions required to realise or overcome a strategic challenge or opportunity. This is especially important for major strategic challenges where collective action (by the private and public sectors) is necessary to achieve critical mass on the one hand and to address the full extent of the complexities of the ecosystem on the other.

Considering the transition towards exascale computing, the HPC IP would have a higher chance in creating lasting societal impacts. This is not a given and depends on how well the stakeholders end up working together. One of the game changers of this technology transition is the ability to promote a tighter integration of HPC in workflows involving simulation and the real-world data collection, in which HPC machines not only serve to generate data but also to ingest and analyse it. Closing the loop between simulations, the real world, digital twins as well as well as embedding HPC in a broader continuum of Edge and Cloud computing would allow for complex workflows in support of societal challenges. With the IP, Europe would then have an opportunity to develop a competitive advantage in this area, given its longstanding competence in telecommunication networks, and expertise in complex workflow management and software development. One example of how Europe is already experimenting with advanced applications in this area is the 'ChEESE' Centre of Excellence hosted at the BSC[54]. One of its projects is systematically exploring signals of seismic sources recorded through digital seismological networks in a common framework based on data-streaming workflows and machine learning. This allows for innovative continuous monitoring and space-and-time statistical analysis in active regions (tectonic, volcanic) of energy-release activity before large earthquakes or volcanic eruptions. Similar approaches can be applied to climate, health and crisis response applications.

The IP is then well placed to develop new access models for urgent computing and for support to global challenges, including specific community access from other key infrastructures, with input from all the stakeholders. While partnerships primarily address the critical needs of a narrow segment of EU society, wider social benefits can be realised indirectly and over many years.

[54] See: https://cheese-coe.eu

Summary

Table 11, below, lists the scores we assigned for each of the policy options, based upon the assessments above, as well as taking into account the support expressed by the different stakeholders.

Table 11: Overview of the options' potential for reaching the likely societal impacts

	Option 0: Horizon Europe calls	Option 1: Co-programmed	Option 3: Institutionalised Art 187
Pathway 4 – Addressing EU challenges and global challenges	+	++	+++
Pathway 6 – Strengthening the uptake of innovation in society	+	++	+++

Notes: Score +++ : Option presenting a *high* potential; Score ++: Option presenting a *good* potential; Score +: Option presenting a *low* potential

Our interviews with the EC and its entrusted entities suggest Copernicus will play an increasingly important role in efforts to mitigate climate change and meet the objectives of the European Green Deal and Paris Agreement, and its ability to successfully develop new or improved monitoring services to inform policy makers as to progress with for example reductions in greenhouse gas emissions depends on advances in both data observations and computer models. At the cutting edge, progress is much more likely where the observational data, computer architecture and simulation software are developed interdependently. A European HPC partnership could do this to an extent that individual member states or even HEU regular calls could not.

6.2 Assessment of coherence

6.2.1 Internal coherence

In this section we assess the extent to which the policy options show the potential of ensuring and maximising coherence with other programmes and initiatives under Horizon Europe, in particular European Partnerships.

Option 0: Horizon Europe calls (baseline)

Horizon Europe calls will routinely signal the existence of other major HEU investments where there may be some value in a more or less intensive coordination, to share information and increase opportunities for synergy. The HEU application guidelines invite bidders to reflect on such issues too and the evaluation panels will also be invited to at least give some consideration to the extent to which bids have understood their position in the broader HEU portfolio and have made a good argument as to where they might (or should not) look to cooperate and coordinate with other HEU activities.

Horizon Europe supported networks and platforms will typically have the capacity to make a good job of these synergies, both at the bid stage and during the implementation. It will be more challenging for the individual research and innovation actions, which understandably prioritise their research efforts and tend to allocate a very much smaller share of what may already be a smaller budget to the coordination and communication.

Option 1: Co-Programmed

The HPC CPP will define its strategy in consultation with key stakeholders across the public and private sectors to ensure there is a high degree of internal coherence. Its proximity to Horizon Europe and implementation of its work programmes through HEU calls means it will align with and link to important parallel activities within the wider EU RTD Framework Programme. For example, the HPC cPPP run by ETP4HPC defined and implemented a research agenda in close discussion with other key players supported by the Commission, including PRACE and the BDVA. The partnership also worked closely with the Commission Services to understand the FET HPC projects and the progress with code optimisation and applications of the centres of excellence.

Option 3: Institutionalised Art 187

The HPC IP will define its strategy in consultation with wider stakeholders to ensure there is a high degree of internal coherence with the other parts of Horizon Europe. The IP's senior management committee and governing body will be fully appraised of the need for the programme to work in concert with other parts of Horizon Europe, and the Commission's representatives will help to ensure that this synergistic outlook works in practice. Moreover, the new HPC IP will absorb several of the existing EU-funded HPC RDI initiatives, for example, the BDVA and EPI, with a view to ensuring a broader and more coherent approach in the HPC space overall.

There was widespread consensus across the interviewees that the initiative should have a strong coherence with other initiatives and partnerships as well as Horizon 2020 and Europe projects. EuroHPC was generally seen as a having a horizontal role across all of these.

6.2.2 External coherence

In this section we assess the extent to which the policy options show the potential of ensuring and maximising coherence with EU-level programmes and initiatives beyond the Framework Programme and/or national and international programmes and initiatives.

Option 0: Horizon Europe calls (baseline)

Horizon Europe's work programmes are developed through a comitology process that involves several iterations of consultation with various key stakeholders, within other DGs and EU member states. Those exchanges will also involve discussions with other European and international actors in the HPC arena, which means the HPC calls are framed to maximise their complementarity with initiatives in the wider landscape, including other programmes under the MFF 2021-27 (e.g. Digital Europe) and other key EU stakeholders like ESFRI.

It is not clear how much the HEU HPC strategy will be able to benefit from closer links with major European centres of excellence or national initiatives. As a case, in point CERN is discussing its ambitions with the Commission as regards the development of exascale computing, which it sees as being critical to its move to the High Luminosity LHC, and is investing in R&D relating to machine learning, triggers, alternative low power, etc. There are similar major investments underway in France, Germany and Spain, many of which are linked to upgrades in national infrastructure and to the satisfaction of national goals around scientific excellence and industrial competitiveness. There is a limit to how much these major players can align their individual strategies within the context of HEU calls at least.

Option 1: Co-Programmed

The HPC CPP's work programmes will be approved through the HEU comitology, which provides an opportunity for input by the Commission, including other DGs, and EU member states. Those exchanges will also involve discussions with other European and international actors in the HPC arena, which means the CPP calls will complement initiatives in the wider landscape, including other programmes under the MFF 2021-27 (e.g. Digital Europe or the Connecting Europe Facility) and other key EU stakeholders like the EIB that have a strong interest in supporting the development and roll-out of HPC to all European industries.[55]

Option 3: Institutionalised Art 185 / Art 187

The HPC IP's strategy and work programmes will be developed with the IP members, following wide-ranging consultation with key stakeholders, and will finally be approved by the Commission. This process includes working with other DGs and EU member states, which facilitates bi-directional information flow with the IP's strategy also being reflected in the HPC strategy of other EU programmes and national and regional initiatives too.

The exchanges will also involve discussions with other European and international actors in the HPC arena, which means the IP calls will complement initiatives in the wider landscape, with opportunities for co-funding through other programmes under the MFF 2021-27 (e.g. Digital Europe or the Connecting Europe Facility) and possibly other key EU stakeholders like the EIB that have a strong interest in supporting the development and roll-out of HPC.

In terms of external coherence, stakeholder opinion was limited. Some interviewees indicated EuroHPC would be building on existing initiatives such as PRACE and GEANT as well as the Digital Europe Programme, the Connecting Europe Facility, and European Open Science Cloud.

Summary

Table 12, below, lists the scores we assigned for each of the policy options, based upon the assessments above, as well as taking into account the support expressed by the different stakeholders.

Table 12: Overview of the options' potential for ensuring and maximizing coherence

	Option 0: Horizon Europe calls	Option 1: Co-programmed	Option 3: Institutionalised Art 187
Internal coherence	+	++	+++
External coherence	+	++	+++

Notes: Score +++ : Option presenting a *high* potential; Score ++: Option presenting a *good* potential; Score +: Option presenting a *low* potential

[55] https://www.eib.org/en/publications/financing-the-future-of-supercomputing

6.3 Comparative assessment of efficiency

In order to compare the policy options under common standards, we developed a standard cost model for all 13 candidate Institutionalised Partnership studies. The model and the underlying assumptions and analyses are set out in the report on the overarching context to the impact assessment studies.

In the case of the HPC impact assessment study, information about the actual costs associated with the set-up and running of the EuroHPC joint undertaking already exists. However, for reasons of consistency with other Impact Assessment Studies, those data are not shown in this report. In practice, the EuroHPC joint undertaking was launched in November 2018 and has gone through the set-up process in the past 12 months. Considering this, preparation and set-up costs for EuroHPC have already been incurred and an HPC IP would be operating mostly under a 'business as usual' environment, implying less difference in running costs than the comparison with the baseline option. In fact, a substantial cost to the community would be imposed if the JU had to be wound down in favour of any other policy option. This needs to be factored into the comparative assessment of efficiency.

Table 13, below, shows the intensity of additional costs against specific cost items for the various options as compared to the baseline, i.e. Option 0 (Horizon Europe calls). In this table we have taken into account that for Option 3 (Institutionalised Partnership) there would be a moderate additional cost for the set-up of a dedicated implementation structure seeing that such a structure is already existing. For Option 1 (Co-programmed), we did not consider an additional cost for the call and project implementation as MS would not be providing contributions.

Table 13: Intensity of additional costs compared with HEU Calls (for Partners, stakeholders, public and EC)

Cost items	Option 0: Horizon Europe calls	Option 1: Co-programmed	Option 3: Institutionalised Art. 187
Preparation and set-up costs			
Preparation of a partnership proposal (partners and EC)	0	++	++
Set-up of a dedicated implementation structure	0	0	++
Preparation of the SRIA / roadmap	0	++	
Ex-ante Impact Assessment for partnership	0	0	+++
Preparation of EC proposal and negotiation	0	0	+++
Running costs (Annual cycle of implementation)			
Annual Work Programme (AWP) preparation	0	+	+
Call and project implementation	0	0	+

Cost items	Option 0: Horizon Europe calls	Option 1: Co-programmed	Option 3: Institutionalised Art. 187
Cost to applicants	0	0	0
Partners costs not covered by the above	0	+	+
Additional EC costs (e.g. supervision)	0	+	++
Winding down costs			
EC	0	0	+++
Partners	0	+	+

Notes: 0: no additional costs, as compared with the baseline; +: minor additional costs, as compared with the baseline; ++: high additional costs, as compared with the baseline; +++: very high additional costs, as compared with the baseline

The scores related to the costs set out above will allow for a "value for money" analysis (cost-effectiveness) in the final scorecard analysis in Section 6.4. For this purpose, in Table 14 where we provide the scores for the scorecard analysis, based on our insights and findings and based on the scores above, we assign a score 1 to the option with the highest costs and a score 3 to the lowest.

Table 14: Matrix on 'overall costs' and 'cost-efficiency'

	Option 0: Horizon Europe calls	Option 1: Co-programmed	Option 3: Institutionalised
Overall cost	3	2	1
Cost-efficiency	3	3	2

Notes: Score 1 = Substantial additional costs, as compared with the baseline; score 2 = Medium additional costs, as compared with the baseline; score 3 = No or minor additional costs, as compared with the baseline

While there is a clear gradation in the overall costs of the policy options, the cost differentials are less marked when we take into account financial leverage (co-financing rates) and the total budget available for each of the policy options, assuming a common Union contribution. From this perspective, there are only one or two percentage points that split the most cost-efficient policy options – the baseline Option 0 and the Co-Programmed policy options – and the least cost-efficient – the Institutionalised Partnership option. Therefore, the overall cost model used by all Impact Assessment Studies assigns a score of 3 to the Option 0 and the Co-Programmed policy options for **cost-efficiency** and a score of 2 for the Co-Funded and Institutionalised Partnership policy options. This does not consider the particularities of the potential HPC partnership, for which there is already a sunk cost that has been incurred in establishing the EuroHPC JU. In this case, a case for a more cost-effective solution can be made in continuing with a model that is closer to the recently launched JU.[56]

It should be noted that the potential for the creation of crowding-in effects for industry has been taken into account when assessing the effectiveness of the policy options, above.

On the issue of directionality, the HPC IP will formulate an ambitious and far-reaching strategic research agenda that will address each of the specific objectives defined earlier in this report. The industry-led partnership will benefit from broad support among EU member states as well as the Commission itself. This tripartite structure will ensure the strategy and resulting programme are far-sighted and ambitious.

The HPC SRIA will provide the platform for the creation of a portfolio of interrelated projects, helping to ensure a more consistent and determined response to the identified problems and defined objectives, providing a more ambitious, integrated and longer-term response than would be achieved through the HEU regular calls or the CPP policy option. Critically, the HPC IP will be able to work with wider interests (e.g. the Digital Europe programme) and pursue a broader range of activities than would be readily achievable or even permissible within Horizon Europe. This will allow the partnership to encircle the multiple challenges, moving forward on multiple fronts in parallel, and thereby increasing the likelihood of achieving a major breakthrough around both exascale systems and the global competitiveness of Europe’s HPC industry. From this perspective, the HPC IP’s strategic capacity, financial leverage and extended toolbox will deliver proportionately greater social and economic impact than would the baseline option or the CPP. The IP will be set up to provide a reasonable degree of flexibility as regards the capacity to include new members.

On the issue of flexibility, the HPC IP will have certain limits defined in its legislation, which may reduce its absolute capacity for being radically altered. However, there are various precedents where other partnerships have gone through major changes and have been able to adapt the underlying legislation (at a cost).

In practice, the scope of the objectives and the partnership will be framed broadly and there should be no immediate requirement for change. More pertinent, the HPC IP SRIA and biennial work programmes will provide a high degree of adaptability as regards major technological breakthroughs or changing market circumstances. The Commission’s supervisory role will provide a useful channel for ensuring the strategy is sufficiently aligned with important developments in the policy or regulatory space, albeit the participating states will also bring this political perspective.

The calls for proposals will be open to different actors, sectors and geographies, which means that new actors can decide to submit applications or join consortia.

Lastly, on the question of long-term commitment, the HPC IP will ensure the research and innovation agenda has a medium and long-range perspective as well as being grounded in an understanding of past success (e.g. through the work of the HPC cPPP). The IP also brings more demanding legal obligations – for all partners – as compared with the alternative policy options, which will deliver the necessary longer-term commitment of all of the key actors.

[56] Caveat: the establishment costs of the candidate initiative are likely to be lower as it would be a continuation of the previously established EuroHPC JU rather than a new entity.

6.4 Comprehensive comparison of the options and identification of the preferred option

Building upon the outcomes of the previous sections, this section presents a comparison of the options' 'performance' against the three dimensions of effectiveness, efficiency and coherence.

In Section 6.4.1, we first compare the policy options against each other for each criterion in the effectiveness and coherence dimensions, resulting in a scorecard with scores from 1 to 3 where 3 stands for a substantially higher performance. Combined with the results from the comparative assessment for efficiency in Section 6.3, above, the final scorecard will allow for the identification of the preferred option in Section 6.4.2, taking all dimensions and criteria into account.

In order to address the issues and support the objectives described, any action in HPC at European level needs a coordination model that allows for the existing functionalities, some of which have been discussed in previous sections:

- Pooling together public and private resources
- Procuring HPC machines
- Openness to new partners, provided that they co-invest in the partnership
- Enabling participation of the private sector, whilst complying with state-aid and other relevant provisions ensuring fairness
- Implementing a R&I programme to address coordination inefficiencies in implementing the HPC strategy, delegating the implementation of the related budgets to the partnership
- Safeguarding the Union's interest through EC participation
- Provisions for ensuring the commitment of stakeholders during the lifetime of the initiative and for winding down the initiative gracefully once the objectives are accomplished or the initiative has run its course

As a general rule, complexity of the governance model that is required should be the minimal that is sufficient to support the functionalities envisaged. Currently, the EuroHPC JU already operates under these assumptions, and has implemented a governance model assured by two bodies: a Governing Board and an Industrial and Scientific Advisory Board.[57]

- The Governing Board is composed of representatives of the Union and Participating States. It is responsible for strategic policy making and funding decisions related to the JU activities (e.g. public procurement).
- The Industrial and Scientific Advisory Boards include representatives of academia and industry, from both HPC user communities and technology developers and suppliers. It provides independent advice to the Governing Board on the SRA and on the acquisition and operation of the supercomputers owned by the JU.

The executive director of the EuroHPC JU legal entity and its team establishes and runs the JU business processes, signs contracts, launches the calls agreed, and carries out any other functions necessary to ensure the deployment of the annual work plans.

[57] Council Regulation (EU) 2018/1488 of 28 September 2018 establishing the European High Performance Computing Joint Undertaking. ST/10594/2018/INIT. OJ L 252, 8.10.2018, p. 1–34. Retrieved from: http://data.europa.eu/eli/reg/2018/1488/oj

6.4.1 Comparative assessment

The following sub-sections explain the scores assigned to each policy option on each criterion, as summarised in Table 15.

