INNOVATION FINANCE ADVISORY STUDIES

Financing the future of **supercomputing**

How to increase investments in high performance computing in Europe

European Commission

European Investment Bank

The EU bank

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Prepared for:
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Foreword

"Disruptive technologies are key enablers for economic growth and competitiveness"

The Digital Economy is developing rapidly worldwide. It is the single most important driver of innovation, competitiveness and growth. Digital innovations such as supercomputing are an essential driver of innovation and spur the adoption of digital innovations across multiple industries and small and medium-sized enterprises, fostering economic growth and competitiveness. Applying the power of supercomputing combined with Artificial Intelligence and the use of Big Data provide unprecedented opportunities for transforming businesses, public services and societies.

High Performance Computers (HPC), also known as supercomputers, are making a difference in the everyday life of citizens by helping to address the critical societal challenges of our times, such as public health, climate change and natural disasters. For instance, the use of supercomputers can help researchers and entrepreneurs to solve complex issues, such as developing new treatments based on personalised medicine, or better predicting and managing the effects of natural disasters through the use of advanced computer simulations.

The study shows that the use of supercomputing is growing rapidly for research and development purposes, and in support of concrete industrial and commercial applications across a broad range of sectors, such as automotive, renewable energy and health. Based on the rapid growth of Big Data, the demand for HPC is expected to increase considerably in the coming years with digitalised business models and innovation propelling Europe's industry to leap forward into the next generation of technological advancement.

The potential is enormous, but challenges remain. A key challenge is to close the investment gap in Europe and to ensure that businesses, public sector authorities and researchers have equal access to supercomputing facilities and services. In fact, while a third of the global demand for HPC capabilities comes from European industry, SMEs and researchers, currently only 5% of the HPC capabilities are being provided by European HPC centres. In order to close the investment gap, significant investments in infrastructure, access to Big Data, the development of tailor-made complex software solutions, as well as investment in new business development are needed.

As the EU bank, we understand both the unique opportunities and the important challenging funding conditions supercomputing projects are facing in Europe. We believe that, with this study, the EIB is providing an important contribution to the future development of the European HPC sector. The report clearly lays out the steps and actions needed to improve access-to-finance conditions for supporting the growth of this strategic sector in Europe. The study demonstrates that, in addition to the continuous use of grants, more advisory support is required to strengthen the HPC ecosystem in Europe and establish the building blocks for enhancing funding models in this sector. The combination of grants with financial instruments will unlock the unprecedented opportunities offered by the next generation of supercomputers.

With important tools such as InnovFin and the European Fund for Strategic Investments, the EIB Group remains committed to supporting innovative ideas in the digital economy.

Werner Hoyer,
President, European Investment Bank

Preface

"European supercomputing infrastructure represents a strategic resource for the future of EU industry, SMEs and the creation of new jobs."

I would like to thank the European Investment Bank for carrying out this study developed under the InnovFin – EU Finance for Innovators Advisory programme mandate.

High Performance Computing (HPC) is indispensable in the new global data economy. The dramatic increase in the amount and variety of Big Data creates new possibilities for sharing knowledge, carrying out research, doing business and developing public policies. Thanks to its ability to process large amounts of data, the applications of the HPC technology are countless and European citizens are already benefiting from them in their everyday life in sectors like health care, weather, clean energy and cybersecurity.

European supercomputing infrastructure represents a strategic resource for the future of EU industry, SMEs and the creation of new jobs. This is also key to ensuring that European scientists reap the full benefits of data-driven science. Europe needs an integrated world-class HPC infrastructure with exascale computing performance. Europe cannot take the risk that data produced by EU research, industry and SMEs will be processed elsewhere because of the lack of supercomputing capabilities. This would increase our dependency on facilities in third countries and would encourage innovation to leave Europe.

However, Europe is not investing in HPC infrastructures and technologies in line with its economic and knowledge potential. Despite significant investments both at national and EU level, Europe is clearly underinvesting in HPC with a funding gap of EUR 500-750 million per year compared to its competitors from the USA, China and Japan. No single country in Europe has the capacity to sustainably set up and maintain an exascale HPC ecosystem in competitive time frames by itself.

Pooling and rationalising efforts is a must. The European Union will co-invest with Member States in the establishment of a new legal and funding structure, the EuroHPC Joint Undertaking. The aim is to jointly invest in world-class HPC machines and support a full European HPC ecosystem. This ecosystem will be capable of deploying a world-class HPC and data infrastructure with exascale capabilities by 2022/2023, securing our own independent and competitive HPC technology supply, and achieving excellence in HPC applications.

It is our role to provide a world-class European infrastructure that will benefit industry, SMEs, science, the public sector and especially Member States without self-sufficient national HPC capabilities. This is a key element for Europe to achieve its ambition of becoming a vibrant data economy and compete globally.

This study confirms the strategic character of HPC for our businesses. Public funding alone will not be enough to finance the broad uptake of HPC in the coming years. We will need a wide range of solutions such as dedicated financial instruments and public-private partnerships to mobilise the significant investments and new ways of financing needed. I am pleased to see that the European Investment Bank endorses the vital importance of HPC as a strategic sector for the European economy and is ready to support the further deployment of HPC-based infrastructure and services in both the public and private sector.

Mariya Gabriel,
Commissioner for Digital Economy and Society

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Executive Summary

HPC – A mission critical-enabler

Supercomputing (or High Performance Computing – HPC)[1] has become an indispensable resource in the digital age, thereby transforming research, businesses and our daily lives. It strongly increases the ability of researchers, industry, SMEs and government to process and analyse large amounts of data. In the context of rapid technological developments in Artificial Intelligence, Big Data, and the Internet of Things (IoT), access to supercomputing is therefore a mission-critical enabling capability for innovation and competitiveness[2].

What is HPC and why does its adoption and use by industry and SMEs matter?

High Performance Computing (HPC) entails the use of 'supercomputers' and massive parallel processing techniques to solve complex computational problems through computer modelling, simulation, and data analysis[3]. HPC brings together several technologies, including computer architecture, programs and electronics, algorithms, and application software under a single system to solve advanced problems quickly and effectively[4]. Whereas a desktop computer or workstation generally contains a single processing chip (a central processing unit, or 'CPU'), an HPC system essentially represents a network of CPUs (e.g. microprocessors), each of which contain multiple computational cores as well as its own local memory to execute a wide range of software programs[5].

The use of HPC has become globally **widespread across all branches of government, academia and virtually all industries and sectors**. HPC is the engine used to power the increasingly connected digital economy. HPCs are particularly well suited to tasks that are either computationally, numerically, or data intensive, as well as tasks that require a large number of complex computations to be executed on vast data sets rapidly. HPC has

1. This report primarily uses the term High Performance Computing. The term Supercomputing is interchangeable with HPC, and both are defined as the use of computing power with significantly higher levels of performance compared to a general-purpose computer.
2. Mazzucato, M. (2018): Mission-Oriented Research & Innovation in the European Union- A problem-solving approach to fuel innovation-led growth, European Commission, Directorate-General for Research and Innovation, Brussels.
3. "High-Performance Computing (HPC)": Techopedia, accessed [22 May 2018].
4. *https://www.techopedia.com/definition/4595/high-performance-computing-hpc.*
5. Ezell, S. and Atkinsom R. : (2016) "The Vital Importance of High-Performance Computing to U.S. Competitiveness, Information Technology and Innovation Foundation", Washington DC: page 4.

become particularly indispensable for modelling complex, multivariate, adaptive and dynamic systems, such as weather patterns, climate change modelling, complex financial models, and the movement of air- or spacecraft. For example, industries use HPC modelling extensively for oil and gas exploration, the development of new drugs and 3D animations to better design consumer products[6].

Thus, the impact of **HPC touches almost every aspect of our daily life**: cars, airplanes, buildings and consumer goods, such as shampoo and toothbrushes, are designed using HPC capabilities. Climate change models, weather forecasts, movie animations, drug discovery and advanced business analytics all use supercomputing power extensively. Finally, supercomputing has become a critical tool for supporting better decision-making; the planning and development of water supply networks, energy grids, strategic transportation networks and manufacturing applications all use HPC-based computer modelling and simulations[7].

The combination of HPC, Big Data and Cloud Computing will foster the rapid development of new applications and HPC services across multiple sectors, including more traditional parts of the economy. For example, HPC can enable the use of advanced computing models and simulations and provide access to software analytics to analyse large amounts of data in very short time periods. In particular, the use of HPC services over the cloud will make it significantly easier for SMEs that do not have the necessary financial means to invest in their in-house HPC infrastructure to make use of HPC capabilities in order to develop and produce better products and services[8].

6. "What is HPC?": The National Institute for Computational Sciences, accessed [22 May 2018], ***https://www.nics.tennessee.edu/*** *computing-resources/what-is-hpc*.
7. IDC: (2015) "High Performance Computing in the EU: Progress on the Implementation of the European HPC Strategy", Brussels: European Commission: DG Communications Networks, Content & Technology.
8. Leonardo Flores Añover and Augusto Burgueño Arjona: (2016) "How to make HPC happen in Europe- European Update" in: Scientific Computing World, 16/02/2016.

The global digital transformation is being enabled by the rapid increase in access to and use of open and Big Data. The important economic value of data is becoming increasingly clear, and data-driven innovations are becoming a key driver – a platform of innovation – for the rapid spread of disruptive technologies and business model innovations. Innovations in HPC, Cloud Computing and mobile web services combined with the rapidly rising access and use of Big Data are transforming businesses, public services and society overall. HPC infrastructure and services are therefore critical enablers for far-reaching innovations for scientific research, industry and SMEs.

The study demonstrates that the use of supercomputing for industrial and commercial applications in Europe has grown rapidly across many sectors such as automotive, renewable energy and mechanical engineering. This provides clear opportunities for further developing and deploying world-class HPC capabilities in the economy and society. To realise this potential, significant public ('cornerstone') investments in strategic HPC infrastructure and services will be essential, expected to lead to the creation of public value via the growth of high-tech companies and the creation of new ecosystems across Europe[9].

At the same time, new thinking is required about how to optimise the use of HPC infrastructure from a predominantly public good approach to ensure that adequate socio-economic returns are generated. It is critical for public investments to also identify adequate return mechanisms that form the basis for ensuring the long-term financial sustainability of HPC investments. Therefore, awareness among policy makers, industry and society at large of the public value created by HPC needs to be increased. This is an important aspect of being able to mobilise the required large-scale public investments and to close the identified investment gap. Broadening and optimising the current use of HPC towards more commercial and industrial applications, as well as increasing awareness of the strategic importance of HPC for industry and SMEs to remain competitive in the global economy, will form the basis for crowding in the necessary private investments.

This study focuses on the access-to-finance conditions for the further development and deployment of supercomputing in Europe. It provides a new rationale for public investment and public value creation as a basis for improving the conditions for robust and long-term financing.

While Europe has made substantial progress in the development of its HPC ecosystem in the last few years, the study has identified a significant investment gap, which has led to a setback in its relative global position. In fact, the demand for supercomputing capabilities from European industry, SMEs and researchers (with 33% of global demand) far exceeds the current European supply of HPC resources (with only 5% of global supply)[10]. As a result, European innovators are increasingly using supercomputers outside the EU, which leads to important risks in terms of access, data protection, cybersecurity, and data privacy.

9. Mazzucato, M. (2015). The entrepreneurial state: Debunking public vs. private sector myths (Vol. 1). Anthem Press.

10. COM (2016) European Cloud Initiative- Building a competitive data and knowledge economy in Europe 178 final: page 5.

In order to address this investment gap, securing the appropriate financing to cover the high costs of funding and maintaining the world-leading position of European High Performance Computing remains a challenge. While the EU and national governments are actively promoting the sector with various initiatives, public funding alone will not be sufficient to finance the broad uptake of HPC by industry and SMEs in the coming years. The EU needs to continue acting as a cornerstone investor, mobilising public funding alongside a clear public value proposition. This should ultimately be recognised and rewarded by the private sector through co-investments.

In this context, this study aims to assess the access-to-finance conditions for the deployment of HPC. In particular, the study's specific objectives were to:

- Identify successful commercial business models in the HPC market.
- Assess the financing requirements in key market segments and identify current financing bottlenecks.
- Provide recommendations to bridge the current gap between technology providers/users (demand side for financing) and investors (supply side).
- Explore options for public-private partnerships in financing HPC and propose ways of funding the HPC sector under the current EU financial instruments.

The study was implemented in close collaboration with Roland Berger, which conducted a large number of interviews with representatives from industry, academia and the financial community, and analysed existing public financing instruments and best practice cases.

Key Concepts

- **Petascale HPC**: The current most powerful supercomputers in the world are petascale HPC. Petascale refers to a computer system capable of reaching performance in excess of one petaflop, i.e. one quadrillion calculations per second.
- **Exascale HPC**: The next generation of supercomputers is exascale HPC[11], a supercomputer operating at 1,000 petaflops or greater. The US, China, Japan, Russia, India and the EU have declared the development of exascale technology to be a strategic priority and are investing into R&D programmes to achieve this target.

11. Exascale refers to the speed of the computing systems capable of at least one exaflop, equivalent to a billion calculations per second or 1,000 petaflops. To put this into context, the existing largest petascale HPC in the world has a performance of 93 petaflops.

- The motivation for developing exascale technologies is not merely to have the fastest supercomputer in the world. The goal is to build a 'first of a kind' system rather than 'one of a kind'. A critical reason why the push to exascale matters is that for every order of magnitude increase in computing capability, a qualitative increase in what can be achieved with that computing power is observed. The types of applications that can be run on exascale platforms – such as for 3-D modelling and simulation – are fundamentally different from the types of applications that can be run on petascale platforms. Thus, development of exascale computing provides countries with an important opportunity to influence a wide range of other digital technologies that will influence the broader ICT market. Countries that manage to transition towards exascale technologies at an early stage will thus have a comparative advantage in terms of defining key technology standards and developing a variety of applications and services.

An HPC 'ecosystem' approach

The study focuses on the following crucial HPC market (ecosystem) players:

- Independent software vendors (ISVs).
- HPC centres (service providers).
- HPC intermediaries.
- HPC customers (users and potential users).

The study recognises the importance of the HPC ecosystem as a whole and the different but interconnected roles of the various HPC market players listed above. Therefore, the study takes a holistic view of the HPC sector, rather than concentrating on any specific player in the HPC ecosystem. This approach reflects the view that the future development and growth of the HPC sector depends on strengthening the role of each of the key players and the linkage among themselves. The HPC value chain schematically presented below depicts the key players in the HPC ecosystem. The segments in green encompassed the focus of this study.

Chip manufacturers/ critical components	System integrators; Storage specialists; Network providers	Independent software vendors (ISV)	HPC centres	HPC Inter-mediaries	HPC customers
• Producers of core components for HPC hardware • Small number of highly specialised manufacturers • No significant footprint in Europe	• Integrate single components providing hardware infrastructures • Have a particular importance in the context of the European Science Cloud	• Develop software solutions for HPC applications	• Offer HPC services (at least partially based on a profit-driven business model)	• Develop HPC and data driven business models • Link HPC service providers with HPC customers	• Make use of HPC services to offer enhanced products and services • Focus on improving SME access to HPC

Figure 1: Overview of the HPC Value Chain

Key players in the HPC ecosystem:

- **Independent Software Vendors (ISVs)** develop and sell software for HPC applications. A considerable number of European ISVs are industry leaders in simulation and modelling applications for HPC on a global scale, and generally focus on highly specialised niche segments. They are facing growing global competition in their niche markets from larger and less specialised providers expanding their presence into these new segments.
- **HPC centres** focus on offering HPC capacity on pre-installed, ready-to-use hardware. Europe has strong **academic HPC provider** infrastructure. Traditionally, these have been mainly financed by public research grants. On the other hand, private and **commercially oriented HPC providers** are less common in Europe. The strong competition, particularly from US-based companies such as Amazon Web Services, Google and Microsoft, has left a relatively small landscape of European players offering HPC capacities on a commercial basis.
- **HPC intermediaries** fulfil an important role as technology facilitators by bringing together HPC centres (infrastructure owners), Independent Software Vendors and HPC customers to work jointly on projects. This role is particularly important in helping first-time users, primarily SMEs, to become acquainted with the potential of HPC for their business.

- **HPC customers.** In Europe, the main customer groups for HPC are public entities, both research and academia. This is reflected in the usage rates of Europe's highest performing HPC systems, where up to 94% of operating time is allocated to research tasks. The commercial users are mainly large corporations that apply HPC to reduce research and development costs by simulating prototypes of new products instead of physically building and testing them. For example, the care industry makes extensive use of HPC modelling to optimise the design and production of new prototypes that meet important requirements, such as energy efficiency. HPC uptake among SMEs is still very limited, due to the lack of awareness of HPC capacity and barriers to accessing adequate financing to acquire it.

SUMMARY OF KEY FINDINGS

Finding 1: Demand for HPC capabilities is rapidly increasing in key sectors of the European economy, such as aerospace, automotive, energy, manufacturing and financial services, while Europe's more 'traditional' SMEs are lagging behind.

The use of HPC has become widespread across academia, government agencies and virtually all sectors of industry and commerce. HPC applications are rapidly being integrated into the design and development of new products across strategic sectors of the economy, such as energy, transportation, manufacturing, medicine, communications and finance.

In combination with the decline in price of supercomputer hardware, the rapid growth of the data economy is leading to a significant increase in demand for HPC infrastructure and services[12] (including commercial uses). The rapid technological developments related to the combination of HPC and Cloud Computing technologies has made it possible to make HPC services accessible to a greater variety of public and commercial users, in particular SMEs.

However, an ongoing critical challenge in terms of the demand for HPC services is the need to better support researchers and entrepreneurs alike in appropriating this technology in line with their needs and adopting it accordance with their requirements. In fact, HPC adoption and use needs to be tailored to the specific needs of each sector and it is therefore critical to provide further support for the development of specialised HPC applications. Too often, HPC use still requires advanced knowledge about the sector and highly specialised technology skills. In this context, HPC intermediaries are

12. In Europe, the three largest and most dynamically growing HPC sub-sectors are: (i) Computer Aided Engineering (CAE), (ii) Bio-sciences, and (iii) Environment and Renewable Energy. Their HPC expenditures equivalent estimated growth projections (CAGR) for 2013-2018, are as follows: (i) 7.9% p.a. for CAE; (ii) 5.1% p.a. for Bio-sciences, including pharma and healthcare; and (iii) 5% for Environment and Renewable Energy.

DeepL:

A breakthrough in machine translation enabled by supercomputing

In 2017, German tech company DeepL (creator of translation search engine Linguee) launched DeepL Translator, leveraging Artificial Intelligence to deliver the world's most accurate and natural-sounding machine translation tool. According to tests pitting DeepL Translator against the competition, translators preferred DeepL's results by a factor of 3:1. The reason for this success is that DeepL uses a supercomputer, capable of 5,100 trillion floating point operations per second, enough power to translate a million words in under a second. DeepL's neural networks are powered by high-quality translated sentences provided by Linguee. (*www.deepl.com*)

playing a critical role supporting industry and SMEs in the use of HPC capabilities for their businesses. While data-driven high-tech SMEs are rapidly engaging in the adoption of HPC into their businesses, a large number of more 'traditional' SMEs (such as engineering SMEs manufacturing components for large automakers) still lack awareness of the important opportunities HPC would provide to their businesses. An important finding from this study is that there is a gap in HPC adoption and usage between large industry players and more 'traditional' SMEs. The demand for HPC services in industry is increasing rapidly across Europe and most large corporates have invested in their own HPC infrastructure and services. Only a few industry players have developed collaboration with public HPC centres, due to the strategic importance of this technology to their companies and data security and privacy concerns about publicly owned and operated HPC centres.

In spite of the rapid increase in the demand for HPC services, important challenges to further broadening the use of HPC for innovative and commercial uses among SMEs remain. HPC providers need to become more flexible and adaptive to the specific needs of SMEs, providing small entrepreneurs with reliable and affordable HPC capabilities as well as a set of tailor-made applications and services that enable SMEs to take full advantage of HPC for their businesses. To strengthen the demand for the adoption and commercial uses of HPC in Europe, it is furthermore critical to support the entire HPC ecosystem. This includes HPC intermediaries and ISVs in particular, as one of Europe's key comparative advantages consists in providing HPC services and developing applications and software tailored to specific sectors.

Examples for cooperation models between public HPC centres and the private sector

Cineca: CPU cycles plus services – directly via HPC centre
Cineca, Italy's leading HPC centre based in Bologna, works through framework agreements with large industrial players, such as ENI. The agreements specify and define the terms of the collaboration, as well as Cineca's expected remuneration. Due to Cineca's reliance on predominately public funding, such collaborations are largely limited to research-centred endeavours. For example, the ENI-Cineca collaboration in the oil and gas sector focuses on researching general seismic activity modelling. For ENI, such activities add value to its business activities, but stop short of offering a clear-cut opportunity for the commercialisation of any given results.

For Cineca, revenues from direct commercial collaboration with industry players are under the limitation of the so-called 80/20 rule: only 20% of Cineca's revenue can be the result of commercially driven HPC activities, while 80% of the centre's revenue must originate from research-driven activities, according to Cineca's statutes. Beyond the 20% of commercial activities, Cineca does cooperate with industrial clients, however, these services are mainly circumscribed to the proof of concept stage, aiming to integrate HPC in business processes. In effect, Cineca is bound by EU statutes and its own mission to limit industrial revenues. Such regulatory set-ups limit the potential and the incentives for HPC centres to generate a larger share of their revenue through commercial activities.

HLRS: CPU cycles plus services – via intermediary
HLRS, a key German HPC centre based in Stuttgart, focuses its offering to the private sector on providing high performance computing infrastructure combined with a limited co-development or service offering for commercial users. Industrial cluster organisations supporting end users in the field of HPC simulation are associated with the centre, e.g. ASCS (Automotive Simulation Centre Stuttgart) and ENSOC (Energy Solution Centre). These clusters then complement the HPC infrastructure as offered by HLRS with a broader set of specific offerings.

Finding 2: Fragmentation and limited coordination at the EU level has resulted in a suboptimal investment climate and an underinvestment in strategic HPC infrastructures in Europe.

The demand for HPC infrastructure and services far exceeds the supply currently being offered by public HPC centres and private operators in Europe. This mismatch between supply and demand has led to the recent development that researchers, industry and SMEs are often relying on non-European HPC providers to carry out simulations and process their data.

A key reason for this trend is the current fragmentation of the HPC sector in Europe. In spite of the EC-supported pan-European PRACE programme (Partnership for Advanced Computing in Europe), which connects public HPC centres across Europe, the majority of HPC centres tend to be stand-alone organisations with a close link to a local academic institution or are embedded in a research cluster. Most of these centres are funded by national or at times, even regional budgets, resulting in fragmentation and limited coordination across Europe.

While the strategic importance of HPC as a key enabler for industrial innovations has been recognised, the majority of EU and national programmes have mainly focused on supporting the development of strategic HPC infrastructure and applications for research and science.

Furthermore, the financing for large-scale HPC facilities is challenging due the large amount of resources required and the need for long-term and sustained financing. This fragmentation and the predominate model of financing HPC centres though national or regional public financing has led to significant underinvestment in this strategically important sector in Europe.

Whereas other countries (e.g. China and the US) have invested heavily in supercomputing infrastructure and capacity, Europe has been somewhat lagging behind. There is currently a race under way in which China, Japan, the US and the European Union are competing to be the first to create an exascale supercomputer processing capacity, with aspirations to do so between 2021 and 2023. This race is also reflected in the significant change in the numbers of supercomputers by country (Figure 2), whereby China, which as of 2001 did not have a single supercomputer, is now the leader in terms of both performance and quantity, owning the highest number of the top 500 supercomputers worldwide.

In order to keep Europe at the forefront of HPC capabilities, public investments in strategic HPC infrastructure should be further expanded, especially for high-end HPC infrastructure (such as exascale computing, or for the development of pan-European HPC/Cloud Computing infrastructure and services).

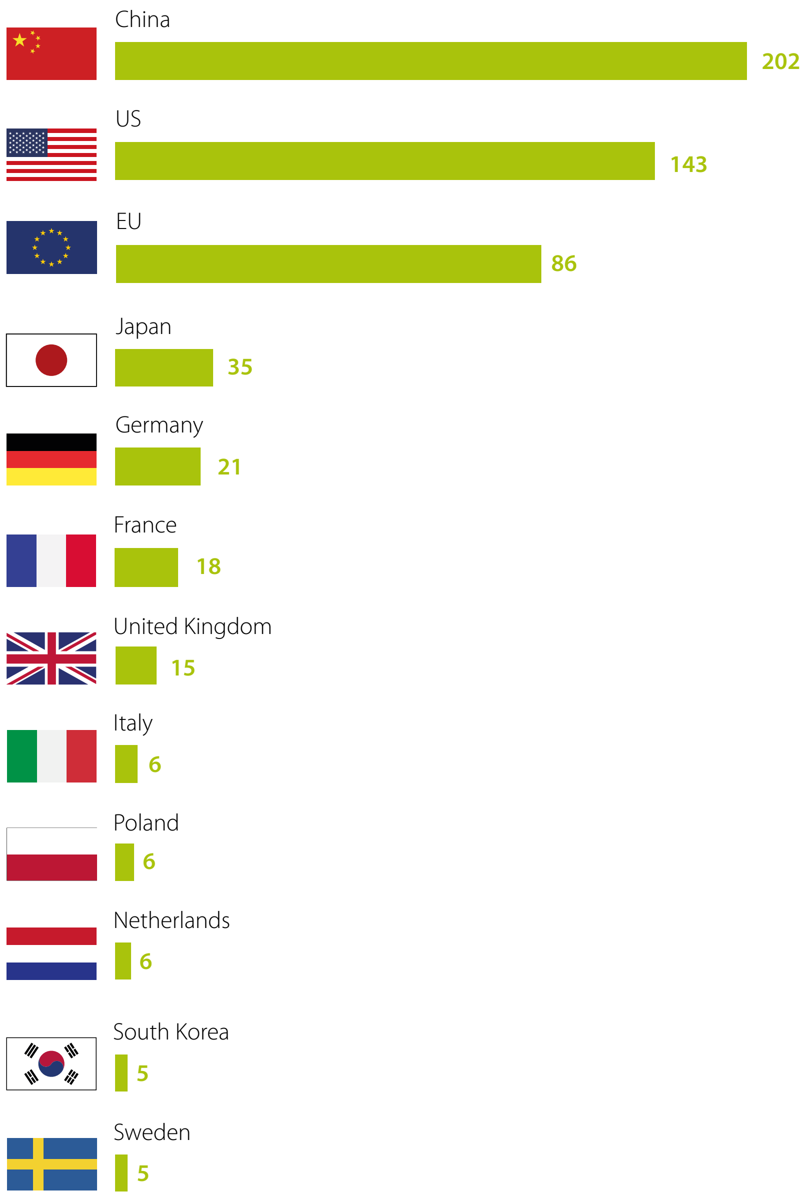


Figure 2: Number of Supercomputers in the Top500 list by country, November 2017

Finding 3: Most European HPC centres are largely publicly financed and owned, and dedicated to research. More commercially oriented HPC centres and activities within public HPC centres are emerging, but are often hampered by rules and regulations.

In Europe, the HPC landscape is mainly driven by the public sector – in terms of usage as well as financing. The majority of HPC capacity and use (over 90% of operating time) is both located at and allocated to universities or academic research centres, whereas the remaining 10% is installed for commercial use or with HPC end users. Most HPC centres offering infrastructure services are public and operated by universities or public research institutions. Most of their financing comes in the form of grants covering both investment needs and operational costs.

However, some of these centres have started to broaden their scope of application towards more commercial uses[13], in order to create new revenue streams. While such a trend is an important condition for developing a viable business model, in many cases there are statutory limits to the share of revenues that can be sourced from the private sector if the centre wants to remain eligible for public funding. Public HPC centres in Europe have gradually opened up to cooperation with the industry (see box p. 17).

Finding 4: Key Stakeholders (from HPC centres to HPC customers) in the European HPC ecosystem face different financial challenges that need tailored solutions.

There is a broad range of different HPC organisations and companies operating within the HPC ecosystem with different business models and financial challenges. An overview is presented below.

- **HPC centres**: The European landscape for HPC centres is largely dominated by publicly owned entities, mainly serving universities and research, and relying on public funding for both capital and operational expenditures. The main financial challenge for these players is the limited propensity towards commercially oriented models, and legal restrictions on increasing revenues from commercially oriented activities.
- **HPC intermediaries**: With a few exceptions, these are very similar to public HPC centres. They are

13. Typically, public HPC centres provide three different types of service models to commercial clients: 1) Pure CPU cycles. Under this model, the HPC centre offers only access to its hardware infrastructure. 2) CPU cycles plus services – directly via the HPC centre. Besides CPU cycles, some HPC centres offer additional services. They engage with industry customers to work on solving particular challenges in a cooperative way, such as mapping HPC process integration for manufacturers. 3) CPU cycles plus services – via an intermediary. Within this model, CPU cycles are provided by a public HPC centre in combination with additional advisory services delivered by a separate organisation, which acts as an intermediary between market demand and the infrastructure supply side.

mainly public entities under the umbrella of an HPC centre with limited viable business models, relying primarily on grants and public budgetary support.

- Independent Software Vendors: While European Independent Software Vendors have established business models (mainly offering Software as a Service) in specialised and niche segments, access to finance is constrained by: 1) lack of tangible assets, and 2) high-risk business model (upfront development costs with limited visibility on revenues), resulting in insufficient growth capital.

- HPC customers: Demand for HPC capacity from commercial users is still very much developing and has not yet reached maturity. The HPC customers can be categorised into 1) large corporates, 2) SMEs, and 3) innovative companies and start-ups. Large corporations are currently the main users of HPC capacity. However, most of them rely on in-house HPC centres. From a financial prospective, large corporates could benefit from more collaborative approaches with HPC centres by reducing investment needs, benefiting from higher computing capacity and expertise from personnel at HPC centres and intermediaries. HPC uptake is still limited among SMEs. The main challenges are linked to lack of awareness of the potential benefits from HPC, limited in-house expertise, and difficulties in accessing finance (limiting investment in HPC). Finally, innovative companies and start-ups represent an emerging new driver for HPC demand. Future demand for HPC service is expected to emerge from the next digital revolution based on Deep Tech innovations[14]. Companies developing Artificial Intelligence or Internet of Things applications and using Big Data will require HPC infrastructure to handle large amounts of data and complex calculations.

Finding 5: HPC intermediaries represent a key link between HPC infrastructure and customers, able to further catalyse commercial exploitation by matching supply with demand.

HPC intermediaries[15] play a critical role in connecting users of HPC services and HPC centres. Many companies lack technical knowledge about HPC and are therefore finding it hard to make use of HPC services. Without support from experts and a good understanding of the exact business case for the use of HPC applications, companies, in particular SMEs, frequently do not realise the possible economic gains that can be derived from the use of HPC services.

14. 'Deep Tech' are technologies that are unique, differentiating, hard to reproduce, are based on technological or scientific advances and that require a thorough understanding of the technology and market to understand their potential. Typically, Key Enabling Technologies, such as micro-electronics, nanotechnology or photonics qualify as such deep technologies. See: EIB InnovFin Advisory Services (2018) Financing the Deep Tech Revolution: How investors assess risks in Key Enabling Technologies (KETs): *http://www.eib.org/infocentre/publications/all/financing-the-deep-tech-revolution.htm.*

15. HPC intermediaries are companies, Research and Technology Organisations, or specialised departments located at HPC centres which provide advisory or consultancy services in the field of HPC, enabling users of HPC services to receive an optimal return on investment in HPC.

HPC intermediaries are acting as enabler for the uptake of HPC uses beyond its use for research and science. In particular, they are essential for mobilising and supporting SMEs in the use of the existing infrastructure or software development offering provided by HPC centres within their geographic vicinity. Their principal business model is to act as a facilitator for HPC users seeking knowledge, advice or specific HPC service.

Therefore, HPC intermediaries are playing a critical role by: (i) serving as competence centres and providing their technical expertise (i.e. how to best develop and modify the underlying algorithms and mathematics behind the commercial use cases dependent on their individual needs) to HPC users; (ii) acting as intermediaries between all relevant stakeholders, offering insightful perspectives on the entire HPC market; (iii) raising awareness of the benefits of HPC use, both for research and commercial applications; and (iv) strengthening the demand for HPC, thereby leveraging innovation and enhancing value creation across multiple sectors.

Given their important role in creating awareness, enhancing knowledge of HPC uses and facilitating access to HPC centres (especially for SMEs), HPC intermediaries are playing a critical role for the further development of the HPC sector. The key challenges HPC intermediaries are facing are the need to strengthen and expand their services, in particular for SMEs, and developing more commercially oriented business models to secure their long-term financial sustainability.

Finding 6: Demand for HPC services among SMEs is not only constrained by the limited knowledge of the benefits of HPC, but also by a lack of finance to invest.

Small and medium-sized companies with an established business model considering the use of HPC in their R&D process typically face a very different situation compared to large corporations. For smaller companies, entering HPC-based product development can require a significant increase in R&D expenditures. In addition to that, the challenge is often also operational.

Particular investments in human resources (either hiring or training) are necessary to support the migration from desktop-based computer simulation processes to HPC sustainably, adding complexity to the transition process. Such migration might also result in early (temporary) losses of productivity (due to the adaptation phase), and this can, in itself, be a material deterrent for SMEs.

SMEs that embrace HPC projects and associated investments furthermore face significant difficulties due to the insufficient availability of finance. Access to financing for HPC projects from commercial banks is significantly constrained due to the following factors: (i) the uncertainty around such projects, perceived to be riskier than investments in tangible assets; (ii) the lack of know-how and expertise among lenders for carrying out balanced assessments, due to the complexity of HPC; and (iii) the relatively smaller size of the funding requirements, resulting in high transaction costs.

Finding 7: Independent Software Vendors (ISVs) are crucial actors in European HPC. However, ISVs have difficulties in accessing finance.

A critical aspect of the European HPC ecosystem is the strong presence of independent software vendor ISVs. While enhancing the strategic HPC infrastructure across Europe is essential, adequate investments in software and HPC applications are as critical as investments in the HPC infrastructure itself. This is an important area where Europe has a significant comparative advantage with respect to other countries, however ISVs require additional support in order to be able to fully reach their potential. In fact, they are playing a critical role in the expansion of the HPC market in Europe.

Their approach of working together closely with research institutions has proven successful. Most European ISVs face important obstacles for scale-up. European ISVs are often market leaders in specific niche segments and can be characterised as small and agile, offering software-based solutions and developing innovations tailored to specific clients. ISVs struggle to expand their businesses successfully due to their difficulties in raising financing.

The key obstacles they face in terms of improved access to finance are primarily due to the following:

- A dearth of tangible assets which leads to lack of debt financing.
- The lack of niche technical HPC knowledge within commercial banks about the sector.
- The high-risk of the investments, due to the uncertainty related to technology trends.
- Relatively small financing requirements resulting in high transaction costs for lenders.

Finding 8: Private investors are already engaged in the financing of commercial HPC infrastructure (especially HPC centres), but not in public HPC infrastructure with limited 'bankability' prospects.

Commercial banks are generally engaged in the financing of private and commercially oriented HPC centres. This infrastructure-based business model is generally well understood by banks. Private HPC centres mainly rely on commercial debt instruments (term loans) to secure funding, as they are often able to sell their capacity in advance, providing visibility on future cash flow to lenders.

However, the availability of repayable types of financing for public HPC centres is currently limited, due to the limited number of viable business models with a more commercial orientation and reliable source of revenue to underpin their bankability.

KEY RECOMMENDATIONS

Against the backdrop of the findings of the study, we have developed a series of recommendations to strengthen the HPC ecosystem in Europe, which are summarised and mapped in the figure below.

The **first recommendation** highlights the **essential role of the public sector** in supporting the development of strategic and enabling HPC infrastructure. The availability of high-end and best in class HPC systems (such as exascale supercomputers) is a key building block for the next wave of digital innovation based on Deep Tech. Public investments in this area have the potential to generate significant public value in the form of economic and societal benefits and returns.

To reap the full benefits of the next digital revolution and to remain competitive on a global basis – meaning at minimum parity in HPC capabilities with those considered as the best in the world – Europe needs to acquire exascale supercomputing capability within the same time frame as the US, Japan and China. This requires enhancing the collaboration between the EC, Member States, regions and the private sector, as well as providing financial support for strategic HPC infrastructure and services.

The **second and third recommendations** focus on the need to strengthen the European HPC ecosystem and support the emerging market for HPC infrastructure and services by supporting more business oriented business models. In this context, the public sector should focus on a 'pull and push' strategy to 1) strengthen demand side: strengthen the uptake of HPC uses, in particular for commercial applications by industry and SMEs and innovative companies and start-ups; and 2) support supply side: support HPC stakeholders (in particular HPC centres and intermediaries) in implementing strategies based on developing more commercially oriented business models.

As more commercially oriented models emerge (supported by actions in recommendations 2 and 3), the study recommends (recommendation 4 and 5) considering the gradual development of more dedicated financial instruments and associated financial advisory services for the HPC sector.

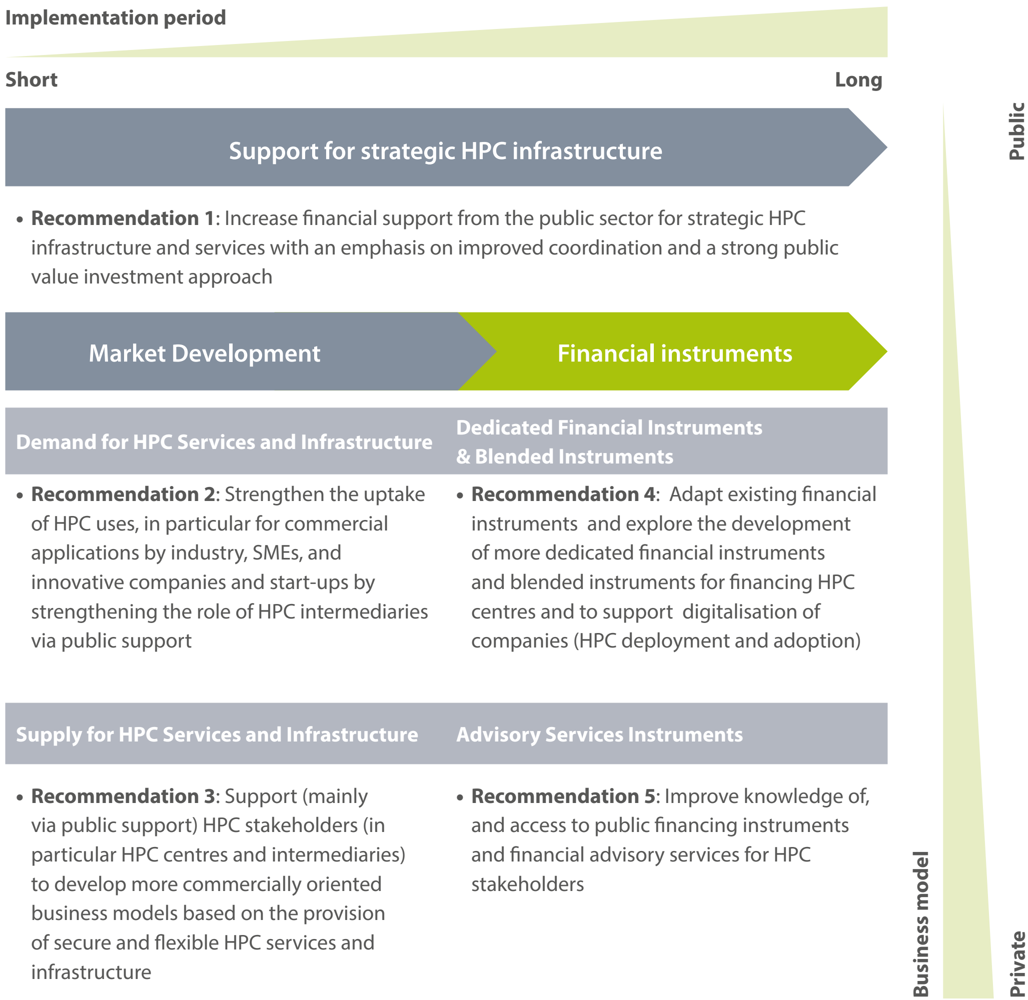


Figure 3: Overview and mapping of the key recommendations

Recommendation 1: Increase financial support from the public sector for strategic HPC infrastructure and services with an emphasis on improved coordination and a strong public value investment approach.

The study demonstrates that there is a lack of coordination of the HPC investments in Europe, fragmentation of the sector, and substantial underinvestment in HPC infrastructure and services in Europe. This is particularly applicable to the case of exascale computing capacity.

A key finding from the study is that the financing of these large-scale facilities is challenging, since private investors will not invest in the required research and development of exascale computing – mainly due to the extremely high investment costs required, as well as the high level of uncertainty and the lack of assured revenues from these investments, until the technology becomes more established and can be directly applied to industrial and commercial applications. The required investments for European HPC infrastructure that can compete with the rest of the world requires substantial investment (estimated at EUR 500-700 million per investment cycle) which cannot be shouldered by any individual Member State.

Therefore, the study recommends **strengthening financial support from the public sector for strategic HPC infrastructure, based on a public value approach** that emphasises: (i) the economic and societal value created by public investments; and (ii) a strengthened return orientation of the investments.

Furthermore, the study recommends **improving the coordination and pooling of financing** by setting up of a mechanism that enhances collaboration between the EC, Member States, regions and the private sector. In particular, the study recommends **jointly developing a financing concept based on a PPP approach for HPC, as planned for the recently launched EuroHPC Joint Undertaking.**

The main objective of the EuroHPC Joint Undertaking (JU), coordinated by the European Commission with the current support of 15 EU Member States, is to cooperate in the development of pan-European HPC infrastructure and HPC-based services. Thus, the EuroHPC is a critical step towards enhancing the coordination and pooling of financing between the EC and Member States, as well as involving industrial private partners (starting with in-kind contributions). The JU is underpinned by the ambition of putting European exascale computing within reach in just a few years.

In the context of the JU, the study also recommends developing approaches to engage SMEs in large publically tendered HPC technology development projects. It suggests developing a procurement mechanism that broadens the access of European SMEs to large public projects, e.g. under the ETP4HPC eINFRA procurement calls. This would support the European SME sector in business and technology development.

STRENGTHEN THE DEMAND SIDE

Recommendation 2: Strengthen the uptake by HPC users, in particular for commercial applications by industry, SMEs, and innovative companies and start-ups by strengthening the role of HPC intermediaries via public support.

The development of viable business models for HPC centres is largely dependent on increasing demand for such services by commercial users. The HPC ecosystem generally is at a relatively early stage, as there is a lack of awareness of HPC's potential benefits among SMEs, while demand from innovative companies (such as companies using Artificial Intelligence) is emerging but still limited.
In this context, HPC intermediaries play an essential role and are critical multipliers for the involvement of HPC customers, and for strengthening the demand for HPC infrastructure and services. Furthermore, business development strongly depends on cooperation among the key HPC stakeholders (from HPC centres to ISVs). Therefore, the HPC ecosystem in Europe could greatly benefit from stronger and expanded activities by HPC intermediaries. It is recommended that HPC intermediaries take the following actions:

- Prepare and implement an overarching communication campaign, disseminating use cases and thus developing awareness for the potential of HPC.
- Promote and support the development of more collaborative models between HPC centres, intermediaries, ISVs and large corporates in order to show large companies the benefits of working with HPC centres vs. in-house HPC (in terms of investment savings, computation potential, etc.) and address key concerns such as data security and privac.
- Support the demand for HPC services arising from HPC user companies (mainly from SMEs and innovative start-ups).
- Provide advice to ISVs in HPC-related business development and the identification of adequate partners.

The main role of HPC intermediaries in the development of the HPC ecosystem is to promote demand for HPC services and support the development of commercial business models to enable private financing or mixed financing models. This function should be offered on a bilateral basis (providing direct advisory services to the HPC stakeholders) as well as through broader dissemination practices (e.g. useful case studies, best practices, etc.).

In order to strengthen the role of HPC intermediaries, the EU and national members should increase public support to these entities (via grants and 'train the trainer' programmes). This can build on existing initiatives such as PRACE and ETP4HPC, Fortissimo and the new EuroHPC JU.

SUPPORT THE SUPPLY SIDE

Recommendation 3: Support (mainly via public support) HPC stakeholders (in particular HPC centres and intermediaries) in developing more commercially oriented business models based on the provision of secure and flexible HPC services and infrastructure.

The study has identified that the European HPC ecosystem is still in an emerging phase from a business perspective. The development of more commercially oriented business models will be an important step in order to access repayable capital and reduce dependence on public funding. In order to achieve this goal, it should be considered not only to promote demand for HPC infrastructure and services (Recommendation 2), but also to support HPC stakeholders (in particular HPC centres and intermediaries) in developing business models in order to capture and better link their offer with the existing and emerging demand for HPC services and infrastructure.

A key aspect of the development of more commercially oriented business models is to build on the specific comparative advantage of European HPC centres in providing HPC services that are based on the highest data protection, cybersecurity and data privacy standards and that ensure the protection of intellectual property and the data ownership of users. In this context, HPC centres and HPC intermediaries could benefit from technical advisory services to:

- Create awareness among HPC stakeholders (in particular, HPC centres and intermediaries) of the potential business models that can be developed (presented below), and their potential benefits.
- Provide training and necessary expertise to develop such business models.
- Support HPC stakeholders in business development and business planning.
- Strengthen the collaboration between HPC centres, intermediaries and ISVs in view of developing more commercially oriented business models.
- Provide guidance and best practices on the critical issues of ensuring data protection, privacy standards, and the protection of intellectual property and data ownership of HPC users, in particular from industry and SMEs.

Such advisory services should be mainly provided via public support. The EU and Member States could consider the development of a central platform to support the business development of HPC stakeholders. Such a platform can build on existing initiatives such as Fortissimo. The study recommends the promotion of business models based on a mix of both public and private users, easing the migration process towards more commercially oriented approaches. The study has developed examples of HPC centre business models based on public/private approaches (see Table 2 below). At the two extremes of the spectrum, there are the fully public model and fully private model. In the middle, there are two mixed models, gradually expanding the commercial/industrial uses of HPC infrastructure and services. These models aim to build the basis for complementing existing public financing (currently provided primarily through grants) with increased revenues from HPC applications for industry and SMEs.

However, it should be noted that the success of such a transition towards more commercially oriented business models is currently constrained by existing rules and regulations that significantly limit the ability of HPC centres to generate more than 20% of their revenues from commercial HPC users. Overcoming this limitation – through appropriate regulatory reform where necessary – would be an important step for the further commercial development of the HPC ecosystem.

	Public/University model	Independent institutions (RTO) model	PPP model	Private model
Ownership	100%	51% / 49%	100%	100%
Utilisation	80% / 20 %	50% / 50%	50% / 50%	
Definition	• Run by university (e.g. GENCI in France)	• Run by independent research institution	• Run by private operator formed by PPP	• Owned and run by private operator (e.g. CPU 24/7)
Business model	• Focus on research • Limited commercial activities (max. 20%, but mostly below)	• Academic and commercial use • As research org. eligible for grants and Horizon 2020	• Utilisation split between academic and commercial use • Model deliberately facilitates public/ private cooperation	• Predominantly commercial use - "off-take agreement" as security • Partly public use (universities) to ensure part of revenues
Financing model	• National public budget / university funding • Horizon 2020 grants for research • Repayable grants/ loans from EU conceivable as bridge loan	• Partly public regional and/ or national governments for research • Partly contract research with industrial partners • Repayable grants/ loans from EU conceivable as bridge loan	• Partly public and partly private funding (larger part) • Private funding part should rely on commercial revenues • Public guarantees enhancing equity	• Mostly private with some public financing for public use • Applicable EIB/NPB instruments • For the ramp-up phase guarantees to achieve bankability
Commercial involvement				

Public Private

Figure 4: Evolving Business Models

DEDICATED FINANCIAL INSTRUMENTS AND FINANCIAL ADVISORY SERVICES

Recommendation 4: Adapt existing financial instruments and explore the development of more dedicated financial instruments and blended instruments for the financing of HPC centres and to support the digitalisation of companies including HPC development and deployment.

As more established commercially oriented business models emerge, the study recommends the adaptation of existing financial instruments and exploration of the use of more dedicated financial instruments to support the financing of HPC infrastructure and digitalisation of companies including supporting the adoption of digital technologies by companies including the use of HPC as a service. Examples of potential actions that could be considered in this area are the following:

4.1) Adapt existing financial instruments and strengthen their use and uptake.

The study recommends adapting existing financial instruments to strengthen the financial support for HPC programmes from both the private and public sector. There exists a diverse and rich offering of financial instruments, such as InnovFin and EFSI. Both InnovFin Science and EFSI could be used to fund the capital needs of HPC centres. In this context, it is recommended to review the existing eligibility criteria of these instruments with the objective of increasing investments in the sector.

4.2) Explore the set-up of dedicated financial instruments for the take up of digital services including HPC as a service. There are two main areas:

(i) The digitalisation of traditional companies often involves a change in business model, moving from buying equipment and hardware (capex) to buying access to digital applications and equipment (opex) such as using HPC services provided by an HPC centre via computer cloud. Such a change in business model is seen as high risk by private investors (in particular banks) due to the uncertainty of the benefits (in terms of speed to market, for new products, reduction in R&D) and migration toward an asset-light approach (lack of collateral). In this context, the study recommends exploring the need for the setting up of dedicated financial instruments to support the digitalisation of companies, including the development and deployment of HPC. This could include risk-sharing instruments with a First Loss Piece (from EFSI or InnovFin) covering risks on loans provided by banks and financial intermediaries for digitalisation projects.

(ii) There is growing demand for HPC services arising from innovative start-ups developing applications with high computing capacity requirements (such as Artificial Intelligence). To support this emerging demand, the study recommends exploring the need for setting up dedicated financial instruments (mainly equity) to invest in these companies. By including a higher-risk tranche from the public sector, this instrument could attract private investors into considering more risky ventures such as start-ups in IoT or Artificial Intelligence.

4.3) Consider the use of blended instruments (i.e. combining private and public funding) for financing HPC centres.

Most public HPC centres are currently financed by public grants. However, blended grants combining public and private funding in a single instrument could provide some financial relief for strained public budgets and thus enable the (or a swifter) establishment and/or upgrading of HPC centres. Hence, the study recommends considering the use of blended financial instruments to address the financing needs related to the establishment of HPC centres. In particular, the study recommends exploring the feasibility of setting up a dedicated HPC infrastructure fund. Such a fund could include a higher-risk taking tranche from public sources (as in the case of the broadband fund, which includes a first loss piece from the Connecting Europe Facility - CEF).

Recommendation 5: Improve knowledge of, and access to, public financing instruments and financial advisory services for HPC stakeholders.

The study identified that there is a lack of knowledge and awareness of existing financial instruments among HPC stakeholders, and a perception that the application process for these instruments is lengthy and cumbersome. A key objective is to increase the use and uptake of existing financial instruments by HPC stakeholders.

The study found that financial advisory services can play an important role supporting HPC project promoters to develop new approaches that are based on strong public value and an enhanced return orientation for public investments.

Therefore, the study recommends strengthening financial advisory services in order to: (i) support the development of HPC programmes that are based on more commercially oriented business models; (ii) promote knowledge on the developing suite of financing mechanisms for HPC stakeholders; and (ii) enhance the bankability of HPC projects that are already more commercially oriented.

1. Background and Introduction

Purpose and objectives of the study

High performance computing (HPC) is a critical enabling technology for industrial research and development as well as for academic research across Europe. It is a crucial driver in expanding Europe's innovation capability and in maintaining its edge in overall economic competitiveness.

Historically, HPC in Europe has mainly been driven by the public sector and by scientific research in particular. National and even regional approaches towards HPC funding and development have led to a diversified, rather fragmented HPC landscape in Europe, consisting of a high number of often small and highly independent public institutions. European private companies with a business model based on HPC have often been established as specialised university spin-offs catering to niche markets, as opposed to their American counterparts where scalable business models and selling high-growth businesses to strategic investors have traditionally played a larger role. In the past 15 to 20 years, concerted efforts have been made by the EU to consolidate, strengthen and promote the European HPC market as a key driver for innovation and growth.

The use of supercomputing for industrial and commercial applications in Europe has grown rapidly across many sectors such as automotive, renewable energy and mechanical engineering. This trend provides clear opportunities for further developing and deploying world-class HPC capabilities in the economy and society. To realise this potential, significant public ('cornerstone') investments in strategic HPC infrastructure and services will be essential, and are expected to lead to the creation of public value via the growth of high-tech companies and the creation of new ecosystems across Europe. At the same time, new thinking is required about how to optimise the use of HPC infrastructure from a predominantly public good approach to ensure that adequate socio-economic returns are generated. The awareness of policy makers, industry and society at large concerning the public value created by HPC needs to be expanded. This will make it possible to develop adequate return mechanisms that can form the basis for ensuring the long-term financial sustainability of HPC investments.

The rapidly increasing demand for HPC uses for industrial and commercial applications will require significant investments in infrastructure, access to Big Data, the development of tailor-made complex software solutions as well as investment in new business development based on HPC and Cloud Computing technologies. A sufficient level of financing will be required to meet these highly strategic needs.

The European Commission (EC) has put HPC on its strategic agenda. Its objectives are to: strengthen European leadership in HPC, provide excellent infrastructure for academia and private sector companies, secure independent European technologies, establish pan-European governance and strengthen the role of the EU as a global player in this field. The EU has allocated approximately EUR 80 billion under its 'Horizon 2020' framework dedicated to digital economy research and innovation, making it the EU's largest R&I initiative so far[1].

Accordingly, various networks and initiatives to support the HPC sector at the European level have been established, for example:

- The partnership for advanced computing in Europe (PRACE): PRACE is an international not-for-profit-association headquartered in Brussels and consisting of 24 member states. The association's mission is to foster high technology engineering research across all areas, harnessing Europe's competitiveness for the benefit of society. Whereas PRACE has taken on the role of a governing organisation for academia, it does also include industry stakeholders (e.g. SHAPE).
- Fortissimo[2] I and II are platforms aimed at helping SMEs to increase their uptake of HPC.
- ETP4HPC is a contractual Public Private Partnership (cPPP) platform that boosts the development of proprietary European HPC technology towards exascale computing.
- An additional cPPP is currently being discussed, with a focus on how to handle large amounts of data and how to leverage synergies among closely related sectors.
- The European Open Science Cloud (EOSC) initiative is, together with HPC, an integral part of the European data infrastructure. The EOSC makes research data openly available and improves the interconnectivity of Europe's research infrastructure. This is essential for the development of industry and academic innovation and applications. In particular, its provision of high quality relevant, up-to-date, just-in-time data can be a significant driver of future market development in Europe. The EOSC is currently under development and under further review.

EU member governments have been supporting and funding HPC activities at the national level for many years. Recently, they have reconfirmed their willingness to cooperate at the European level and to make HPC a priority item on their national agendas. Representatives from seven European governments (Germany, Portugal, France, Spain, Italy, Luxembourg and the Netherlands) signed a declaration establishing the EuroHPC Joint Undertaking as the framework for cooperation on HPC in Rome on 23 March 2017. Its objective is to pool together and leverage national resources in order to drive the sector forward. The agreement is underpinned by a shared goal of putting European exascale computing within reach in just a few years. As a first step, it aims to develop the technology that enables Europe to deploy HPC resources built on mainly European hardware. As it stands, six additional countries have joined this initiative (Belgium, Slovenia, Bulgaria, Switzerland, Greece and Croatia).

While the EU and national governments recognise the strategic value of HPC for Europe, there is a significant investment gap. In order to address this investment gap, securing the appropriate financing to cover the high costs of funding and maintaining a world-leading position for European HPC remains a challenge. While the EU as well as national governments are actively promoting the sector with various initiatives, public funding alone will not be sufficient to finance the broad uptake of HPC by industry and SMEs in the coming years. The EU needs to continue acting as a cornerstone investor whereby it mobilises public funding alongside a clear public value proposition, which should ultimately be recognised and rewarded by the private sector through co-investments. However, crowding-in additional private sector investments remains one of the key challenges of the HPC sector in Europe.
Although HPC uptake by large corporations is fairly widespread and the technology well established, the HPC uptake by SMEs is still developing with commercial business models just beginning to evolve. Overall, the complexity of the technology and associated business models induce a certain degree of caution on the side of private financiers, increasing their transaction costs, tempering their perceived returns and increasing their financing risk. Hence, the current hurdles for private investment and financing, especially for SMEs, are significant, as detailed below.

This study focuses on the access-to-finance conditions for the further development and deployment of supercomputing in Europe. It provides a new rationale for public investment and public value creation as a basis for improving the conditions for robust and long-term financing.
The studies' objectives are to:

- Identify successful commercial business models in the HPC market;
- Assess the financing requirements in key market segments and identify current financing bottlenecks;
- Provide recommendations to bridge the current gap between technology providers/users (demand side for financing) and investors (supply side);
- Explore options for public-private partnerships in financing HPC and propose ways to fund the HPC sector under current EU financial instruments.

To this end, this study conducted a series of in-depth interviews with the borrower and investors/lender side and analysed the broad range of existing public financing instruments. The study focuses on the following HPC market actors: Independent software vendors (ISVs) HPC centres (service providers), HPC intermediaries and HPC customers/(potential) users.

Current market situation

In Europe, the HPC landscape is mainly driven by the public sector – in terms of usage as well as financing. The majority of HPC capacity and utilisation (over 90% of operating time) is installed at universities or academic research centres, whereas the remaining 10% serves commercial purposes and/or HPC end users. Moreover, the academic community has invested the largest amounts in absolute terms between 2013 and 2018 when it comes to new HPC servers, and is only surpassed by government entities[3]. Presently, the HPC sector in Europe is largely being financed by national budgets, university funds/grants and also through significant support from European Union funds.

Currently, commercial users are mainly large corporations who apply HPC to reduce research and development costs by simulating prototypes of new products instead of physically building and testing them. A number of these commercial users cooperate closely with academia, using academic HPC infrastructure and partly co-developing software solutions. The use of HPC resources has recently come into reach for many SMEs. Until approximately five years ago, the use of HPC resources had been considered too complex, costly and hence out of reach for many smaller businesses. This was largely attributed to the lack of software integration and limited cloud capacity for running HPC applications and providing users with easily accessible HPC services. There are, however, continuing barriers to the effective use of HPC by SMEs due to constraints related to access to adequate software packages that suit the specific needs of SMEs. A critical aspect of the further development of supercomputing is that the architectures of these computers are designed in such a way that coders can develop effective software programs that can run on them. In fact, the scalability of software (the ability to use a large portion of computational capabilities of an HPC on a single program) is considered a critical barrier for the scalability of HPC systems.

Although HPC use has become much more easy to use and affordable, many SMEs still rely on workstation-based simulations with very limited computational capacity in their R&D processes. This is somewhat surprising as the combination of HPC and cloud-based solutions can exponentially surpass the performance of conventional workstation set-ups. In this context, a key element of this study is analysing the factors limiting the uptake of HPC by SMEs in the European market.

HPC in the academic context

In Europe, most HPC centres are attached to scientific research institutions and academia, predominately led by research interests and focused on the public good of scientific discovery. Their financing hinges on public subsidies with very limited commercial revenue streams. Examples of these largely academically driven models include the University of Southampton, the ETH Zurich and the University of Cambridge.

Some academic HPC centres in Europe have gradually opened up to cooperation with industry. Among them, HLRS (High Performance Computing Centre Stuttgart), EPCC (Edinburgh Parallel Computing Centre), the Hartree Centre of the Science and Technology Facilities Council and Cineca are prominent examples. These commercially oriented HPC centres have developed diverse service offerings to cooperate with the industry, facilitating innovation and a wider application of HPC resources. These centres partly finance themselves with payments from their industry partners and provide various good practice cases for building commercial business models. Overall, however, the industrial outreach of academic HPC centres is in itself partly curtailed by centres' statutory funding limitations. Hence, these limitations need to be reviewed and made more flexible, in order to develop a commercial model, through private-sector funding mechanisms.

HPC in the context of industrial applications

HPC use and application is already fairly widespread across European industry. HPC has become an integral component of business processes, particularly within certain industrial sectors such as automotive, aerospace, defence, bio-sciences and environmental/renewable energy. However, this mainly holds true for the big players, such as large multinationals, while the uptake of HPC by European SMEs is rather sluggish in comparison.