Scientific impacts

We have given a score of 3 to Option 0, in recognition of the proven ability of the EU RTD Framework Programmes to make important contributions to the stock of knowledge through its support for science (e.g. the ERC) and future and emerging technologies. We concluded that Horizon Europe would perform a little more strongly than either Option 1 or Option 3, on this criterion, with the central role played by industry within either the Co-Programmed or Institutionalised Partnership options likely to result in relatively greater emphasis being placed on work at higher TRLs. Policy Options 1 and 2 would however still make substantial investments in pre-competitive research, and as such we have given both options a score of 2.

On human capital, we have given a score of 3 to Option 0, in recognition of the EU RTD Framework Programmes' contributions to the training of early career researchers through its support for researcher mobility and capability development (e.g. the MSCA) as well as the benefits to established scientists and engineers that follow from their participation in cross border research and innovation actions. We concluded that Horizon Europe would perform a little more strongly than either Option 1 or Option 3. Policy Options 1 and 2 would however still make substantial contributions to skills formation, particularly among smaller member states through the improvement in access to next-generation HPC infrastructure, and as such we have given both options a score of 2.

On knowledge diffusion, we have given a score of 3 to Option 3, in recognition of its commitment to invest heavily in new HPC infrastructure – to reduce the digital divide – and provide extensive support for community-wide networking and events. We concluded that the Institutionalised Partnership would perform a little more strongly than either Option 0 or Option 1, on this criterion. Policy Options 1 and 2 would however still make substantial contributions to the diffusion of knowledge through support for networking and the production of scientific and technical publications that can be widely accessed and cited by others across Europe and globally, and as such we have given both options a score of 2.

Economic and technological impacts

On job creation, we have given a score of 3 to Option 3, in recognition of its ability to attract higher levels of investment by industry as compared with Options 0 and 3 and its ability to link substantive investment in pre-competitive research with wider investments in higher TRL activities. We concluded the Institutionalised Partnership would perform more strongly than either Option 0 or Option 1, on this criterion. Policy Option 1 would however still make substantial contributions to job creation in the longer-term with its industrially-oriented and integrated strategy, its engagement of actors across the HPC value chain and wide-ranging support for strategic applied research relating to next generation HPC, and as such we have given both it a score of 2. We have given a score of 1 to Policy Option 0 as it would be likely to deliver lower levels of industrial engagement and would tend to focus more on research and the lower TRL levels and community-wide networking.

On innovation-based growth, and for similar reasons to job creation, we have given a score of 3 to Option 3 in recognition of its integrative strategy and industrial focus, as score of 2 to Policy Option 1 and a score of 1 to Policy Option 0. Policy Option 1 would deliver substantial knowledge spillovers as a result of its broader industrial membership, where the lower levels of commitment required, as compared with an IP, would allow for a more extensive partnership with members from across the value chain and potentially from wider end-users.

On leverage, we have given a score of 3 to Option 3 in recognition of the ability of Institutionalised Partnerships to generate very substantial financial investment from both the public and private sectors, far beyond what is possible through HEU calls. These partner investments would be matched by Union contributions, and would also be able to attract (crow-in) further investment for more openly commercial development activities. We have given a score of 2 to Policy Option 1 in recognition of its ability to generate at least some co-investment by its private members, and a score of 1 to Policy Option 0, which is likely to be dominated by universities and research institutes, with proportionately less private investment.

Societal impacts

On EU and global challenges, we have given a score of 3 to Option 3, in recognition of its strategic focus and ability to invest at scale in a wide range of HPC applications, which have the potential to deliver notable software performance improvements – as well as hardware improvements – in areas ranging from climate modelling to cybersecurity. The major focus on novel architectures and green HPC also has the potential to deliver major advances in the environmental performance of advanced computing the world over. We have given a score of 2 to Policy Option 1 in recognition of its ability to focus future investments on a more coherent and strategic set of priorities than would be likely through the regular HEU calls. We have given a score of 2 to Policy Option 0, in recognition of its strong support historically for major centres of excellence, such as the European Centre for Medium Range Weather Forecasting (ECMWF) and its work on advanced software applications and numerical weather prediction. Policy Option 0 may provide greater opportunities for more novel applications, relating to global challenges that would not be a clear priority for Europe’s HPC industries and supply chains.

On societal innovation, we have given a score of 3 to Option 3, in recognition of its ability to convene public and private sectors and invest at scale in a wide range of HPC applications, with the potential to deliver improvements in many areas within the public realm, whether that is smarter government and improved public services or the more efficient management of public infrastructure from smart grids to smart cities. We have given a score of 2 to Policy Option 0 in recognition of its strong support historically for major centres of excellence, public agencies and various NGOs / CSOs. We have given a score of 1 to Policy Option 1 in recognition of its sharper focus on industrial challenges, albeit any breakthroughs in next generation HPC would quickly spillover to more mainstream computing systems. As such, there would still be societal benefits in the longer term.

Coherence

On internal coherence, we have given a score of 3 to Policy Option 0. The HEU calls benefit from long-established procedures and integrating mechanisms, which ensure that annual work programmes have been developed in conjunction with all parts of the wider FP. We have given a score of 2 to Policy Option 1, as while it will benefit from the EC’s comitology process, there would be a less good basis for information exchange and meaningful cooperation with other partnerships. We have given a score of 2 to Policy Option 2 as the HPC Institutionalised Partnership would need to work a little harder than the other Policy Options to ensure its strategy and work programmes are fully aligned with other relevant parts of the FP. Policy Option 3 would benefit from established relationships among several key programmes and partnerships, which are expected to continue to exist under the next MFF.

On external coherence, we have given a score of 3 to Policy Option 3 in recognition of its ability to bring relevant EU and MS-level actors and initiatives within its strategic ambit, as partners and funders. We have given a score of 2 to Policy Option 0 in recognition of its established procedures concerned with coherence and its many coordination structures that help make those principles a reality. have given a score of 1 to Policy Option 1, on the basis that it would have a narrower membership and a lower level of integration within the Horizon coordination structures.

Table 15: Scorecard of the policy options

	Criteria	Option 0: Horizon Europe calls	Option 1: Co-programmed	Option 3: Institutionalised
Effectiveness	**Scientific impacts**			
	Pathway 1 – Creating new, high quality knowledge	3	2	2
	Pathway 2 – Strengthening human capital in R&I	3	2	2
	Pathway 3 – Fostering diffusion of knowledge	2	2	3
	Economic/technological impacts			
	Pathway 7 – Creating more and better jobs	1	2	3
	Pathway 8 – Generating innovation-based growth	1	2	3
	Pathway 9 – Leveraging investment in research and innovation	1	2	3
	Societal impacts			
	Pathway 4 – Addressing EU challenges and global challenges	2	2	3
	Pathway 6 – Strengthening the uptake of innovation in society	2	1	3
Coherence	**Internal coherence**	3	2	2
	External coherence	2	1	3
Efficiency	**Overall cost**	3	2	1
	Cost-efficiency	3	3	2

Notes: Scores for effectiveness and coherence: 3 = *substantially higher performance*; 2 = *higher performance*; 1 = *lower performance*. Scores for efficiency: 1 = *substantial additional costs*, as compared with the baseline; 2 = *medium additional costs*, as compared with the baseline; 3 = *No or minor additional costs*, as compared with the baseline

On overall cost, we have given a score of 3 to Policy Option 0 in recognition of the smaller overall investment fund available for HPC and the higher levels of administrative efficiency achieved by the REA. We have given a score of 2 to Policy Option 1 in recognition of its use of HEU procedures in the main, with some additional costs associated with its additional coordination by private members and additional supervision by the Commission. We have given a score of 1 to Policy Option 3, reflecting its substantially larger investment funds and marginally less efficient administrative set up. The differences narrow on cost-efficiency, and we have given a score of 3 to Policy Options 0 and 1 and a score of 2 for Policy Option 3.

6.4.2 Identification of the preferred option

The scorecard in Table 15 shows that Option 0 performs comparatively well on scientific impacts, internal coherence and cost-efficiency. It performs best overall on cost-efficiency. It performs relatively poorly on economic and technological impacts, with Policy Option 1 and Policy Option 3 being scored as substantially stronger. It performs better than Policy Option 1 on societal impacts and but less well than Policy Option 3. well against close to all dimensions and criteria compared to the Option 1 and Option 3. Policy Option 2 performs less well on most criteria, as compared with Policy Option 0 (Scientific and societal impacts) and Policy Option 3 (economic and technological impacts. Policy Option 3 performs most strongly on technological, economic and societal impacts and performs reasonably well on scientific impacts.

Overall, our impact analyses and comparative assessment found that Policy Option 3 would be the preferred policy option, with its large-scale, ambitious integrated strategy judged likely to deliver substantially greater social and economic benefits, notwithstanding its slightly weaker performance on cost-efficiency. We also judged it to be the preferred option in terms of its European added value and its strategic flexibility.

The scorecard shows that benefits are clearly maximised under the third option, Institutionalised Partnership under Art. 187. In particular, compared with the other options, Option 3 would:

- Provide greater effectiveness by maximising structuring and leverage effects through fostering the diffusion of knowledge, creating more and better jobs, generating innovation-based growth, leveraging investment in research and innovation, addressing EU and global challenges, and finally strengthening the uptake of innovation in society.
- Offer a reasonable level of cost-efficiency as compared with other options, considering the starting point of an EuroHPC JU that is already established and in operation.
- Improve coherence by enhancing both internal coherence with other parts of Horizon Europe as well as external coherence by complementing other programmes such as Digital Europe and the Connecting Europe Facility.

The conclusion of our assessment is that Option 3 Institutionalised Partnership under Art. 187 is the preferred option, showing higher overall benefits than the other options.

7 The preferred option

7.1 Description of the preferred option

An HPC Institutionalised Partnership (CFP) will provide the platform for the European HPC community to design and implement a strategic research and innovation agenda that directly addresses each of the specific objectives listed in Section 4.

The IP HPC strategy will be led by industry in conjunction with EU member states (a public-private partnership) and will be developed in consultation with stakeholders from across the HPC value chain across Europe. It will encompass the views of the HPC industry and the research community and as well as lead users in a wide range of application areas, including those targeting EU and global challenges as well as urgent computing needs. A complete discussion of what an Institutionalised European Partnership in HPC would entail can be found in sections 5.3 and 6.3.

In Table 16, below, we indicate the alignment of the preferred option with the selection criteria for European Partnerships defined in Annex III of the Horizon Europe Regulation. Seeing that the design process of the candidate Institutionalised Partnerships is not yet concluded and several of the related topics are still under discussion at the time of writing, the criteria of additionality/directionality and long-term commitment are covered in terms of *expectations* rather than ex-ante demonstration.

Table 16: Alignment with the selection criteria for European Partnerships

Criterion	Alignment of the preferred option
Higher level of effectiveness	The preferred option would be more effective than the Horizon Europe calls in achieving the related objectives of the Programme through involvement and commitment of partners. Under this scenario, critical aspects of the IP SRA are delivered by the partnership through its own calls. This policy option should result in more EU investment in HPC, assuming the EC's preparedness to invest in HPC-related research is the same under each Policy Option. In this case, it would be matched by an equivalent investment by member states. The partnership's direct management of its investments should allow for stronger oversight of its project portfolio than would be possible with other policy options. Call topics will, to a large extent, align with a roadmap and priorities that have been significantly influenced by the industrial community. The IP allows bringing all relevant actors together to fund/execute all actions required to realise or overcome a strategic challenge or opportunity. This is especially important for major strategic challenges where collective action (by the private and public sectors) is necessary to achieve critical mass on the one hand and to address the full extent of the complexities of the ecosystem on the other.
Coherence and synergies	The preferred option presents the most coherent choice to maximise synergies within the EU research and innovation landscape. Policy makers are committed to strengthening HPC in the EU, as it is increasingly critical for EU industry, science and citizens, and an HPC IA would work closely with the Digital Europe Programme and the Connecting Europe Facility, amongst others. An HPC IA would also be more coherent with other parts of Horizon Europe. Many challenges have led to the creation of multiple RDI initiatives and an HPC Partnership should provide strategic leadership and closer coordination, to add value to those many HPC initiatives. The problem analysis has shown that HPC investment in Europe has been historically fragmented, uneven and too low. The preferred option would pool and leverage additional investment, and would ensure more equitable access through new investment on the one hand and better optimization on the other. This would make EU support for HPC more coherent with other initiatives involving other DG's, MS and EU regions.
Transparency and openness	The preferred option will maximise its impacts by involving all the stakeholders and remaining open during its lifetime. To achieve this, an IP in HPC will have broad representation of stakeholder groups, including: European associations involved in furthering research agendas; Intermediary organisations providing access to a range of users; Member States (MS) and the European Commission (EC); End-users using HPC resources, research and industrial domains (CoEs); Industry as active members of their respective HPC industry associations; and Cross-participation of industry in related initiatives (e.g. EPI, Fortissimo). Based on the current work of the EuroHPC JU, areas where there is scope to broaden participation include more industrial end-users directly, and

Criterion	Alignment of the preferred option
	strategic collaborations with other flagship infrastructure (e.g. those in the ESFRI roadmap).
Additionality and directionality	An institutionalised partnership in HPC would, ex-ante, provide a better approach to ensure flexibility of implementation and to adjust to changing policy, societal and/or market needs, or scientific advances. While the main pillars would be established in the regulation establishing the IP, these could be general enough to satisfy the different issues identified, covering a range of activities, from procurement through to fostering HPC applications. Priority setting would occur through the development of Strategic research agendas driven by stakeholder advisory groups and signed off by the IP, ensuring adequate directionality of investments. To achieve this the IP would need to establish a vision, clear strategy, monitoring of progress and exit strategy. Its governance would ensure that this vision is delivered via annual workplans and stakeholder involvement would keep checks and balances to the IP governance to ensure the IP supports the functionalities described. In terms of additionality the IP will seek to generate and leverage investments that would not have happened otherwise. In terms of partner contributions and R&I investments the current EuroHPC JU has already corroborated strong interest from Member States. Initial leverage from MS will be seen by end of 2019 and an IP would also provide the same incentives for pooling and additionality of investments.
Long-term commitment	The expectation is that the HPC IP will be able to secure a minimum share of public and private investments. In the case of institutionalised European Partnerships, the financial and in-kind, contributions from partners other than the Union, will at least be equal to 50% and may reach up to 75% of the aggregated European Partnership budgetary commitments. As a case in point the EuroHPC JU has already published the Financial Commitments of the EuroHPC Participating States for the Work Plan 2019 Research and Innovation Actions.

7.2 Objectives and corresponding monitoring indicators

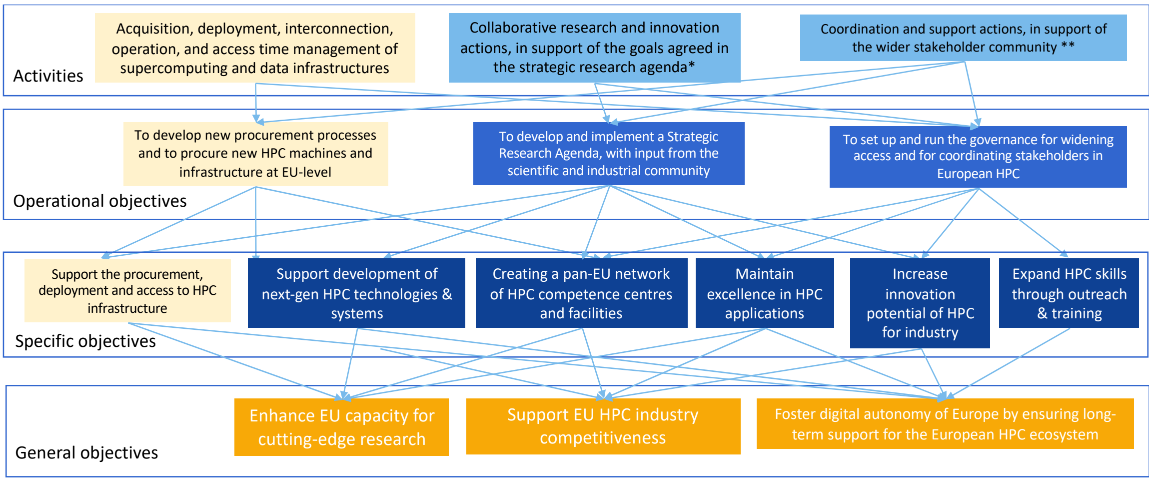
7.2.1 Operational objectives

Figure 7, below, lists a range of actions and activities, going also beyond the R&I activities that can be implemented under Horizon Europe (highlighted in yellow). This reflects the definition of European Partnerships in the Horizon Europe regulation as initiatives where the Union and its partners "commit to jointly support the development and implementation of a programme of research and innovation activities, including those related to market, regulatory or policy uptake." These activities would include:

- Activities for supporting a research and innovation agenda for establishing an innovation ecosystem addressing hardware and software supercomputing technologies and their integration into exascale supercomputing systems, advanced applications, services and tools, skills and know-how. These would include:
  - Collaborative research and innovation actions (RIA or IA) which include Research and Innovation Actions (RIA, typically TRL 3-5) and Innovation Actions (IA, covering TRL 5-7/8)
  - Coordination and support actions (CSA), which allow for the funding of networking, specific analytical studies, the development of Strategic Research and Innovation Agenda's, outreach and communication activities, including funding and support to Centres of Excellence and HPC National competence centres
- General administrative activities for the operation and management of the initiative.

- Activities for the acquisition, deployment, interconnection, operation and access time management of world-class supercomputing and data infrastructures.
  - For this specific case, non-R&I activities concern mainly the procurement and operation of HPC systems. It is our understanding that funding of another MFF programme would be required for these, which would come from the Connecting Europe Facility (CEF) / Digital Europe (DEP) Programmes.

Figure 7: Operational objectives of the initiative



* Including research and innovation actions to support the devt. of the 1st generation of EU low-power microprocessor technology as well as exascale HPC.
** Including as actions in support of European Centres of Excellence (CoE) and National HPC Competence Centres.

7.2.2 Monitoring indicators

We have identified the following key monitoring indicators for tracking progress of the initiative towards its targeted impacts in addition to the ones identified for the Horizon Europe key impact pathways.

Table 17: Monitoring indicators in addition to the Horizon Europe key impact pathway indicators

	Short-term (typically as of year 1+)	**Medium-term (typically as of year 3+)**	**Long-term (typically as of year 5+)**
Scientific impact	Value of R&I actions Peer reviewed scientific publications in HPC	Citation index of peer reviewed publications in HPC Publication of open-source software	Eu share in EU supply chain Comparative bibliometric performance of Europe; domains with European leadership
Technological / economic impact	Petascale and pre-exascale systems acquired Codes and applications developed Computing cycles used by the public and private sectors	Exascale systems acquired (with European technology) Number of European flagship systems Patent/IP performance Number of support businesses across the HPC stack	Post-exascale systems acquired Number of European flagship systems Additional jobs created in the HPC industries (and beyond)

	Short-term (typically as of year 1+)	**Medium-term (typically as of year 3+)**	**Long-term (typically as of year 5+)**
		BERD & GVA of EU's HPC industry Number of HPC start-ups Time/cost to solution	
Environmental / sustainability impact	Value of R&I actions in support of green HPC development Codes and applications developed with potential environmental sustainability impact	Share of computing power used for climate, energy and health research	Green HPC flagship systems
Social impact	Number of researchers/individuals trained through the initiative	Availability of European suppliers for critical components HPC usage by European SMEs	Dependency of European system integrators on non-EU critical components

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Appendix B Synopsis report on the stakeholder consultation – Focus on the candidate European Partnership for EU-AFRICA Global Health

Disclaimer: the views expressed in the contributions received are those of the respondents and cannot under any circumstances be regarded as the official position of the Commission or its services.

B.1 Introduction

Following the European Commission's proposal for Horizon Europe in June 2018,[58] 12 candidates for institutionalised partnerships within 8 partnership areas have been proposed, based on the political agreement with the European Parliament and Council on Horizon Europe reached in April 2019.[59] Whether these proposed institutionalised partnerships will go ahead in this form under the next research and innovation programme is subject to an impact assessment.

In line with the Better Regulation Guidelines,[60] the stakeholders were widely consulted as part of the impact assessment process, including national authorities, the EU research community, industry, EU institutions and bodies, and others. These inputs were collected through different channels:

- A feedback phase on the inception impact assessments of the candidate initiatives in August 2019,[61] gathering 350 replies for all 12 initiatives;
- A structured consultation of Member States performed by the EC services over 2019;
- An online public stakeholder consultation administered by the EC, based on a structured questionnaire, open between September and November 2019, gathering 1635 replies for all 12 initiatives;
- A total of 608 Interviews performed as part of the thematic studies by the different study teams between August 2019 and January 2020.

It is important to note that the HPC impact assessment study differs from the other 12 parallel impact assessment studies inasmuch as the EU recently approved the creation of the EuroHPC Joint Undertaking "EuroHPC JU". This study will provide input to a Commission SWD but it will not be an impact assessment. In addition, the European High-Performance Computing initiative was not included in the Open Public Consultation on the European Partnerships as an OPC specific for this initiative was organised in the previous year.

This document is the synopsis report for the initiative "European High-Performance Computing". It provides an overview of the responses to the different consultation activities (excluding the OPC). A full analysis of the results is provided in the study Data Report.

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[58] https://ec.europa.eu/commission/presscorner/detail/en/IP_18_4041

[59] https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_19_2163

[60] https://ec.europa.eu/info/files/better-regulation-guidelines-stakeholder-consultation_en

[61] The full list of inception impact assessments is available here. They were open for public feedback until 27 August 2019.

B.2 Feedback to the inception impact assessment on candidate initiatives for institutionalised partnerships

Following the publication of the inception impact assessment, a feedback phase of 3 weeks allowed any citizen to provide feedback on the proposed initiatives on the "Have your say" web portal. In total 350 feedbacks were collected for all initiatives.

For the initiative "European High-Performance Computing" 4 individual feedbacks were collected, mainly from companies and business organisations.[62] Among the elements mentioned were:

- **Business associations (1 feedback):** indicated overall support for the creation of a partnership in this area but commented there is room for improvement in terms of addressing industrial needs. In their view, HPC was too narrowly defined in terms of supercomputers alone rather than all forms of HPC (cloud resources, graphics processor arrays, and quantum computing). The stakeholder argued that a future HPC partnership would only be successful if; application sectors are aligned with industrial and scientific competences; HPC software technologies are supported; initiatives across the entire supply-chain are fostered; collaboration between international academic and industrial parters takes place; precise goals and KPIs are set; and participation of and use by SME's is facilitated.
- **Companies/business organisations (2 feedbacks)** expressed their full support for the continuation of EuroHPC given the digital transformation of industry and society. Moreover, a worldclass supercomputing infrastructure was considered to be an absolute necessaity for maintaining or increasing global industrial competitiveness.
- **Public authroties (1 feedback)** argued that the links between Smart networks and services, High Performance Computing, Key digital technologies, Innovative Health, and other relevant partnerships should be more clearly defined in order to create stronger synergies between them.

B.3 Structured consultation of the member states on European partnerships

A structured consultation of Member States through the Shadow Strategic Configuration of the Programme Committee Horizon Europe in May/ June 2019 provided early input into the preparatory work for the candidate initiatives (in line with the Article 4a of the Specific Programme of Horizon Europe). This resulted in 44 possible candidates for European Partnerships identified as part of the first draft Orientations Document towards the Strategic Plan for Horizon Europe (2021-2024), taking into account the areas for possible institutionalised partnerships defined in the Regulation.

The feedback provided by 30 countries (all Member States, Iceland and Norway) has been analysed and summarised in a report, with critical issues being discussed at the Shadow Strategic Programme Committee meetings.

The results indicate a high level of satisfaction with the overall portfolio, the level of rationalisation achieved, and policy relevance. While delegations are in general satisfied with the thematic coverage, the feedback suggests the coverage could be improved in cluster 2 "Culture, creativity and inclusive society" and cluster 3 "Civil Security for Society".

Despite high satisfaction with the portfolio and candidates put forward by the Commission, countries put forward a high number of additional priorities to be considered as European Partnerships. A closer examination suggests that these additional proposals are motivated by very different reasons. Whilst some proposals are indeed trying to address gaps in the

[62] Feedback on inception impact assessment to be found on https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2019-4972282/feedback_en?p_id=5722166

portfolio and reach a critical mass, then, others are driven by the wish to maintain existing networks, currently not reflected in the Commission proposal (e.g. those based on JPIs, ERA-NETs). In addition, some proposals reflect worries over some topics not being sufficiently covered in the existing proposals, but could be possibly well covered within the scope of existing partnerships, or by traditional calls under the Framework Programme.

Country feedback suggests dissatisfaction with the high number of proposed Article 187 TFEU partnerships. Notably smaller as well as EU-13 countries raise concerns with regards to the potential insufficient transparency and openness of the partnership model. In the feedback, countries either directly support or ask to carefully analyse whether the objectives of this proposal could be reached with the co-programmed model.

For those partnerships that will be set up on the basis of Article 187, the country feedback stresses the need to ensure a clear shift towards openness in the governance, membership policy and allocation of funding of these partnerships. Notably, it is emphasised that the JU rules should not have any limitations or entry barriers to the participation of SMEs and other partners, including from academia.

Although the feedback suggests a general criticism, there are few concrete and broadly supported proposals, including to reduce the number of institutionalised partnerships mergers or by alternative implementation modes.

The current proposal foresees 5 partnerships in the area of transport (for rail, air traffic management, aviation, connected and automated driving, zero-emission road transport), and 2 that in closely related technologies for radically reducing carbon emissions (hydrogen, batteries). Several delegations would wish to see a systemic approach to developing mobility and addressing related challenges (optimisation of overall traffic, sustainable mobility solutions for urbanisation), and do not support a mode-dependent view only. This suggests the need to discuss how to ensure greater cooperation between transport modes and cross-modal approaches in establishing partnerships in the area of mobility.

The composition and types of partners is an important element for the success of a partnership, e.g. to ensure the right expertise and take-up of results. Ensuring broad involvement without overly complicating the governance of the partnership remains an important an important challenge in the design of future partnerships.

In the feedback, several Member States express their interest to join as a partner in partnerships that have traditionally been industry-led. However, individual comments suggest there are different views on what their involvement means in practice, with some countries expressing readiness to commit funding, while others support limiting their involvement to alignment of policies and exploiting synergies. This suggests the need to discuss further what the involvement of Member States means in practice (notably in terms of contributions, in the governance), and what would be possible scenarios/options in Horizon Europe. There is special interest in testing and deployment activities, in synergies with Cohesion Funds and CEF priorities and investments.

Although it is too early to determine the interest of industry/ businesses in the topics proposed for partnerships where the main partners are public authorities, their involvement in in public centric partnerships will also be an important question in the design and preparation of future proposals.

The analysis of feedback per partnership candidates suggests that some proposals are more mature, while others would need more time to determine the scope, objectives, partner composition and contribution and appropriate mode of implementation. This relates to in particular to partnerships with no predecessors and those where the main partners are public. It suggests that the proposals would need to be developed at different paces in order to achieve good quality, and thus, not all partnership proposals may be ready for implementation at the start of Horizon Europe.

For the initiative "European High-Performance Computing" the following overall feedback was received from Member States. Delegations strongly support the proposed High Performance Computing partnership, with high relevance in the national context. This is furthermore reflected by the 23 countries clearly stating their interest to participate in the partnership. There is strong support for the selected implementation mode (Article 187 initiative), and delegations underline the importance of links and synergies with other EU programmes (Digital Europe Programme, Connecting Europe Facility).

The majority of countries (82%) are at this stage interested to participate, with only 4 countries undecided (CY, NL, UK, RO) and only IS excluding participation. Research infrastructures (92%) are identified as main potential partners or contributors. A number of countries state that their final decision to participate will be taken at a later stage. Most countries (93%) expressed interest in having access to results produced in the context of the partnership.

Overall there is a strong agreement (97%) on the use of a partnership approach in addressing this specific priority. There is broad agreement (89%) that the partnership is more effective in achieving the objectives and delivering clear impacts for the EU and its citizens, and (78%) agree that it would contribute to improving the coherence and synergies within the EU R&I landscape.

Countries indicate good agreement with the proposed objectives at short, medium and long term (97%) and the expected scientific, economic and societal impacts at European level (96%), with the remaining ones being neutral. Slightly less (93%) consider the impacts relevant in the national context. There is good agreement (81%) with the envisaged duration of the proposed partnership.

There is broad agreement (96%) between countries on the type and composition of partners, with some comments on the evolution of partners in time (e.g. industry to be more included later) as well as the importance of links and synergies with other EU programmes (Digital Europe Programme, Connecting Europe Facility) and other already running and foreseen partnerships.

Most countries (75%) agree with the proposed implementation mode as Article 187, with the rest expecting more details in order to be able to make an informed decision. Only one country proposes co-programmed as implementation mode.

B.4 Targeted consultation of stakeholders related to the the initiative "High Performance Computing"

In addition to the consultation exercises coordinated by EC services, the external study thematic teams performed targeted consultations with businesses, research organisations and other partners on different aspects of potential European Partnerships.

This section sets out the interview strategy that was developed specifically for the impact assessment study of the candidate institutionalised partnership in high performance computing and its implementation.

B.4.1 Approach to the targeted consultation

The stakeholder interviews have constituted a primary source of information that was been used to feed in all impact assessment of the final report in order to complement the analyses based on desk research as well as primary and secondary data. This applies in particular to section 4, which used inputs from the interviews to discuss the likely scientific, economic, and societal impacts of the initiative. The interviews also informed section 5 focussed on the selection and description of the policy options for the initiative, section 6 with the comparative options assessment, and section 7 where the preferred option was described.

The interviewees were selected based on the extent of their involvement in EuroHPC or the European HPC landscape across research, industry, and the public sector. The vast majority of interview invitations were sent out via email and were followed up with reminders every two to three weeks. Additional candidates were invited throughout the process based on suggestions made by previous interviewees. In cases where targeted interviewees were unresponsive telephone calls were also made as follow-up.

B.4.2 Overview of respondents to the targeted consultation

Based on our review of the HPC landscape in Europe we identified 5 stakeholder groups that were subsequently targeted for interviews. These stakeholder groups are research initiatives involved in furthering research agendas, industrial stakeholders developing HPC technologies and using HPC resources, infrastructure providers, intermediary organisations and HPC centres providing access to a range of users, and finally members states involved in the EuroHPC JU.

The distribution of interviewees between the different stakeholder groups is a result of the number of individuals that were targeted initially but also the extent to which these were willing to participate in the interview programme. In this regard, we found that stakeholders from industry were somewhat less inclined to contribute to interviews hence their share of 11.4%. While stakeholders from research and infrastructure providers were generally willing to contribute, there were fewer of such European initiatives relevant to HPC that were targeted to begin with. On the other hand, there was a wide range of HPC intermediaries, HPC centres, and member states to reach out to and therefore these feature more prominently in the number of interviewees.

It is worth noting that several interviewees were interviewed in one capacity while also having views on the subject matter from additional perspectives given their involvement in other stakeholder groups.

Table 18: Number of interviews per stakeholder category

Stakeholder category	Number	Share (%)
Research initiatives	6	13.6%
Industrial stakeholders	5	11.4%
Infrastructure providers	6	13.6%
Member States	14	31.8%
Intermediaries and HPC centres	13	29.5%
TOTAL	**44**	**100%**

B.4.3 Key results/messages from the targeted consultation

This section provides a summary of the interview programme per relevant topic. These topics correspond to the main headings of the final impact assessment study, i.e. Political/legal context; Problems; Why should EU act?; Objectives; etc.

Emerging challenges in the field

Stakeholders from industry referred to the innovations in HPC moving towards a digital continuum of Edge computing and IoT as an emerging challenge. Many industrial stakeholders also pointed to the energy consumption of HPC and the growing need for low-power processors as a key area of debate today.

Infrastructure stakeholders also described energy consumption as a key challenge as well as the increasing relevance of HPC in the context of the rise of Big Data.

What are the problems?

Across all stakeholder groups there was a general consensus that European investments in the area of HPC have historically been insufficient

Industry stakeholders felt that more public funding will be needed both from the EU as well as individual MS in order to build up a European HPC ecosystem.

Infrastructure providers mentioned in particular the lack of investments in CoEs which should be delivering considerable impacts in terms of applications. Some interviewees pointed to the lack of critical mass in EU industry and the lack of strengths in terms of technological hardware.

Stakeholders from research confirmed the lack of funding for CoEs as well as the lack of HPC skills across all technical silos as problems.

Member States further reiterated the problem of a skills gap and the fact that Europe is lagging behind in terms of technical competencies and the diffusion of knowledge to industry. In particular, the lack of sustainable career paths in Europe for researchers was seen as a problem by several interviewees.

What are the problem drivers?

Industrial stakeholders felt there was a shortage in the European skills base in terms of know-how to use and program large computers and develop applications for them. Furthermore, the lack of diversity in the relevant industrial base and SMEs was also seen as a problem driver.

Interviewees from infrastructure providers referred to the fragmentation of the European ecosystem as an issue and .

Stakeholders from research were of the opinion that European developments in processor architecture were not advancing fast enough to be able to keep up with international competitors.

Added value of EU action

Industry saw EU action as a necessity in order to catch-up in field where Europe has been lagging behind, processors in particular before major scientific or technological breakthroughs can be seen. Interviewees saw it as unlikely that the private sector in Europe would lead the way in terms of developing HPC technologies and applying these in the context of Edge computing, AI, or machine learning.

Research stakeholders felt European efforts to develop processor technologies have to be accelerated. Otherwise, next generation HPC systems would not be built around said technologies in Europe.

Specific objectives

In terms of objectives of the future initiative, there was a strong consensus across stakeholder groups that the development of HPC applications were an absolute priority. It was felt that it was crucial for applications to be developed in parallel to architectures so that there can be a strong level of integration between the two, maintaining Europe's leadership in this regard. In a similar fashion, it was deemed a necessity for architectures to be co-developed with specific applications and workloads in mind.

Stakeholders from industry further pointed to the importance of prioritising energy efficient HPC and novel cooling technologies as well as including SMEs more closely.

Researchers also indicated that there is no need for EuroHPC to reinvent the wheel in terms of OS but to use off the shelf solutions. Linux in particular was cited by interviewees across all stakeholder groups as a preferred option.