The business case behind industrial HPC use is relatively clear-cut. Its main purpose is to upgrade companies' R&D processes. As opposed to testing new products by developing costly physical prototypes, HPC makes it possible to transfer the process into a digital environment through which development costs can be minimised through 'digital twins'. For example, in discussions with market participants, a leading original equipment manufacturer (OEM) in the automotive industry stated that HPC enabled its R&D process to fully abandon early prototypes, which previously required costly customised tools and machinery. Although some physical processes such as crash test simulations have not yet been fully replaced (partially attributed to meeting regulatory demands), the current prototypes come close to serial production. Furthermore, HPC reduces the time to market by shortening the R&D cycle. Bringing new products or product upgrades to the market before the competition does is an essential competitive advantage in many commoditised industry sectors. On the other hand, SMEs are only just beginning to apply HPC for the optimisation of R&D processes. The three largest and most dynamically growing HPC sub-sectors are Computer Aided Engineering (CAE), Bio-sciences and the Environment and Renewable Energy:

- Computer-Aided Engineering (CAE) has a projected growth rate of HPC expenditure of 7.9% p.a. (CAGR) between 2013 and 2018[4]. Modern engineered products usually require extensive testing, not only of the final product but also of production methods, materials and processes. While in the past, testing was often done through prototyping, today HPC simulations replace the need for lengthy physical testing, thus cutting time to market and securing the competitiveness of the final product. The field of CAE covers a broad range of applications, e.g. simulation of structural mechanics will analyse the stability of the passenger compartment of a car in the event of a crash. Predicting the airflow through a turbine will eventually lead to energy conservation and quieter engines for airplanes. The combination of both issues can be used to determine the stability of a wind turbine's rotor blade. The cross-cutting industrial aspect of CAE and its ability to leverage cross-sectoral synergies is very powerful and ensures that the most important European industries in terms of value creation are supported (e.g. all of manufacturing). The use of simulations frees engineers from creating expensive prototypes in the early stages of product development, hence enabling more flexibility, reducing production costs, and speeding up the time to market. In effect, and on a far-reaching scale, CAE is likely to increase the EU's competitiveness in manufacturing[5]. The manufacturing sector contributes 26.1% to the EU's GDP and employs 29.7 million people, mostly highly qualified engineers and workers[6].

- Bio-sciences, including pharma and healthcare, have a projected growth rate of HPC expenditure of 5.1% (CAGR)[7]. Bio-sciences represent one of the fastest growing sectors with regard to the use of HPC in Europe, as well as globally. This trend is driven by the idea of personalised medicine and customised treatments, which creates high demand for the advanced computational analysis of individual patients (as well as certain pathogens) seeking a more effective and targeted tailor-made treatment. Considering that personalised medicine is facilitated by the comparison of a particular patient to data from patients with similar characteristics, and that by the year 2020 healthcare data will reach 25,000 petabytes – a 50-fold increase from 2012 – finding the right treatment requires the use of HPC resources[8]. This includes, in particular, the development towards advanced diagnostic methods through the use of bio-informatics, i.e. genome analytics, which is rooted in Big Data analytics. One important factor in choosing the bio-sciences as a focus sector for the study was its equal importance for both research and industry, as well as its enormous potential for the public good. Both research and industry are working on the challenges of aging societies and/or in developing new drug therapies for cancer, Alzheimer's and similar diseases. While potentially greatly beneficial in improving public health and well-being, the prospective opportunities in commercialising new solutions are reflected in the high R&D expenditure of pharmaceutical and biotechnology companies[9]. Additionally, bio-sciences include some of the most R&D intensive subsectors. The pharmaceutical and biotechnology industries combined spent 14.4% of their realised net sales in 2014 on R&D. On average, this is 10% higher than the mean for the entire industry, and 11.5% more than was spent by the industrial engineering sector[10].
- Environment and renewable energy (E/RE) have a projected growth rate of HPC expenditure of approximately 5% (CAGR)[11]. The environment and renewable energy sector is a cross-cutting segment of the European economy contributing resources and energy efficiency. Starting with the design and construction of renewable energy production systems, such as wind turbines, and the testing of new and more efficient forms of materials, such as silicon for highly efficient solar panels, the E/RE sector draws from different disciplines. Geosciences and the weather sector involve, for example, terrain simulations on the placement of wind parks for optimising the position of each windmill and the plant as a whole. Calculations are also required to determine the effects of wind turbines on radar for air traffic control, especially in the proximity of airfields and airports. In addition, simulations are inherent in geothermal energy, seismic exploration and in complex infrastructure projects, such as reservoirs. As a broader rationale, the importance of renewable energy, which made up 25.4% of total primary energy production, increasing 73.1% over a decade in the EU, cannot be understated[12]. The International Renewable Energy Agency (IRENA) expects that the share of renewables will further increase and will have doubled globally by 2030. At that point, it will have boosted global GDP by 1.1%, equivalent to USD 1.3 trillion[13]. This development is estimated to provide additional employment to 24.4 million people.

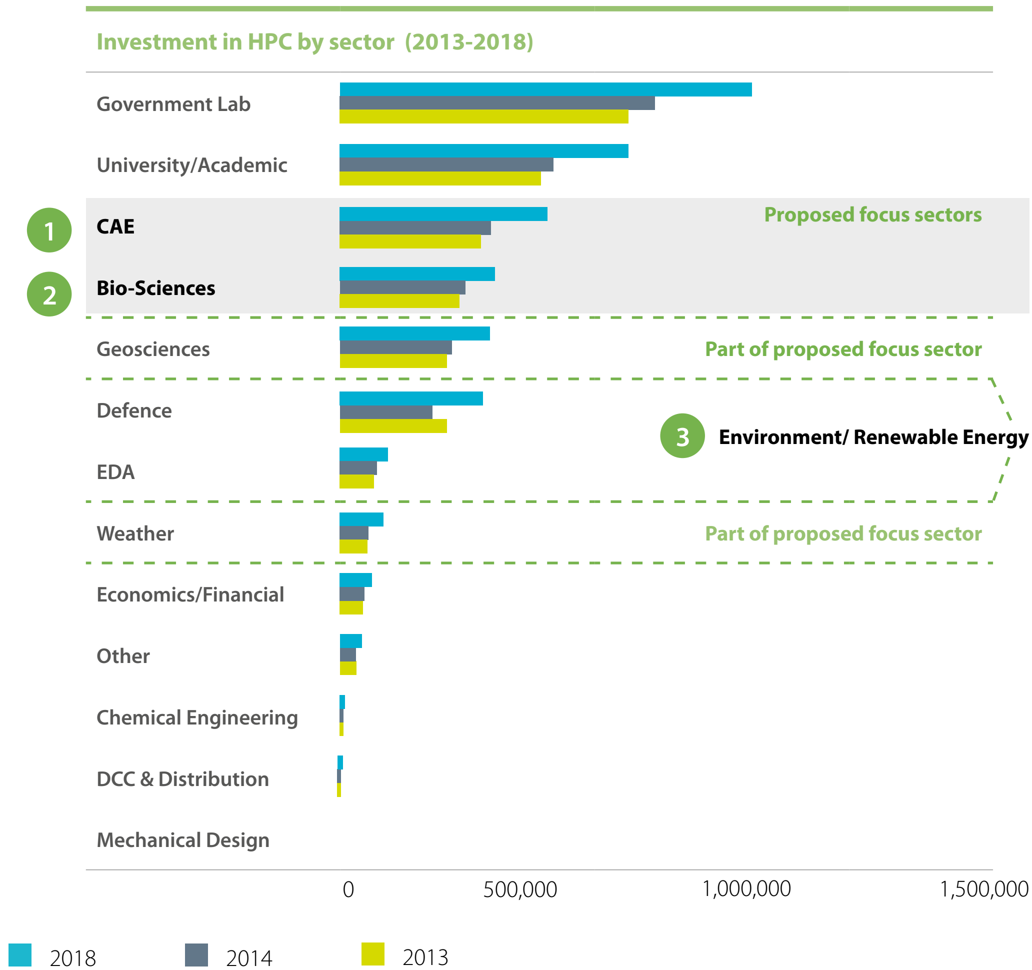


Figure 5: Investment (in EUR million) in HPC servers by sector [2013 - 2018] (EU, IDC, 2015) and focus areas of this study

Overall, large multinationals finance HPC activities within their standard business cycles, supported through their balance sheets. Most SMEs with more constricted balance sheets do not have comfortable financing options and face various hurdles as will be detailed below, among others a lack of own financing and equity, small investment volumes, lack of collateral, and a limited risk appetite for growth investment by investors. Given that SMEs are a crucial building block of the European economy, mobilising their HPC uptake and improving their access to finance are critical for the successful development of the sector.

A paradigm change in industrial HPC application: The convergence of HPC and Cloud Computing

The trend for convergence between the previously separated fields of HPC and Cloud Computing is likely to shape the development of Europe's innovation ecosystem over the coming years.

The market up to now

So far, users have categorised their computing tasks and analysed which IT architecture is more suited to tackling the challenge: either an (on-premises) HPC system or distributed cloud infrastructure for applications that were less dependent on latency. Typical use cases for a solution via an HPC system were high frequency trading or numeric weather simulations. Common cloud infrastructure use cases were traffic monitoring and personalised health. Each system provider adopted the solution best-suited to providing an optimal service to its customers.

The change in demand

However, the more recent exponential growth of data intensity in many industrial processes and service-oriented business models has brought about different opportunities and challenges for end users. While HPC capabilities were traditionally used for highly specialised, complex use cases in R&D, they are now being increasingly used for industrial applications that require real-time or near-real-time data processing. Examples are applications based on the Internet of Things (IoT) and Artificial Intelligence, which are based on Big Data and require very powerful computational capabilities. At the same time, providers are starting to offer HPC resources on-demand and via 'the cloud'. In effect, Cloud Computing does not always involve the classical distributed grid architecture.

What does it mean for the HPC ecosystem?

The paradigm shift described above means, in simple terms, that HPC will become more relevant in the future – with growing demand, supply will also rise. Traditional Cloud Computing providers like Amazon Web Services and niche providers like UberCloud have already started to offer HPC computing resources via the cloud. On the other hand, this trend can question the commercial viability of investments in dedicated, large-scale HPC infrastructure.

HPC trends in international comparison

Whereas other countries (e.g. China and the US) have invested heavily in supercomputing infrastructure and capacity, Europe has been lagging behind. In the past few years there has also been a significant change in locations of supercomputers (as seen in Figure 6 below). China is now the leader in performance and number of the top 500 supercomputers worldwide, having superseded the US in June 2016. The loss of market share for European supercomputers is also a result of the Chinese HPC programme. The US is also mindful of the new leadership by China and is focusing on re-attaining its number one position.

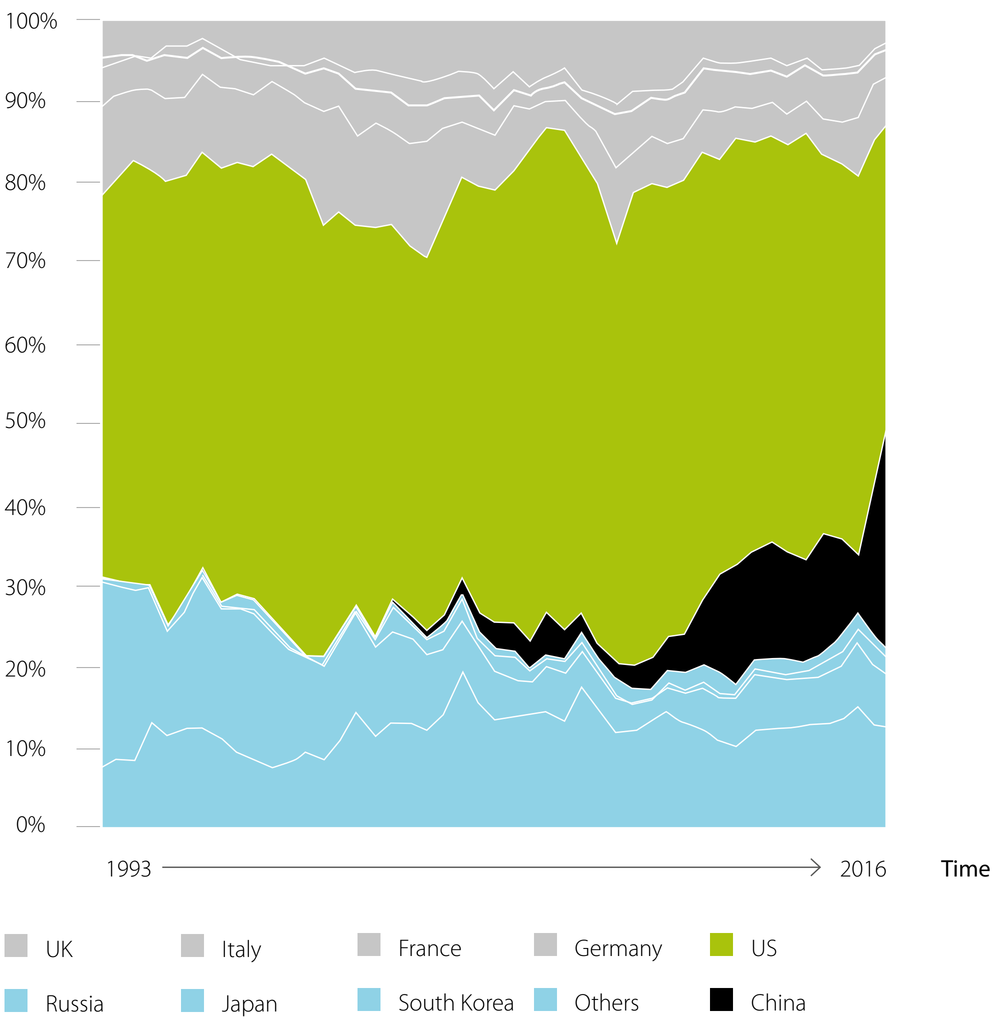


Figure 6: Development of the geographic distribution of supercomputers worldwide over the past 23 years: The US and, most recently, China dominate the market while Europe has fallen behind (source: top500.org)

At the same, time Europe's HPC market is forecasted to grow by an annual rate (CAGR) of 7.0% through to 2018[14]. This makes HPC and Cloud Computing strategic technologies crucial in securing Europe's economic competitiveness and future growth. The EU's share of the global HPC server market amounts to approximately 30%, whereas that of the US, which is the largest market, reaches almost 50%. The following figure shows the revenues of HPC servers clustered by regions. The most significant HPC server markets by revenues are the United States, EU, China and Japan.

		2009	2010	2011	2012
Revenue	North America	3,141,484	3,024,375	3,344,075	3,475,831
	EMEA	1,791,362	2,179,440	2,310,807	2,395,782
	EU Only	1,526,503	1,867,046	1,979,021	2,049,407
	EU+ Only[1]	1,610,838	1,969,132	2,086,994	2,161,036
	Asia/Pacific w/o Japan	644,286	873,956	1,098,139	1,145,739
	Japan	588,231	588,231	412,820	563,871
	China	254,171	359,689	437,180	472,757
	Rest of World	53,359	73,090	99,150	74,916
	Total	**6,218,722**	**6,563,682**	**7,416,042**	**7,990,375**
Share	North America	50.5%	46.1%	45.1%	43.5%
	EMEA	28.8%	33.2%	31.2%	30.0%
	EU[1] Only	24.5%	28.4%	26.7%	25.6%
	EU+[1] Only	25.9%	30.0%	28.1%	27.0%
	Asia/Pacific w/o Japan	10.4%	13.3%	14.8%	14.3%
	Japan	9.5%	6.3%	7.6%	11.2%
	China	4.1%	5.5%	5.9%	5.9%
	Rest of World	0.9%	1.1%	1.3%	0.9%

Figure 7: HPC Revenue by Region (in EUR thousands, source: IDC 2015)

1) Refers to EU 28 plus Norway and Switzerland

2013	2014	2015	2016	2017	2018	CAGR 13-18
3,251,811	3,471,455	3,691,099	3,910,743	4,130,388	4,350,032	6.0%
2,233,407	2,410,801	2,588,195	2,765,589	2,942,983	3,120,377	6.9%
1,904,746	2,049,684	2,204,614	2,363,781	2,512,684	2,670,860	7.0%
2,008,565	2,161,486	2,324,361	2,491,435	2,648,206	2,795,167	6.8%
1,376,967	1,304,967	1,411,676	1,518,385	1,625,094	1,910,513	6.8%
898,107	508,895	540,214	571,532	602,851	634,169	5.8%
726,517	573,025	623,716	677,986	705,291	853,336	3.3%
75,350	83,809	92,268	100,728	109,187	117,646	9.3%
7,415,111	**7,260,601**	**7,717,126**	**8,256,167**	**9,329,459**	**10,132,736**	**6.4%**
43.9%	47.8%	47.8%	47.4%	44.3%	42.9%	
30.1%	33.2%	33.5%	33.5%	31.5%	30.8%	
25.7%	28.2%	28.6%	28.6%	26.9%	26.4%	
27.1%	29.8%	30.1%	30.2%	28.4%	27.6%	
18.6%	18.0%	18.3%	18.4%	17.4%	18.9%	
6.4%	7.0%	7.0%	6.9%	6.5%	6.3%	
9.8%	7.9%	8.1%	8.2%	7.6%	8.4%	
1.0%	1.2%	1.2%	1.2%	1.2%	1.2%	

A country-wide comparison of supercomputers demonstrated the clear leadership of the US and Chinese markets:

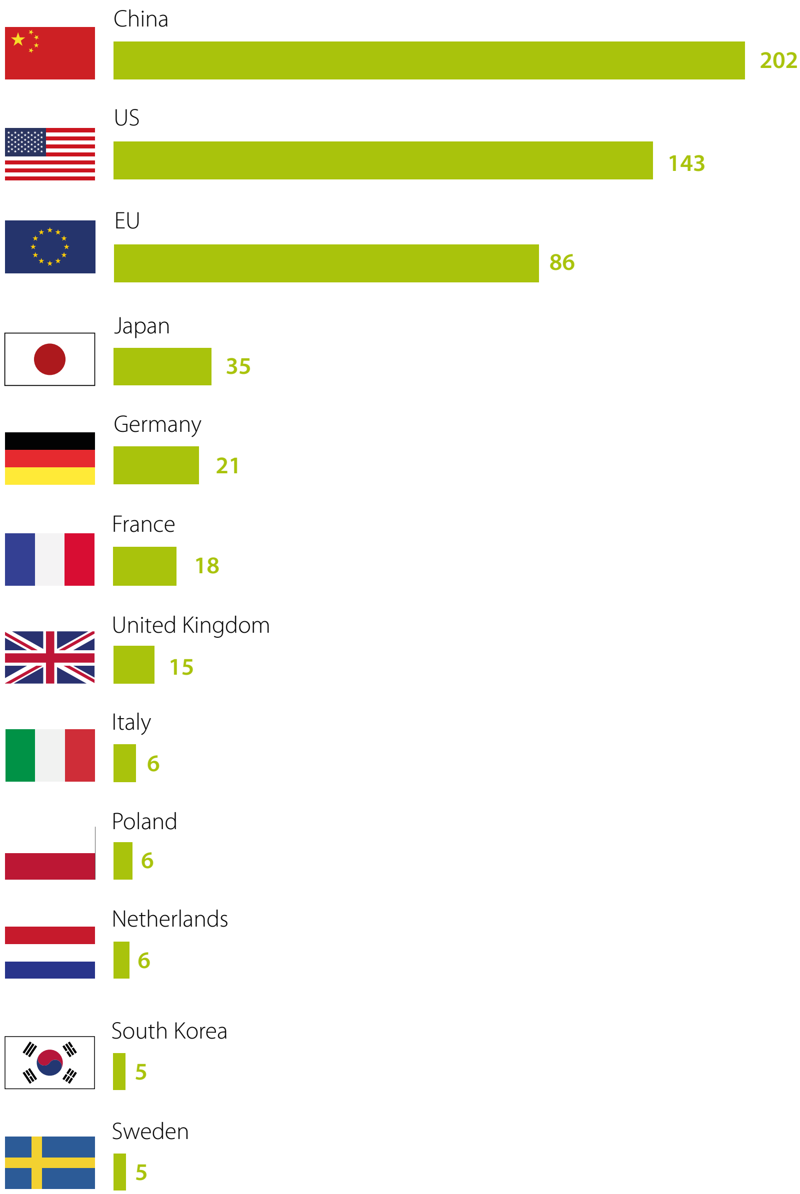


Figure 8: Number of Supercomputers in the Top500 list by country, November 2017

Each of these countries have taken policy measures to promote their HPC sector and are also strategically investing in its development, as the following figure illustrates:

Country	HPC Strategy/Program and Description	Investment Level[1]
United States	National Strategic Computing Initiative (NSCI)	Approx. EUR 285 m/year
China	13th Five-Year-Development Plan (Develop Multiple Exascale Systems)	Approx. EUR 178 m/year (for next five years)
Japan	Flagship2020 Program	Approx. EUR 178 m/year (for next five years)
European Union	ExaNeSt, PRACE, ETP4HPC	Approx. EUR 893m total allocate over 2014-2020 (annual allocations N/A)
India	National Supercomputing Mission	Approx. EUR 124 m/year (for five years from 2016-2020)
South Korea	National Supercomputing Act	Approx. 18 m/year (for five years from 2016-2020)
Russia	HPC Focus of Medvedev Modernisation Programme	N/A

[1]USD amounts converted to EUR based on current exchange rate (08.06.2017)

Figure 9: Summary of National HPC Strategies by Country (Source: IDC, 2015)

In its efforts to keep up with the Chinese programme, the US has made a significant push for their domestic HPC sector. Back in 2015, US president Obama launched the National Strategic Computing Initiative (NSCI). Its mission is to ensure that the US continues to maintain a top position, regaining the number one spot, in the High Performance Computing field over the coming decades. There are several efforts within the NSCI to achieve this goal, and its key objectives include:

- Foster the deployment of exascale supercomputers (supercomputers which have a floating point calculation power of a factor of 100 times higher than the top systems deployed in the EU today) in the coming years;
- Keep the United States at the forefront of HPC capabilities;
- Improve HPC application developer productivity;
- Make HPC readily available; and
- Establish hardware technology for future HPC systems.

NCSI aims at supporting the science community as well as the industry. On 7 September 2016, the US Department of Energy released the first round of funding for the Exascale Computing Project (ECP). Almost USD 40 million has been granted to 22 developing applications for exascale systems.

Additionally, the United States is keeping its market closed to foreign vendors. The domestic industry is currently strongly supported with a 'Buy-American' requirement for the purchase of supercomputers, e.g. under the Pre-Commercial Procurement and Public Procurement of Innovation programmes. In addition, the spending volume of the United States in this sector is significantly higher, especially in exascale development, in comparison to the EU, which also results in its securing the top-two position. Similar to the US Procurement programmes, the Chinese and Japanese governments apply restricting regulations to protect local market participants.

Overall, the US software market is substantially underinvested. This has been raised as a concern for its future development. Its leadership potential is also threatened by the European competition in this segment as will be argued below[15].

The combination of HPC with Cloud Computing

From the perspective of a number of market participants, HPC hardware is approaching its limits in terms of its processing capacities. By 2025, hardware configurations could come to the end of exponential capacity increase. Thus, software (application) development and services related to HPC should be given priority in order to use limited hardware capacities to the best possible extent. Powerful HPC software will enable optimisation of the existing hardware installations. In addition, flexible and cost-efficient use of software is crucial for the wider application of HPC by private businesses.

The EC stresses that the main economic value is generated through the underlying data and emphasises the importance of data-driven innovations as a key source of economic growth and employment generation. The economic benefits from applications based on data that utilise Cloud Computing services are estimated to account for 0.1% and 0.2% of GDP growth in Europe. The cumulative economic effect is estimated to have reached EUR 763 billion between 2010 and 2015 in Germany, France, Spain, the UK and Italy alone. The number of new jobs created by Cloud Computing is estimated to be between 70,000 and 800,000. The Cloud Computing segment is expected to grow much more dynamically than the HPC segment. Cloud computing is forecasted to grow 34% p.a. (2014

2018) compared to 8.2% p.a. (EMEA 6.9%) for HPC. In 2015, the total Cloud Computing segment had a volume of about USD 75.3 billion with Software as a Service (SaaS) covering about two thirds of this market. Infrastructure as a Service (IaaS) had a share of about 31% of the market and Platform as a Service (PaaS) of 3%.

In this context, the combination of HPC services with Cloud Computing provides an unprecedented opportunity in terms of making HPC capabilities much more accessible to a broader user base, in particular from both innovative high-tech SMEs and SMEs from traditional sectors. Cloud Computing enables SMEs to make use of HPC services without having to invest in costly HPC infrastructure.
The following figure depicts the services and key players in each category:

Software- as-a-Service	Platform- as-a-Service	Infrastructure-as-a-Service
• Provided by a software company or a partner • Customer usually uses software for regular fee	• Development environment provided as a service • Scalable and usually lower total cost of development	• IT infrastructure provided as a service, typically virtualised • Scalable and usually charged by actual usage

While there are many more XaaS categories (e.g. Business Process as a Service), this paper focuses on the three most popular types SaaS, PaaS and IaaS

Figure 10: Overview of Cloud Computing services and providers)

The following figure shows growth and projections in each category up until 2026. Growth is expected to continue proportionately. It demonstrates that while each segment is growing steadily, the strongest growth can be seen in 'SaaS'.

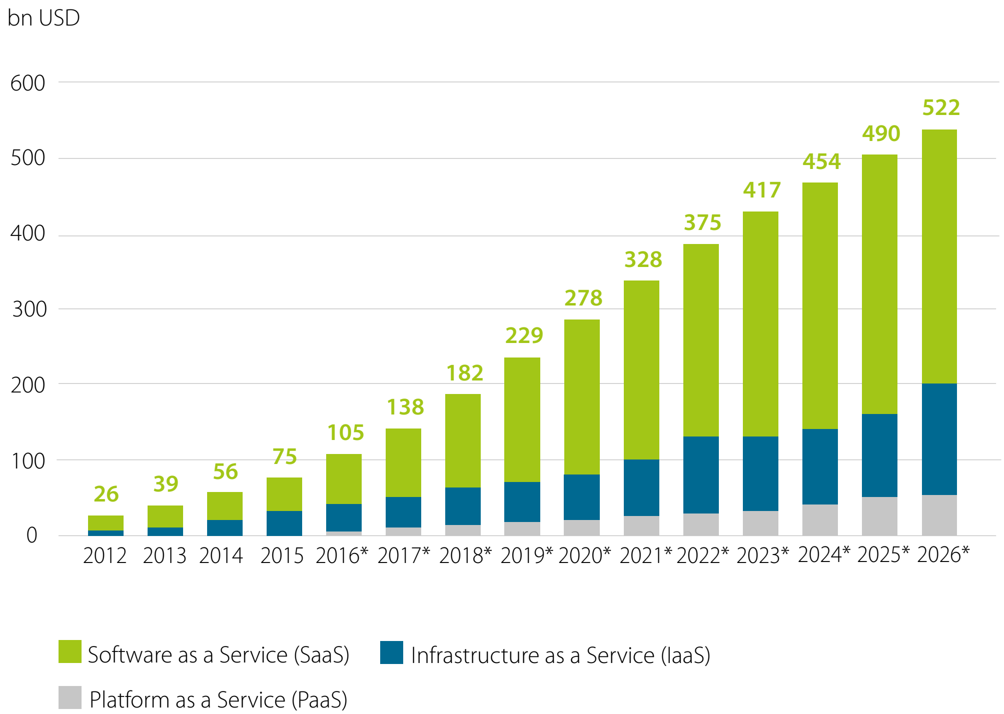


Figure 11: Public cloud revenue worldwide from 2012 to 2026, by segment (in billion US dollars, source: statista.com)

The growth of Cloud Computing is strongly driven by the leveraging of scale, accelerating market consolidation. The five largest grid computing providers, all headquartered in the US, have a combined market share of 55% and reach growth rates which exceed the average expected market growth rate (see Figure 8). However, other global technology companies are currently attempting to enter the market, e.g. the Chinese e-commerce company Alibaba. SAP is the largest European cloud service provider with revenues in this market of about EUR 2.2 billion (USD 2.5 billion) in 2015 and a 3% market share.

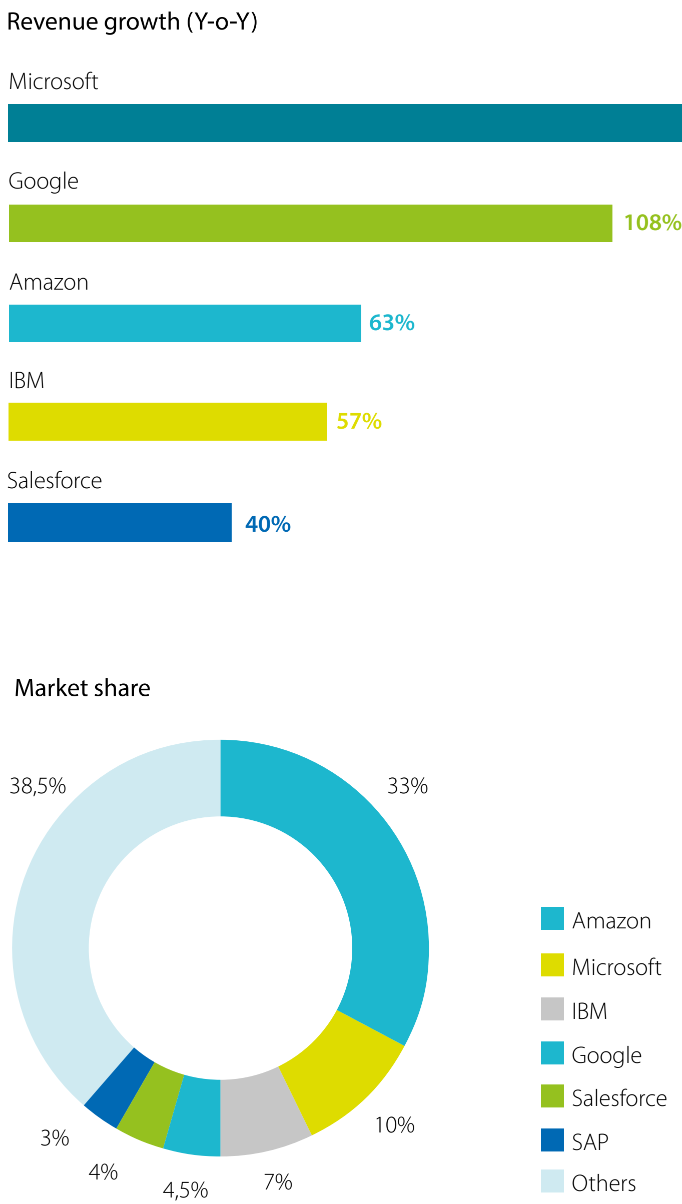


Figure 12: Cloud Infrastructure Services Q4 2015, for the largest Cloud Computing providers (Source: Synergy Research Group)

Data security is a key condition for HPC and CC use in general and a particular need driving the establishment of European data infrastructure. HPC application on its own or via cloud offerings is often perceived to carry significant data security risks, raising red flags on vulnerabilities and data integrity concerns. Private sector HPC users often point to the following as the key risks associated with HPC:

- Open infrastructure – HPC is often used in scientific research and government settings. In a research institution like a university there may be fewer controls over system access as well as back-end administrative access. Thus the system may be accessible by multiple entities, given the open and sharing spirit of academic research.
- Distributed data sources –The creation of 'data lakes' used in Big Data, powered by HPC, may not have adequate security controls in place. Reasons for these deficiencies vary, but they often emerge from the ad-hoc creation of a data repository from multiple sources.
- Clusters – HPC environments are taypically clustered, an architecture that exposes them to multiple risks. Given their generally heterogeneous nature, clustered HPC systems may require multiple management systems to operate. This can slow down the implementation of security policies and processes like security patch management – with vulnerabilities going un-remediated as a result.

Greater private sector provision of HPC aims to address the perceived risk of data security attributed to open infrastructure systems used by many public HPC providers. Additionally, there also needs to be greater efforts in raising users' awareness about potential security risks, and towards implementing standards to better manage cybersecurity threats. Data security is a challenge that requires continuous efforts and vigilance, as well as clear policies and guidance.

In response to data protection and cybersecurity challenges in the operation of HPC centres, there is an emerging niche market of fully commercially driven HPC providers in Europe. Companies such as CPU 24/07, Arctur and others offer highly flexible on-demand cloud-based HPC services that abide by the highest data security and privacy standards. These companies are able to differentiate themselves from strong international competitors, such as Softlayer or Amazon Web Services, as well as from public HPC centres, by providing highly specialised and secure HPC services to clients from industry and SMEs. Their services ensure comprehensive security measures for the protection of intellectual property through private and dedicated HPC cluster infrastructure.

At the same time, there is a significant market trend in Europe pointing to increased reliance on cheaper, flexible, on-demand cloud-based service providers outside of the EU. As data processing is not bound by geographic borders, demand for certain services predominantly goes to the lowest-priced provider. Despite significant data integrity concerns, European industry stakeholders increasingly use American HPC and CC data services. The study outlines strategic options to address this challenge in further detail below.

2. Approach and methodology

Data and Sources

To achieve the purpose and objectives as outlined in chapter 1.1, this study aimed to fulfil two major requirements:

a) **Provide genuine market insights:** Generate comprehensive, up-to-date and original insights on access-to-finance conditions from relevant market players and institutions in the field of HPC, considering both the borrower's and the lender's perspective.

b) **Build on existing initiatives:** Take into account and build on existing programmes, financing instruments and best practices established by the European Commission, the European Investment Bank, public entities on a national level, private market players and academia.

In order to provide **genuine market insights**, a broad approach, composed of the following methodologies, was taken:

- **Semi-structured expert interviews:** Interviews were held with representatives from both relevant HPC organisations (receivers of financing) and relevant investor institutions (providers of financing). Serving as a basis for the interviews, two questionnaire guidelines (for relevant HPC organisations and for relevant investor organisations) were developed containing approximately 40 questions concerning the organisational set-up, business model, financing needs and financing experiences of the relevant organisations. In chapters 2.2.1 and 2.2.2, a detailed description of the selection process of the interview partners is provided. In total, 44 one-hour interviews were conducted. 27 interviews were held with relevant HPC organisations, representing four groups: Independent Software Vendors (ISVs), HPC centres, HPC intermediaries and HPC customers. These interviews covered ten European markets, including the EU's seven largest economies as well as three representatives from US market-leading corporations. 17 interviews were conducted with investors in HPC, representing commercial banks, national promotional banks, corporate ventures, venture capital funds and, selectively, government authorities. The latter interviews covered seven European markets, including the EU's four largest economies. All interviews were conducted from March 2017 to May 2017.

- **Expert conferences:** The project team participated in both the 64th HPC User Forum from 28 February to 1 March 2017 in Stuttgart (Germany), and the 7th Annual General Assembly of the European Technology Platform for High-performance Computing (ETP4HPC) held in Munich (Germany) on 21 March 2017. Both conferences were considered to be the most important gatherings of HPC experts that coincided with the study period. At the 64th HPC user forum, in-depth discussions of future developments in the HPC sector were carried out with a focus on HPC centres. Detailed discussions were convened with experts from HLRS, PayPal, IBM, ETP4HPC, SICOS, par-tec, Hartree Centre, Clustervision and Daimler. During the Annual General Assembly of ETP4HPC an outline of the study was presented and discussed with some 70 sector experts.
- **Research and exchange on international best practices**: In the context of this study, international best practices for HPC financing instruments were identified and analysed. The ten most relevant instruments for the European HPC sector were evaluated in detail and a number of background interviews with the respective instrument owners were held in order to obtain a clear understanding of the funding mechanisms in place and the potential transferability to a European environment.
- **Validation discussions**: Subsequent validation discussions were held with a number of partners who had already taken part in the semi-structured expert interviews. These discussions were based on an initial set of draft recommendations. During these discussions, the scope, feasibility, implementation effort and effectiveness of the developed recommendations were probed and challenged. The findings and recommendations of this study were also aligned with Roland Berger's international experts for technology, media and telecommunications.

In order to **build on existing initiatives**, the following broad approach was taken:

- **Comprehensive review of current programmes, initiatives and policy targets** established by the European Commission and by the EIB, among them High Performance Computing in the EU: Progress on the Implementation of the European HPC Strategy, PRACE Special Report - Supercomputers for all, High Performance Computing in the EU: Progress on the implementation of the European HPC strategy.
- **Review of existing financing instrument**s: Screening of a wide range of European financing instruments with relevance for HPC (including debt and equity-based instruments, with a focus on EFSI and Horizon 2020 instruments).
- **Background talks** with the EIB's experts on financial instrument design in order to obtain a clear picture of the design features and possible regulatory constraints of financing instruments. Insights and further background information from the European Commission were discussed during both a kick-off and scoping workshop.

Confidentiality was assured to all participants in this study. Therefore, quotes and data provided by interviewees are presented anonymously.

The study has been accompanied by the **Fraunhofer Institute for Algorithms and Scientific Computing (Fraunhofer SCAI)**, a scientific partner that played a substantial role in overseeing the overall design, provided inroads to interview partners and peer reviewed the final report.

Scoping (HPC organisations and lender/investor institutions)

Both the very broad spectrum of the HPC sector and the limited time frame available for this study made it necessary to clearly scope the approach, focusing on those market segments that would benefit most from improved access-to-finance conditions for HPC and Cloud Computing in Europe. In alignment with the study's objectives, separate scoping approaches were used to identify the most relevant HPC organisations (demand side for receiving financing, see chapter 2.2.1) and on the lender's side (supply side for financing, i.e. in the form of debt or equity, see chapter 2.2.2).

Selection of relevant HPC organisations

Overarching selection criteria

The HPC organisations analysed by this study were selected based on four overarching criteria:

- **Criterion 1: Successful commercialisation**: A commercially successful (or potentially commercially successful) business model is a requirement for improved access to finance. Positive future returns from business activities are needed to pay out dividends to equity holders or to repay loans to debt providers. Therefore, purely academic projects and early-stage research without a clear commercial purpose are not the focus of the study. In the context of the study, successful commercialisation was assessed by analysing companies' balance sheets (P&L, cash flows). Where commercial viability had not yet been reached, commercialisation potential was assessed in collaboration with Fraunhofer SCAI, based on available studies and expert interviews.
- **Criterion 2: Tangible innovation potential**: HPC in Europe is an evolving and highly dynamic market. Market segments with high innovation potential and a significant growth dynamic are of particular importance because of their possible contagion effect for spurring further innovation, growth and employment, contributing to strengthening Europe's position as a key player in the global HPC market. Innovation potential was assessed by Fraunhofer SCAI based on available studies and expert interviews.
- **Criterion 3: High PPP potential**: Finding approaches that complement public financing on HPC with private investment is one of the key objectives of this study. Public-private partnerships (PPP) can play an important role in this respect. Therefore, particular emphasis was given to organisations with functioning PPP models and existing, publicly financed HPC institutions with strong outreach activities into the private sector.
- **Criterion 4: Relevance for the European market**: HPC activities with significant relevance to the European market were considered to be the focus of this study. Conversely, market segments like

HPC hardware production, which is dominated by American and Chinese providers with little or no market share held by European players, were considered to be out of scope. Relevance for the European market was determined based on a review of available studies on the market share of different HPC segments complemented by an assessment from Fraunhofer SCAI.

Stages of the selection process

In a next step, the four selection criteria outlined above where applied to three different stages, identifying:

- The most relevant segments of the HPC **value chain** (stage 1);
- The most relevant **industry sectors** for the application of HPC (sector selection, stage 2); and
- The most relevant **individual organisations** to be approached as potential interview partners (selection of organisation, stage 3).

Stage 1: Value chain: The **HPC value chain** is a commonly accepted approach to structuring the HPC market[16]. It served as an important filter to narrow the scope of this study. Figure 9 below displays the HPC value chain and the study's focus areas:

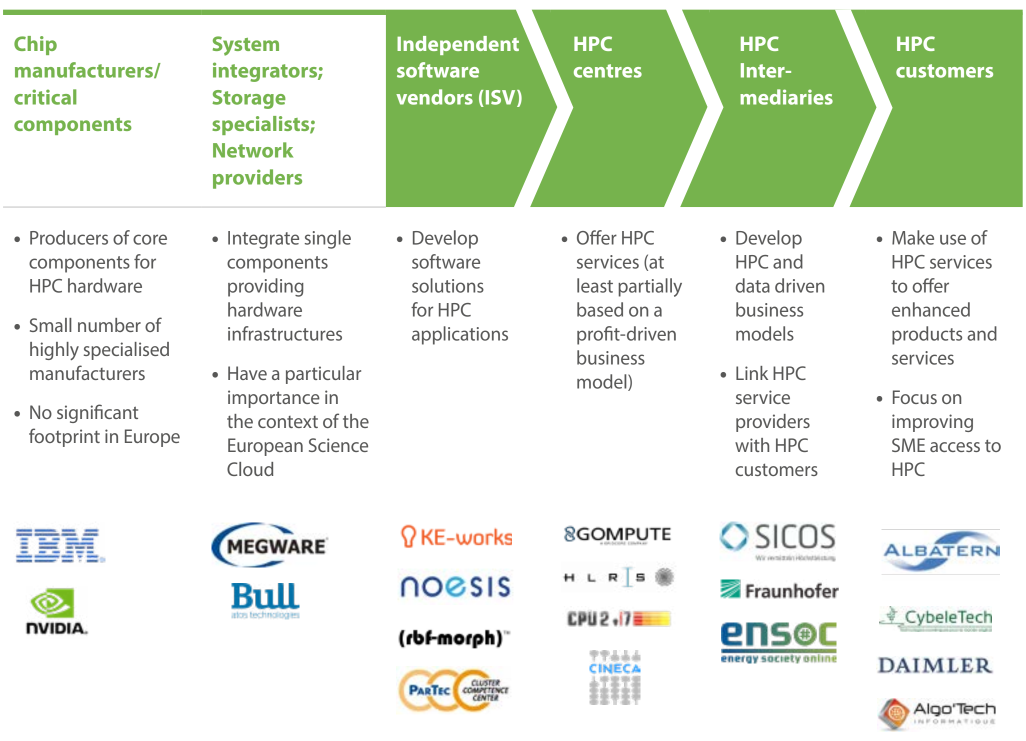


Figure 13: Schematic HPC Value Chain, incl. short descriptions of the different value chain stages, and sample organisations in each value chain step. The focus areas of this study are highlighted (Source: Fraunhofer SCAI)

The rationale behind the selection of focus areas within the value chain is described below:

- **Chip manufacturers** and **system integrators** are excluded in the context of this study. Nevertheless, it is noted that they can play a substantial role in the procurement processes of large computing systems. There are only a few chip manufacturers operating worldwide. System integrators depend on buying their processors at competitive prices in order to be able to make competitive bids. Hence, chip manufacturers have the ability to influence the outcome of bidding processes by offering different prices to different system integrators for the same or similar types of chips/processors in the same procurement process. With the tight integration of I/O fabrics to certain chip/processor models, dependency on the pricing dictated by the chip manufacturer is even more severe since other hardware components also need to be acquired from them (vendor lock-in).

- **Independent Software Vendors, ISVs** develop and sell software for HPC applications. A considerable number of European ISVs are industry leaders in simulation and modelling applications for HPC on a global scale. In providing suitable software, ISVs help to maximise the performance of HPC hardware and generate genuine, high value-added products. On the other hand, the relatively small and specialised European ISVs are being challenged by growing global competition in this market segment. Therefore, they are of particular interest to the study.

- **HPC centres** mainly focus on offering HPC capacity on pre-installed, ready-to-use hardware. Europe has strong academic HPC provider infrastructure. Traditionally, these providers have been financed by public research grants. More recently, however, many academic HPC centres have started to establish commercially driven business models in order to generate additional income or to complement increasingly scarce public funding. While still being practised on a rather modest scale today, such commercially driven approaches make academic HPC service providers highly relevant in the context of this access-to-finance study. On the other hand, commercial HPC providers offering computing capacity services as a business model are exceptionally scarce in Europe. The strong competition, particularly from the US (such as from Amazon Web Services, Google, IBM and Microsoft) has left relatively few European players offering HPC capacities on a commercial basis. The dominance of US-based service providers has sparked concerns about data security and the protection of intellectual property rights for European HPC users. Considering that HPC is often applied to run simulations on cutting-edge product innovations, this exposes highly sensitive data to a HPC service provider and potentially to other competitors. The relatively weak position of European commercial HPC service providers, combined with their strategic importance for Europe, makes them a focus of this study.

- **HPC intermediaries** support industry and SMEs in the successful application of HPC. HPC intermediaries thus play a particularly critical role in helping European SMEs tap into the potential of HPC for their business, e.g. by reducing time to market for new products and/or by cutting costs in resource-intensive R&D processes. Thus, HPC intermediaries (such as CEA, Fraunhofer ITWM, Fraunhofer SCAI, SICOS, and others) fulfil four significant functions by: (i) serving as competence centres and providing their technical expertise to HPC users; (ii) acting as intermediaries between all relevant stakeholders, offering insightful perspectives on the entire HPC market; (iii) raising awareness of the benefits of HPC use, both for research and commercial applications; and (iv) strengthening the demand for HPC, hence leveraging innovation and enhancing value creation across multiple sectors. Their dynamic position in the HPC ecosystem makes them an integral part of the study.

- HPC customers make use of HPC services in order to offer enhanced products and processes. HPC customers in Europe (i.e. automotive, renewable energy, biotechnology industries) are driving the constant development of new simulation solutions, based on their strong application interest. However, HPC application is more common amongst large industrial players than smaller ones. HPC uptake among SMEs is still very limited, meaning that the potential of High Performance Computing is not fully leveraged by a significant portion of European businesses. Therefore, HPC customers are included as a focus group relevant to this study. In this context, a particular emphasis is given to success factors leading to stronger uptake of HPC by SMEs.

Stage 2: Sector selection: Identification of high priority sectors using HPC: Given the scope of the study, a maximum of three sectors where HPC applications are intensively used are examined in-depth. Based on a comprehensive review of studies and a market assessment, three sectors were chosen that, on the one hand, already have a strong HPC application track-record and, at the same time, plan the highest level of expenditure for HPC in the mid-term, including:

- Computer-aided engineering;
- Bio-sciences (incl. pharma and healthcare); and
- Environment/renewable energies.

Stage 3: Selection of individual organisations: Within the selected value chain steps and sectors, a long list of relevant companies was gathered based on a broad range of sources:

- Participant lists from relevant conferences;
- Membership in industry associations and user fora, such as ETP4HPC, HPC User Forum, Big Data Value PPP, IEEE/acm Supercomputing Conference, ISC Cloud and Big Data conference, PRACE;
- Desk research in relevant industry databases;
- Organisations identified by Fraunhofer SCAI, the Roland Berger expert network, the EIB, as well as others, as recommended by interview partners.

All organisations fitting the selection criteria were approached for interviews[17]. Within each organisation, the highest-ranking suitable interview partner was targeted (i.e. CEO, CFO or head of division).

The following figure summarises the approach outlined above:

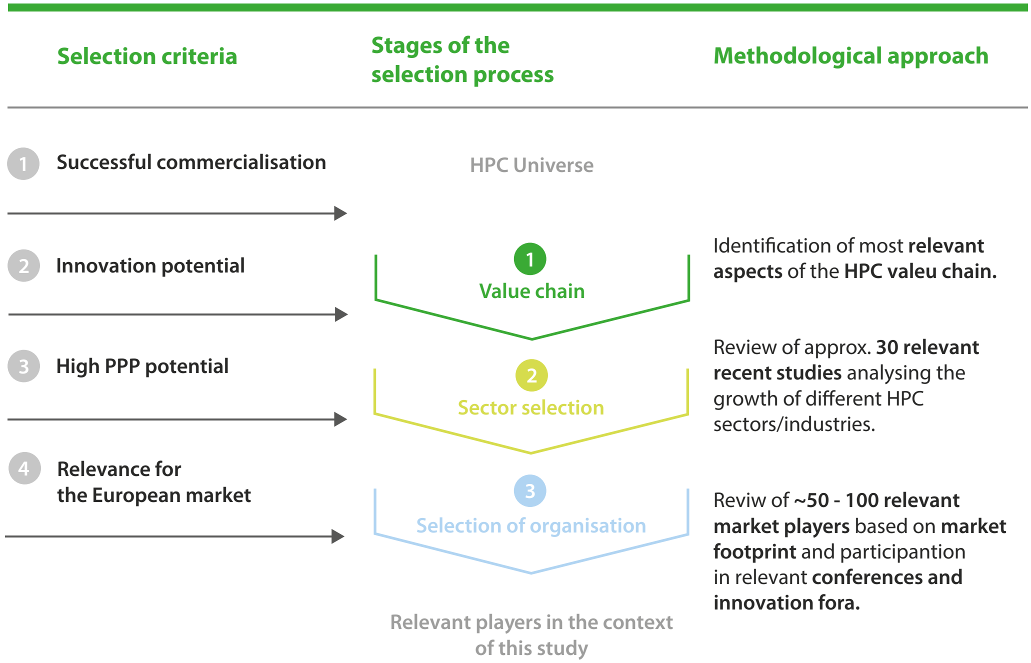


Figure 14: Summary of the selection process of the borrower side

As a result, 30 structured expert interviews were conducted, representing ISVs, HPC centres, HPC intermediaries and HPC users from the following organisations:

Figure 15: Overview of key HPC expert interviews conducted in the context of this study (organisations and geographic coverage)

Selection of relevant lender/investor institutions

A systematic scoping exercise was carried out in order to identify the most relevant financing institutions to be approached for structured expert interviews. Based on a review of current studies and a number of exploratory expert interviews, six types of financial institutions were found to be potentially relevant in the context of this study:

- Private equity funds: Private equity funds are typically set up as a partnership formed by private equity firms aiming to invest in private companies. They are mostly independent, commercially driven investment vehicles with the goal of restructuring and growing the companies acquired in order to divest at a significant profit after several years.
- Venture capital funds: Venture capital funds are a type of private equity funds where financing is provided to small, emerging companies. Venture capital funds finance early-stage companies and expect to turn some of their portfolio companies into profitable and sellable ventures.
- Commercial banks: Commercially driven financing institutions mainly provide term loans (debt) to private businesses. In order to qualify for a loan, a business typically has to provide collateral (i.e. real estate, other tangible assets), to have a financial track-record and adhere to fixed conditions for the loan (covenants).
- Corporate ventures: Are directed by a large firm taking an equity stake in a small but innovative or specialist firm, to which it may also provide management and marketing expertise; the objective is to gain a specific competitive advantage[18].
- Public banks: Publicly owned financing institutions (with public ownership on regional, national or European level). Whereas commercial viability ('bankability') is often a key lending criterion for public banks, other aspects like the development of key market segments, support for SMEs or innovation financing can also be highly weighted in lending decisions. In this study, the focus mainly lies on public banks in the format of National Promotional Banks (NPB). NPBs are defined as legal entities carrying out financial activities on a professional basis that are given a mandate by a Member State or a Member State entity at central, regional or local level to carry out development or promotional activities, as set out in Article 2(3) of the EFSI Regulation[19].
- Institutions providing other forms of public funding: Ministries and other public authorities providing funding (i.e. grants to cover CAPEX and OPEX) to qualifying (research) institutions.

In order to identify the most relevant types of financial institutions outlined above for improving access-to-finance conditions for HPC, all institutions were evaluated against six specific criteria as described below:

- Criterion 1: Do the financial institution's return expectations (Return on Equity[20]) fit the typical returns achievable through investments in HPC?
  - Private equity funds typically expect returns of up to 20%. As commercially oriented HPC centres are still in a nascent stage, upfront investments tend to be high and returns are difficult to estimate, the overall fit of PE return expectations for investments in HPC centres is limited. ISVs might generate suitable rates but tend to be too small for PE funds.

- **Venture capital funds**. Early-stage VCs are looking for a '10 time opportunity' (selling a company at ten times the original investment), which might be difficult to achieve, given the limited number of commercially oriented HPC centres (implying a rather poor fit, with the possible exception again being ISVs).
- **Commercial banks** typically expect much lower returns, with returns on equity ranging between 6% and 10%, making an HPC venture more palatable (subject to the availability of a commercially oriented business model).
- **Corporate ventures** typically have industry-specific return expectations. Consider for example automobile companies such as Porsche or Daimler, with expected returns set around 10%. They could potentially invest in a HPC venture, however, their interest depends on the funds' strategic objectives and alignment with their own.
- **Public banks (i.e. promotional banks)** do not pursue the objective of maximising profits per se, nevertheless many do define return targets and a large number of national promotional banks in Europe are currently profitable[21]. Overall the expected return of an HPC venture has less relevance for public banks and therefore the fit to HPC financing is better in comparison to PE and VC funds (subject to the availability of a commercially oriented business model).
- **Public funding** as such, does not pursue the objective of maximising profits, but rather aims to foster economic development and innovation in a broader context. It is therefore considered to be a good fit for HPC.

• **Criterion 2: Do the typical investment amounts ('ticket sizes') in HPC fit the ticket sizes of the financial institutions (assumed typical investment of EUR 250,000 to EUR 1 million for SMEs and ISVs, and over EUR 10 million for HPC centres)?**

- A **venture capital/corporate venture** investment typically involves a minority investment in a high-growth firm with minimal revenue where these investments are typically below an investment size of EUR 5-10 million. Therefore, the investment size would fit with investments in HPC ventures.
- **Commercial banks, public banks** as well as **public funding** have different limitations. However, they can offer large-scale financing for projects. An HPC venture (especially HPC centre) could therefore be eligible.

• **Criterion 3: Does the typical time horizon for investments in HPC (assumption: about 5 to 10 years) fit the expectations of financial institutions?**

- **Venture capital** and private equity funds typically have a life of 10 years with an investment period of 2-3 years. Therefore, it would theoretically fit an HPC venture.
- **Commercial banks and public banks** have financing time horizons dependant on the area of investment, between 10 and 20 years in real estate and for major infrastructure works (e.g. wind parks). HPC centres' lending time horizons can be assumed to be similar, which makes it a fit.
- **Public funding** is the most patient capital. Hence, this provides a great fit with any HPC ventures.

- **Criterion 4: Do investments in HPC fit the risk appetite (capital costs, regulatory demands) of the identified financial institutions?**
  - Overall return expectations go together with risk appetite, which is why this criterion will not be evaluated in isolation. With relatively high return expectations, **private equity** and (corporate) VC **funds** are ready to take higher risks. Therefore, both types of financing institution are a good fit for HPC financing needs, especially SMEs and ISVs. However, a pre-requisite for such an investment is that it can achieve the target returns and have high potential growth (not always evident for HPC ventures as explained above).
  - In the case of **commercial banks**, risk appetite is strongly influenced by regulatory demands such as Basel III and respective capital requirements to underlie high-risk lending. Hence, not a good fit for the potentially high-risk lending required by some HPC ventures such as ISVs.
  - **Public banks** have similar regulatory capital requirements to commercial banks. However, they often manage funds on behalf of national governments and EU institutions, where they can invest in higher-risk projects.
  - **Public funding** is generally a good fit in terms of risk appetite, as grants and public funding mainly target early-stage, unproven and innovative projects.
- **Criterion 5: Do investments in HPC fit the industry development mission (economic development interests) that financial institutions might have?**
  - Overall the HPC industry is generally an eligible investment for public financing institutions. Alignment with an industry development mission is therefore good for **public funding** and for **public banks**.
  - **Commercial banks** and **private equity** or (corporate) **VC funds** do not support the development of an industry as their goal, and their incentive systems do not remunerate industry development. As such, their fit with the criterion is modest.

The study focuses on commercial banks, corporate ventures and public banks, which were identified as the most relevant investors in HPC in Europe based on the analysis above. Private equity and venture capital funds were considered on a selective basis only, mainly tapping into their expertise in evaluating emerging business models in the HPC sector. Selectively, the study builds on insights from public funding institutions in order to gain a better understanding of how public funding might be complemented by commercially driven approaches in the HPC sector.

Based on this scoping, actual financial institutions approached for expert interviews were selected based on the following criteria:

- Experience in HPC and Cloud Computing financing.
- Experience in public-private co-financing projects.
- Innovative or best practice approaches in HPC financing (where applicable).
- Broad geographic coverage across Europe.

3. Analysis and findings

The analyses and findings referring to HPC organisations presented in this chapter are structured in line with the focus segments of the HPC value chain: ISVs, HPC centres, HPC intermediaries and HPC customers. At the outset of the chapter a summary of the overall findings is provided. For each of above-mentioned four groups, the key characteristics of the market structure and of the business model are provided together with an assessment of current access-to-finance conditions and an outline of specific needs for action. A dedicated sub-chapter summarises the study's findings concerning the European Open Science Cloud initiative (EOSC). In a separate sub-chapter about the commercial investor's side, the profiles, business models and specific bottlenecks of all relevant investor groups are described. In the sub-chapter on public financing, existing instrument offers on European and national levels are matched with the needs of the relevant organisations on the HPC value chain. Selected deep dives, quotes from market participants and quantitative information complement this chapter. The study derives recommendations from the analysis and findings in the subsequent chapter.

SUMMARY OF KEY FINDINGS

Finding 1: Demand for HPC capabilities is rapidly increasing in key sectors of the European economy, such as aerospace, automotive, energy, manufacturing and financial services, while Europe's more 'traditional' SMEs are lagging behind.

The use of HPC has become widespread across academia, government agencies and virtually all sectors of industry and commerce. HPC applications are rapidly being integrated into the design and development of new products across strategic sectors of the economy, such as energy, transportation, manufacturing, medicine, communications and finance. HPC is particularly well suited to performing tasks that are computationally and data intensive and that require a large number of complex number computations to be executed on very large data sets in very short time periods.

In spite of the rapid increase in demand for HPC services, important challenges to further broadening the use of HPC for innovative and commercial uses among SMEs remain. HPC providers need to become more flexible and adaptive to the specific needs of SMEs, providing small entrepreneurs with reliable and affordable HPC capabilities as well as a set of tailor-made applications and services that enable SMEs to take full advantage of HPC for their businesses. To strengthen the demand for the adoption and commercial use of HPC in Europe, it is furthermore critical to support the entire HPC ecosystem. This includes HPC intermediaries and ISVs in particular, as one of Europe's key comparative advantages consists in providing HPC services and developing applications and software tailored to specific sectors.

Finding 2: Fragmentation and limited coordination at an EU level has resulted in a suboptimal investment climate and an underinvestment in strategic HPC infrastructure in Europe.

While the strategic importance of HPC as a key enabler for industrial innovations has been recognised, both European and national public investment programmes have often prioritised investments in research and science programmes. As a consequence, the demand for HPC infrastructure and services far exceeds the supply currently being offered by public HPC centres and private operators in Europe. A key reason for this trend is the current fragmentation of the HPC sector in Europe. Most of these centres are funded by national or at times even regional budgets, resulting in fragmentation and limited coordination across the continent.

Furthermore, the financing for large-scale HPC facilities is challenging due the large amount of resources required and the need for long-term and sustained financing. This fragmentation and the predominate model of financing HPC centres though national or regional public financing has led to significant underinvestment in this strategically important sector for Europe.

Finding 3: Most European HPC centres are largely publicly financed and owned, and dedicated to research. More commercially oriented HPC centres and activities within public HPC centres are emerging, but are often hampered by rules and regulations.

In Europe, the HPC landscape is mainly driven by the public sector – in terms of usage as well as financing. The majority of HPC capacity and use (over 90% of operating time) is both located at and allocated to universities or academic research centres, whereas the remaining 10% is installed for commercial use or with HPC end users. Most HPC centres offering infrastructure services are public and operated by universities or public research institutions. Most of their financing comes in the form of grants covering both investment needs and operational costs.

However, some of these centres have started to broaden their scope of application towards more commercial uses, in order to create new revenue streams. Public HPC centres in Europe have gradually opened up to cooperation with the industry.

Finding 4: Key Stakeholders (from HPC centres to HPC customers) in the European HPC ecosystem face different financial challenges that need tailored solutions.

There is a broad range of different HPC organisations and companies operating within the HPC ecosystem with different business models and financial challenges. An overview is presented below.

- HPC centres: the European landscape for HPC centres is largely dominated by publicly owned entities, mainly serving universities and research, and relying on public funding for both capex and opex needs. The main financial challenge for these players is the limited propensity towards commercially oriented models, and legal restrictions on increasing revenues from commercially oriented activities.
- HPC intermediaries: with a few exceptions, these are very similar to public HPC centres. They are mainly public entities under the umbrella of an HPC centre with limited viable business models, relying primarily on grants and public budgetary support.
- ISVs: While European ISVs have established business models (mainly offering Software as a Service) in specialised and niche segments, access to finance is constrained by: 1) lack of tangible assets, and 2) high-risk business model (upfront development costs with limited visibility on revenues), resulting in insufficient growth capital.
- HPC customers: Demand for HPC capacity from commercial users is still very much developing and has not yet reached maturity. However, future demand for HPC service is expected to emerge from the next digital revolution based on Deep Tech. The HPC customers can be categorised into 1) large corporates, 2) SMEs, and 3) innovative companies and start-ups. Large corporations are currently the main users of HPC capacity. However, most of them rely on in-house HPC centres. HPC uptake is still limited among SMEs. The main challenges are linked to lack of awareness of the potential benefits from HPC, limited in-house expertise, and difficulties in accessing finance (limiting investment in HPC). Finally, innovative companies and start-ups represent an emerging new driver for HPC demand. Companies developing Artificial Intelligence and Internet of Things applications that are based on the use of Big Data will require HPC infrastructure to handle large amounts of data and complex calculations.

Finding 5: HPC intermediaries represent a key link between HPC infrastructure and customers, able to further catalyse commercial exploitation by matching supply with demand.