Likely scientific impacts

All stakeholder groups agreed that a key scientific impact would be to drive the development of new system architectures, codes and algorithms, and applications, especially in the context of the convergence of data analytics with AI, ML and HPDA. There was also widespread agreement that positive contributions would be made to human capital developments in terms of technical architects, hardware designers, software developers, etc. across the HPC stack. The majority of interviewees also highlighted the cross-cutting nature of the benefits flowing from these skill enhancements in a wide range of sectors and scientific fields.

Member States felt that building up human capital would also offer more sustainable career prospects to researchers and that it may help prevent the brain drain of HPC related expertise out of Europe.

Opinions on the impact of EPI were somewhat mixed with most industrial and infrastructure stakeholders agreeing it had the potential of developing a successful low-power processor while researchers, member states, and intermediaries where more sceptical of its future success with some expressing concerns that its first generation processor was likely to be sub-optimal.

Positive impacts were generally expected in terms of the diffusion of knowledge, in particular through the mobility of labour as well as publications and demonstrations.

Likely economic/technological impacts

Overall, stakeholders were in agreement that a major economic impact would be the development of a European HPC ecosystem. Furthermore, most stakeholders expected to see impacts on both the hardware and software side of the HPC value chain. Infrastructure providers and members states largely took the view that the more significant impacts were to be expected in terms of software rather than in hardware industries.

In terms of broader industries that stand to benefit from European HPC, a wide variety was listed by the interviewees. The main industries that were frequently cited across the different groups were automotive, aerospace, oil & gas, engineering, energy, and pharmaceuticals.

Member states and intermediaries also indicated that European sovereignty might be an outcome provided EPI is successful across the European value chain and is complemented by the necessary software developments. Interviewees from these two groups also agreed that there can be an opportunity for SMEs to benefit but issues of access and wider usability of HPC resources remains a challenge.

Likely societal impacts

The interviewees were generally of the opinion that EuroHPC has the potential to contribute towards addressing EU and global challenges. More specifically, HPC was frequently described as a key enabling technology that would permit simulations, predictions, and modelling that allows us to address previously unattainable problems. In particular, interviewees had high expectations of the role of HPC in acceleration science and research into areas including weather and climate, healthcare and medicine, energy, agriculture, cybersecurity, and disaster management. Out of these climate and weather research was the single most frequently cited area of impact across all interviewees.

In addition, member states and intermediaries were somewhat sceptical as to the likelihood that individual citizens would directly interact with HPC in the future. Rather, the expectation is that these will benefit in a much more indirect way.

Finally, the ECMWF, DG GROW and DG Connect have all expressed an interest in principle in developing a digital twin earth model, which would link all aspects of earth systems (oceans, atmosphere, weather, etc.) in a far more comprehensive model that would deliver reliable forecasts for a variety of phenomena. The scale and complexity of the model – and its data inputs – would be critically dependent upon advances in next-generation HPC architectures and software in order to cope with the number of variables and still achieve reasonable run times, and earth systems scientists would like to see these concepts being developed in tandem with post-exascale systems.

Scientific impacts

Interviewees generally favoured the wide dissemination and open publication of results. Industrial stakeholders in particular felt this was an important aspects as the results of the work conducted in the initiative would otherwise be less likely to flow from the research communities to industry.

Economic/technological impacts

Broad membership was largely seen as a desirable aspect of the initiative but only up to a certain point. There was wide consensus that all MS should be involved in the initiative but it was also felt that the involvement of the private sector should not be dominant. Stakeholders from research and member states in particular stated that public control should be maintained as strong involvement of the private sector may constrain the initiative’s activities and IP strategy.

Societal impacts

Our interviews with the EC and its entrusted entities suggest Copernicus will play an increasingly important role in efforts to mitigate climate change and meet the objectives of the European Green Deal and Paris Agreement, and its ability to successfully develop new or improved monitoring services to inform policy makers as to progress with for example reductions in greenhouse gas emissions depends on advances in both data observations and computer models. At the cutting edge, progress is much more likely where the observational data, computer architecture and simulation software are developed interdependently. A European HPC partnership could do this to an extent that individual member states or even HEU regular calls could not.

Coherence

There was widespread consensus across the interviewees that the initiative should have a strong coherence with other initiatives and partnerships as well as Horizon 2020 and

Europe projects. EuroHPC was generally seen as a having a horizontal role across all of these.

In terms of external coherence, stakeholder opinion was limited. Some interviewees indicated EuroHPC would be building on existing initiatives such as PRACE and GEANT as well as the Digital Europe Programme, the Connecting Europe Facility, and European Open Science Cloud.

Appendix C Methodological Annex

The Impact Assessment studies for all 13 candidate institutionalised European Partnerships mobilised a mix of qualitative and quantitative data collection and analysis methods. These methods range from desk research and interviews to the analysis of the responses to the Open Consultation, stakeholder analysis and composition/portfolio analysis, bibliometrics/patent analysis and social network analysis, and a cost-effectiveness analysis.

The first step in the impact assessment studies consisted in the definition of the context and the problems that the candidate partnerships are expected to solve in the medium term or long run. The main data source in this respect was desk research. The Impact Assessment Study Teams went through grey and academic literature to identify the main challenges in the scientific and technologic fields and in the economic sectors relevant for their candidate partnerships. The review of official documentations, especially from the European Commission, additionally helped understand the main EU policy proprieties that the initiatives under assessment could contribute to achieve.

Almost no candidate institutionalised European Partnership is intended to emerge ex nihilo. Partnerships already existed under Horizon 2020 and will precede those proposed by the European Commission. In the assessment of the problems to address, the Impact Assessment Study Teams therefore considered the achievements of these ongoing partnerships, their challenges and the lessons that should be drawn for the future ones. For that purpose, they reviewed carefully the documents in relation to the preceding partnerships, especially their (midterm) evaluations conducted. The bibliography in Appendix A gives a comprehensive overview of the documents and literature reviewed for the present impact assessment study.

Finally, the description of the context of the candidate institutionalised European Partnerships required a good understanding of the corresponding research and innovation systems and their outputs already measured. The European Commission services and, where needed the ongoing Joint Undertakings or implementation bodies of the partnerships under Article 185 of the TFEU, provided data on the projects that they funded and their participants. These data served as basis for descriptive statistic of the numbers of projects and their respective levels of funding, the type of organisations participating (e.g. universities, RTOs, large enterprises, SMEs, public administrations, NGOs, etc.) and how the funding was distributed across them. Special attention was given to the countries (and groups of countries, such as EU, Associated Countries, EU13 or EU15) and to the industrial sectors, where relevant. The sectoral analysis required enriching the eCORDA data received from the European Commission services with sector information extracted from ORBIS. We used the NACE codification up to level 2. These data enabled identified the main and, where possible, emerging actors in the relevant systems, i.e. the organisations, countries and sectors that will need to be involved (further) in the future partnerships.

The horizontal teams also conducted a Social Network Analysis using the same data. It consisted in mapping the collaboration between the participants in the projects funded under the ongoing European partnerships. This analysis revealed which actors – broken down per type of stakeholders or per industrial sector – collaborate the most often together, and those that are therefore the most central to the relevant research and innovation systems.

The data provided by the European Commission finally served a bibliometric analysis aimed at measuring the outputs (patents and scientific publications) of the currently EU-funded research and innovation projects. A complementary analysis of the Scopus data enabled to determine the position and excellence of the European Union on the international scene, and identify who its main competitors are, and whether the European research and innovation is leading, following or lagging behind.

All together, these statistical analyses will complement the desk research for a comprehensive definition of the context in which the candidate institutionalised European Partnerships are intended to be implemented. The conclusions drawn on their basis will be confronted to the views of experts and stakeholders collected via three means:

- The comments to the inception impact assessments of the individual candidate institutionalised European partnerships received in August 2019
- The open public consultation organised by the European Commission from September to November 2019
- The interviews (up to 50) conducted by each impact assessment study team conducted between August 2019 and January 2020.

For instance, in all three exercises, the respondents were asked to reflect on the main challenges that the candidate institutionalised European Partnerships should address. In the open public consultations, they mainly reacted to proposals from the European Commission like when they were given to opportunity to give feedback to the inception impact assessment.

The views of stakeholders (and experts) were particularly important for determining the basic functionalities that the future partnerships need to demonstrate to achieve their objectives as well as their most anticipated scientific, economic and technological, and societal impacts. The interviews allowed more flexibility to ask the respondents to reflect about the different types of European Partnerships. Furthermore, as a method for targeted consultation, it was used to get insights from the actors that both the Study Teams and the European Commission were deemed the most relevant. For the comparative assessment of impacts, the Study Teams confronted the outcomes of the different stakeholder consultation exercises to each other with a view of increasing the validity of their conclusions, in line with the principles of triangulation. Appendix B includes also the main outcomes of these three stakeholder consultation exercises.

The comparison of different options for European partnerships additionally relied on a cost-effectiveness analysis. When it comes to research and innovation programmes, the identification of costs and benefits should primarily be aimed at identifying the "value for money" of devoting resources from the EU (and Member States) budget to specific initiatives. Based on desk research and consultation with the European Commission services, the horizontal study team produced financial estimates for different types of costs (preparation and setup costs, running costs and winding down costs) and per partnership option. The costs were common to all candidate European Partnerships. The results of the cost model were displayed in a table, where each cost was translated on a scale using "+" in order to ease the comparison between the partnership options.

A scorecard analysis, which allocated each option a score between 1 and 3 against selected variables, was used to highlight those options that stand out as not being dominated by any of the other options in the group: such options are then retained as the preferential ones in the remainder of our analysis. It also allowed for easy visualisation of the pros and cons of alternative options.

Appendix D Additional information on the policy context

D.1 Relevant other European initiatives in HPC and programmes under the MFF 2021-27

Europe has been investing heavily in the development of next-generation HPC systems and skills over several previous financing periods, launching the EuroHPC Joint Undertaking towards the end of the current programming period in order to better coordinate those many investments.

Through this Joint Undertaking, the EU and participating states coordinate efforts and resources in order to deploy a European HPC infrastructure together with a competitive innovation ecosystem in terms of technologies, applications, and skills. The joint undertaking will be fully operational by 2020 ahead of the next programming period (MFF 2021-27) and will be able to provide the strategic leadership and oversight needed to expand overall investment and produce a step change in Europe’s deployment and use of next generation HPC.

The EuroHPC joint undertaking is working closely with several established EU networks and infrastructure initiatives that have been supporting the HPC ecosystem in Europe, including:

- **The Partnership for Advanced Computing in Europe (PRACE)** provides a pan-European supercomputing infrastructure which makes available computing and data management resources and services for large-scale scientific and engineering applications at high levels of performance. PRACE operates as an inter-governmental agreement with the infrastructure consisting of national supercomputers. Therefore, the European Commission is not involved in its governance. PRACE currently has 26 member countries, 5[63] of which are hosting computing and data management resources. It is funded by member countries as well as H2020.
- **GÉANT** – Similar to PRACE, GÉANT provides a pan-European data infrastructure focussed on research and education communities. Specifically, it links national research and education networks (NRENs) to supercomputing centres. The GÉANT network extends beyond the EU. GÉANT funding cannot wholly attributed to HPC, as GÉANT has a wider remit covering communication networks for research more generally, however it remains a critical component of the commitment to maximise access to and usage of next-generation HPC infrastructure across the EU member states

Aside from PRACE and GÉANT, the majority of EU-level HPC activities and initiatives have been folded into the EuroHPC Joint Undertaking since its establishment. For example, EuroHPC activities will cover actions previously delivered through H2020 projects and initiatives such as the EPI, EXDCI, and others. Furthermore, ten **Centres of Excellence (CoE)**[64] were set-up by the European Commission for the purposes of applying HPC in the domains of science, industry, and society. They were designed to be user-focused providing support, competences, and training to user communities. Most of the Centres of Excellence are co-located with national HPC nodes and their focus is on code/applications development and software upgrades/maintenance, amongst other things.[65] Finally, the ETP4HPC and

[63] Currently, the 5 Hosting Members of PRACE are France, Germany, Italy, Spain and Switzerland.

[64] For an overview of the nine current CoEs, see: https://www.focus-coe.eu/index.php/centres-of-excellence-in-hpc-applications/

[65] This does not apply to Compbiomed (https://www.compbiomed.eu) which is managed by UCL rather than a national HPC node.

BDVA Associations are participating in the Joint Undertaking as Private Members, representing the particular interests of the HPC industry and key user groups.

The candidate European Partnership in HPC would be funded under the Horizon Europe Pillar II Cluster 4 – Digital, Industry and Space.[66] Cooperation with the Digital Europe Programme (DEP) and the Connecting Europe Facility (CEF-2) programme established under the next MFF (2021-2027) would support the partnership in developing and building the HPC infrastructure and ecosystem throughout the EU.[67] The Connecting Europe Facility-2 Programme is expected to ensure terabit connectivity between existing and future supercomputing centres, while the DEP support "will focus on large-scale digital capacity and infrastructure building, aiming at a wide uptake and deployment across Europe of critical existing or tested innovative digital solutions".[68]

The EC has proposed to support the new institutionalised HPC partnership with €2.7b from the Digital Europe Programme as well as further funding from the next Framework Programme and Connecting Europe Facility (CEF). Furthermore, the EuroHPC JU has also made the argument that additional investments from structural funds (ERDF) may be needed to realise a supercomputing infrastructure as well as the development of applications[69]. Such ERDF contributions would have to be coordinated with deployment and innovation actions funded through DEP in the case of projects with a common European interest or regional relevance.

D.2 Support for the priority in previous framework programmes

Within Horizon 2020 alone, funding is administered through three separate Work Programmes namely, e-infrastructures, LEIT-ICT, and FET. Table 19 below shows a summary of these funding streams.

Table 19: Horizon 2020 funding streams for HPC

	Name	Period (start)	Total Funding	Notes
FET (Future and Emerging Technologies)	H2020-FETHPC-2014 FET-Proactive 'Towards Exascale High-Performance Computing'[70]	WP2014-2015	€97.4m	Aims to deliver a broad spectrum of extreme scale High Performance Computing (HPC) systems and to develop a sustainable European HPC Ecosystem. 21 projects have been selected and started in autumn 2015.
	H2020-FETHPC-2016-2017	WP2016-2017	€85m	The FET Proactive call "High Performance Computing" has 3 initiatives: co-design of HPC systems and

[66] *To be confirmed*

[67] European Commission (2019) *Orientations towards the first Strategic Plan implementing the research and innovation framework programme Horizon Europe*. Co-Design via web open consultation

[68] European Commission (2019) *Partnership for European High-Performance Computing*. Fiche for the consultation with Member States

[69] See: https://eurohpc-ju.europa.eu/

[70] See: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/high-performance-computing-hpc

	Name	Period (start)	Total Funding	Notes
	"FET Proactive HPC topic"[71]			applications, transition to exascale computing, exascale HPC ecosystem development. 2016: €41m[72] / 2017: €44m
	FET flagship Human Brain Project	WP2016-2017	€25m	The EC plans to contribute €25 million in 2016- 2017 for the advanced HPC platform of the project;
	H2020-FETHPC-2018- 2020	WP2018-2020	€4.5m	2018: €4m [FETHPC-01-2018 (RIA)] / 2019: n/a / 2020: €0.5m [FETHPC-04-2020 (CSA)]
European Research Infrastructures (including e-Infrastructures)[73]	H2020-EINFRA-2014/2015 e-Infrastructures[74]	WP2014-2015	€175.5m	2014: 95m / 2015: 80.5m
	H2020-EINFRA-2016-2017[75] e-Infrastructures	WP2016-2017	€122m	2016: 36m / 2017: 86m
	H2020-INFRAEDI-2018-2020[76] European Data Infrastructure	WP2018-2020	€118.9m	2018: 98.9m / 2019: n/a / 2020: 20m
	GÉANT Partnership projects	2015-2020	€217m	2015: 25m / 2016: 64m / 2018: 128m
ICT-LEIT	H2020 – EUB – 2015 EU-Brazil Research and Development Cooperation in Advanced Cyber Infrastructure	WP2014-2015	€2m	The work aims at the development of state-of-the-art High Performance Computing (HPC) environment that efficiently exploits the HPC resources in both the EU and Brazil and advances the work on

[71] Ibid.

[72] See: http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-fet_en.pdf#page=17

[73] Includes support for PRACE, CoEs, and SESAME-NET

[74] http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/main/h2020-wp1415-infrastructures_en.pdf#25

[75] http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-infrastructures_en.pdf#page=29

[76] http://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/main/h2020-wp1820-infrastructures_en.pdf

	Name	Period (start)	Total Funding	Notes
	EUB 2 – 2015: High Performance Computing (HPC)[77]			HPC applications in domains of common interest.
	ICT-42-2017: Framework Partnership Agreement in European low-power microprocessor technologies	WP2016-2017	-	Opened in September 2017[78], see below
	Framework Partnership Agreement in European low-power microprocessor technologies (Phase 1)	WP2018-2020	€80m	Within the Framework Partnership Agreement in European low-power microprocessor technologies awarded in 2017, the selected consortium will be invited to submit a Research and Innovation Action proposal for the design and development of European low-power processors and related technologies for extreme-scale, high-performance big-data and emerging applications, in the automotive sector for example, in accordance with the research roadmap defined in the FPA. The designs should follow a modular approach that would allow a rapid scale-up or scale-down.
	European Data Infrastructure: HPC, Big Data and Cloud technologies	WP2018-2020	The EC considers proposals requesting €12-13m and for subtopic a),	a) Innovation Actions targeting the development of large-scale HPC-enabled industrial pilot test-beds supporting big data applications and

[77] http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/main/h2020-wp1415-leit-ict_en.pdf

[78] http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-leit-ict_en.pdf

	Name	Period (start)	Total Funding	Notes
			and €15-18m for subtopic b)	services by combining and/or adapting existing relevant technologies (HPC / BD / cloud) in order to handle and optimize the specific features of processing very large data sets. b) Innovation Actions targeting the development of large-scale IoT/Cloud-enabled industrial pilot test-beds for big data applications by combining and taking advantage of relevant technologies (Big Data, IoT, cloud and edge computing, etc.).