Within the broader ecosystem, HPC intermediaries play a critical role in connecting users of HPC services and HPC centres. HPC intermediaries are companies, RTOs, or specialised departments located at HPC centres that provide advisory or consultancy services in the field of HPC, enabling users of HPC services to receive an optimal return on investment in HPC. Many companies and public research centres lack technical knowledge about HPC and are therefore finding it hard to make use of HPC services. Without support from experts and a good understanding of the exact business case for the use of HPC applications, companies, in particular SMEs, frequently do not realise the possible economic gains that can be derived from the use of HPC services.

HPC intermediaries are acting as enabler for the uptake of HPC uses beyond its use for research and science and thus are playing a critical role for the further development of the HPC sector. The key challenges HPC intermediaries are facing are focused on the need to strengthen and expand their services, in particular for SMEs, and develop more commercially oriented business models to secure their long-term financial sustainability.

Finding 6: Demand for HPC services among SMEs is not only constrained by the limited knowledge of the benefits of HPC, but also by a lack of finance to invest.

Small and medium-sized companies with an established business model considering the use of HPC in their R&D process typically face a very different situation compared to large corporations. For smaller companies, entering HPC-based product development can require a significant increase in R&D expenditures.

SMEs that embrace HPC projects and associated investments furthermore face significant difficulties due to the insufficient availability of finance. Access to financing for HPC projects from commercial banks is significantly constrained due to the following factors: (i) the uncertainty around such projects, perceived to be riskier than investments in tangible assets; (ii) the lack of know-how and expertise among lenders for carrying out balanced assessments, due to the complexity of HPC; and (iii) the relatively smaller size of the funding requirements, resulting in high transaction costs.

Finding 7: Independent Software Vendors (ISVs) are crucial actors in European HPC. However, ISVs have difficulties in accessing finance.

A critical aspect of the European HPC ecosystem is the strong presence of independent software vendors (ISVs). While enhancing the strategic HPC infrastructure across Europe is essential, adequate investments in software and HPC applications are as critical as investments in the HPC infrastructure itself. This is an important area where Europe has a significant comparative advantage with respect to other countries, however ISVs require additional support in order to be able to fully reach their potential. In fact, they play a critical role in the expansion of the HPC market in Europe. Their approach of working together closely with research institutions has proven successful. However, most European ISVs face important obstacles for scale-up. ISVs struggle to expand their businesses successfully due to their difficulties in raising financing.

Finding 8: Private investors are already engaged in the financing of commercial HPC infrastructure (especially HPC centres), but not in public HPC infrastructure with limited 'bankability' prospects.

Commercial banks are generally engaged in the financing of private and commercially oriented HPC centres. This infrastructure-based business model is generally well understood by banks. Private HPC centres mainly rely on commercial debt instruments (term loans) to secure funding, as they are often able to sell their capacity in advance, providing visibility on future cash flow to lenders. However, the availability of repayable types of financing for public HPC centres is currently limited, due to the limited number of viable business models with a more commercial orientation and reliable source of revenue to underpin their bankability.

The following table provides an overview of the main characteristics, existing funding sources and investment needs of the different actors in the HPC ecosystem, pointing to the key financial challenges they each face. While highlighting that the majority of HPC capacities in Europe are in public hands and that private HPC centres primarily operate in niche markets and focus on industrial customers, it also demonstrates that HPC intermediaries are playing a critical role as facilitators between HPC centres and clients.

	HPC centres		
	Public HPC centres	**Private HPC centres**	**HPC intermediaries**
Main characteristics	• Majority of HPC capacity is public in Europe • Own most powerful computing capacities in Europe • Mainly used for scientific and academic purposes • Emerging efforts to increase revenues from commercial use	• Niche market in Europe • Less powerful computing capacities • Mainly focused on industrial customers • Business model based on offtake agreements	• Facilitators between HPC centres and clients • Mainly public entities under the umbrella of HPC centres • Organised by sector, geography or target customers (SMEs)
Funding sources	• Grants and public funding for capex and Opex	• Debt and equity	• Public budget, project grants and membership fees
Investment needs	• Short investment lifecycle (5-6 years) • High capex (up to EUR 300 million for petascale HPC) and Opex	• Short investment lifecycle (5-6 years) • Small players with limited investments (below EUR 10 million)	• Mainly small entities with limited financing needs (investments and opex up to EUR 1 million
Key financial issues	• Lack of viable business models • Legal limitations to increasing revenues from commercial activities	• Risk of HPC computing capacity to commoditise • Need to develop high value-added services	• Similar to public HPC centres, limited revenue-generating commercial activities and lack of viable business model

Table 1: Main Characteristics and Financing Issues of Key HPC Actors

Commercial customers

ISVs	Large corporates	SMEs
• In Europe, mainly small companies specialised in niche markets • Dominance of large generalist software houses (mainly US) • Business model moving towards Software as a Service (SaaS)	• Currently, main commercial users of HPC • Usually own in-house HPC centre • Industrial HPC applications require less computing capacities (vs. research)	• Traditional SMEs mainly use workstation-based solutions • Low adoption due to lack of knowledge • Emerging start-ups with products and services based on HPC
• Mainly equity and internal cash flows	• Debt and equity	• Mainly debt and equity
• Development costs of new software around EUR 1m • Capital to support expansion	• Depending on HPC capacity, but similar to private HPC centres • Funded via general capex plans	• Limited investments (up to EUR 1.5 million) • Additional costs due to training, hiring, etc.
• Lack of tangible assets • High-risk business model (upfront development costs with limited visibility on revenues) • Lack of growth capital	• Limited use of collaborative models with external HPC centres (resulting in insufficient demand for HPC centre	• Lack of awareness of HPC potential • General difficulties in accessing finance typical for SMEs (indirectly affected HPC investments)

HPC organisations – Demand side of financing

Independent Software Vendors (ISVs)

Summary

- The European ISV market is characterised by smaller companies focusing on highly specialised niche markets. Within their respective niches, however, many ISVs are considered to be global market leaders.
- Software development for HPC is regarded by most experts to be a strategic driver for future growth and innovation in the European high performance computing sector.
- Most ISVs are working on high-risk business models, mainly due to their narrow niche markets, small and unpredictable revenue streams and substantial needs for a high level of upfront investment in product development.
- The financing needs of individual ISVs are rather small in volume (approximately EUR 800,000 or less for development and commercialisation of new software).
- Access to finance for most ISVs is considered to be a key challenge. This is mainly due to a lack of tangible collateral for lending (IP and source codes are not recognised as collateral by financing institutions).
- Funding for business scale-up is limited. In many cases, the only viable growth option for European ISVs is through acquisition by US-based competitors. This leads to a loss in strategic HPC capabilities for the European market.
- To facilitate access-to-finance conditions for ISVs there is a need for equity-enhancing instruments and venture capital (equity/debt) for scale-up

“Hardware is dead, software is the future.”

Head of an HPC Centre in Europe

The above bold statement by the head of one of Europe's largest HPC centres provides an indication of the importance of ISVs in the HPC ecosystem. ISVs, most of them run as commercial businesses, are an essential cornerstone for HPC in Europe mainly for two reasons[22]:

01. **Highly specialised European ISVs are global market leaders for HPC software**. European ISVs successfully deliver highly specialised HPC software that is needed by all sectors of the industry to run complex HPC simulations resulting in market-leading engineering products. The software programmed by European ISVs is usually configured to cater individually for the highly individualised needs of single industries and even single customers. For example, the Belgium-based ISV Noesis specialises in crash simulations and robust design, while the Germany-based ISV GNS provides highly specialised simulations for sheet metal forming. RECOM, another ISV, has developed a leading software to optimise processes in industrial furnaces and boilers, while the Danish ISV Quantumwise concentrates on simulation software for nanomaterials. Due to their high degree of specialisation, European ISVs can generate a very deep understanding of their customers' needs and requirements, resulting in highly apt software solutions. This high degree of specialisation and close industry collaboration results in Europe's global market leadership in HPC applications[23].

02. **Trends in technology development are favouring the further development of software**. Hardware development for HPC is currently focusing on increasing the number of cores on each HPC processor: at a Computex trade fair event in Taipei (Taiwan) on 30 May 2017, US-based chip manufacturer Intel released the i9-7980XE, a single processor with 18 cores working in parallel. Processors designed for HPC applications with an even higher number of computing cores are currently under development. While the world's 20 fastest supercomputers work with over 100,000 processor cores in parallel already, many current HPC software applications are designed to run on a maximum of five cores[24]. Only about 1% of HPC software can exploit 10,000 or more processor cores[25]. ISVs will have to significantly modify their programs in order to keep up with the increasing parallelisation of hardware architectures. At the same time, efforts by the hardware industry to further increase the speed of their processor cores are reaching limits: at their current 15 nm architecture, processor cores are approaching limitations set by quantum physics preventing further exponential improvement of their processing speed[26]. With hardware development reaching a natural ceiling in this area, further performance improvements can only be achieved by optimising HPC software. These trends are likely to make ISVs innovation frontrunners in the HPC market over the next couple of years.

ISVs: Key characteristics of the market structure

The European ISV market is characterised by relatively small, highly specialised niche market companies. These companies often develop their software in close collaboration with their key industrial customers. However, designing a customised solution around the particular needs of one anchor client might limit the ability to scale up their business. As a result, the headcount of European ISVs rarely exceeds 100 FTE.

Outside Europe, the HPC software market is largely dominated by US corporations like Altair, Autodesk, Ansys or MSC software. Taking an alternative approach, non-European competitors often aim at providing software solutions that are versatile enough to cover a wide range of industry applications. Typically, small European ISVs partner with larger counterparts (mainly from the US) in order to gain access to wider distribution channels. In return, the small ISVs receive royalties for their offerings. For larger ISVs, this model is an opportunity to add more specific offerings to their portfolio at no additional development cost.

Due to strong competition from larger players, and limited availability of scale-up funding, European ISVs struggle to scale up their operations. In many cases, the only viable option for growth is through acquisitions of European niche market leaders by their US competitors. Large competitors often show a particular interest in successfully scalable solutions. Instead of offering distribution channels to these applications, larger ISVs or end customers acquire the respective ISVs. The main investors operating in this market are US-based software companies. This trend leads to a loss in strategic HPC capabilities in the European market.

> "There is no European drive to be the owner of the ISV industry!"
>
> **Senior manager, financing institution**

ISVs: Key characteristics of the business model

The market structure described in the previous chapter strongly influences the business model of most ISVs. The main offerings by ISVs are complex, highly customised HPC software products that are delivered in a Software-as-a-Service (SaaS) model. Particular customer needs are based around R&D processes that do not repetitively use the same methodologies and also profit from technology advances. This constantly changing landscape creates a project-based interaction between the ISVs and their main customers. The respectively short lifecycle of software products often causes unsteady and insufficiently predictable revenues for most ISVs. For many ISVs, the unsteady revenue stream is in sharp contrast to their relatively stable cost basis with software programming experts being the main source of expenditure.

Traditionally, ISVs have generated revenue through licensing fees charged for software products. This business model has usually been based on long-term or annual licensing schemes. Licence costs for specialised HPC software can easily amount to EUR 50,000 – EUR 100,000 p.a., a sum that has often not been affordable for SMEs willing to work with HPC in their product development process. As a consequence, recent demand trends have put pressure on ISVs to give up their traditional licensing approach in favour of more flexible models like pay-as-you-use licences, or token-based licence schemes. Whereas such trends favour the uptake of HPC by SMEs, they tend to increase the uncertainty for ISVs concerning their future revenue streams.

Current access-to-finance conditions for ISVs

The issues that ISVs face based on the market structure and their business models are reflected in their financing situation. Over 80% of the ISVs interviewed in this study regard access to finance as hard or very hard, an assessment that has been widely confirmed by other market participants.

> "Different licensing models are used to tailor the products to specific customer needs. Legacy models span over a period of three years and are either based on a purchase agreement or a lease while we are currently implementing a pay-as-you-go model."

CEO, ISV

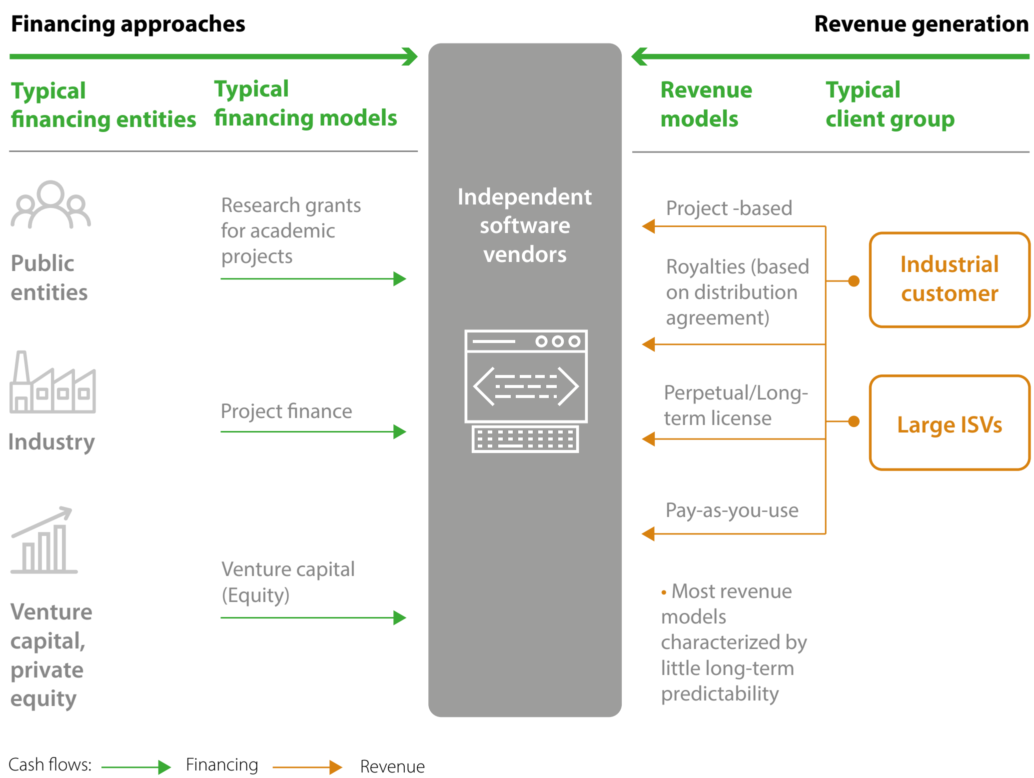


Figure 16: Schematic overview of the ISV business model

→ **Typical financing through grants, equity or project finance**

→ **ISV have predominantly intangible assets resulting in limited lending capacity**

The following observations were made in the context of this study:

Lack of tangible assets leads to limited availability of debt financing: ISVs find it very hard to obtain debt financing (i.e. bank loans). The lack of tangible assets to serve as collateral for a bank loan is an important barrier for ISVs:

> "We experience that banks do not provide risk financing to us. Even if we had a very stable future cash flow, guarantees would be needed as a replacement for missing collateral."

CEO, ISV

Lack of specific knowledge within commercial banks: The ISVs interviewed in this study believes that there is a critical lack of specific knowledge within commercial banks about their business models and technologies:

> "Banks have no idea about the ISV business."

CFO, ISV

> "Banks sometimes do not fully understand and appreciate ISV business models, which then results in a reluctance to provide financing."

CFO, ISV

Failure to obtain commercial debt financing results in constrained business activities: The majority of ISVs have so far not managed to obtain external debt financing. The lack of access to debt finance can limit their capability to execute commercially viable projects:

"We have been in discussions with a number of commercial banks for a term loan but could not reach a mutually beneficial agreement."

CFO, ISV

"We had to reject projects with a highly profitable underlying business case because we could not finance them."

CFO, ISV

Strong reliance on equity financing: Given the adverse debt-financing situation described above, the majority of ISVs rely on equity financing:

"A Bank would be the last resort. We prefer private equity."

CFO, ISV

"Our owner is basically our business angel with in-depth engineering knowledge. So far he has financed the whole endeavour privately."

CEO, ISV

Public grants are regarded as an alternative financing source: A common strategy by ISVs in response to unsteady revenue streams and difficult access to finance is to participate in public, grant-financed projects in the field of research and academia. Such projects contribute to covering the operational costs of ISVs:

"Our product development is mainly financed by EU research projects. Typically, we work with our well-trusted partners so that everybody can leverage some part of the project for its own use."

CEO, ISV

"10-15% of our OPEX need is covered by public funding via research projects."

CFO, ISV

"We work closely with APER (Agency for the Promotion of European Research) to secure potential EU funding."

CEO, ISV

Scepticism persists towards existing public financing offerings: Whereas grant-based public research programmes are frequently used by ISVs to generate revenue, financing instruments are often not considered to be a suitable lever to grow their business:

"Although we know that there are SME funds available, only a few ISVs we know ever succeeded in acquiring them. The administrative hurdles are simply too high."

CFO, ISV

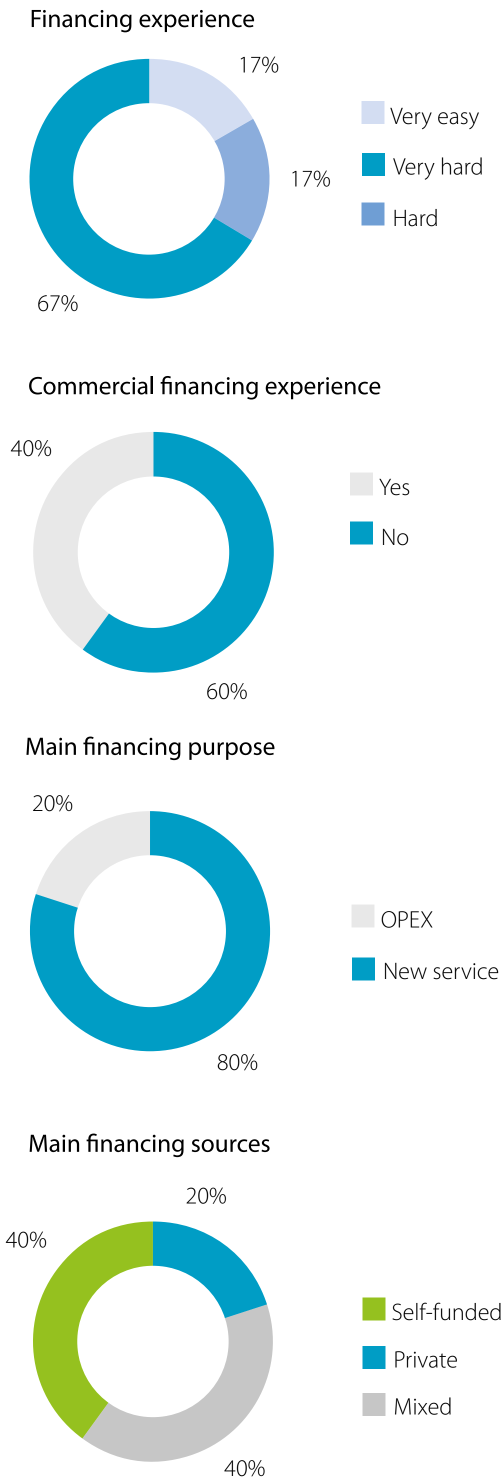


Figure 17: Schematic overview of the ISV business model

Access to Finance for ISVs- summary of interview findings

Current financing situation

- ISVs face difficulties acquiring external financing for their new product or service development due to missing collaterals.
- Product development currently financed via participation in grant financed co-development projects or via revenues.

Investment needs

- Mainly for development of new solutions/services or OPEX
- Project-based earnings model and low working capital requirements make equity financing suitable
- IP based lending to address the lack of brick-and-mortar collateral
- Recurring need of up to EUR 800,000 p.a.

Challenges

- Earnings model needs to demonstrate long term cash flows as a substitute for missing collateral – Trend towards pay-as-you-use models makes cash flows less predictable

HPC centres

Summary

- Publicly funded scientific or academic HPC centres dominate the European market for high performance computing infrastructure. Public HPC centres possess Europe's most powerful computing capacities, employ highly qualified HPC specialists and have a good network with all relevant research communities.
- The investment required to set up or modernise public HPC centres is very high (approximately EUR 150–500 million). So far, such investments have been primarily covered by public funding, provided by EU Member States and EU funds.
- Fragmentation and limited coordination at EU level has resulted in a suboptimal investment climate and underinvestment in strategic HPC infrastructure in Europe.
- Efforts to broaden the use of HPC infrastructure from predominantly research activities to industrial/commercial applications are at an early stage (largely attributed to the recently emerging public-private operating models in HPC centres). However, there are regulatory constraints restricting public HPC centres from branching outside academic and scientific purposes.
- The few HPC centres with relatively successful commercialisation activities are closely linked to large industrial clients and/or to regional technology clusters bringing together HPC expertise and technology-driven SMEs.
- A stronger role of commercial financing for public HPC centres is achievable, provided that more commercially oriented models emerge.
- HPC capacity per se is likely to become an affordably priced commodity for most commercial applications. Against this background, HPC centres will need to develop business models that are centred around a high level of dedicated client service, individualised solutions and synergies between different market participants.
- Private (commercial) HPC centres in Europe operate in a niche market due to the dominance of large, US competitors

HPC centres are a focal point of the European high performance computing sector. Typically, HPC centres are closely linked to many relevant research projects within their field of expertise. Many HPC centres share their knowledge and insights by providing HPC training for interested third parties. Nevertheless, a fundamental differentiation has to be made between public HPC centres, which are usually owned and operated by universities or public research institutions on the one hand and **privately owned HPC centres** on the other.

HPC centres: Key characteristics of the market structure

Public HPC centres

Public HPC centre infrastructure is relatively centralised and hierarchically structured. The overall hierarchy of HPC centres as established by the PRACE initiative divides the market into four tiers of HPC centres. Four Tier 0 centres are intended to receive dedicated, direct EU funding to establish and operate the fastest available HPC infrastructure. Tier 1 centres are national HPC centres aiming to qualify for Tier 0 status. On the national level, the Tier 1 national supercomputing centres are the entity responsible for providing and operating the national research infrastructure. The regional level is served by Tier 2 centres and the local level has Tier 3 centres. In essence, these large, publicly owned, academic structures dominate the HPC sector.

In the context of this study, mainly Tier 0 and Tier 1 supercomputing centres were interviewed. Three of the four Tier 0 centres were covered. These centres were of particular interest because industry engagement typically focuses on the expertise and experience within Tier 0 and Tier 1 entities.

Most of the centres are funded by national or, occasionally, even regional budgets, resulting in fragmentation and limited coordination across Europe. For example, German supercomputers are mainly funded by the German Federal budget. Here the three top supercomputing centres are organised under the Gauss Centre for Supercomputing (GCS). The GCS serves as a shared service organisation that manages access to the computing capacity of each centre and handles cross-cutting tasks such as HPC training. However, the three research centres represented within GCS are still individual organisations and have their proprietary governance structures. France is taking a similar approach, e.g. with GENCI (Grand Équipement National de Calcul Intensif).

While the strategic importance of HPC as a key enabler for industrial innovations has been recognised, the majority of EU and national programmes have mainly focused on supporting the development of strategic HPC infrastructure and applications for research and science.

It should be noted that the financing for large-scale HPC facilities is challenging due the large amount of resources required and the need for long-term and sustained financing. This fragmentation and the predominant model of financing HPC centres though national or regional public financing has led to significant underinvestment in this strategically important sector in Europe.

The financing and investment needs of an HPC centre depend heavily on the type of centre concerned as well as existing infrastructure. The following examples indicate the volumes applicable for typical cases:

Examples of financing needs of public HPC centres

	IT Innavation - Czech national Supercomputing Center	HLRS, Stuttgart
Type	Supercomputer "Anselm"	Cray XC40 "Hazenhen"
N° of cores	3,344	185,376
Operanting system	Linux	Cray Linux Environment
Total theoretical peak performance	94 TFLOP/s	7,420 TFLOP/s
Estimated Infrastructure cost (source: expert interviews		
CAPEX	EUR 10m	EUR 75m
OPEX	EUR 2m/year	EUR 11m/year

Private HPC centres

In parallel to the public HPC centres described above, there exists a small market of privately operated HPC structures in Europe. Although the current size of this market is negligible if compared to the public capacities, the private sector displays interesting differences to the public models and can therefore be used to draw potential conclusions for the further development of public offerings.

Private HPC offerings are a niche market served by a number of smaller providers in Europe. Examples of such European companies that focus on providing HPC services are Gridcore/Gompute, CPU 24/7 and Arctur. They run highly specialised architecture that differs from that of commercial Cloud

Computing providers. Nevertheless, they are in competition with the regular cloud providers such as AWS, Microsoft Azure or Softlayer as well as with commercial offerings by public HPC centres.

With HPC cloud solutions, a competing business model has recently emerged on the market. HPC cloud solutions offer real HPC capacities in a cloud environment. Companies such as Penguin on Demand and UberCloud are operating on-demand HPC-as-a-Service models.

The majority of Europe's large, engineering-driven corporations (i.e. car manufacturers), however, do not rely on HPC services delivered by third parties but have invested in proprietary HPC infrastructure. Proprietary HPC infrastructure gives their owners full HPC availability at any given time and ensures the confidentiality of the data used for simulations.

A particular PPP under development in Luxembourg could offer an innovative approach towards public-private partnerships in the field of HPC infrastructure. Luxembourg has adopted a multiannual action plan to become a digital nation.

The plan that has been defined as a conclusion of the study "The Third Industrial Revolution Strategy" includes a number of flagship projects with the aim to build out and scale up Luxembourg's ICT ecosystem to provide state of the art digital infrastructures for the data driven economy.

In this context, the Luxembourg Ministry of the Economy has initiated an innovative HPC-Big Data project based on a public-private partnership approach. Luxembourg has planned the creation of a High Performance Computing and Big Data Competence Centre in order to implement the adopted national strategy and accelerate the digital transformation of the national economy. The objective is to facilitate the use of High-Performance Computing resources and Big Data applications to deliver reliable and sustainable digital services to the market.

The business model of the Center is commercially oriented, i.e. relies on clients paying for the proposed services. This initiative is currently mobilising clients and envisages binding them through forward sales ("offtake agreements") for the future use of the Centre's capacities. This approach should provide sustainable long-term revenues.

The Center should facilitate the translation of technology advances into concrete business opportunities by simplifying the access to HPC-Big Data resources. The intention is to build up a new type of "Data Operator" to support the digitisation process of the national economy with a major focus on the valorization of data sets generated by the Internet of Things (IoT) and the datafication of business processes.

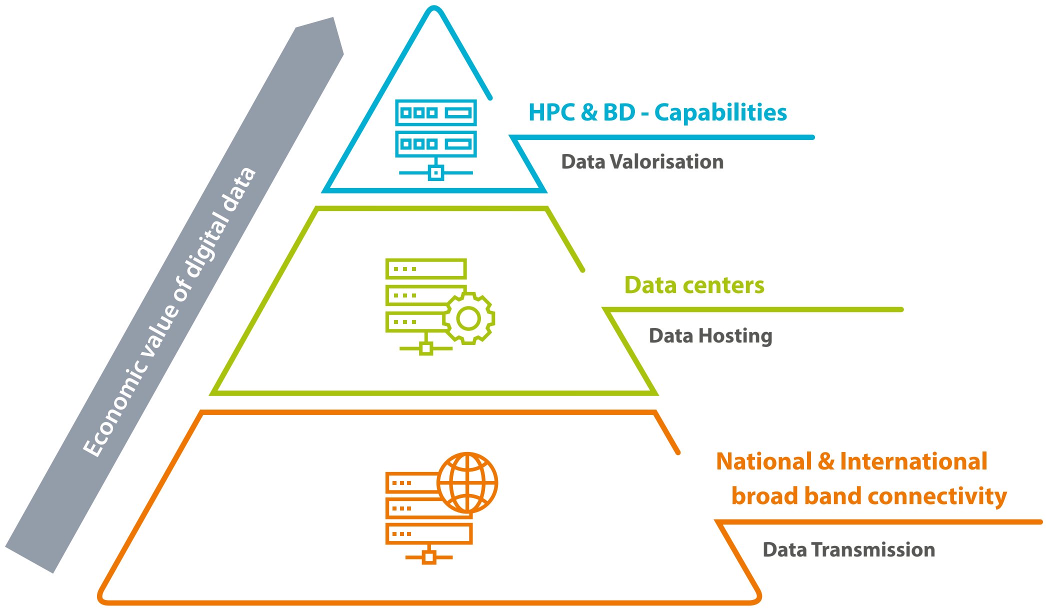


Figure 18: Luxembourg HPC and Big Data project

"A model with the strong involvement of a private telecom provider sounds very promising. It will be highly interesting to see whether Luxembourg's plans in this direction materialise from a bankability perspective."

Senior manager, HPC centre

HPC centres: Key characteristics of the business model

Public HPC centres

The business model of public HPC centres tends to be based on three key priorities: providing and managing research infrastructure, conducting computational research and awareness-raising. The main objective of the public HPC centres is therefore to provide state-of-the-art Infrastructure-as-a-Service to academia. Hence, the **academic utilisation rate of most public HPC centres is around 95%**.

> “We give 96% of our capacity to the university.”
>
> **Public HPC centre**

Academic HPC centres offer free CPU cycles to their university and to larger research projects in their function as National Supercomputing Centres or European Supercomputing Centres. Computing capacities are assigned to academic users via a proprietary capacity management system or via the PRACE peer review system. An alternative way in which HPC centres provide computing capacities is by participating in grant-funded research projects in Europe.

Some European academic HPC centres have gradually opened up to cooperation with industry. HLRS (High Performance Computing Centre Stuttgart, Germany), EPCC (Edinburgh Parallel Computing Centre, UK), Hartree Centre of the Science and Technology Facilities Council (Warrington, UK) and Cineca (Bologna, Italy) are the most prominent examples.

Typically, public HPC centres provide three different types of service models to commercial clients:

- **Service model 1 - Pure CPU cycles**: Under this model, the HPC centre offers only access to its hardware infrastructure. Being a pure Infrastructure-as-a-Service model, it refrains from offering additional services based on the use of proprietary systems or support activities. This set-up keeps the need for highly qualified staff low. Access to the HPC infrastructure requires thorough know-how on the customer side. As a consequence, only highly experienced HPC users have the capability to access it. This model typically rules out any cooperation with first-time users or SMEs and is primarily targeted at large industrial clients with sound HPC expertise. However, the competition from commercial HPC cloud offerings is intense. Commercial service providers can typically offer pure CPU cycles at a significantly lower cost than public HPC centres. The price for a CPU core hour at CPU 24/7, provided by a private service provider, starts at EUR 0.15 whereas the price for a core hour provided by a publicly owned HPC centre starts at EUR 0.50. Although such pricing comparisons are limited in their validity as the interconnects at public HPC centres have significantly more bandwidth, they give an indication that private service providers are better positioned to cater for the needs of price-sensitive clients.