D.3 Results of current and previous initiatives

Table 20 below summarises the scope and objectives of each of these initiatives, including the recently launched EuroHPC. The table also outlines the nature and scale of funding, to give a sense of the level of past investment and coordination at EU level. A partial degree of overlap exists between some of the budgets described above. For instance, a portion of the funding pledged by industry in the EuroHPC JU was redirected from the cPPP's budget and that some of the EPI's budget has also been rechannelled towards the EuroHPC JU.

Table 20: Summary of the support for the priority from previous Framework Programmes

Name and nature of initiative	Scale / budget / period	Scope and objectives	
		Scientific & technological focus	Role and objectives
EuroHPC JU (institutionalised partnership, joint undertaking)	2019-2020: €988m (€486m from EU, a matching contribution from MS, and contributions by private members)[79]	Whole spectrum of technologies from low-power microprocessors and related middleware technologies to software, programming models and tools, to novel architectures and their system integration through a co-designed approach	Acquiring and providing a world-class petascale and pre-exascale supercomputing and data infrastructure for Europe's scientific, industrial and public users. Supporting a research and innovation agenda to develop and maintain in the EU a world-class HPC.

[79] The EuroHPC Joint Undertaking supports activities through procurement and open calls in 2019 and 2020 and will initially operate from 2019 to 2026. The EuroHPC JU foresees an initial co-investment with Member States of about EUR 1 billion, out of which EUR 486 million come from the actions already planned by the Commission in Horizon 2020 and Connecting Europe Facility (CEF) programmes in the current Multiannual Financial Framework (MFF). An additional EUR ~422 million will be contributed by private or industrial players in the form of in-kind contributions to the JU activities.

Name and nature of initiative	Scale / budget / period	Scope and objectives	
		Scientific & technological focus	Role and objectives
cPPP on HPC (public private partnership between the EC and ETP4HPC)	Horizon 2020: €700m* + a similar amount to be leveraged from the private sector[80]	Focus areas (based on SRA 4 model) ;[81] system architecture, system hardware components, system software & management, programming environment, I/O & storage, mathematics & algorithms, centre-to-edge framework, application co-design	To build a European world-class HPC technology value chain that will be globally competitive, fostering synergy between the three pillars of the HPC ecosystem (technology development, applications and computing infrastructure)
PRACE (inter-governmental agreement)	The total funding of the PRACE Projects amounts to €132M over 9 years (2010 – 2019) of which €97M is provided by the EC The key contribution, however, is the amount of computing hours offered to the scientific community	pan-European supercomputing infrastructure, providing access to computing and data management resources and services for large-scale scientific and engineering applications at the highest performance level. PRACE has a strong interest in improving energy efficiency of computing systems and reducing their environmental impact.	The mission is to enable high-impact scientific discovery and engineering R&D across all disciplines to enhance European competitiveness for the benefit of society. PRACE seeks to realise this mission by offering world class computing and data management resources and services through a peer review process.
GEANT (FPA)	Current iteration GN4-3 (2019-2022) has a total budget of €119m, €77.5m of which is Union contribution	Interconnections between 38 national research and education network (NREN) partners across Europe and supporting all scientific disciplines.	GÉANT is a fundamental element of Europe's e-infrastructure for scientific excellence, research, education and innovation. Through its integrated catalogue of connectivity, collaboration and identity services, GÉANT provides users with reliable, unconstrained access to computing, analysis, storage, applications and other resources.
EPI European Processor Initiative (FPA)	The Union contribution under the Horizon 2020 is	High-performance, low-power processor, implementing vector instructions and specific accelerators with high	The project will develop a roadmap, develop the first generation of technologies, tape-out of the first-generation chip by integrating the IPs

80 See: https://www.etp4hpc.eu/cppp-budget.html

81 See: https://www.etp4hpc.eu/sra-019.html

Name and nature of initiative	Scale / budget / period	Scope and objectives	
		Scientific & technological focus	Role and objectives
	expected to be c. €120 million[82]	bandwidth memory access[83]	developed, and validate this chip in HPC and automotive contexts using a demonstration platform.

Table 21 below provides a summary of results reached by the current and previous initiatives, based on desk research. As some of these predecessor initiatives have been integrated into EuroHPC, some of the outstanding issues identified in the past for the predecessor initiatives are currently being addressed by EuroHPC.

Table 21: Summary of the Outcomes of the EuroHPC JU and related or predecessor initiatives

Name	Results of previous evaluations / assessments / annual reports	
	Outcomes	**Problems to address / Identified needs**
EuroHPC	A Joint Undertaking (JU) was considered the best instrument capable to implement the goals of EuroHPC while offering the highest economic, societal, and environmental impact while best safeguarding the Union's interests[84] *However, the EuroHPC JU only launched its first calls in 2019 and at this stage it is too early to assess its effectiveness.*	4 key problems were identified in the EuroHPC Impact Assessment. Since the launch of EuroHPC, the JU has already coped effectively with issues (1) and (2), and is in the process of contributing to addressing issues (3) and (4): (1) The procurement of systems is still done by MS and in an uncoordinated way. (2) Implementation of the R&I agenda proposed by the cPPP is still fragmented. MS have national programmes and the EU uses two programmes: CEF & H2020 (with multiple WPs). (3) Innovation procurement instruments like the Pre-Commercial Procurement (PCP) and the Public Procurement for Innovation (PPI) have been used sparingly by MS in the area of HPC. (4) European suppliers face limitations in acceding to public procurements of HPC in USA, China or Japan. In contrast the EU is still the most open market, with no restriction in most of the public procurements on HPC
HPC cPPP	Progress in terms of open discussion on roadmaps, portal of project results, dissemination activities, easy access to information and membership, links to other cPPPs and EU actions and	More progress needed in the following evaluation dimensions: high number of industry and RTO representatives, KPI reporting, Methodology to compute Leverage KPI, and Inclusion of SMEs[86]

[82] See: https://ec.europa.eu/digital-single-market/en/news/european-processor-initiative-consortium-develop-europes-microprocessors-future-supercomputers

[83] See: https://www.european-processor-initiative.eu/project/epi/

[84] European Commission. (2018). Impact Assessment accompanying the Proposal for a Council Regulation on establishing the European High Performance Computing Joint Undertaking.

[86] Ibid.

Name	Results of previous evaluations / assessments / annual reports	
	Outcomes	**Problems to address / Identified needs**
	instruments, and the inclusion of EU13 was found to be 'Well on Track'[85]	
PRACE	PRACE KPIs[87]: Offer and demand of resources: average of 1.9b core hours (per call) offered to HPC scientific community & oversubscription ratio of 3:1 Number of projects: recent rise in number of projects awarded Recurring users: ratio between first applicants and first-time users approximately 50% International and transnational cooperation: approximately 60% of resources awarded to 'foreign projects' Co-funding: On average, 75% of PRACE users have declared that their awards are complemented with EC, national or international funds Know-how: rise in participants of PRACE courses (2361 in 2018) Industry: The average participation of industry in PTC trainings is 15.68%between 2012 and 2017 (19.7% in 2017).	PRACE KPIs: Co-funding: International funding remains low, with 8% being the average contribution. Industry: The reduction and stabilisation of projects awarded after the 7th Call has had a strong impact on the number of projects awarded with industrial participants. In other words, industry suffers more from the competition for PRACE resources than academia. We expect this trend will start to change with the PRACE 2 programme.

D.4 EuroHPC Scientific and Technological Analysis

For this scientific and technological analysis of EuroHPC, we pay particular attention to the types of partners that are involved in supported projects. Scientific publications can mainly be expected from academic partners as well as research organisations, but much less so from industry partners. In cases where industry is involved in scientific publications this is almost exclusively in collaboration with an academic partner.

Patents, on the other hand, can be expected from industry partners since they have a genuine interest in protecting their innovation. However, due to competition, business practices and the pre-competitive nature of collaborative R&D projects at EU-level, etc. most industrial partners are likely to apply for IPR outside the context of the treatment. Therefore, the numbers of IP recorded in the database used here may underestimate the real effects.

The analysis of EuroHPC covered a total of 54 projects. The distribution of these projects by call topic and year is presented below.

[85] Mid-term review of the contractual Public Private Partnerships (cPPPs) under Horizon 2020

[87] For the PRACE KPIs see: http://www.prace-ri.eu/prace-kpi/

Table 22: Number of HPC projects by call topic and year

Topics of calls	2014	2015	2016	2017	2018	Total nr projects
Centres of Excellence for computing applications		9				9
Co-design of HPC systems and applications			2			2
Customised and low energy computing (including Low power processor technologies)				6		6
Exascale HPC ecosystem development				2		2
HPC Core Technologies, Programming Environments and Algorithms for Extreme Parallelism and Extreme Data Applications	19					19
HPC Ecosystem Development	2					2
International Cooperation on HPC					2	2
Network of HPC Competence Centres for SMEs	1					1
Transition to Exascale Computing				11		11
Total	**22**	**9**	**2**	**19**	**2**	**54**

Source: DG RTD, calculation: Technopolis Group

D.5 HPC scientific analysis

The following section presents breakdowns of scientific publications that resulted from HPC projects. In total, **433 scientific publications** were identified. The table below shows that the majority of these publications (61%) resulted from the Research Infrastructures Work Programme.

Table 23: Evolution of HPC publications by types of calls

Topics of calls	2015	2016	2017	2018	2019	Total	Share
Future and Emerging Technologies (FET)	7	30	55	65	9	166	38%
Information and Communication Technologies				1		1	0%
Research Infrastructures	3	65	108	87	3	266	61%
Total	10	95	163	153	12	433	100%
Share	2%	22%	38%	35%	3%	100%	

Source: DG RTD, calculation: Technopolis Group

Below, the distribution of publications is shown across the different call topics. It is worth pointing out that the call on Centres of Excellence is associated with the majority (61%) of publications.

Table 24: Evolution of HPC publications by call topics

Topics of calls	2015	2016	2017	2018	2019	Total	Share
Centres of Excellence for computing applications	3	65	108	87	3	266	61%
Co-design of HPC systems and applications			2	3	1	6	1%
Customised and low energy computing (including Low power processor technologies)				1		1	0%
HPC Core Technologies, Programming Environments and Algorithms for Extreme Parallelism and Extreme Data Applications	7	30	53	62	7	159	37%
Transition to Exascale Computing					1	1	0%
Total	10	95	163	153	12	433	100%
Share	2%	22%	38%	35%	3%	100%	

Source: DG RTD, calculation: Technopolis Group

Overall, a total of 29 projects in the field – listed below - produced these 433 publications. The primary projects in this regards are MaX and NoMad (each with 68), and BioExcel (41).

Table 25: Number of publications by project

Project acronym	Number of publications by project	Project acronym	Number of publications by project
ALLScale	6	ExaNeSt	1
ANTAREX	10	ExaNoDe	2
BioExcel	41	ExCAPE	18
COEGSS	12	EXTRA	14
ComPat	33	INTERTWINE	4
CompBioMed	26	MANGO	8
DEEP-EST	3	MaX	68
E-CAM	9	Mont-Blanc 3	10
ECOSCALE	2	NoMaD	68
EoCoE	30	POP	4
ESCAPE	9	READEX	6
ESiWACE	8	RECIPE	1
EuroEXA	3	SAGE	9
ExaFLOW	10	TeamPlay	1
ExaHyPE	17		

Source: DG RTD, calculation: Technopolis Group

These projects also report on whether a publication is a joint public-private co-publication, or not. In the case of HPC, less than 10% of publications are co-published, which is by far the lowest share of public-private co-publications among all the candidate partnerships.

Table 26: Number and share of collaborative publications, by year

Joint Public/Private publications	2015	2016	2017	2018	2019	Total	Share
No	9	91	154	137	10	401	93%
Yes	1	4	9	16	2	32	7%
Total	10	95	163	153	12	433	100%

Source: DG RTD, calculation: Technopolis Group

The 433 publications were published in 200 different journals. The following lists those journals that account for at least five publications.

Table 27: Main journals for HPC publications (5+)

Journal Title	Total	Journal Title	Total
Journal of Chemical Theory and Computation	26	Geoscientific Model Development	6
Computer Physics Communications	15	IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems	6
Nature Communications	12	Journal of Computational Science	6
Journal of Computational Physics	11	Monthly Notices of the Royal Astronomical Society	6
PHYSICAL REVIEW B	10	Physical Chemistry Chemical Physics	6
Frontiers in Physiology	9	ACM Transactions on Architecture and Code Optimization	5
Nano Letters	9	Microprocessors and Microsystems	5
IEEE Transactions on Parallel and Distributed Systems	7	Physical Review Letters	5
Physical Review B - Condensed Matter and Materials Physics	7	Procedia Computer Science	5
Scientific Reports	7	The Journal of Chemical Physics	5

Source: DG RTD, calculation: Technopolis Group

As the distribution of HPC publications per call topic demonstrates, there has been a stronger focus on HPC applications instead of development. This is further confirmed by the overview of main journals for HPC publications which suggests a strong focus on computational sciences rather than computer science.

D.6 HPC and international scientific benchmarking

In order to analyse how EuroHPC is performing in comparison of the rest of the world, we first need to define it in terms of scope. This can be done, for example, through journals or keywords. In this case, key words were drawn from publication titles –however, it is not straightforward to delineate the field.

Table 28: Most frequently used keywords for HPC project descriptions (11+)

Key-word	Frequency	Key-word	Frequency
data	27	model	16
dynamics	25	protein	16
molecular	22	computing	15
prediction	21	based	15
approach	21	binding	13
performance	20	computational	13
analysis	20	calculations	13
simulations	20	functional	13
theory	20	energy	12
structure	19	efficient	12
electronic	18	parallel	11
simulation	17	high	11
modelling	17	multiscale	11
properties	17	density	11
systems	17		

Source: DG RTD, calculation: Technopolis Group

In terms of co-words, a number of technological couples can be detected. The following are the most relevant ones (in decreasing occurrence):

'energy management', 'optimization constraints', 'mechanisms batteries', 'performance analysis', 'li-ion batteries', 'optimal energy', 'optimal management', 'energy building', 'management building', 'robust control' and 'wireless networks'.

In order to see the main performing countries and organisations in the field of HPC, a bibliometric analysis was performed.

Between 2010 and 2018, 18.500 publications were published. An annual average growth of 7.4% can be calculated. With 59.0%, conference papers dominated the type of publication followed by articles and reviews (33.3%).

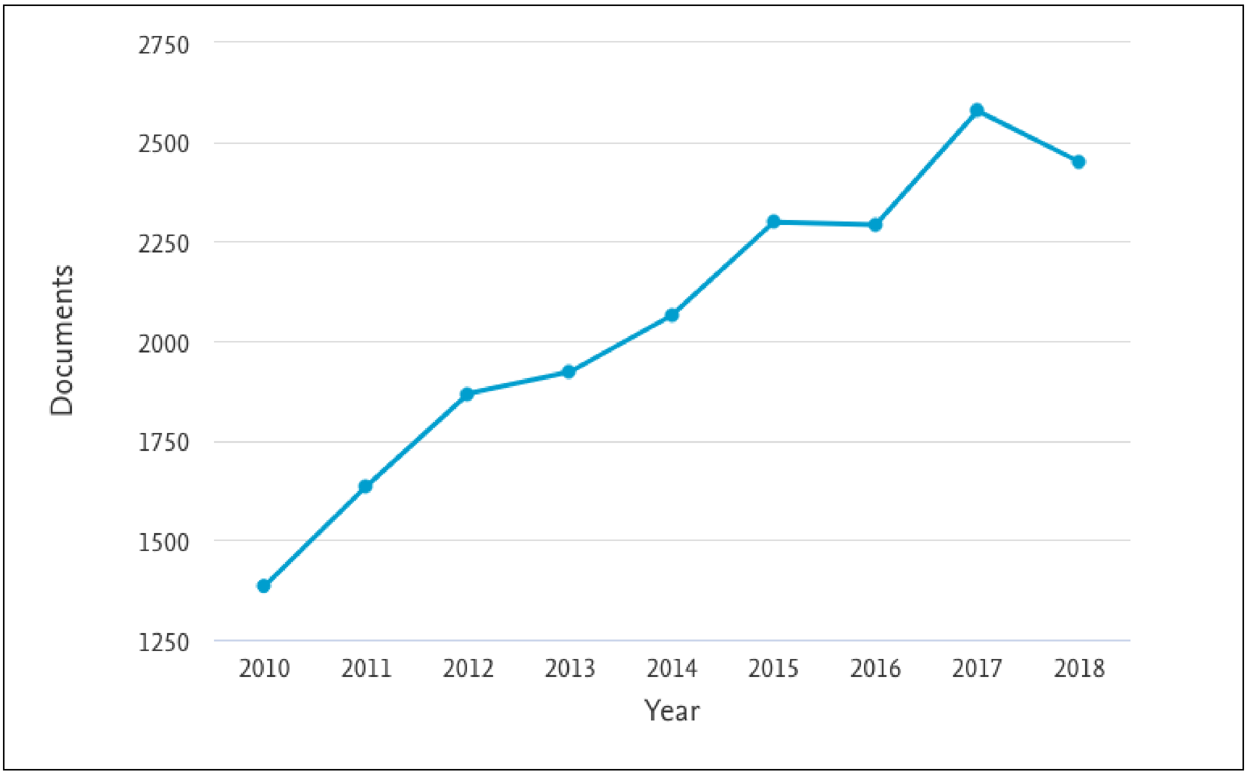
The following table includes the most often used keywords in these publications (worldwide).

Table 29: 20 Most frequently used keywords in the field of 'HPC (2010-2018)

Keyword	Frequency	Keyword	Frequency
High Performance Computing	8761	Cluster Computing	1023
Program Processors	1860	Digital Storage	948
High-performance Computing	1799	High Performance Computing Systems	938
Supercomputers	1411	Parallel Architectures	922
HPC	1400	Optimization	898
Distributed Computer Systems	1394	Energy Efficiency	885
Computer Architecture	1182	Benchmarking	839
Algorithms	1120	Big Data	832
Cloud Computing	1077	Hardware	780
Computer Software Selection and Evaluation	1073	Scheduling	774

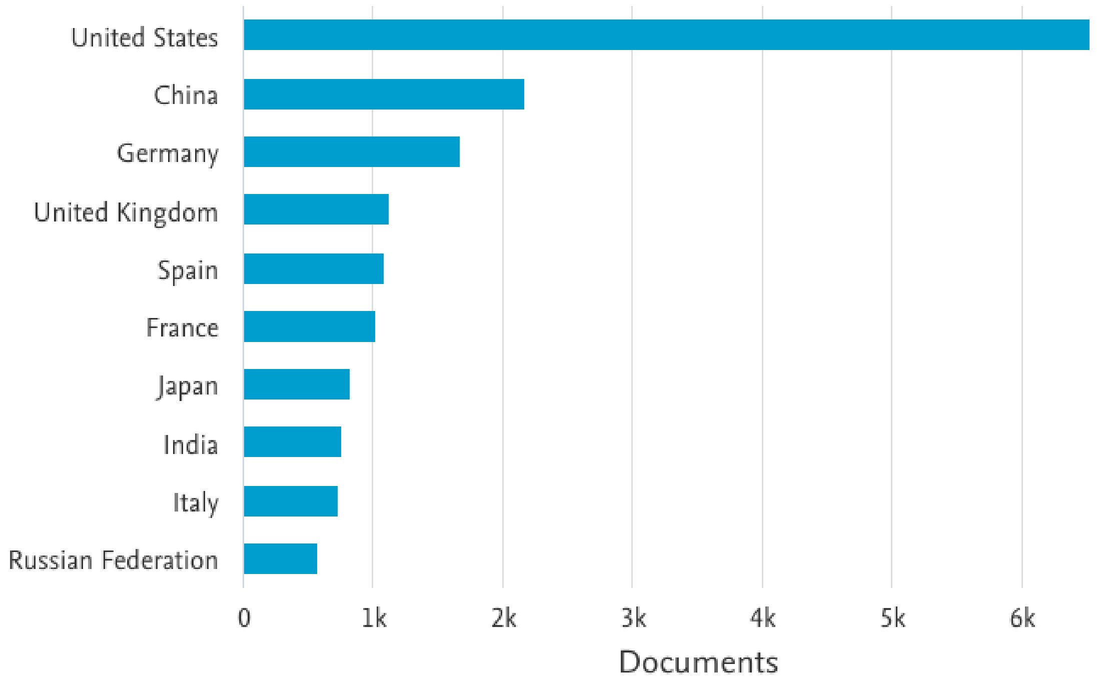
Source: Scopus, calculation: Technopolis Group. Note: the search excluded biomedical and health fields.

Figure 8: Evolution of the number of publications in 'HPC'



Source: Scopus, calculation: Technopolis Group

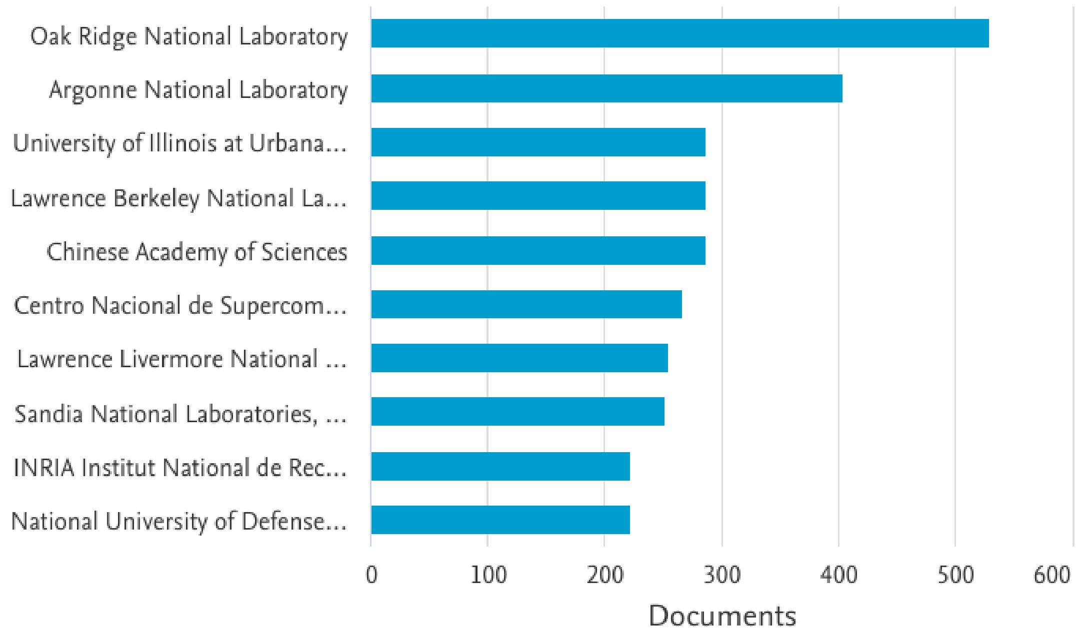
Figure 9: Main publishing countries in HPC (2010 – 2018)



Source: Scopus, calculation: Technopolis Group

In terms of leading (most prolific) organisations, we find with the Spanish National Supercomputing Centre as well as the French INRIA among the top ten. Otherwise, the field is dominated by US organisations.

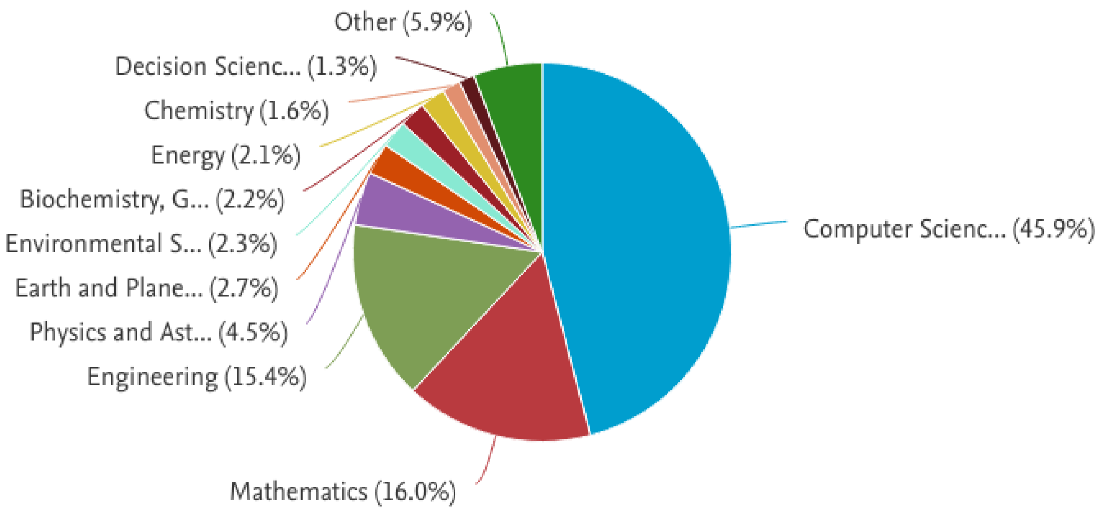
Figure 10: Top 10 most prolific organisations in the field of HPC worldwide (publications 2010-2018)



Source: Scopus, calculation: Technopolis Group

In terms of scientific disciplines which are forming the basis of this field, the following graph indicates that -unsurprisingly – computer sciences dominate, followed by mathematics and engineering.

Figure 11: Scientific disciplines forming the field



Source: Scopus, calculation: Technopolis Group

HPC and innovation

In total, a total of five patent applications were made which were associated with three projects.

Ambitions

In the area of big data, HPC gets pivotal do deal with the growing datasets and analytics. They are key infrastructure for (big) data-driven science be it in climate modelling, quantum chemistry or gene sequencing. Obviously, the scientific forefront is (still) in the US however, Europe has a number of national HPCs.

The HPC candidate's ambition is to achieve high performance computing. This is an enabling infrastructure for scientific research but also commercial applications (e.g. health).

Europe is not leading in terms of science base, but it has a number of competences through research organisations.

Appendix E Additional information related to the problem definition

E.1 Taxonomy of failures requiring policy intervention

Table 30 below provides a summary of the most relevant failures affecting the development of a competitive European HPC landscape. This summary builds on the consultations carried out in this Impact Assessment study and the substantial amount of stakeholder feedback and evidence collected in the 2018 EuroHPC Impact Assessment. This collection of identified failures ultimately results into two main drivers for the problems identified, namely **insufficient investment** and **lack of stakeholder coordination**. The following sections describe these in more detail.

Table 30: Categorisation of the problem drivers

Market failures	
Character of Science and technology (indivisibility)	The size of the technical challenge in setting out pre-exascale and exascale HPC infrastructure is too great for individual private actors and even Member States to tackle individually. The final benefits are accompanied by uncertainty, may only yield returns in the long run, and would be difficult to appropriate by single actors. All of this hampers investment.
Market power	European HPC is largely dependent on non-European HPC supply chains with the increasing risk of not having access to latest strategic technology even if resources were available
Externalities	It is too hard to appropriate enough of the results of research or innovation in new pre-Exascale and Exascale HPC architectures to make private investment worthwhile. Innovation may depend upon the presence of external networks across the supply chain, which are beyond the means of single companies or research organisations to create
Information asymmetry	Small EU companies may not have all the information needed to access HPC services. This reduces the potential demand for the service from the private sector. Only large companies may have the resources and networks to be aware of the possibility of accessing HPC
Systemic failures	
Capability	Differences between the capabilities of real firms in the EU HPC supply chain and those needed to maintain competitiveness of indigenous industry Lack of absorptive capacity of some firms (especially SMEs) to use HPC
Network	Weak integration of EU suppliers in European HPC
Institutional	Implementation of the HPC strategy not effective Fragmentation of funding instruments to deliver on the needed research agendas

	Current innovation procurement instruments not being used for HPC procurement Lock-in due to unequal treatment on public procurement (e.g. USA and China restrict the development and procurement of the high-end machines to domestic suppliers, while available clauses to do the same in Europe are not being used)
Infrastructural	Funding gap vis-a-vis main competitors (US, Japan, China)
Transformational failures	
Demand articulation	Current HPC capacity does not match scientific demand
Policy coordination	National investment and procurement plans / processes not coordinated at European level, causing inefficiencies

Source: Technopolis Group (2018), Modified from Weber & Rohracher (2012)

E.2 DG Connect baseline for the HPC market in Europe

Note: The following data is based on the IDC study[88] as well as more recent market figures published by Hyperion Research. "EU" represents the 28 Member States of the European Union. "EU+" represents the 28 Member States, plus Norway and Switzerland. Figures for the years up to and including 2013 are historical unless specified otherwise. Figures for 2014 and beyond are forecast numbers unless otherwise specified. Finally, the term "revenue" in the titles of the tables is synonymous with spending.

All HPC servers spending

In terms of GDP, the EU (€16.40 trillion) is now relatively close to the United States (€19.23 trillion).[89] However, the U.S.A. has substantially outspent the EU (and EU+) region on HPC server systems[90] and Hyperion forecasts that this pattern will continue. On the spending (consumption) side, the U.S.A. will continue to handily outspend the EU and other global regions at least through 2023 (the end of Hyperion's current forecast period).

The EU region has remained relatively consistent in the worldwide percentage with respect to the 2009 baseline (from 24-26% to 26.3% in 2019) and has outspent and will continue to handily outspend China and every global region other than the U.S.A. through 2019. Hence, where the entire HPC server market is concerned (all price points), Europe has maintained, and is forecast to maintain, relatively constant share of slightly more than one-quarter of global spending. Hyperion does not foresee these spending patterns changing markedly by the year 2023.

[88] IDC. (2015). High Performance Computing in the EU: Progress on the Implementation of the European HPC Strategy. A study prepared for the European Commission DG Communications Networks, Content & Technology.

[89] International Monetary Fund statistics. 2019

[90] All HPC servers refer to all HPC market categories, from the smallest technical servers to the biggest supercomputers

Table 31: HPC Server sales by region (US$ millions)[91]

	2018	2019	2020	2021	2022	2023	CAGR 18-23
North America	$6,342	$6,664	$6,972	$7,197	$9,185	$9,597	8.6%
EMEA	$3,978	$4,189	$4,385	$4,590	$5,322	$5,629	7.2%
EU	*$3,592*	*$3,792*	*$3,974*	*$4,212*	*$4,900*	*$5,180*	*7.6%*
Asia/Pacific w/o Japan	$2,349	$2,488	$2,605	$2,739	$3,233	$3,414	7.8%
Japan	$768	$772	$784	$1,549	$899	$913	3.5%
Rest-of-World	$269	$291	$304	$318	$352	$368	6.5%
Total	**$13,706**	**$14,405**	**$15,050**	**$16,393**	**$18,993**	**$19,922**	**7.8%**
Share							
North America	46.27%	46.26%	46.33%	43.90%	48.36%	48.17%	
EMEA	29.02%	29.08%	29.14%	28.00%	28.02%	28.26%	
EU	26.21%	26.32%	26.41%	25.69%	25.80%	26.00%	
Asia/Pacific w/o Japan	17.14%	17.27%	17.31%	16.71%	17.02%	17.14%	
Japan	5.60%	5.36%	5.21%	9.45%	4.73%	4.58%	
Rest-of-World	1.96%	2.02%	2.02%	1.94%	1.85%	1.85%	

Source: Hyperion Research 2019

The HPC market share per segment: systems over €2.25 million

Supercomputers sold for €2.25 million and up are the most important class for advanced scientific and engineering work. These supercomputers are a high-end subset of the overall Supercomputers category discussed in the prior section. Spending levels for these high-end supercomputers are therefore also an important measure of HPC leadership. When considering these findings, **it is important to note that spending in this small but strategically important high-end market can vary greatly from year to year**, because it is driven by a small number of large financial transactions that are subject to non-annual, cyclical renewals.

Table 32: Number of EU systems in the world top 10 and top 20

	Top 10 # EU Systems	Top 20 # EU Systems
2019	1	5
2018	0	3
2017	0	5

[91] Hyperion Research. (2019). Research Highlights in HPC, HPDA-AI, Cloud Computing, Quantum Computing, and Innovation Award Winners. Presented at the ISC High Performance 2019, June 18.

	Top 10 # EU Systems	Top 20 # EU Systems
2016	0	4
2015	1	3
2014	1	7
2013	2	6
2012	4	7
2011	1	2
2010	1	4

Source: TOP500, November 2019

The EU has only one supercomputer in the top 10 and five in the top 20 (June 2019), dropping from a peak 4 and 7 systems in 2012. Spending increased substantially in the EU/EU+ for large supercomputers from 2009 to 2012 thanks mainly to the PRACE procurements (112 million euros in 2009, to 658 million in 2012), but then declined (down to 362 million euros in 2014).

In the period 2009-2014, worldwide spending on large supercomputers grew by 25.9% to reach €1.2 billion. Growth for specific regions often varied greatly from year to year. 2012 was an atypically strong year, owing especially to several major new installations in Europe, China and Japan, the largest of which (Japan's K supercomputer and China's Tianhe 2 system) alone added €400 million and €237 million in spending, respectively. More recently, total HPC spending (including public cloud spending) grew from $22b in 2013, to $26b in 2017, and is projected to reach $44b in 2022.[92]

As of 2018, the HPC market segments can be divided in supercomputers, divisional, departmental, and workgroup systems. EU-specific revenues for 2018-2023 associated with these segments are presented below.[93] While supercomputers and departmental systems are currently the largest segments, the strongest growth is forecasted by Hyperion in Divisional and Workgroup systems with CAGRs of 21.8% and 11.4% respectively for 2018-2023. Overall EU revenues across all segments are associated with a CAGR of 7.6% for the same timeframe.