"Commercial HPC and HPC cloud offerings are a strong competition, rendering the offering of pure CPU cycles hardly profitable for us."

Director of a public HPC centre

- Service model 2 - CPU cycles plus services – directly via the HPC centre: Besides CPU cycles, some HPC centres offer additional services. They engage collaboratively with industry customers and tackle together particular challenges. In addition to computational time, the HPC centre's experts help for example to map HPC process integration for manufacturers or to improve customers' software algorithms. Under this model, public HPC centres can charge commercial clients for both CPU cycles and additional services, rendering this approach more profitable for HPC centres.

- Service model 3 - CPU cycles plus services – via an intermediary. In this model, CPU cycles are provided by a public HPC centre in combination with additional advisory services delivered by a separate third-party organisation acting as an intermediary between market demand and the infrastructure supply side. The HPC intermediaries chapter describes this model in more detail.

Overall, the revenue generated by public HPC centres trough commercial offerings is very limited. Income from commercial activities is projected to contribute approximately 25% to HLRS's 2017 budget while Cineca obtains 20% of its revenue from the private sector[27]. It should be noted that these HPC centres are the frontrunners of commercialisation. In contrast, in many national supercomputing centres, the private contribution share is a mere 4 5% of the centre's annual budget. Such minor contributions are not sufficient to significantly reduce the dependency of public HPC centres on direct, grant-based government funding.

Examples of cooperation models between public HPC centres and the private sector

Cineca: CPU cycles plus services – directly via HPC centre
Cineca, Italy's leading HPC centre based in Bologna, works through framework agreements with large industrial players, such as ENI. The agreements specify and define the terms of the collaboration, as well as Cineca's expected remuneration. Due to Cineca's reliance on predominately public funding, such collaborations are largely limited to research-centred endeavours. For example, the ENI-Cineca collaboration in the oil and gas sector focuses on researching general seismic activity modelling. For ENI, such activities add value to its business activities, but stop short of offering a clear-cut opportunity for the commercialisation of any given results.

For Cineca, revenues from direct commercial collaboration with industry players are subject to the limitation of the so-called 80/20 rule: only 20% of Cineca's revenue can be the result of commercially driven HPC activities, while 80% of the centre's revenue must originate from research-driven activities, according to Cineca's statues. Beyond the 20% of commercial activities, Cineca does cooperate with industrial clients, however, these services are mainly circumscribed to the proof of concept stage, with a view to integrating HPC in business processes. In effect, Cineca is bound by EU statues and its own mission to limit industrial revenues. Such regulatory set-ups limit the potential and the incentives for HPC centres to generate a larger share of their revenue through commercial activities.

Hartree Centre: CPU cycles plus services – directly via HPC centre
Hartree Centre is a national laboratory focused on HPC. It has developed strategic partnerships with the private sector in order to cover a significant portion of its financial needs: while public financing from both national and EU sources provides a major source of funding for CAPEX and fixed costs, the centre manages to cover most of its operating costs with revenue streams from commercial activities. Aside from the sale of CPU cycles to the private sector, Hartree Centre offers a broad menu of additional commercial services, including:

- PaaS using the centre's infrastructure to test new software for commercial clients
- Training for private sector clients, including on how to use the centre's infrastructure
- Collaboration agreements with private sector partners, such as IBM research or Intel, on R&D projects
- Business development concepts for Cloud Computing

HLRS: CPU cycles plus services – via intermediary
HLRS, a key German HPC centre based in Stuttgart, focuses its offering to the private sector on providing high performance computing infrastructure combined with a limited co-development or service offering for commercial users. Industrial cluster organisations supporting end users in the field of HPC simulation are associated with the centre, e.g. ASCS (Automotive Simulation Centre Stuttgart) and ENSOC (Energy Solution Centre). These clusters then complement the HPC infrastructure as offered by HLRS with a broader set of specific offerings.

Private HPC centres

The private HPC centre sector in Europe either takes a generalist approach or specialises in a specific sector.

- **Generalist approach:** Centres taking a generalist approach intend to be open for all sector applications. Accordingly, there are many applications offered through the system and the architecture is not specialised regarding particular features of applications. The field of expertise and support level of the company staff therefore has to be very broad. An advantage of this approach is that the open business model design helps to scale cross-functional HPC applications across all industries. A disadvantage is that such a large bandwidth does not allow centres to focus specifically on one customer group or to develop a specialised product offering. Consequently, under a generalist approach competitive pricing becomes the main argument to attract customers.
- **Specialised approach:** The specialised approach tends to focus on very few, sometimes even only one industry. The entire system architecture including all applications and service offerings are tuned towards the sector's specific sector. The approach requires a solid potential customer base in one industry (typically the automotive, defence and aerospace sectors) and staff at a very high skill level to support the customer. Specialised approaches are often centred on one or two anchor customers that cooperate closely with the respective private HPC centre. Successful specialised private HPC centres offer full service solutions in which the customer approaches the HPC centre with a problem and the HPC centre takes on the responsibility of providing a solution. For HPC centre customers, such a full service offering is a way to reduce the costs of internal HPC experts.

> "Selling CPU cycles is not necessarily a profitable business. We mainly generate profits from consulting services and integrated service offerings."
>
> **Private HPC centre taking a specialised approach**

Private HPC centres tend to put a stronger emphasis on data security than their public counterparts. Many private HPC centres invest significantly in achieving ISO/IEC 27001 certification for information security, typically spending substantial amounts on the protection of their physical locations.

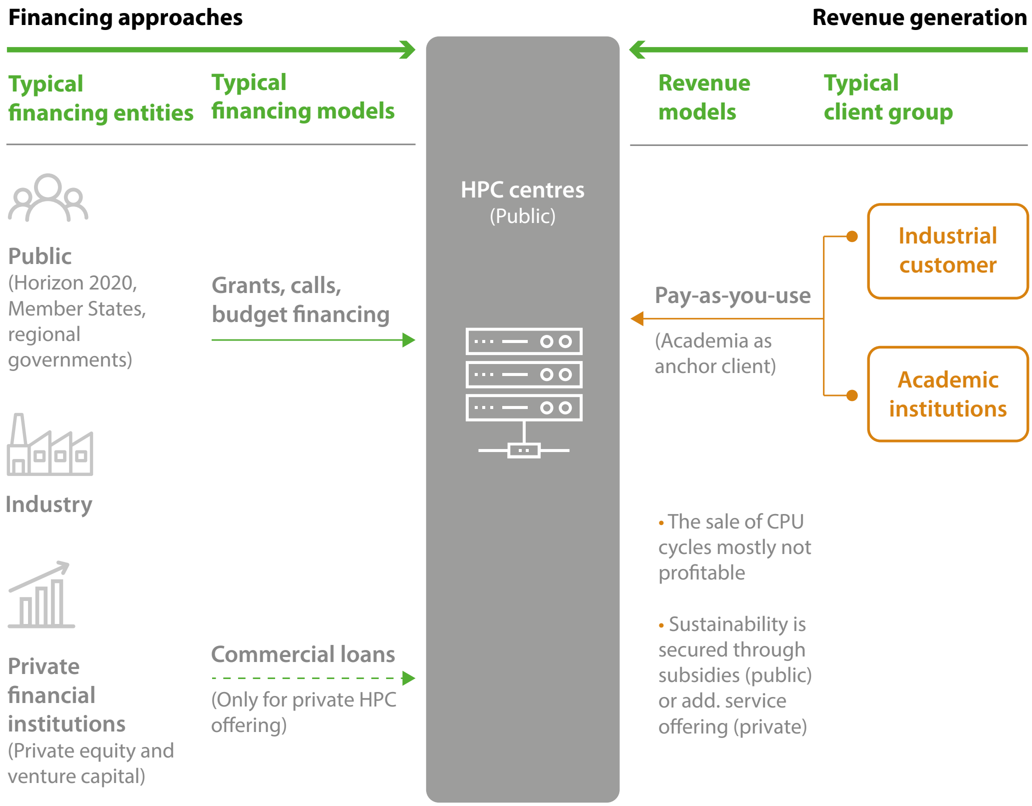


Figure 19: Schematic overview of the Public HPC business model

→ **HPC centre in Europe focus predominantly on the academic sector with limited use by industry and SMEs**

Current access-to-finance conditions for HPC centres

Public HPC centres

Public HPC centres are mainly funded by a combination of regional and national budget funding. The respective Ministries in charge of education, academia, research or innovation make the necessary public funding available. Funding is typically committed upfront without the use of financial instruments such as public loans to fund the projects.

The study identified that fragmentation and limited coordination of funding programmes at the EU level has resulted in a suboptimal investment climate and underinvestment in strategic HPC infrastructure in Europe. This is particularly true for large-scale HPC centres such as exascale and pre-exascale supercomputers.

Whereas other countries (e.g. China and the US) have invested heavily in supercomputing infrastructure and capacity, Europe has been somewhat lagging behind. Currently there is a race under way, in which China, Japan, the US and the European Union are competing to be the first to create an exascale supercomputer processing capacity, with aspirations to achieve this between 2021 and 2023.

This race is also reflected in the significant change in the numbers of supercomputers by country, whereby China, which as of 2001 did not have a single supercomputer, is now the leader in terms of both performance and quantity, owning the highest number of the top 500 supercomputers worldwide.

In order to keep Europe at the forefront of HPC capabilities, public investments in strategic HPC infrastructure should be further expanded, especially for high-end HPC infrastructure (such as exascale computing, or for the development of a pan-European HPC/Cloud Computing infrastructure and services).

> "We are entirely financed by public budgets. One third comes from the national Government and two thirds from the region."

Director of a public HPC centre

There are different variations regarding the funding distribution between regional and national government budgets. The authorities do not always fund the HPC centres directly, but sometimes via fully government-owned entities such as Helmholtz Association in Germany. Particularly in a regional setting, close collaboration with local academic institutions as well as local industry clusters provides important opportunities for the centres to benefit from existing regional and/or local innovation ecosystems. Overall, the study has found that it is important to closely embed the activities of the HPC centre into the principal regional economic activities. Several HPC centres analysed have been successful in developing close collaboration with key industries and strategic sectors, such as the automotive, media or energy sectors, in their regional ecosystems.

A good example of an HPC centre that has developed strong collaboration with regional industry players is High Performance Computing Centre Stuttgart (HLRS), which is hosted at the University of Stuttgart and has developed very strong partnerships with key Baden Württemberg industries, in particular the automotive industry. This collaboration has led to the expansion of the use of the HPC centre beyond research, to include commercial applications for local industry and SMEs.

> "We need up to EUR 300 million for a pre-exascale machine in 2019 or 2021. The desired split would be 1/3 by EC; 1/3 by the government and 1/3 by private partners"

Director, public HPC centre

The financing need for public HPC centres is substantial, both in terms of investment in new hardware (CAPEX) and in terms of running the system (OPEX). According to available data, the currently installed top 10 systems in the TOP 500 list costs between EUR 159 million EUR 358 million in terms of capital expenditure. CAPEX requirements for new HPC system procurements need to be differentiated between the Tier 0 HPC centres aspiring to install pre-exascale and exascale systems and the Tier 1 national supercomputing centres that have a somewhat lower level of ambition.

The interview partners estimated that a high performance pre-exascale system would cost around EUR 300 million to install and future exascale systems up to EUR 500 million. On the other end of the spectrum, the national supercomputing centres have systems installed that are considerably less pricey. For example, one national supercomputing centre mentioned that the investment in its recent computing infrastructure amounted to EUR 10 million.

Based on interview feedback, the cost of purchasing HPC infrastructure depends heavily on the negotiation approach of the buying entity.

> "The same HPC computer with the same capacity can cost EUR 10 million or 100 million - depending on the private or public buyer, procurement strategy and market conditions. That bandwidth in pricing is quite significant."

Senior Expert, HPC intermediary

Interview feedback also highlights the considerable amount of OPEX required to run an HPC centre. Over the lifecycle of approximately five years, operational expenses tend to equal the initial capital investment required to build the respective HPC infrastructure. The main driver for the high OPEX levels involved in running HPC is the significant electricity consumption in HPC centres.

> "The typical price of an HPC model suited to industrial needs could be around EUR 15 million. Assuming a life-cycle of five years, the expected operating costs would be around EUR 15 million too."

Director, HPC centre

Overall, the financing approaches and sources of financing of Tier 0 and Tier 1 HPC centres do not differ fundamentally. Key differences are the size of the investment needed and the better access of Tier 0 centres to national and European funds for large-scale research funding.

Private HPC centres

Private HPC centres are generally successful in financing themselves via existing market offerings. They rely on commercial debt instruments (term loans) to secure funding. However, there are also slight differences depending on the bankability of the respective business model. A finding from the interviews was that private HPC centres mainly back their business case by forward-selling their capacity to interested market participants, typically their anchor clients. Prior to approaching a bank, the private HPC provider secures commitments from existing or future customers to take off the capacity that is expected to be added to the existing system.

The evidence of future cash flows is a strong basis for the overall debt application. Modelling of future cash flows also becomes transparent and can easily be integrated into the overall business planning. The ex-ante commitments by customers are a result of the very close market interaction of the private HPC centre with its customers. The private centres tend to have a very good indication of customer needs and can directly align the conditions of long-term customer commitments. Combined with a viable history of business performance and existing collateral, private HPC companies can rely on debt financing via commercial banks. The data centre that is to be expanded is used as collateral.

"Our house bank was able to understand the business model and funded three rounds of loans."

CEO, private HPC centre

The financing need of private HPC centres is considerably lower than that of public centres. Even large private HPC users, e.g. in the automotive industry, have no practical need for the full computing power of large-scale research-driven public HPC centres. Accordingly, the systems of private HPC centres are customised to their clients' needs and do not exceed the necessary performance and/or size. As an indication, an interview partner stated that the investment size for privately operated HPC systems is around EUR 4.5 million. Reinvestments to upgrade and extend established private HPC infrastructure are usually conducted on an annual basis with costs of approximately EUR 1 million.

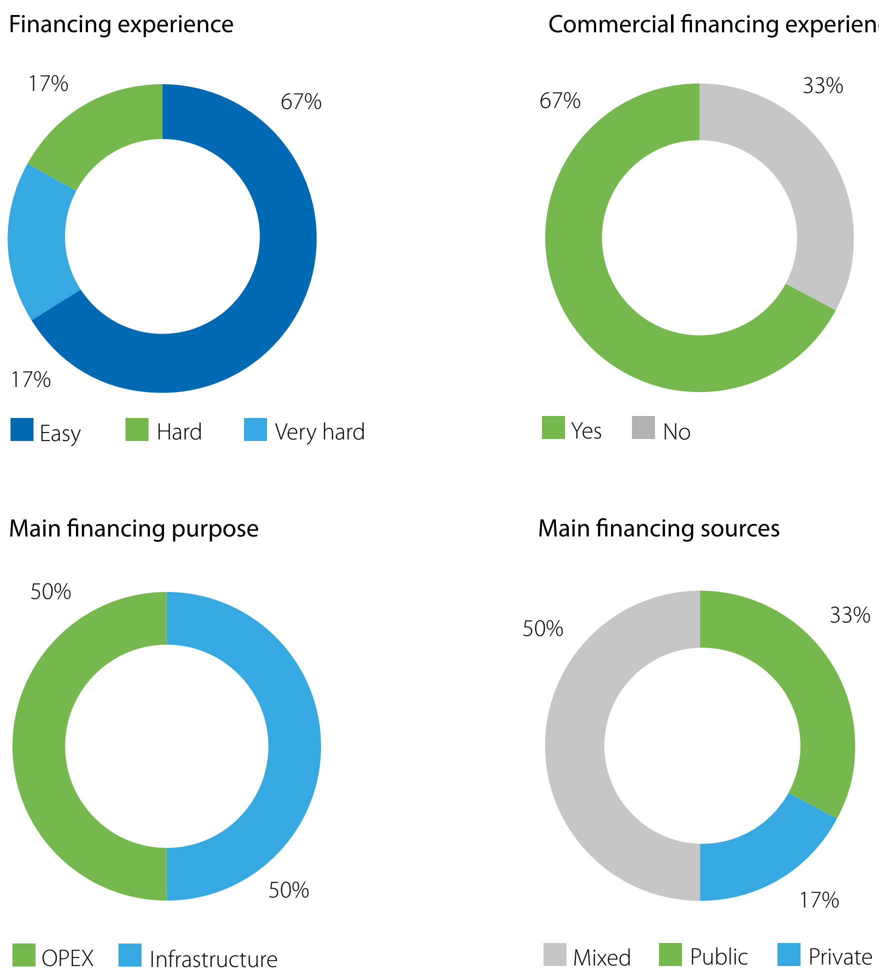


Figure 20: Access-to-finance situation of HPC centres (public and private): snapshot from interviews

Access to finance for HPC centres- summary of interview findings

Current financing situation

- Public financing, predominately from national and regional governments.
- Procurement cycles of 5 years.
- High operational cost because of large energy consumption Investment needs.
- Mainly for the purchase of new infrastructure.
- 5 year procurement cycles with investments of up to EUR 150m per center.

Challenges

- Limited revenues through private clients obstruct the potential to complement public funding with commercial financing elements.
- The earmarked use of public funding in its specific context (either from the ministry of research or the ministry of the economy) presents political challenges when engaging with private users on a broader basis.

HPC intermediaries

Summary

- HPC intermediaries fulfil an important role as technology facilitators by bringing together HPC centres (infrastructure owners), ISVs and HPC customers for joint projects. This role is particularly important in helping first-time users, primarily SMEs, to become acquainted with the potential benefits and opportunities of HPC in growing their business.
- Beyond providing technical expertise to HPC users, intermediaries can further seize opportunities to help their clients establish viable business cases and financing models around HPC.
- With their current outreach capacities and organisational set-up, HPC intermediaries are playing a critical role in promoting the use of HPC applications in industry and among SMEs in Europe.

Intermediaries are a focal point of this study because they are fostering the uptake of HPC among potential users. HPC intermediaries can be defined as organisations that are active between the supply side (HPC centres, ISVs) and the demand side (customers) of HPC in order to facilitate business synergies.

> "We act as a mediating platform to facilitate contacts for SMEs to software providers, HPC centres and other relevant stakeholders in order to get started with HPC."

Director, HPC intermediary

HPC intermediaries: Key characteristics of the market structure

Within the broader ecosystem, HPC intermediaries play a critical role in connecting users of HPC services and HPC centres. HPC intermediaries are companies, RTOs, or specialised departments located at HPC centres which provide advisory or consultancy services in the field of HPC, enabling users of HPC services to receive an optimal return on investment in HPC.

Most intermediaries are set up around existing public HPC centres in regions where significant interest in HPC usage by private companies is expected. Many HPC intermediaries are public entities working under the umbrella of public HPC centres or universities. Many companies and public research centres often lack technical knowledge about HPC and thus have difficulties in making use of HPC services. Without the support of experts and a good understanding of the exact business case for the use of HPC applications, companies, in particular SMEs, frequently do not realise the possible economic gains that can be derived from the use of HPC services.

Other HPC intermediaries have originated in the industry itself with the intention of sharing knowledge about complex HPC simulations. Such intermediaries typically organise workshops or projects around the latest developments in application software.

HPC intermediaries act as enablers for the uptake of HPC uses beyond research and science applications. In particular, they are essential for mobilising and helping SMEs to use the existing infrastructure or software development offering provided by HPC centres within their geographical vicinity.

> "We are basically the result of a large car manufacturer's initiative to bring the big local sector players together."

Director, HPC intermediary

HPC intermediaries typically organise themselves according to one of the following market logics:

- Sector logic. Engineering-driven industry sectors often share common basic interests in the field of HPC. For example, automobile OEMs work extensively with specific computational fluid dynamics applications to simulate aerodynamics on which other interested companies could exchange knowledge. The sector logic often brings competitors together (e.g. in ASCS, Daimler, Porsche, Ford, Hyundai) around R&D programmes of common interest. Therefore, participant organisations increasingly aim to work through an open and collaborative innovation approach. Such an approach is, however, only possible in specific and well-defined R&D activities.
- Geographical logic. Regarding the geographical focus of HPC intermediaries, there is a strong tendency towards organisations with a deliberately limited, regional scope. The complexity of HPC application in combination with the limited expertise of many users often requires intense interaction between all parties involved in an HPC project. This is most easily facilitated through geographical proximity. Local business networks, industry associations or clusters often support this regionalised approach. National and European initiatives also exist, however they have more of a platform character and lack direct access to a specific set of customers.
- SME logic. There are intermediaries that focus specifically on SMEs. As already highlighted, the HPC uptake potential is highest for SMEs. There is therefore a considerable number of HPC intermediaries focused on integrating HPC into the business reality of SMEs. The specific customer group focus is necessary because many SMEs have less knowledge about HPC and need more extensive explaining around the topic.

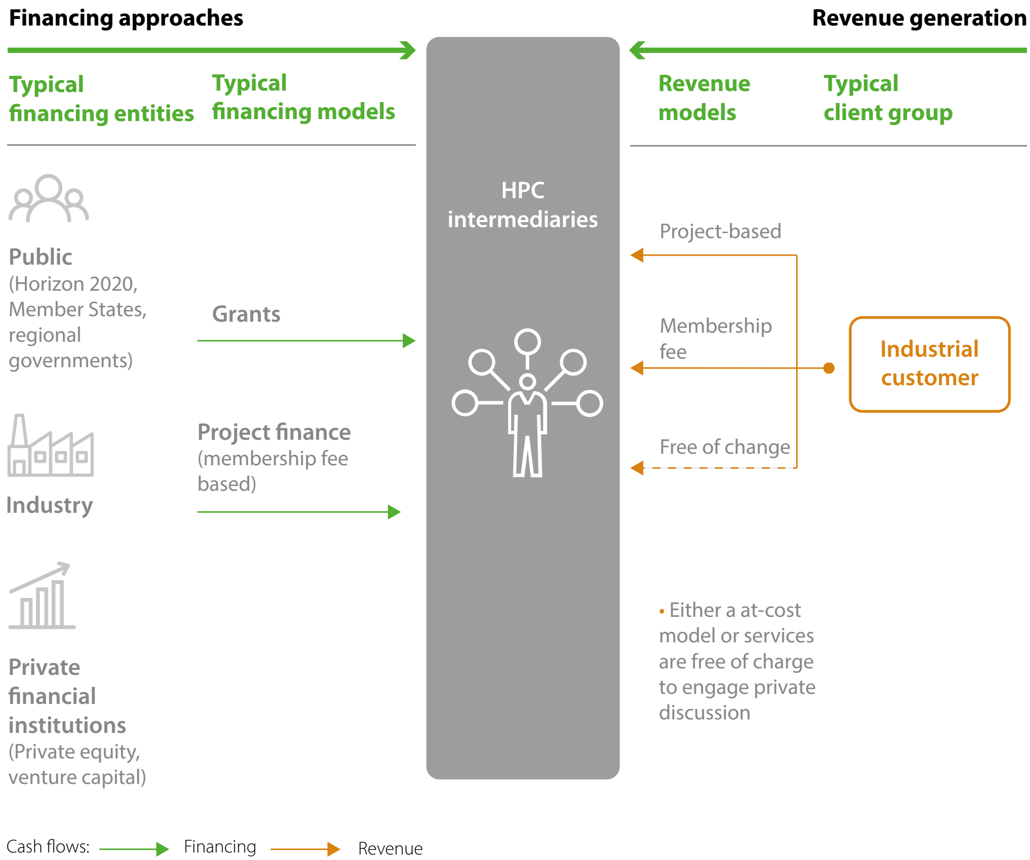


Figure 21: Schematic overview of the HPC intermediaries' business model

HPC intermediaries are critical to establish the link between a public HPC centre and industrial and SME users

Business model

Intermediary organisations are all similar in their function. Their target is to offer a centralised gateway for customers that want to implement an HPC project. In concrete terms, this means that a customer approaches the intermediary with a business challenge that could potentially be solved by HPC. The intermediary analyses the problem and suggests which organisation, be it a specialised ISV or an HPC centre, to engage to find a solution. This single point of contact reduces the complexity for the client in engaging with the entire HPC ecosystem to find a viable solution.

"One central point of contact lowers the costs of complexity and makes HPC access easy and transparent for companies."

HPC intermediary

Typically, all relevant stakeholders needed to solve a business challenge through the use of HPC are part of the intermediary's platform or network, e.g. system integrators, ISVs and HPC centres. To address the customer's challenge, the respective stakeholders work together in a co-development approach. Co-development means a cooperative project in which all involved stakeholders work together to arrive at a viable outcome. At the end, the customer receives a ready-to-use solution from the cooperation project. This can be, for example, a fully integrated simulation process combining a software solution with the necessary hardware interface. All intermediaries offer this kind of platform. However, they differentiate themselves by the level of service that they offer alongside the process. Some are only matchmakers with a purely facilitating role, others actively steer the cooperation project between the different stakeholders. Some intermediaries even go one step further: they substitute one function of the HPC ecosystem, for example the ISVs, with their own service offering. It means that the intermediary itself offers software development.

Usually, intermediaries are **owned by HPC centres**, meaning they are governed by public institutions and academia. Despite their legal ownership, HPC intermediaries are often organised as a separate entity. The entity is usually made up of a small team of around five to 30 researchers and usually has no fixed infrastructure or any other assets on its balance sheet. The overall operating cost of HPC intermediaries consists primarily of staff salaries. Ultimately, the objective of many HPC intermediaries is to sell CPU cycles (computing capacity) of the HPC centre they are associated with. Additionally, HPC intermediaries offer the opportunity to engage with different HPC stakeholders to develop HPC-based applications cooperatively.

HPC intermediaries typically target R&D-intensive SMEs without explicit HPC knowledge. HPC intermediaries are usually funded from public budgets, as there is only little potential for direct remuneration. Within this business model setting, additional revenue can mostly be generated by offering services like paid co-development or code improvement. Funding for the intermediary is often linked to a governing body that is research-oriented, e.g. an education ministry or a university. EU projects like Fortissimo also make grants available for HPC intermediaries.

Finally, there are also some **private intermediaries**. Although they involve some preferred partners from the HPC ecosystem, their business model tends to be based on an integrated service concept in which most of the HPC project for the customer is delivered by the intermediary itself. Strong technical capabilities as well as in-depth market knowledge are their key success factors. These private organisations can be considered full service offerings and are deemed not relevant in the context of the study, as they do not take on the role of overcoming the information asymmetries between the supply and demand sides that hinder further HPC uptake especially among SMEs.

Financing

The annual financing need for HPC intermediaries was stated to be in the range of EUR 400,000 – EUR 1,000,000. The main sources of funding were public budgets, project grants, and to a lesser extent, private membership contributions.

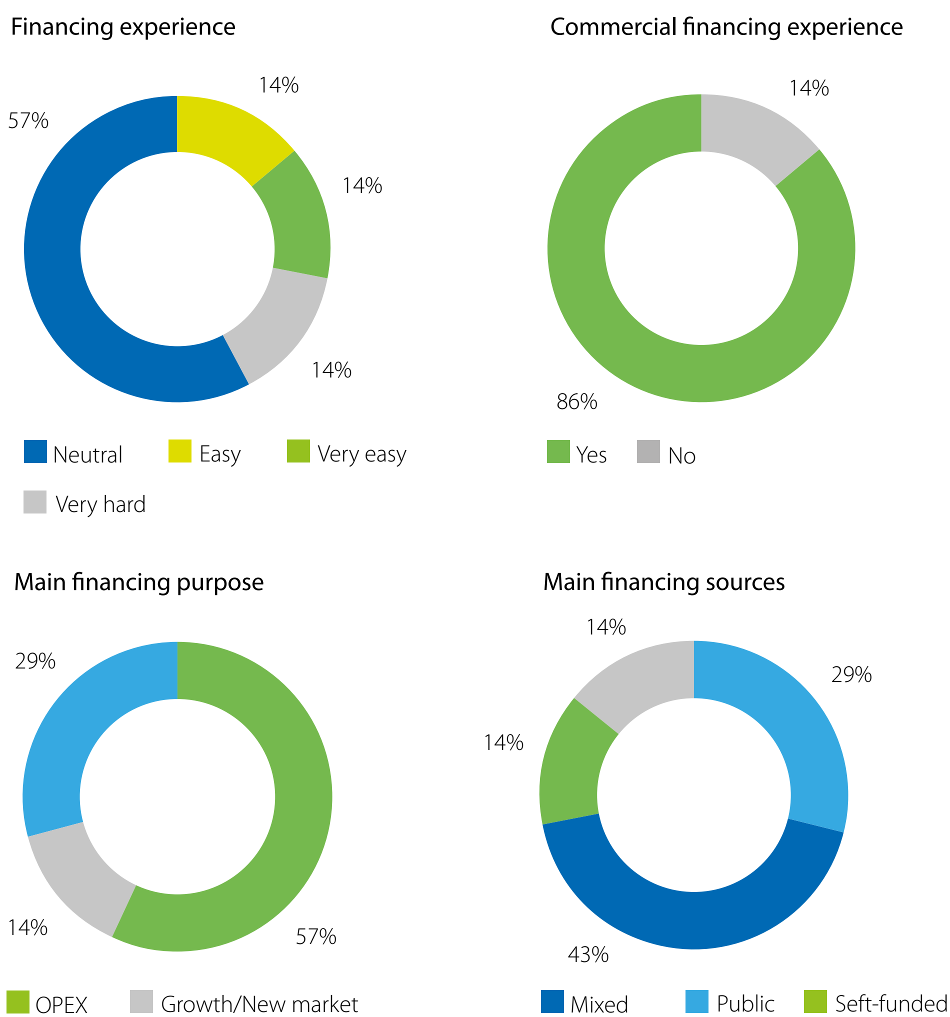


Figure 22: Access-to-finance situation of HPC intermediaries: snapshot from interviews

→ **HPC intermediaries are mainly publically financed (grants)**

→ **Advice needed to develop product and service offerings to attract private revenues**

Access to finance for HPC intermediaries- summary of interview findings

Current financing situation

- Intermediaries are predominately small institutions with primarily overhead costs.
- Predominately financed by public funding, mostly in line with the funding of the local HPC infrastructure.

Investment needs

- Mainly for covering OPEX (overhead).
- Recurring need of approximately EUR 1-3m.

Challenges

- Shortage of qualified staff to deliver higher value services, like algorithm improvements etc.
- Facilitation of access to HPC ecosystem for first time users usually for free to convince new clients to make use of HPC – sale of CPU cycles not profitable enough to structure sustainable business case.