Table 33: EU only Technical Computer Market Revenue Forecast by Competitive Segments

	2018	2019	2020	2021	2022	2023	CAGR 18-23
Supercomputer (>$500,000)	$1,611	$1,760	$1,845	$1,955	$1,523	$1,610	0.0%
Divisional ($500,000-$250,000)	$457	$460	$482	$511	$1,156	$1,222	21.8%
Departmental	$1,055	$1,084	$1,136	$1,204	$1,459	$1,542	7.9%

[92] Hyperion Research. (2019). Research Highlights in HPC, HPDA-AI, Cloud Computing, Quantum Computing, and Innovation Award Winners. Presented at the ISC High Performance 2019, June 18.

[93] Ibid.

	2018	2019	2020	2021	2022	2023	CAGR 18-23
($250,000-$100,000)							
Workgroup (<$100,000)	$470	$488	$512	$542	$761	$805	11.4%
EU-Only Total	**$3,592**	**$3,792**	**$3,974**	**$4,212**	**$4,900**	**$5,180**	**7.6%**

Source: Hyperion Research 2019

The Rest of the HPC Ecosystem: Beyond the HPC Servers

Regarding the HPC overall budget (server systems, storage, middleware, applications software, and service), computer hardware remains the largest item in the HPC budget. During the period 2013-2018, European revenues in the broader HPC ecosystem grew from $5.6b to $7.1b (or from 24.4% to 25.6% of worldwide revenues) and are expected to grow to $10.2b (a worldwide share of 25.9%) by 2023 based on Hyperion forecasts. Spending on HPC servers represented 50.5% of total EU spending on the HPC ecosystem in 2018.

Table 34: EU Revenues by the Broader HPC Market Areas

	2018	2019	2020	2021	2022	2023	CAGR 18-23
Server	$3,592	$3,792	$3,974	$4,212	$4,900	$5,180	7.6%
Storage	$1,400	$1,498	$1,570	$1,663	$1,906	$2,015	7.6%
Middleware	$395	$425	$445	$472	$544	$575	7.8%
Applications	$1,150	$1,217	$1,276	$1,352	$1,573	$1,663	7.7%
Service	$542	$571	$598	$634	$701	$741	6.5%
Total Revenue	$7,080	$7,503	$7,863	$8,332	$9,624	$10,174	7.5%

Source: Hyperion Research 2019

Hyperion forecasts that European HPC ecosystem spending will increase by 43.7% (7.5% CAGR) between 2018 and 2023 which is slightly higher than the projected global growth of 41.7% (7.2% CAGR). Furthermore, the EU is expected to have particularly strong relative growth in terms of applications and services in comparison to global revenues in said areas.

Table 35: Global revenues by the Broader HPC Market Areas

	2018	2023	CAGR 18-23
Server	13,706,088	19,979,016	7.8%
Storage	5,547,188	7,771,184	7.0%
Middleware	1,582,892	2,217,801	7.0%
Applications	4,627,492	6,431,592	6.7%
Service	2,229,921	2,858,820	5.1%
Total Revenue	27,693,580	39,240,413	7.2%

Source: Hyperion Research 2019

HPC supply in Europe

U.S.A. vendors represented 89.6% of all European (EU+) HPC server system revenue/spending in 2009 and 81.2% in 2014. The only sizeable Europe-based vendor, Atos (formerly Bull), accounted for 1.7% of spending in 2009 and 2.0% in 2014. In its largest revenue year during this period, 2011, however, Atos/Bull captured 9.7% of European HPC server system revenue. U.S.A. HPC system vendors have the lion's share of the European market today, but Atos' acquisition of Bull may create a stronger competitor for U.S.A. (and other non-European) HPC vendors over a longer period.

Market share for U.S.A. vendors declined slightly from 95.0% in 2009 to 93.2% in 2014 in the more strategic supercomputer category (HPC systems sold for €360000 or more). IBM and HP were the strong leaders in this segment. Atos/Bull market share grew slightly from 4.2% in 2009 to 4.5% in 2014, but had a peak of 18.6% market share in 2011.

Regarding the strategic category of high-end supercomputers (sold for €2.25 million or more) during the historical period 2009-2014, U.S.A. vendors captured 86.9% of European revenue in this category in 2009 and 96.7% in 2013 (the most recent year for which IDC had European revenue figures for this category). In 2009, revenue for IBM alone accounted for 66.7% of European revenues, while Atos/Bull had a 4.58%. In 2014, combined revenue for IBM and HP represented 58.9% of European revenue. Cray had an exceptionally strong 2014 in Europe and accounted for 39.2% of revenue in this high-end category. In 2011, Atos/Bull had an exceptional year and captured 20.3% of European high-end supercomputer revenue, while in 2013 it reduced to 3.33%.

Currently, HPE has by far the largest share of the EU HPC market out of all vendors, accounting for more than 55%. The second most prominent vendor, Dell EMC, represents 19.7% of the market. Europe's one and only vendor, Atos, accounts for a mere 4.1% of the European market.

Table 36: EU HPC Market by vendor shares

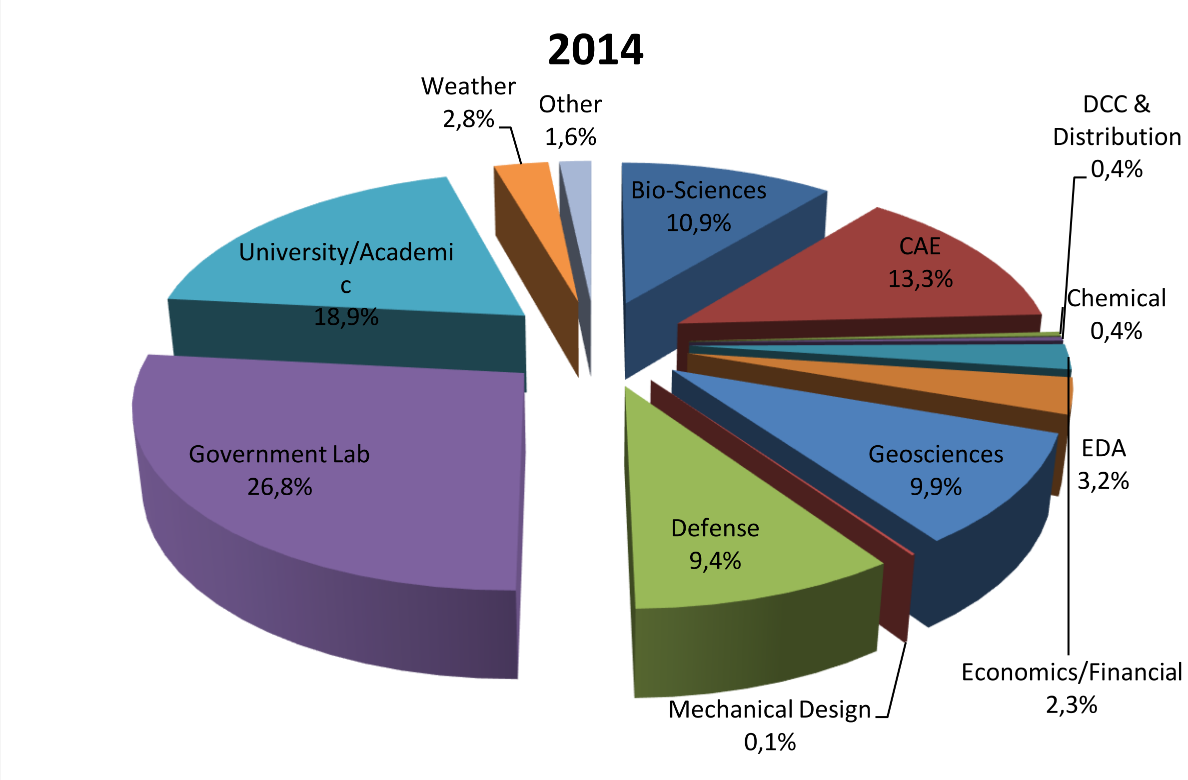
OEM	2019 shared of sales
HPE	55.3%
Dell EMC	19.7%
Lenovo	8.7%
Other	6.9%
Atos	4.1%
IBM	3.8%
Cray	0.9%

Source: Hyperion Research

Application sectors

In 2014 European spending for HPC systems was distributed over the following main industry/application sectors (according to the IDC split of sectors):

Figure 12: Distribution of European spending for HPC systems in 2014



Source: Hyperion Research 2019

For the five-year forecast period 2013-2018, IDC predicts that the strongest growth will occur in computer-aided engineering (CAE), which is heavily used in the manufacturing sector. Other predicted fast-growth areas including weather/climate (7.6%), government labs/centres (7.6% CAGR), chemical engineering (7.2% CAGR), academia (7.0% CAGR) and geosciences (6.9% CAGR). Geosciences use today is primarily related to "upstream" oil and gas exploration and will secondarily for alternative energy research. The largest segments for EU HPC spending in 2018 will be, sequentially, government labs/centres, academia, CAE, bio-sciences, and geosciences.

In 2018 EU spending for HPC systems was distributed over the main industries/application sectors presented below.[94] The most significant areas of application were government labs, universities and academia, computer aided engineering (CAE), and geosciences. Between 2018 and 2023, Hyperion forecasts the strongest growth in government labs (8.8% CAGR), mechanical design (8.4% CAGR), and university and academia (8.1% CAGR).

Table 37: Worldwide HPC Systems Revenue by Applications (US$ million)

	2018	2019	2020	2021	2022	2023	CAGR 18-23
Government Lab	$986	$1,037	$1,086	$1,221	$1,421	$1,502	8.8%
University/Academic	$681	$717	$751	$817	$951	$1,005	8.1%
CAE	$484	$518	$543	$535	$623	$658	6.4%
Geosciences	$353	$372	$390	$411	$479	$506	7.4%

[94] Hyperion Research. (2019). Research Highlights in HPC, HPDA-AI, Cloud Computing, Quantum Computing, and Innovation Award Winners. Presented at the ISC High Performance 2019, June 18.

	2018	2019	2020	2021	2022	2023	CAGR 18-23
Defence	$337	$356	$373	$389	$452	$478	7.2%
Bio-Sciences	$364	$386	$404	$385	$447	$473	5.4%
EDA	$115	$121	$127	$135	$158	$167	7.6%
Weather	$103	$109	$114	$121	$140	$148	7.5%
Economics/Financial	$82	$87	$91	$97	$113	$120	7.8%
Other	$57	$60	$63	$65	$76	$81	7.2%
Chemical Engineering	$14	$14	$15	$16	$18	$19	7.4%
DCC & Distribution	$13	$14	$14	$15	$18	$19	7.5%
Mechanical Design	$3	$3	$3	$4	$4	$5	8.4%
EU-Only Total	$3,592	$3,792	$3,974	$4,212	$4,900	$5,180	7.6%

Source: Hyperion Research 2019

Other elements in the HPC ecosystem

Parallel Software

Europe is already strong in important areas of parallel software development, and a global leader in this area of the supporting Computer Science; some of Europe's best firms are ahead of their international competitors in exploiting HPC for innovation. The worldwide commercial market for HPC software[95] was worth €4.4 billion in 2013. IDC estimates that the European portion of global spending in this market closely matched Europe's portion of global spending in the HPC server market (~27%) and was therefore worth roughly €1.2 billion in 2013. IDC forecasts that the **worldwide HPC software market will expand to about €6.4 billion in 2018 and European spending in this market will be about €1.7 billion**.

Companies such as Allinea (UK), Bright Computing (Netherlands), Dassault Systèmes (France), Schrödinger (Germany), and others have demonstrated that European software vendors can achieve notable success in both the European and global HPC markets. IDC estimates that European independent software vendors (ISVs) today represent 15-20% of the global HPC market for ISV software, and 25-30% of the European market.

The situation regarding highly parallel software in Europe has not changed markedly since 2011.[96]

- The vast majority (83%) of the most important parallel software applications in use at the surveyed European HPC sites were created in Europe. Intellectual property rights for a substantial majority of the sites' most important application codes (66%) were exclusively owned by European organizations. But many of these important codes are used only by one or a handful of HPC sites.

[95] IDC. (2015). High Performance Computing in the EU: Progress on the Implementation of the European HPC Strategy. A study prepared for the European Commission DG Communications Networks, Content & Technology.

[96] IDC Study "Financing a Software Infrastructure for Highly Parallelised Codes"

- Europe has a number of globally successful scientific and engineering software firms, a larger number of nationally and regionally successful software firms, and is strong in many important areas of parallel software development. In addition, great strides have been made within initiatives such as CRNS, INRIA, Germany's Special Programme on Exascale Computing, and others, as well as within large industrial firms such as Daimler, EDF, Airbus, and quite a few others. Where extreme-scale software is concerned, however, Europe (like the rest of the world) has been overly focused on funding parallel hardware to the detriment of parallel software, and on "big science" in comparison with industry.
- Where funding has been made available for parallel software development, the funding typically has been for only a year or two, compared with at least 5-10 years of funding needed to develop robust, production-quality software that can remain useful for 10-20 or even 30 years and across multiple generations of HPC hardware systems.

HPC and Clouds

Worldwide, the proportion of sites exploiting cloud computing to address parts of their HPC workloads rose[97] from 13.8% in 2011 to over 70% in 2019. Furthermore, over 10% of all HPC jobs are now running in clouds.

Although European cloud use for HPC was not always separable—some clouds are multi-continental or worldwide—it was clear that the percentages in Europe closely matched global counterparts. IDC projected that HPC cloud use would double in 2015 from a modest base, especially as advances in virtualization capabilities becoming more efficient and HPC-friendly.

IDC research indicated that HPC usage within public clouds are was best suited for highly parallelized workloads, and accordingly, such workload use is seeing some of the fastest growth rates within the cloud especially from new or first time commercial HPC users. However, there will be a growing emphasis within the cloud service sector to target the HPC user base looking to solve more traditional modelling and simulations problems that are not as easily parallelized, and. as a result, IDC expects to see even more cloud centres offering dedicated HPC hardware. Currently, the particulars for pricing models for these new HPC-centric cloud systems are in flux.

The EU has an overall plan for general-purpose cloud computing.[98] To move forwards, EU HPC leadership should embrace cloud-based HPC as an integral element in any HPC-related program, both for so-called capacity computing and for capability computing (as public clouds evolve sufficiently to support more capability computing).

Cloud-base access, by its very nature, offers the ability for EU HPC leadership to acquire and provision flexible, on-demand HPC cycles to a wide range of potential users from government, academia, and industry, in a relatively low cost environment **–helping the "democratisation of HPC"**. Such capabilities will be especially important for potential new users and SMEs that are not wholly committed to or technically capable of justifying an in-house HPC capability, and that can benefit from easy-to-use, on-demand Cloud-access HPC services and pay as they use them.

Hyperion[99] forecasts that spending in public clouds will increase from less than $1,000m in 2013 to over $5,000m by 2022.

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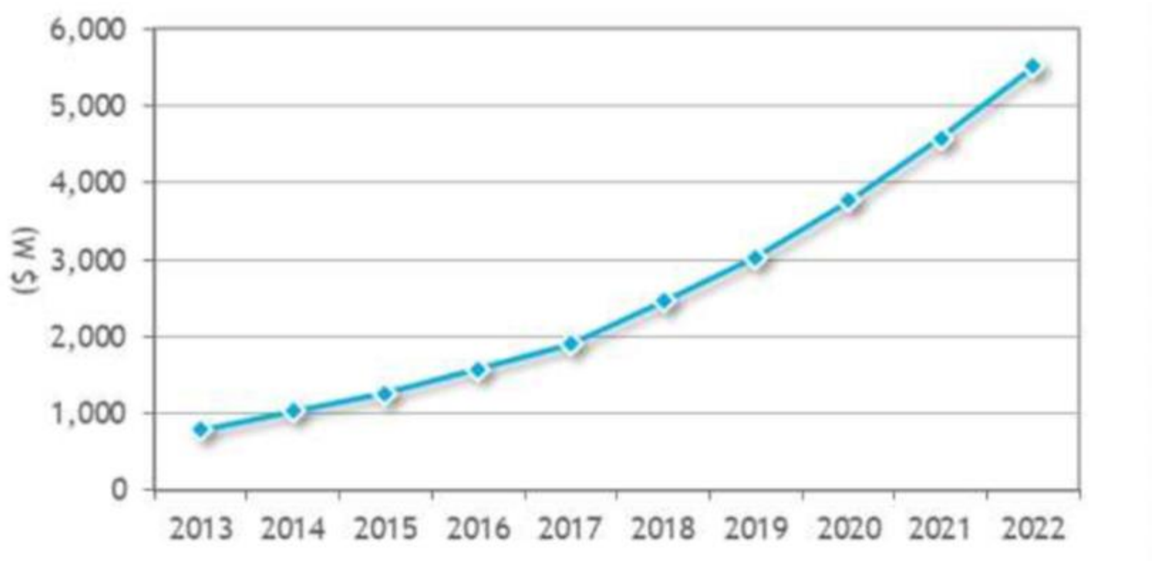
[97] IDC Worldwide Study of HPC End-User Sites. 2013.