HPC customers

Summary

- For large industrial corporations, HPC-based simulations are an established component of their R&D process. Simulations are usually carried out in HPC centres owned and managed by the industrial corporation itself in an effort to protect valuable intellectual property. Investments in HPC are generally financed through free cash flows or as part of the corporation's overall financing activities without any significant access-to-finance problems.

- Small and medium-sized industrial companies provide significant potential for the uptake of HPC in Europe. Yet, most SMEs use small-scale, in-house desktop simulations instead of making use of far more powerful HPC capacities. This conservative approach by many SMEs limits both their own innovation potential and HPC uptake on the broader market.
- The emerging demand from innovative companies offering digital services based on Artificial Intelligence or other applications requiring high computing capacity represents a potential new customer segment for HPC centres.
- The grants provided by Fortissimo entice SMEs into the use of HPC assistance and acquaint businesses with the new technology. However, such grants also generate a 'free rider' mentality among participating businesses without providing clear incentives for commercialisation.

In Europe, the main customer groups for HPC are public entities, research and academia. This is reflected in the utilisation rates of Europe's highest performing HPC systems where up to 94% of operating time is occupied by research tasks[28]. As this study focuses on the commercial application of HPC, it refrains from further investigation into the detailed structure of academic HPC use. The commercial customers of HPC are mainly research-driven businesses in areas such as engineering, bio-sciences, renewable energy, climate or geo-sciences. Accordingly, the following findings are primarily focused on engineering, bio-sciences and the environment/renewable energy.

HPC customers: Key characteristics of the market structure

When analysing the market structure a clear distinction has to be made between **large corporations** and **SMEs**.

Large corporations usually have a very clear understanding of the potential offered by HPC. HPC-based simulations are usually an integrated part of such companies' R&D processes. For example, HPC-based research and development has been a standard process at Daimler for decades: as early as 1987, the German car manufacturer would explicitly mention HPC-based cooperation with IBM or Siemens Nixdorf in its annual report[29].

Back then, Daimler was already making use of high-performance computers, and computer-based modelling of drive shafts in order to increase efficiency. Other European industry leaders in the fields of aerospace, pharmaceuticals, and oil and gas have taken similar approaches. Large corporations usually possess and operate their own HPC infrastructure (HPC centres). Investments in own HPC infrastructure are primarily taken to protect proprietary data (i.e. simulations of prototypes) from being accessed by unauthorised users. Using external HPC infrastructure is often considered to be an unaffordable risk by large corporations:

> "Using commercial HPC from outside our company is unimaginable for us."
>
> **Senior R&D manager, large corporation**

In terms of computing capacity and investment required, the HPC infrastructure that large corporations establish for their R&D processes is smaller than that usually established by academia and research institutions. The main reason for the comparatively small HPC centres established by large corporates is that current industrial HPC applications do not require the computing capacities often needed by academic research projects.

Typically, the HPC systems are shared investments via budget contributions from the departments that are mainly using the capacities, as one interview partner described. If, however, external financing were required, it would not be in a project finance set up, but generally integrated in an overall financing round (i.e. corporate bond issuance).

Many **SMEs** in the European manufacturing sector do make use of computer-based simulations. However, most of these simulations are still run locally on workstations (enhanced desktop computers) and not on HPC systems[30]. With the increasing degree of complexity of computer-based simulations, workstation-based solutions are reach a level at which it takes a very long time to calculate the necessary results due to the limited computing power available. Many SMEs do not progress beyond this point. This is either because workstation-based simulations are sufficient from their perspective or because many SMEs are not aware of any alternative, commercially viable solution.

An estimate by Fortissimo's management provided during an interview highlighted that approximately 30,000 European SMEs would probably benefit from introducing HPC-based processes[31]. One of the main reasons for this lack of uptake is that many SMEs are not aware of the technological and commercial benefits that the application of HPC could bring to their businesses.

More recently, large corporations with long supply chains have started to push their suppliers (often SMEs) into HPC-based simulations for the parts they are providing. By doing so, large corporations aim to speed up the innovation cycles of their suppliers and receive fully digitalised models to integrate in their own HPC-based simulations.

Finally, there is an emerging segment of new customers for HPC centres consisting of **innovative and start-up companies** offering digital products based on Artificial Intelligence and other applications requiring high computing capacity. They are not using HPC to cut costs in the R&D process, but they are developing HPC-based processes and products that can be combined with specific customer data in order to derive optimisation potential for the customer's business. HPC is therefore not a part of a more extensive business model, but the foundation of the business model and the companies are intending to grow their organisation on this premise.

HPC customers: Key characteristics of the business model

The R&D process is the main focus for the application of HPC in manufacturing and traditional sectors. Whereas traditional R&D relies on reiterative testing of physical prototypes, HPC application makes it possible to reduce the need for prototyping to a minimum and therefore reduces costs. The simulation applications narrow down the many options to only a few viable prototypes that have to be built. Costs are reduced because the building of prototypes requires specialised instruments and machinery that can be scaled back due to the upfront exclusion of several options.

Moreover, HPC applications can help to optimise the use of resources and accordingly minimise overall costs. Therefore, the application of HPC can lead to shorter innovation cycles and earlier commercialisation of industrial products and processes.

Apart from the dominant R&D business case for HPC application in the European manufacturing sector, it also has a service-oriented business model application. This model is to be found mostly in start-up businesses. As an example, during the interview phase a start-up was identified that provided HPC-based yield optimisation of crops using genetic plant information combined with data on the characteristics of the micro-environment (e.g. climate, soil, etc.) as a novelty in the agricultural sector.

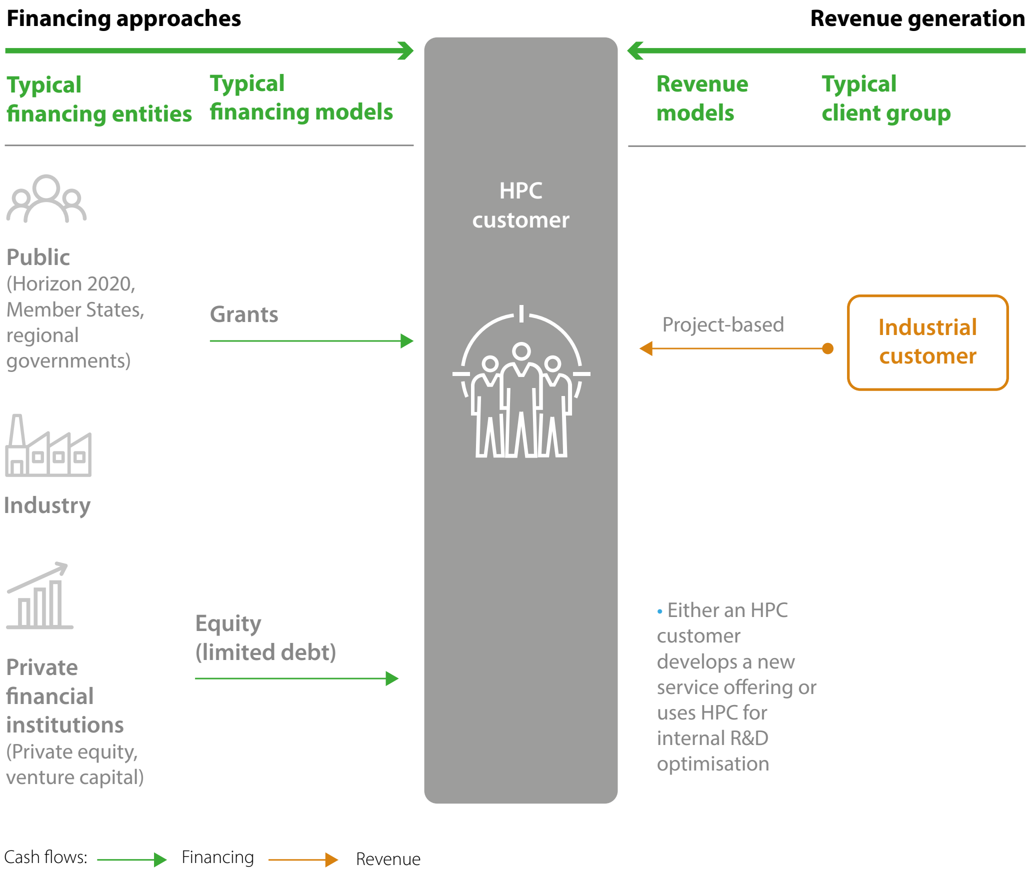


Figure 23: Schematic overview of the HPC client business model

HPC customers mainly use grants for integrating the use of HPC into their R&D programmes

Access to finance for HPC customers (SMEs) - summary of interview findings

Current financing situation

- Initial use of HPC is either self-funded (as the investment need is rather small), but mostly available grants are utilized to achieve a fully subsidized HPC trial run
- External commercial financing for incorporating HPC is rather limited

Investment needs

- Mainly for covering the initial introduction of HPC in a R&D process, for licensing fees, for CPU cycles
- Recurring need per SME user at approximately EUR 800,000- 1,5m

Challenges

- Small ticket size for financing the project is not served by existing commercial HPC financing instruments – SMEs rely on grants
- Key obstacle is the lack of awareness of the commercial use case for HPC and missing internal capacity

Current access-to-finance conditions for HPC customers

Large corporations currently face limited issues with regard to access-to-finance conditions in Europe, mainly due to the record-low level of EURIBOR interest rates. Large corporations finance their HPC activities either through free cash flows from their overall commercial activities or by general financing rounds (i.e. corporate bond issuance) meaning that there is no need to present a bankable HPC business case to investors before each financing round.

> “Our HPC activity is financed from the incoming cash flows of our business activities.”

Head of department, large corporation

"We did not look at the specific details of the HPC endeavour too much; we knew we were lending to the company overall, not to a specific HPC project."

Director of a corporate bank lending to a large industrial corporation

Small and medium-sized companies with an established business model considering the use HPC in their R&D process typically face a different situation. The range of investment required for the first-time introduction of an HPC-based process is well documented through the relevant Fortissimo projects. The typical investment need ranges between EUR 100,000 to EUR 250,000 depending on how much prior knowledge about HPC was present in the implementing organisation and, respectively, how many new employees needed to be hired[32]. This figure might seem relatively small, but it is indeed significant for many SMEs. According to a study conducted by KfW in 2015 on innovation within European SME's, the average spending of small and medium-sized companies on research and development is 3.5 per cent of their revenue. For an SME with a revenue of EUR 10 million and thus average R&D spending of EUR 350,000, the investment of entering HPC-based product development would require a 30-70% increase in its R&D spending. For smaller companies, entering HPC-based product development can even require doubling or tripling R&D expenditure. Furthermore, many expenditure categories for HPC processes are yearly recurring costs, e.g. for software licences. Given the unclear returns from such significant expenditure, many smaller companies shy away from making the step from workstation-based to HPC-based simulations. In addition to that, the challenge is often not solely the lack of capital. Particular investments must be undertaken in human resources to support the migration from regular simulation processes to HPC sustainably. These advanced competencies are often not easily available to SMEs.

The main challenge from a financing perspective is the change in the business model related to the switch from workstation-based simulations to HPC-based simulations. SMEs needs to migrate from a model based on acquiring assets and equipment (capex) to acquiring HPC as a service (opex). Such a switch is usually perceived as risky by finance providers (especially banks) because it is an asset-light model (lack of collateral) with unclear benefits in terms of cost reduction and profitability. Therefore, financing for these transformational deals is generally limited (especially from commercial banks).

Start-up companies again deal with a different financing environment. Venture capital or corporate venture capital firms are one of the key sources of funding for these organisations. They tend to have in-depth market experience and external support networks of knowledgeable experts that help evaluate the respective business case. Interview partners have indicated that apart from capital injections by the founders themselves, venture capital is one of the main sources of external funding. The feedback of respective market participants indicated an investment need of around EUR 350,000 up to EUR 1,500,000.

However, this is not to say that the interviewed start-ups do not make extensive use of grant financing as well. In fact, they reported that they were eager to secure grant funding, if available, within their field of activities.

"We use almost exclusively equity and grants to grow our business"

CEO of a start-up focusing on HPC-based business models

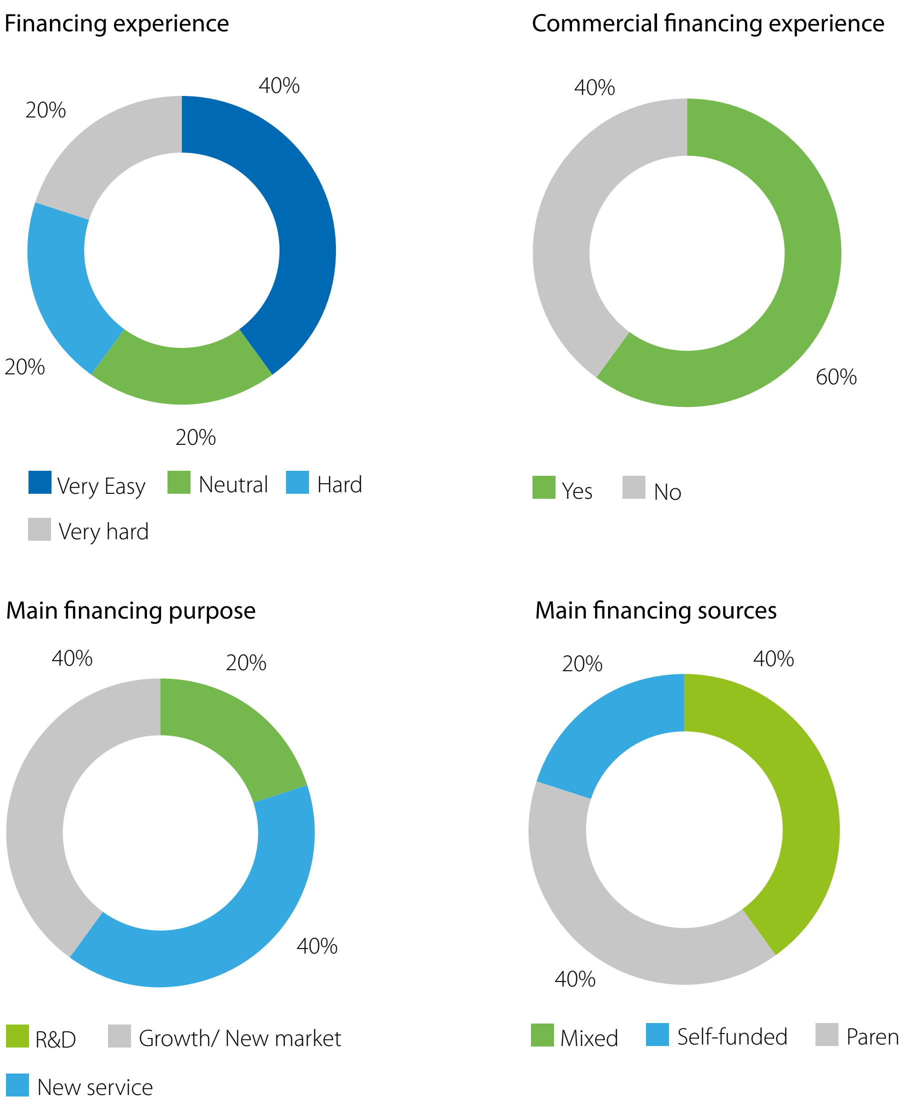


Figure 24: Access-to-finance situation of HPC customers: snapshot from interviews

European Open Science Cloud (EOSC)

Summary

- Being bold and visionary, the European Open Science Cloud initiative could provide a substantive positive impulse for the further development of HPC and Cloud Computing in Europe.
- So far, however, the EOSC initiative is little known and understood by private businesses. Hands-on use cases and dedicated content marketing activities are necessary to stimulate substantive engagement by commercial players in the EOSC.
- Access to relevant, commercially interesting data is needed to engage businesses in the EOSC. In contrast to that, there is little need for additional hardware capacity in the market.
- In order to become relevant for commercial activity, industry data security standards and service levels need to be met.

Objectives and current status of the European Open Science Cloud

According to the first report and recommendations of the Commission High Level Expert Group on the European Open Science Cloud (HLEG EOSC), the EOSC "aims to accelerate the transition to more effective Open Science and Open Innovation in a Digital Single Market by removing the technical, legislative and human barriers to the re-use of research data and tools, and by supporting access to services, systems and the flow of data across disciplinary, social and geographical borders[33]".

The report draws a parallel between the EOSC and the early days of the internet, when early standardisation combined with decentralised, interconnected IT systems led to fundamental changes in the use of IT. However, the EOSC is still much more a concept on its way to implementation than a fully implemented structure. Nevertheless, the potential use of the EOSC by the private sector can be regarded as significant.

According to HLEG EOSC, HPC and the EOSC are regarded as two interdependent concepts and shall form future European data infrastructure. As the EOSC is aimed at facilitating access to scientific data in an open format, these significant amounts of data will increasingly require more HPC capacity. Consequently, the provision of more data in the system could fuel the use of HPC and also open up opportunities for innovation and new businesses.

So far the EOSC is in its early post-inception stage. One of the objectives of this access-to-finance study was to evaluate how the future development of the EOSC could be best advanced and leveraged by commercially driven business models that build on the services, data and infrastructure potentially provided by the EOSC. This study, in particular, investigated which framework conditions (i.e. in terms of data protection and property rights) will need to be met by the EOSC in order to be attractive as a partner and service provider for private businesses.

In assessing the role and impact of the EOSC, the overall awareness of the EOSC is a critical factor. In the course of this study, a total of 44 market representatives from both public institutions and private companies were interviewed concerning their views on the EOSC initiative. 61% of the interviewed experts were not aware of the EOSC initiative. Looking only at public organisations such as HPC centres and intermediaries, 71% of the interviewed experts were indeed familiar with the EOSC concept (as opposed to a mere 25% of experts from private businesses).

The close link between intermediaries and HPC centres makes the EOSC a relevant concept for both stakeholders. They tend to belong to networks in which upcoming EC concepts are discussed or even supported with expert advice.

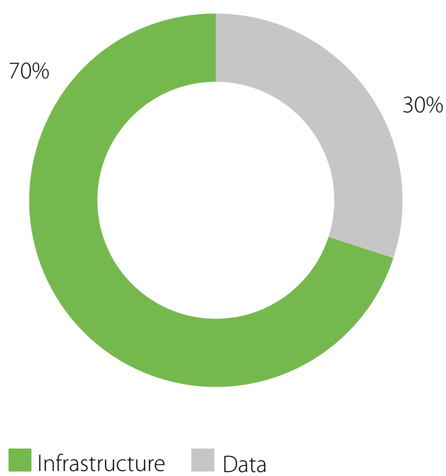


Figure 25: Potential demand for EOSC offerings in the fields of infrastructure (i.e. CPU cycles) and data offerings

The interviews conducted show that there is, however, a strong potential for private sector demand in the EOSC. To increase awareness among the private sector, the study has identified important opportunities for developing potential collaborations with the private sector related to Big Data and improved access to scientific knowledge. The interview partners stated that a data-driven offering would be interesting for the market.

Important factors are the quality and commercial potential of the data contained in the EOSC. Interview partners have stated that not all scientific data per se is potentially interesting for commercial users.

> "The EOSC's open data will not be interesting for private use unless Big Data from public institutions (i.e. hospitals and social insurance agencies) will become openly available. However, under current EU regulations this is highly unlikely."

Senior manager, HPC customer

> "Data in an anonymous form can already be a very valuable asset for the development of new solutions. In concrete terms, our company would like to use specific public traffic data to predict city pollution levels."

Senior manager, HPC customer

"The EOSC's open data approach could generate added value if it succeeded in integrating different data streams of public agencies (i.e. in the field of oceanography, vulcanography or high energy physics). This unique data combination could offer a value proposition to private companies as a side product of the data integration, for example to make use of wave energy simulations (tidal energy)."

Director, HPC intermediary

Explaining the use case of the EOSC and building trust around the infrastructure are in the eyes of the interview partners the most important success factors of a partly commercial offering. As a totally new concept, the EOSC would need to reach out to potential customers and prove its value proposition. The demonstration of use cases as a form of content marketing (a technique that has proven to be successful in the market) would be the appropriate way of engaging private parties.

In order to demonstrate the potential of the EOSC for commercial applications, many interview partners suggested the compilation of concrete use cases. Such ready-to-publish use cases would illustrate how real companies have managed to establish viable business models based on EOSC data. The Fortissimo initiative could be used to generate suitable use cases.

“We need concrete use cases by real companies demonstrating precisely the potential of the EOSC.”

CEO, ISV

Based on specific use cases, many interview participants suggested targeted communications and marketing activities on the EOSC offering:

“In the highly dynamic HPC market, decision-makers experience a constant information overflow with new offerings. Targeting the really relevant decision-makers with high-quality materials is critical for the success of the EOSC.”

CEO, ISV

Alongside the application focus, for commercial users the security of the infrastructure is also an important topic. Industry standard certifications etc. could be an approach to mitigating the industry’s need for reassurance.

“Data security is the prime issue. Our aerospace data needs to remain confidential for 60 years.”

Senior manager, HPC customer

Complementary factors of success include the pricing of infrastructure capacities and the service level offered to private clients. The service level of the EOSC's offering needs to adhere to industry standards. The academic institutions behind the Cloud Computing services are not necessarily known for extensive experience with delivering services to private customers. As the HPC cloud product offering will need support structures, the EOSC operators need to be able to serve private customers in an adequate way. For example, private HPC offerings provide service and technical expertise 24 hours a day.

> "Private providers of HPC hardware cover 24 hours of the day with their service and technical assistance offering. We would expect a similar agility from EOSC offerings."

Head of department, HPC customer

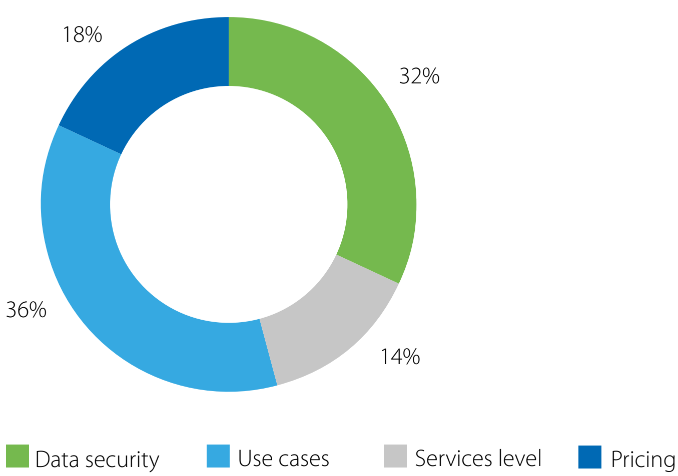


Figure 26: Success factors of the European Open Science Cloud from the perspective of the interviewed experts

A number of interview participants mentioned that the most relevant use case in the EOSC is a low-cost test environment for new algorithms and other software-based products from SMEs:

> "We would want to be able to access this sort of magnitude of data to test new products or to improve them at a low level of cost for us."

CEO, ISV

> "Testing algorithms could be an interesting field for us."

CEO, ISV

Additionally, the EOSC would also be appreciated as a further platform for intensive stakeholder exchange, leading to knowledge spillover and/or client relationships. Collaborative research could be conducted via this point of exchange:

> "The EOSC could become an outstanding platform for HPC matchmaking between customers (SMEs), intermediary organisations, consultants and ISVs facilitating HPC readiness in the broader market."

Director, HPC intermediary

EOSC – Needs for action

- Raising awareness is critical: The applicability of the scientific data potentially contained in the EOSC for private industry is still unclear. So far, only a few institutions have heard of the EOSC. The intention, benefits, opportunities and use cases need to be clearly developed and communicated.
- The business model of the EOSC needs to be structured around data, not primarily infrastructure: The unique selling point (USP) of the EOSC is the magnitude of data in the context of the convergence of HPC, Big Data and machine learning.

- It is recommended that private companies be involved in the early market model to shape the discussion about a mixed model (e.g. in working groups or steering committees). SMEs in particular could benefit from inexpensive access to the cloud: smaller ISVs as well as HPC customers could use the EOSC as a test environment for new codes and algorithms.
- Demonstrative use cases and data security are key success factors: The EOSC will not succeed if it cannot clearly highlight specific, commercially viable fields of application. Additionally, security certification would be necessary to attract private users.

Lenders and investors – Supply side of financing

In assessing the supply side of HPC financing in Europe, 20 interviews were conducted with different types of financing institutions: national promotional banks (NPBs), national funding agencies/ governments, venture capital and private equity funds, corporate venture capital companies and commercial banks. Please see chapter 2.2.2, for a detailed description of the financing strategies as well as scoping of the institutions considered on the lenders' side.

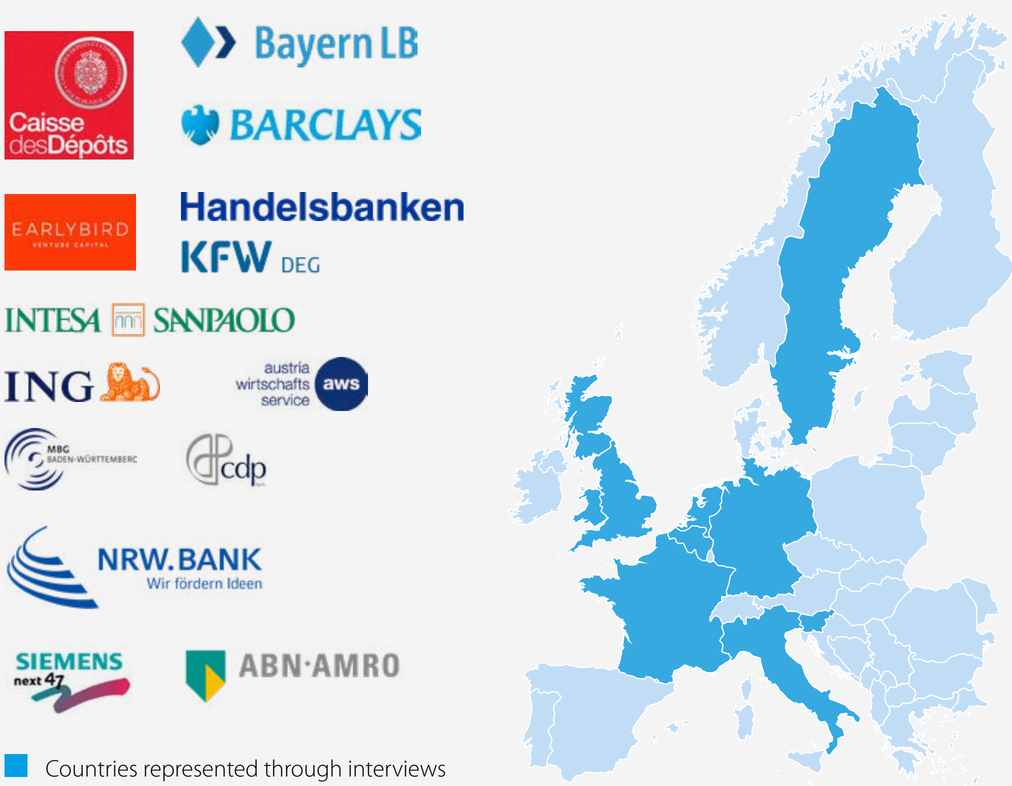


Figure 27: Selection of expert interviews conducted (institutions and geographic coverage)

Findings based on financing institutions

Summary

- Private financing institutions are generally interested in investing in the European HPC sector. The main barrier impeding a stronger involvement of commercial banks and equity investors in HPC is the lack of commercially viable business models in the market. If these are identified and meet certain requirements, lenders are generally open towards financing the sector.
- Equity investors have the least difficulty in understanding innovative business models in the HPC market. They play an important role in fuelling the growth of smaller companies with a clear business case. Compared to the US, however, the activities of private investors in Europe are modest in scale.
- The majority of commercial banks apply a traditional due diligence approach (based on historical financial track record, future cash flows, available collateral, etc.). This approach can result in constrained access-to-finance for borrowers in the HPC sector due to the risk profile of these ventures. HPC players such as ISVs often face situations where either future markets are not yet sufficiently developed or sufficient collateral cannot be provided.
- Investments in the HPC sector (in particular, HPC infrastructure) are generally eligible for financing from national and/or regional promotional banks, and public financial institutions, which also offer crucial financing instruments for smaller volumes as well as risk-sharing instruments necessary to crowd in private investments.

Findings regarding the ease of HPC sector financing

The lenders' side has a diverse range of experiences and perceptions with regard to the ease of HPC financing, as shown in the diagrams below. Views on ease of financing change from one financing institution to another, and it also depends on the HPC player (HPC centres, HPC intermediaries, ISV, etc.) taken in consideration.

Different types of financial institutions differ in their perception on financing the HPC sector

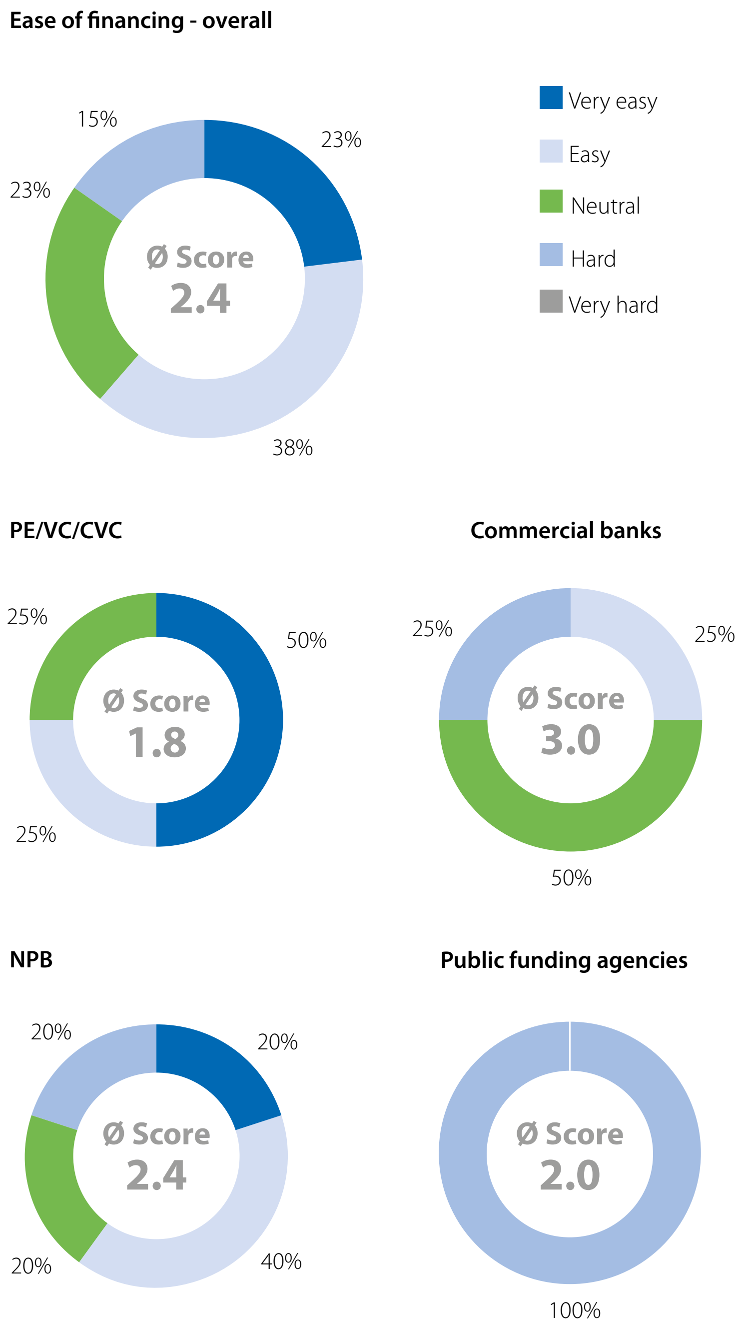


Figure 28: Ease of financing HPC as perceived by financing institutions (from interviews)

(Corporate) venture capital firms mainly focus on software companies (such as ISVs). 50% of interviewed firms said they found financing software companies such as ISVs very easy. They consider start-ups in the software segment, in particular, to be an attractive target market and have the necessary technical expertise and knowledge, mostly in-house or at arm's length through their expert networks. The experts mostly support the evaluation of these business models. Overall, (corporate) venture capital firms finance software companies including ventures with a focus on service, data and applications based on HPC.