[98] Communication " *Unleashing the Potential of Cloud Computing in Europe",* COM(2012) 529 final

[99] Hyperion Research. (2019). Research Highlights in HPC, HPDA-AI, Cloud Computing, Quantum Computing, and Innovation Award Winners. Presented at the ISC High Performance 2019, June 18.

Figure 13: Project spending in public clouds for HPC applications



Source: Hyperion

High-Performance Data Analytics (HPDA)

Another important new area for the European HPC ecosystem is high performance data analysis (HPDA). HPDA is a term to describe the convergence of the established data-intensive HPC market and the high-end commercial analytics market that is starting to move up to HPC resources. The HPDA market represents the convergence of long-standing, data-intensive modelling and simulation methods in the HPC industry/application segments, and newer high performance analytics methods that are increasingly employed in these segments as well as by commercial organizations that are adopting HPC for the first time. HPDA may employ either long-standing numerical methods, newer methods such as large-scale graph analytics, semantic technologies, and knowledge discovery algorithms, or some combination of long-standing and newer methods.

HPC is used for advanced data analytics to spot patterns in hour-by-hour weather observations and domestic fight data to help airlines manage more efficiently the scheduling[100]*. Data may be used to build computer modelling software that could predict the outcome of an infinite number of hypothetical flight and weather scenarios, helping airlines spot likely weather delays in advance. That knowledge could enable airlines to adjust their schedules to account for weather patterns. It may also lead to better communication with travellers and a less stressful flight experience.*

HPC server spending dedicated to high performance data analysis (HPDA) refers to HPC servers purchased primarily to run data-intensive simulation or analytics workloads. **Hyperion forecasts that worldwide revenue for HPDA servers will grow robustly (15.4% CAGR) during the period 2018–2023, increasing from £3/1 million to about $6.4 billion in 2023 (see table below)**. This is more than double the forecasted growth rate of the worldwide HPC server market as a whole. Europe's share of this HPC-related market is similar to Europe's share of the HPC server system market as a whole, about one-quarter of the global total.

HPDA requirements are increasing in many scientific domains and are driving more commercial companies, including SMEs, to exploit HPC technology for the first time. 67%

[100] http://hpc-asia.com/big-data-reduce-holiday-flight-delays/

of the HPC sites said[97] they use HPC systems for HPDA, and that HPDA use consumes 30% of their HPC cycles on average. The same study found that 23.5% of the HPC sites were using cloud computing to address parts of their HPC workloads rose, with public and private cloud use about equally represented among the sites.

The convergence of HPC and big data analytics is being driven by HPC users and the growing contingent of commercial firms that are adopting HPC solutions to tackle data analytics jobs that are too complex or time critical for enterprise IT resources to handle efficiently and cost effectively. In addition:

- Within the HPC ranks, HPDA is already becoming mission critical in the government, academic, manufacturing, energy, weather/climate, life sciences, and digital content creation markets — not to mention high frequency trading as an important addition to existing HPC-driven financial services applications.
- Many commercial firms have moved up to HPC for the first time for advanced business analytics/business intelligence, fraud/error/anomaly detection, real-time affinity marketing, and other applications. Even though the existing HPC solutions they use may not be explicitly designed to excel at data analytics, it is not unusual for these firms to save $10 million or more per year from upgrading to HPC sold for a fraction of that amount

Hyperion[101] identifies HPD as a high growth area as of May 2019. Moreover, HPDA is growing faster (15.4%) than the overall HPC market (7.8%). In addition, the AI subset is growing faster (29.5%) than the entire HPDA segment (15.4%).

Table 38: Worldwide HPC-based AI revenues vs total HPDA revenues (US$ million)

	2018	2019	2020	2021	2022	2023	CAGR 18-23
HPC Server Revenues	13,706	14,195	17,780	17,736	18,983	19.947	7.8%
HPDA Server Revenues	3,153	3,598	3,932	4,737	5,467	6,450	15.4%
HPC-based AI (ML, DL, and Other)	747	938	1,094	1,399	1,810	2,725	29.5%

Source: Hyperion Research 2019

[101] Hyperion Research. (2019). Research Highlights in HPC, HPDA-AI, Cloud Computing, Quantum Computing, and Innovation Award Winners. Presented at the ISC High Performance 2019, June 18.

Appendix F Additional information related to the objectives definition

F.1 Type and composition of the actors involved

In order to obtain an overview of the major HPC stakeholders in Europe in addition to the aforementioned value chain, a composition analysis was conducted, based on the eCorda database. This allows us to analyse who was already heavily involved in HPC-related activities under H2020 and the cPPPs, from the perspective of the largest recipients of Horizon 2020 funding. As can be seen in Table 39, the top 10 recipients are primarily public HPC centres and universities.

Table 39: Top 10 recipients of H2020 funding for HPC

Participant Legal Name	Type stakeholder	Country	Total EU contributions (€)
Barcelona Supercomputing Centre	REC	Spain	10,440,427
The University of Manchester	HES	UK	8,884,361
Jülich Research Centre	REC	Germany	7,604,679
Alternative Energies and Atomic Energy Commission (CEA)	REC	France	6,475,816
Bull/Atos	PRC	France	6,092,265
The University of Edinburgh (EPCC)	HES	UK	6,052,590
KTH Royal Institute of Technology	HES	Sweden	5,578,689
Iceotope Research & Development	PRC	UK	5,549,544
European Centre for Medium-Range Weather Forecasts (ECMWF)	REC	UK	5,068,198
Foundation for Research & Technology – Hellas (FORTH)	REC	Greece	4,926,717

REC = research centres (public), HES = higher education (universities), PRC = private research companies
Source: Technopolis analysis based on the eCorda database

Table 40 lists the top 10 EU-based firms engaged in Horizon 2020, sorted in descending order by total value of EU contributions to HPC-related contract awards. Aside from Bull/Atos as the biggest recipient, the major recipients are either located in the UK or in Germany. In several cases, the companies are European branches of non-EU companies such as Arm (now owned by the Japanese Softbank Group), Fujitsu and Intel.

Table 40: Top 10 private companies receiving H2020 funding for HPC

Participant Legal Name	Country	Total EU contributions
Bull/Atos	France	6,092,265
Iceotope Research & Development	UK	5,549,544
Seagate Systems	UK	4,468,768
MEGWARE	Germany	4,236,097
Arm	UK	3,566,888
Fujitsu	Germany	2,785,000
Intel	Germany	2,219,316
Maxeler Technologies	UK	2,125,000
Pro Design Electronic	Germany	1,860,964
EXTOLL	Germany	1,651,590

Source: Technopolis analysis based on the eCorda database

The great majority of these public and private sector organisations are currently involved in the EuroHPC JU, either directly or indirectly as active members of their respective HPC industry associations. Some of the organisations listed are not involved in the EuroHPC JU but are involved in related initiatives such as the Fortissimo project (including KE-works, Noesis, rbf-morph, and Algo'Tech) or the European Processor Initiative (such as EXTOLL). Organisations with no formal involvement in the EuroHPC JU or other initiatives are independent HPC providers such as GOMPUTE and CPU 24/7 or individual users such as the Energy Solution Centre (ENSOC), Albatern, and Daimler.

Based on our review of the HPC landscape, we identified six stakeholder groups that need to be involved in any future partnership on HPC. These are currently involved in the EuroHPC Joint Undertaking and align with the groups consulted for this Impact Assessment study:

- European associations involved in furthering research agendas
- Industrial stakeholders developing HPC technologies
- Infrastructure providers
- Intermediary organisations providing access to a range of users
- Member States (MS) and the European Commission (EC)
- End-users using HPC resources, in research and industrial application domains

Table 41 shows the stakeholder groups involved in HPC initiatives at a European level.

Table 41: Stakeholder groups to be involved in the partnership

Stakeholder group	Stakeholder	Function	Expertise/focus
Current JU	EuroHPC	JU	Members of Boards and CEO Setup of partnership / policy options
Research	ETP4HPC	Industry association involved in cPPP	Exascale technologies

Stakeholder group	Stakeholder	Function	Expertise/focus
	BDVA	Industry association involved in cPPP	Data
	HiPEAC	Research network	High performance and embedded architecture and compilation
	EPI	Technology initiative	low-power European processors for extreme scale computing and high-performance Big-Data
Industry	ETP4HPC members	Industry association	Exascale technology, its members are part of the supply chain being supported through the initiative
	BDVA members	Industry association	Data, its members are part of the supply chain being supported through the initiative
Infrastructure	PRACE	Partnership	Advanced computing
	GÉANT	Pan-European network	Connectivity between national research networks
MS/PS	Signatories of the EuroHPC declaration	MS	Procurement
EC	DG-CNECT & DG-RTD	EC	Policy context
Intermediaries	FocusCoE	Platform for all CoEs	Interaction with industry & SMEs
	HPC Supercomputing centres	Intermediaries	Provision of HPC resources
	EXDCI	Coordination project	Extreme data and computing
Downstream and End-users	Users in the public sector (research, government departments / agencies)	End-users	Users of HPC facilities in different application domains
	Users in the private sector (industry, SMEs, industry consortia)	End-users	Users of HPC facilities in different application domains

Appendix G Additional information related to the policy options descriptions

G.1 Degree of coverage of the different functionalities by policy option

Table 42: Type and composition of actors (including openness and roles)

Option 0: Horizon Europe calls	Option 2: Co-funded	Option 3: Institutionalised Art 185	Option 1: Co-programmed	Option 3: Institutionalised Art 187
What is possible? *Any legal entity* in a consortiu**m** can apply to Horizon Europe calls in ad hoc combinations Calls are open to participation from across Europe and the world (not all entities from third countries are eligible for funding)	***What is possible?*** Partners can include *any national funding body or governmental research organisation*, Possible to include also *other type of actors*, including foundations.	***What is possible?*** Partners can include *MS and Associated Countries*.	***What is possible?*** Suitable for *all types of partners*: private and/or public partners, including MS, regions, foundations. By default open to AC/ 3rd countries, but subject to policy considerations. Can cover a *large and changing community.* HE rules apply by default to calls included in the FP Work Programme, so any legal entity can apply to these.	***What is possible?*** Suitable for *all types of partners*: private and/or public partners, including MS, foundations. By default open to legal entities from AC/ 3rd countries, but subject to policy considerations. In case of countries participating non-associated third countries can only be included as partners if foreseen in the basic act and subjected to conclusion of dedicated international agreements HE rules apply by default, so any legal entity can apply to partnership calls.

Option 0: Horizon Europe calls	Option 2: Co-funded	Option 3: Institutionalised Art 185	Option 1: Co-programmed	Option 3: Institutionalised Art 187
What is limited? Systematic/ structured engagement with public authorities, MS, regulators, standard making bodies, foundations and NGOs.	***What is limited?*** Requires substantial national R&I programmes (competitive or institutional) in the field. Usually only legal entities from countries that are part of the consortia can apply to calls launched by the partnership, under national rules.	***What is limited?*** Non-associated third countries can only be included as partners if foreseen in the basic act and subjected to conclusion of dedicated international agreements. Needs good geographical coverage – participation of at least 40% of Member States is required Requires substantial national R&I programmes (competitive or institutional) in the field. While by default the FP rules apply for eligibility for funding/participation, in practice (subject to derogation) often only legal entities from countries that are Participating States can apply to calls launched by the partnership, under national rules.	***What is limited?*** If MS launch calls under their responsibility, usually only legal entities from countries that are part of the consortia can apply to these, under national rules	***What is limited?*** Requires a *rather stable set of partners* (e.g. if a sector has small number of key companies). Basic act can foresee exceptions for participation in calls / eligibility for funding.
What is not possible? To have a joint programme of R&I activities between the EU and committed partners that is implemented based on a common vision.	***What is not possible?*** To have industry/ private sector as partners.	***What is not possible?*** To have industry/ private sector as partners.	***What is not possible?***	***What is not possible?***

Table 43: Type and range of activities (including flexibility and level of integration)

Option 0: Horizon Europe calls	Option 2: Co-funded	Option 3: Institutionalised Art 185	Option 1: Co-programmed	Option 3: Institutionalised Art 187
What is possible? Horizon Europe standard actions that allow *broad range of individual activities* from R&I to TRL 7 or sometimes higher. Calls for proposals published in the Work Programmes of Horizon Europe (adopted via comitology).	***What is possible?*** Activities may range from R&I, pilot, deployment actions to training and mobility, dissemination and exploitation, but according to national programmes and rules. Decision and implementation by "beneficiaries" (partners in the co-fund grant agreement) e.g. through institutional funding programmes, or by "third parties" receiving financial support, following calls for proposals launched by the consortium.	***What is possible?*** Horizon Europe standard actions that allow a broad range of coordinated activities from R&I to uptake. In case of implementation based on national rules (subject to derogation) Activities according to national programmes and rules. Allows integrating national funding and Union funding into the joint funding of projects	***What is possible?*** *Horizon Europe standard actions* that allow a broad range of coordinated activities from R&I to uptake. The association representing private partners allows to continuously build further on the results of previous projects, including activities related to regulations and standardisation and developing synergies with other funds Union contribution is implemented via calls for proposals published in the Work Programmes of Horizon Europe based on the input from partners (adopted via comitology). Open and flexible form that is simple and easy to manage.	***What is possible?*** *HE standard actions* that allow to build a portfolio with broad range of activities from research to market uptake. The back-office allows dedicated staff to implement integrated portfolio of projects, allowing to build a "system" (e.g. *hydrogen*) via pipeline of support to accelerate and scale up the take-up of results of the partnership, including those related to regulations and standardisation and developing synergies with other funds. E.g. setting up biorefinery plants and promoting their replication by additional investments from MS/ private sector. Procuring/purchasing jointly used equipment (e.g. HPC) Allows integrating national funding and Union funding into the joint funding of projects
What is limited?	***What is limited?*** Scale and scope of the programme the resulting funded R&I actions and depend on the participating programmes, typically		***What is limited?*** Limited control over precise call definition, resulting projects and outcomes, as they are implemented by EC agencies.	***What is limited?*** Limited flexibility because objectives, range of activities and partners are defined in the Regulation, and negotiated in the Council (EP).

Option 0: Horizon Europe calls	Option 2: Co-funded	Option 3: Institutionalised Art 185	Option 1: Co-programmed	Option 3: Institutionalised Art 187
	smaller in scale than FP projects			
What is not possible? To design and implement in a systemic approach a portfolio of actions. To leverage additional activities and investments beyond the direct scope of the funded actions				

Table 44:Directionality

Option 0: Horizon Europe calls	Option 2: Co-funded	Option 3: Institutionalised Art 185	Option 1: Co-programmed	Option 3: Institutionalised Art 187
What is possible? Strategic Plan (as implementing act), annual work programmes (via comitology). Possible also to base call topics on existing or to be developed SRIA/roadmap	***What is possible?*** Strategic R&I agenda/roadmap agreed between partners and EC Annual work programme drafted by partners, approved by EC Objectives and commitments are set in the Grant Agreement.	***What is possible?*** Strategic R&I agenda/roadmap agreed between partners and EC Objectives and commitments are set in the legal base. Annual work programme drafted by partners, approved by EC Commitments include obligation for financial contributions (e.g. to administrative costs, from national R&I programmes).	***What is possible?*** Strategic R&I agenda/roadmap agreed between partners and EC Objectives and commitments are set in the contractual arrangement. Input to FP annual work programme drafted by partners, finalised by EC (comitology) Commitments are political/best effort, but usually fulfilled	***What is possible?*** Strategic R&I agenda/roadmap agreed between partners and EC Objectives and commitments are set in the legal base. Annual work programme drafted by partners, approved by EC (veto-right in governance) Commitments include obligation for financial contributions (e.g. to administrative costs, from national R&I programmes).
What is limited? No continuity in support of priorities beyond the coverage of the strategic plan (4 years) and budget (2 years Annual work programme).				
What is not possible? Coordinated implementation and funding linked to the concrete objectives/ roadmap, since part of overall project portfolio managed by agency				

Table 45: Coherence (internal and external)

Option 0: Horizon Europe calls	Option 2: Co-funded	Option 3: Institutionalised Art 185	Option 1: Co-programmed	Option 3: Institutionalised Art 187
What is possible? Coherence between different parts of the Annual Work programme of the FP ensured by EC	***What is possible?*** Coherence among partnerships and with different parts of the Annual Work programme of the FP can be ensured by partners and EC Synergies with national/regional programmes and activities	***What is possible?*** Coherence among partnerships and with different parts of the Annual Work programme of the FP can be ensured by partners and EC Synergies with national/regional programmes and activities Synergies with other programmes	***What is possible?*** Coherence among partnerships and with different parts of the Annual Work programme of the FP can be ensured by partners and EC If MS participate: Synergies with national/regional programmes and activities Synergies with industrial strategies	***What is possible?*** Coherence among partnerships and with different parts of the Annual Work programme of the FP can be ensured by partners and EC Synergies with other programmes or industrial strategies If MS participate: Synergies with national/regional programmes and activities
What is limited? Synergies with other programmes or industrial strategies	***What is limited?*** Synergies with other programmes or industrial strategies	***What is limited?*** Synergies with industrial strategies	***What is limited?*** Synergies with other programmes	
What is not possible? Synergies with national/regional programmes and activities				

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