Middle ware and infrastructure software businesses are considered to be the most attractive investment targets as the companies in this segment develop generic software and applications useable for a broad range of industry customers, e.g. in simulations, Big Data or Artificial Intelligence applications. Hence, the business case is built on a service that can be applied by other customers, rather than being tailored to one field of application. Overall, with numerous attractive targets in the European market and a smaller VC market (compared to the US), this group of financiers can selectively choose their investments. The investment volumes range from EUR 0.1 to EUR 10 million. (C)VCs mentioned that EIF involvement supports their fund-raising in general.

In contrast to other lenders in Europe, VCs are quite advanced in terms of industry and business development know-how. However, in contrast to US VC and PE firms, the European counterparts are, in general, smaller and have less fire power. US venture funds have been more successful in systematically investing and binding together companies operating in sectors that they have financed before. Thereby, they have created and organically grown an excellent expert network that supports them in evaluating highly technological business models.

Commercial banks are mainly focused on financing HPC infrastructure with established commercially oriented business models (mainly private HPC centres). Private HPC centres are considered to be the most attractive investment target for banks due to the existing collateral, larger and fairly stable revenue streams, proven business models and larger investment volumes. Experience of financing commercially oriented data centres (as in the UK, for example) provides valuable insights. Financing decisions are mostly taken on a case-by-case basis. The investment decision is based on either cash flow or real estate. For most banks in the study, cash flow is the most crucial factor, whereas real estate as collateral helps. Based on experience with financing data centres, an EBITDA of 10 20% and a positive historic cash flow is considered by many banks that were interviewed for this study as conditions for a positive investment decision. If this is given, leverage can amount to up to four to six times the equity volume.

However, excluding private HPC centres, the HPC sector (from public HPC centres to ISVs) is mostly considered as a high-risk sector with:

01. Commercially oriented business models that have not yet been proven or are 'lacking' entirely in the case of public HPC centres and HPC intermediaries;

02. High-risk proposition with high revenue uncertainty and lack of collateral in the case of ISVs and innovative start-ups;
03. Change in business model (from capex to opex) with limited visibility as regards the economic benefits in the case of SMEs adopting HPC services.

This leads to an overall financing gap. However, most banks, especially those with an emerging technology orientation, find the sector very interesting, provided the revenue stream is reliable. As one interview partner put it, "banks only understand the business model once it has data-driven evidence of success... Banks lack willingness to work with hypotheses".

Investments in HPC sectors are generally eligible for financing from national promotional banks and public financial institutions (such as the EIB). They generally have the necessary expert sector knowledge to evaluate business models and have a broad approach ranging from start-up financing to SME financing, as well as the financing of large projects including HPC infrastructure. Overall, they consider the development of the HPC sector highly important. However, most NPBs and public financial institutions do not offer dedicated HPC financial instruments, but rather offer their general innovation-focused financing instruments.

As highlighted in the section before, the lending gap on the commercial market is mainly linked to the high-risk proposition, and/or uncertain business models of key players in the HPC sector (such as ISVs and SMEs considering the use of HPC as a service). National promotional banks and public financial institutions can help to address this funding gap. For example, KfW, the German national promotional bank, offers an instrument called 'ERP-Innovations programme'. This programme offers SMEs financing for projects with a high degree of innovation for the country and the EU. The key eligibility criteria are: incorporation for at least two years and revenues not exceeding EUR 500 million. The maximum loan amount defined in this program is EUR 5 million. Other European NPBs as well as regional banks, such as the NRW Bank, have similar products for projects involving a high degree of innovation.

The EIB and EIF offer a wide range of financing instruments, under which HPC investments would be eligible. The EIB focuses on three activities (lending, blending and advisory) with a preference for larger investment volumes (often intermediated). It also provides higher risk-taking instruments in order to support the crowding-in of other investors. The EIB also undertakes intermediary financing via national or sector-specific funds. In this case, the ticket sizes and risk profile may vary from the typical EIB focus, e.g. the financing volumes may be considerably smaller. The EIF is the partner organisation of the EIB and focuses more on equity-financing approaches, having strong operational and knowledge capabilities in this sector. Financing for innovation relevant to the HPC sector is offered either through the EIB/EIF directly or via national promotional banks or funds as intermediaries under both the InnovFin and EFSI programmes.

In general, EU Member States have a fragmented public financing/funding landscape with many cross-cutting initiatives (with HPC financing initiatives being one example). The types of financing instruments of various stakeholders partially overlap. Although many private financiers have mentioned that EIB/EIF involvement is a positive signal, many have also mentioned that they perceive the landscape and modalities of accessing public financing to be complex and difficult to grasp. Hence, some kind of simplification could help engage private financiers (see chapter on recommendations).

Key learnings from access-to-private-finance conditions

Key stakeholders (from HPC centres to HPC customers) in the European HPC ecosystem face different financial challenges that need a tailored solution.

There is a broad range of different HPC organisations and companies, operating within the HPC ecosystem with different business models and financial challenges. An overview is presented below.

- HPC centres: the European landscape for HPC centres is largely dominated by publicly owned entities, mainly serving universities and research, and relying on public funding for both capex and opex needs. The main financial challenge for these players is the limited propensity towards commercially oriented models, and legal restrictions on increasing revenues from commercially oriented activities.
- HPC intermediaries: with a few exceptions, these are very similar to public HPC centres. They are mainly public entities under the umbrella of an HPC centre with limited viable business models, relying primarily on grants and public budgetary support.
- ISVs: While European ISVs have established business models (mainly offering Software as a Service) in specialised and niche segments, access to finance is constrained by: 1) lack of tangible assets; and 2) high-risk business model (upfront development costs with limited revenue visibility), resulting in insufficient growth capital.
- HPC Customers: Demand for HPC capacity from commercial users is still very much developing and has not yet reached maturity. At the same time, it is expected that the demand for HPC infrastructure and services will rapidly increase in the near future, due to the rapid spread of digital innovations and the rise of Big Data. HPC customers can be categorised into 1) large corporates, 2) SMEs, and 3) innovative companies and start-ups. Large corporations are currently the main users of HPC capacity. However, most of them rely on in-house HPC centres. From a financial prospective, large corporates could benefit from more collaborative approaches with HPC centres by reducing investment needs, benefiting from higher computing capacity and expertise from personnel at HPC centres and intermediaries. HPC uptake is still limited among SMEs. The main challenges are linked to lack of awareness of the potential benefits of HPC, limited in-house expertise, and difficulties in accessing finance (limiting investment in HPC). Finally, innovative companies and start-ups represent an emerging new driver for HPC demand. Companies developing Artificial Intelligence applications and Internet of Things, and using Big Data will require HPC infrastructure to handle large amounts of data and complex calculations.

Findings regarding public financing instruments

Summary

- In order to crowd in private financing while facing the challenges of an emerging technology market, public financing plays a major role (e.g. in providing grant financing as well as reducing financing risks that private financiers do not absorb).
- Fragmentation and limited coordination of public funding at the EU level has resulted in a suboptimal investment climate and underinvestment in strategic HPC infrastructure in Europe.
- International best practices in HPC financing show that there are no fundamental differences in approaches taken in countries like the US, Japan and South Korea vis-à-vis Europe. However, it can be noted that the success rate for the commercialisation of HPC is highest where sector initiatives (effectively bringing together HPC businesses, universities, investors and public agencies) are managed in a resourceful, integrating, agile and persisting way throughout all stages of the HPC business lifecycle.

The focus of this review is to assess the spectrum of EU public financing instruments, match them with the identified financing needs of the HPC value chain segments and compare them to international best practice. Examples of the reviewed instruments have been referenced where appropriate.

The financial instruments selected were reviewed with a view to assessing their suitability for the HPC value chain and the focus areas of this study. For this purpose, the following factors were taken into account:

- Regional coverage.
- Sectorial focus.
- Total and project-based investment volume.
- Typical stage of investment (maturity of underlying project).
- Type of investment.

Available European instruments

The EC has made innovation and digital research a top priority. To actively promote the development of this sector, Horizon 2020 was initiated as a framework. Horizon 2020 is a research and innovation programme with a total budget of approximately EUR 80 billion covering the period 2014-2020. Horizon 2020 forms a further source of innovation financing – in addition to EIB, EIF and Member States funding. Horizon 2020 was launched to support the EU's mission of forming an 'Innovation Union' to boost Europe's global competitiveness through innovation. Horizon 2020 provides:

- Grants – for research, co-development and strategic procurement.
- Institutionalisation – to structure innovation processes and cluster relevant stakeholders.
- Commercial financing and advisory – via InnovFin (EIB).

In previous chapters, the study assessed the financing situation of various HPC borrower segments. Below, the most suitable instruments for public financing are matched with the segments.

ISVs

From a European perspective, it is crucial to cater for the financing needs of ISVs in an adequate manner in order to avoid the brain drain and keep key capabilities in the European market. The public financing tools needed to address these financing needs mainly include equity-enhancing instruments and venture capital (equity/debt) for scale-up.

The European public financing framework offers some suitable tools to partially address these financing needs. For example, Seedcamp, which operates across the EU, is a good example for equity enhancing instruments and venture capital in this field:

	01. Source of financing	02. Type of financing	03. Investment volumes	04. Borrower category
Seedcamp	• EIF	• Equity/Venture Capital	• Up-to EUR 50,000	• Start-ups, seft-employed • Micro, SMEs, (<249 employees)

The EU has introduced specific initiatives to promote growth financing. COSME is an EU programme with a budget of over EUR 1.3 billion. It facilitates access to loans and equity finance for SMEs where market gaps have been identified. Certain growth financing instruments have been funded by COSME as well. At national level, there are several initiatives for this purpose as the following German example of the ERP/EIF Growth facility illustrates. This financing instrument has a total investment volume of EUR 500 million and has the mandate of financing innovation and growth:

	01. Source of financing	02. Type of financing	03. Investment volumes	04. Borrower category
Federal Ministry for Economic Affairs and Energy	• EIF	• Equity/Venture Capital	• Up-to EUR 20 m	• Start-ups, seft-employed • Micro, SMEs, (<249 employees)

HPC centres

Publicly funded, scientific or academic HPC centres dominate the European market for high performance computing infrastructure. The typical investment volumes to set up or modernise public HPC centres is very high (ranging from approximately EUR 150 to EUR 500 million). So far, such investments have been largely covered by public funding, provided by EU Member States and EU funds .

The study demonstrates that there is a lack of coordination of HPC investments in Europe, fragmentation of the sector, and substantial underinvestment in HPC infrastructure and services in Europe. This is particularly applicable to the case of exascale computing capacity.

A key finding from the study is that the financing of these large-scale facilities is dependent on public funding, since private investors will not invest in the required research and development of exascale computing – mainly due to the extremely high investment costs, as well as the high level of uncertainty and the lack of assured revenues from these investments, until the technology becomes more established and can be directly applied to industrial and commercial applications. A European HPC infrastructure that can compete with the rest of the world requires substantial investment (estimated at EUR 500-700 million per investment cycle) which cannot be shouldered by any individual Member State.

At the same time, it is vital to improve the business models of HPC centres, in order to improve access to private funding (especially for smaller regional and national HPC centres, which could develop more commercially oriented business models to fund their capex and opex needs). The increase of private sector involvement, for example by assigning the operation to a telecommunications provider, could improve bankability. Similarly, the benefits of providing advisory services to users from academia on how to convert their scientific research into commercially viable products could also improve the bankability of an HPC centre offering such services as they could generate a steady revenue stream.

HPC intermediaries

HPC intermediaries have a key role in promoting the uptake of HPC services, and they could play a key role in supporting the growing market for HPC applications. In this context, HPC intermediaries require public support mainly in the form of grants and training programmes to carry out and expand their functions. In particular, HPC intermediaries should further develop:

- An in-depth industry network comparable to the distribution network of an established telecommunications provider; and
- Service offering and know-how to advise clients on how to establish a viable business case and financing model in the HPC sector.

International best practices

Looking beyond European borders, financing needs in all parts of the HPC value chain are similar to those within the EU. While the public financial instruments offered to the HPC sector outside Europe are not fundamentally different to EU financing, it is worthwhile highlighting certain enhancement mechanisms and tools introduced by selected countries in the international HPC market. These examples include suggestions on how to improve the European market as well.

South Korea has introduced instruments designed to promote access to loans for ISVs without tangible collateral:

The initiative was founded under the 'Financial Assistance to New Technology Businesses Act', which was revised and renamed 'Korea Technology Finance Corporation Act' in 2002 and provides for public guarantees tailored to the needs of ISVs in the SME segment lacking adequate collateral for debt financing. There are three types of guarantees with varying financial thresholds:

- Guarantees for technology-intensive SMEs: buyer credits for industrial research cooperatives.
- Guarantees for trade and export loans: collateralised guarantees and contract performance guarantees for technology-intensive companies.
- Guarantees for CAPEX requirements of technology-intensive SMEs.

These guarantees help ISVs to obtain debt financing despite lacking tangible collateral. From a lender perspective, the guarantee is a suitable instrument to secure its interests. This allows ISVs to remain independent and to convert their business ideas into reality.

The guarantee is funded by the Government and guarantee fees/technology appraisal fees as well as interest and other operational income. The guarantee fee for SMEs ranges from 0.5% to 3%, depending on the company's rating, the guarantee amount and transaction period. These "Technology Guarantees" are supplemented by 'Technology Appraisals' as part of the service offerings, which help identify the potential of the products. To boost the success of the ISV, the service offering also includes technology business consulting and legal rights management.

To limit the triggering of guarantees, the initiative thoroughly assesses the performance criteria and conducts detailed appraisals to encourage and validate the commercial feasibility.

South Korea has also taken additional proactive steps in promoting innovation in HPC and Cloud Computing with tangible success: the K-Start-up Grand Challenge is a new initiative launched in 2016 as a measure to catch up in innovation globally. The K-Start-up Grand Challenge is a platform bringing together carefully selected innovative start-ups and established corporates, such as Samsung. The first round of this project was publicly financed, however, for the coming rounds, the aim is to achieve a higher degree of private participation in the funding and administration. The established corporates support the start-ups, which may even lead to an investment in the start-ups.

The success of the first round has been impressive in multiple ways. Of the 20 participants, 19 have successfully taken their next step in their business launch. In addition, the number of applicants, particularly from Europe, far exceeded expectations.

For the next rounds, the initiative plans to focus more strongly on Europe from a strategic perspective in view of its high potential and to shift a larger portion of administration to the private sector to improve efficiency.

For Europe, it is crucial to understand these developments and watch them closely as the high interest and participation of European companies in the Korean initiative clearly indicate the potential Europe has in the HPC sector. Without encouraging this potential, these companies may seek opportunities outside Europe.

Japan has taken active measures to enable access to management expertise for its HPC sector:
The following best-practice case is particularly relevant in addressing the need to support commercialised business models: the Innovation Network Corporation of Japan initiated a PPP between the Government and 19 major corporations to boost the competitiveness of Japanese firms and create an innovative ecosystem through open innovation and new businesses in promising technologies by providing both capital and expert knowledge. This initiative is supervised by the Ministry of Economy, Trade and Industry (METI).

The idea behind this initiative is to provide easy access to significant amounts of capital paired with management support. For this purpose, a combined venture capital and private equity fund was formed with the aim of:

- Supporting SME growth.
- Facilitating consolidation among large incumbents to enable them to become global leaders.
- Promoting direct investments in new companies.

The total investment capability of this fund is approximately JPY 1,900 billion consisting of:

- JPY 10 billion from corporate investors.
- JPY 102 billion from the Government.

- JPY 1,800 billion of guarantees from the Government.

The focus of this initiative is on start-ups and smaller enterprises, which particularly need support and suitable financing in the HPC/cloud sector. The aim is not only to provide seed financing and advice but also to support financing over the medium to long term. Besides early-stage facilitation, the initiative assists in the growth stages by encouraging collaborations with major corporations and supporting more advanced stages with spinoffs and overseas expansions.

Furthermore, the initiative also promotes international exchanges with:

- Kauffman Fellows Program (Silicon Valley).
- National Institute of Advanced Industrial Science and Technology.
- Japan Science and Technology Agency.

This case is a good example on how to develop a model to promote commercialisation and bankability in the SME segment. This PPP in Japan also has the advantage of being a one-stop-shop for SMEs in this segment, which promotes visibility and transparency.

3. Recommendations

Based on the findings of the study, we have developed a series of recommendations to strengthen the HPC ecosystem in Europe, which are summarised and mapped in the figure below.

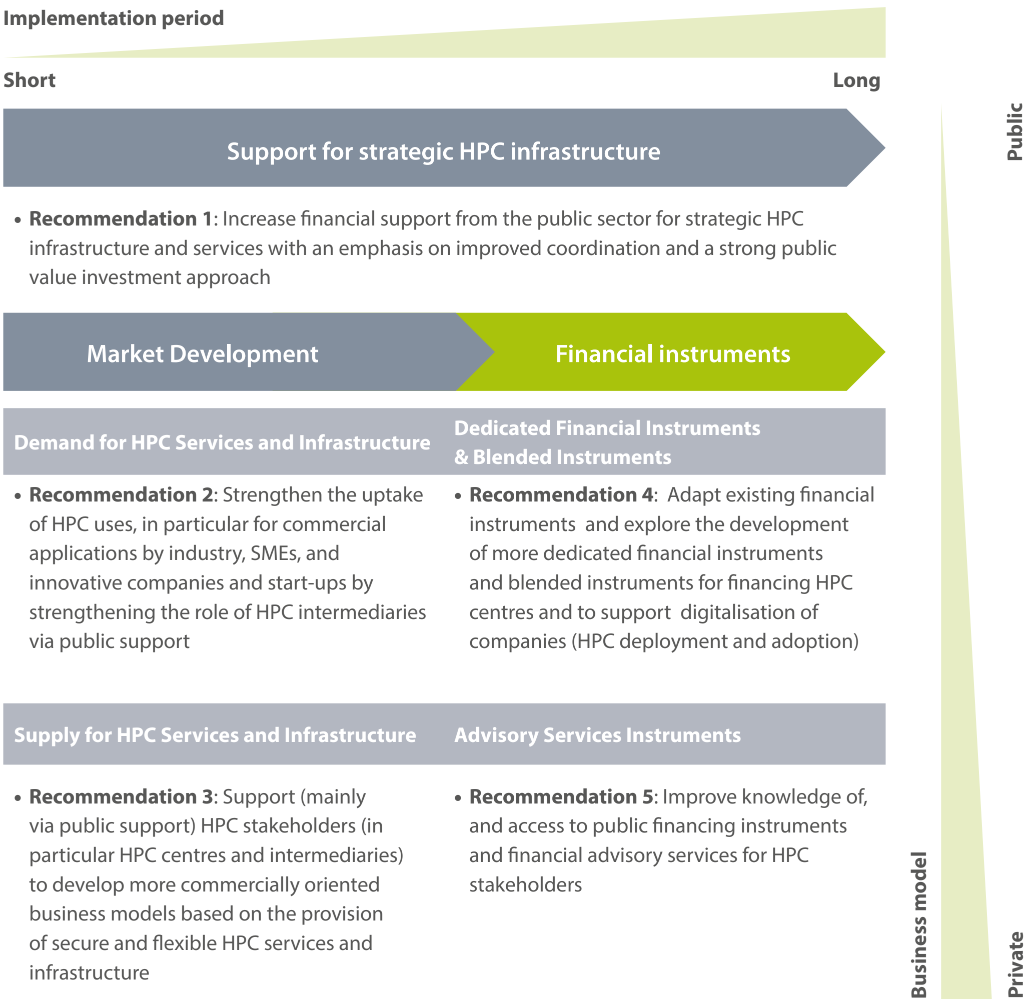


Figure 29: Overview and mapping of the key recommendations

Recommendation 1: Increase financial support from the public sector for strategic HPC infrastructure and services with an emphasis on improved coordination and a strong public value investment approach.

The findings from the study highlight the essential role of the public sector in supporting the development of strategic and enabling HPC infrastructure. The availability of high-end and best-in-class HPC systems (such as exascale supercomputers) is a key building block for the next wave of digital innovation based on deep technology. Public investments in this area have the potential to generate significant public value in the form of economic and societal benefits and returns. To reap the full benefits of the next digital revolution and to remain competitive on a global basis — meaning at least parity in HPC capabilities with those considered as the best in the world — Europe needs to acquire exascale supercomputing capability within the same timeframe as the US, Japan and China. This requires enhancing the collaboration between the EC, the Member States, regions and the private sector, as well as providing financial support for strategic HPC infrastructure and services.

A key finding from the study is that the financing of these large-scale facilities is challenging, since private investors will not invest in the required research and development of exascale computing – mainly due to the extremely high investment costs required, as well as the high level of uncertainty and the lack of assured revenues from these investments, until the technology becomes more established and can be directly applied to industrial and commercial applications. The required investments for a European HPC infrastructure that can compete with the rest of the world, requires substantial investment (estimated at EUR 500-700 million per investment cycle) which cannot be shouldered by any individual Member State.

Hence, the study recommends strengthening financial support for strategic HPC infrastructure and improving the coordination and pooling of financing by setting up a mechanism that enhances collaboration between the EC, its Member States and the private sector.

It also recommends increasing financial support for HPC infrastructure and services across Europe by **promoting the development of mixed public and private financing models**. In particular, the study recommends jointly developing a financing concept based on a PPP approach for HPC under the recently launched Euro HPC Joint Undertaking.

The critical role of Joint Undertakings:
The EU has developed a unique platform to overcoming market failures for technology development and investment: the so-called Joint Undertakings are public private partnerships comprised of industry stakeholders (private corporations), EU representatives as well as EU member state representatives and research organisations. Their aim is to promote the research, development, commercial application and, ultimately, the commercialisation of new technologies eligible for funding under the Horizon

2020 programme. Currently, six such Joint Undertakings exist, including Electronic Components and Systems for European Leadership (ECSEL), which aims to boost Europe's electronics manufacturing capabilities.

The Joint Undertakings mobilise large amounts of funding from both private and public sources to develop technologies that would otherwise not receive such large investments. For example, ECSEL is based on a three-component funding structure:

- The EU is contributing EUR 1.17 billion of funding via the Horizon 2020 budget.
- The Member States participating in ECSEL are contributing another EUR 1.17 billion.
- Private members are contributing (in the form of in-kind contributions) roughly EUR 5 billion.

By pooling resources in this way, technology development can be financed from public and private sources. The following conditions need to be fulfilled for establishing such Joint Undertakings:

- Existence of market failure (i.e. lack of private investment in a commercially crucial technology field).
- Additionality of funding (i.e. clearly complementing already committed public funding).
- Governance (i.e. a governance and management structure that reflects the membership).
- Role of Member States (i.e. active contributions from EU Member States to promoting the technologies).

Euro-HPC Joint Undertaking

The main objective of the recently established Euro-HPC Joint Undertaking, coordinated by the European Commission with the current support of 15 EU Member States, is to cooperate in the development of a pan-European HPC infrastructure and HPC-based services. This initiative underpins the ambition of putting European exascale computing within reach in just several years. The study emphasises the key role that the Euro-HPC Joint Undertaking plays in fostering the development of HPC centres and the overall HPC Ecosystem in Europe.

In the context of the Euro-HPC Joint Undertaking, the study also recommends the establishment of approaches to engage SMEs in large publicly tendered HPC technology development projects. It suggests developing a procurement mechanism that improves the access of European SMEs to large public projects, e.g. under the ETP4HPC eINFRA procurement procedures. This would support the European SME sector in business and technology development.

STRENGTHEN THE DEMAND SIDE

Recommendation 2: Strengthen the uptake of HPC uses, in particular for commercial applications by industry, SMEs, innovative companies and start-ups, by strengthening the role of HPC intermediaries via public support.

The development of viable business models for HPC centres is largely dependent on increasing the demand for such services by commercial users. The HPC ecosystem is generally at a relatively early stage, as there is a lack of awareness of HPC's potential benefits for SMEs, and demand from innovative companies (such as companies using Artificial Intelligence) is emerging but still limited.

In this context, HPC intermediaries play an essential role and are critical multipliers for the involvement of HPC customers, and demand for HPC infrastructure and services. Furthermore, business development depends heavily on cooperation among the key HPC stakeholders (from HPC centres to ISVs). Therefore, the HPC ecosystem in Europe could greatly benefit from stronger and expanded activities by HPC intermediaries. It is recommended that HPC intermediaries provide the following services:

- Prepare and implement an overarching communication campaign, disseminating use cases and thus developing awareness for the potential of HPC.
- Promote and support the development of more collaborative models between HPC centres, intermediaries, ISVs and large corporates in order to show large companies the benefits of working with HPC centres over in-house HPC (in terms of investment savings, computation potential, etc.) and address key concerns such as data security and privacy.
- Support the demand for HPC services arising from HPC users (mainly SMEs and innovative start-ups).
- Provide advice to ISVs on HPC-related business development and the identification of appropriate partners.

The main role of HPC intermediaries from the point of view of the development of the HPC ecosystem is to promote demand for HPC services and support the development of commercial business models to enable private financing or mixed financing models. This function is to be offered on a bilateral basis (providing direct advisory services to the HPC stakeholders) as well as through broader dissemination practices (e.g. useful case studies, best practices, etc.).

In order to strengthen the role of HPC intermediaries, the EU and national members should increase public support to these entities (via grants and 'train the trainer' programmes). This can build on existing initiatives such as PRACE, ETP4HPC, Fortissimo and the new EuroHPC JU.

SUPPORT SUPPLY SIDE

Recommendation 3: Support (mainly via public support) HPC stakeholders (in particular HPC centres and intermediaries) in developing more commercially oriented business models based on the provision of secure and flexible HPC services and infrastructure.

The study has identified that the European HPC ecosystem is still in an emerging phase from a business perspective. The development of more commercially oriented business models will be an important step in accessing repayable capital and reducing dependence on public funding. In order to achieve this goal, it should be considered not only to promote demand for HPC infrastructure and services (Recommendation 2), but also to support HPC stakeholders (in particular HPC centres and intermediaries) in developing business models in order to capture and better link their offer with the existing and emerging demand for HPC services and infrastructure.

A key aspect of the development of more commercially oriented business models is to build on the specific comparative advantage of European HPC centres in providing HPC services that are based on the highest data protection, cybersecurity and data privacy standards and that ensure the protection of intellectual property and the data ownership of users. In this context, HPC centres and HPC intermediaries could benefit from technical advisory services to:

- Create awareness among HPC stakeholders (in particular, HPC centres and intermediaries) of the potential business models that can be developed (presented below), and their potential benefits.
- Provide training and necessary expertise to develop such business models.
- Support HPC stakeholders in business development and business planning.
- Strengthen the collaboration between HPC centres, intermediaries and ISVs with a view to developing more commercially oriented business models.
- Provide guidance and best practices on the critical issues of ensuring data protection, privacy standards and the protection of intellectual property and data ownership of HPC users, in particular from industry and SMEs.

Such advisory services should be mainly provided via public support. The EU and Members States could consider the development of a central platform to support the business development of HPC stakeholders. Such a platform can build on existing initiatives such as Fortissimo.

The study recommends the promotion of business models based on a mix of both public and private users, easing the migration process towards more commercially oriented business models.

The study has developed examples of HPC centre business models based on public/private approaches. At the two extremes of the spectrum, there are the fully public model and fully private model. In the middle, there are two mixed models, gradually expanding the commercial/industrial uses of HPC infrastructure and services. These models aim to build the basis for complementing existing public financing (currently provided primarily through grants) with increased revenues from HPC applications for industry and SMEs.

However, it should be noted that the success of such a transition towards more commercially oriented business models is currently constrained by existing regulations that limit the ability of HPC centres to generate more than 20% of their revenues from commercial customers. Overcoming this limitation would be an important step for the further development of the HPC ecosystem.

The different models are summarised as follows:

	Public/University model	Independent institutions (RTO) model	PPP model	Private model
Ownership	100%	51% / 49%	100%	100%
Utilisation	80% / 20 %	50% / 50%	50% / 50%	
Definition	• Run by university (e.g. GENCI in France)	• Run by independent research institution	• Run by private operator formed by PPP	• Owned and run by private operator (e.g. CPU 24/7)
Business model	• Focus on research • Limited commercial activities (max 20%, but mostly below)	• Academic and commercial use • As research org. eligible for grants and Horizon 2020	• Utilisation split between academic and commercial use • Model deliberately facilitates public/private cooperation	• Predominantly commercial use - "off-take agreement" as security • Partly public use (universities) to ensure part of revenues

Financing model	• National public budget / university funding • Horizon 2020 grants for research • Repayable grants/ loans from EU conceivable as bridge loan	• Partly public regional and/ or national governments for research • Partly contract research with industrial partners • Repayable grants/ loans from EU conceivable as bridge loan	• Partly public and partly private funding (larger part) • Private funding part should rely on commercial revenues • Public guarantees enhancing equity	• Mostly private with some public financing for public use • Applicable EIB/NPB instruments • For the ramp-up phase guarantees to achieve bankability

Commercial involvement

Public Private

Figure 30: Overview of HPC centre business model

Public/University Model

Currently, most HPC centres in Europe are predominantly research oriented and publicly owned. Under this model, the HPC centre is also mostly operated by a university or research organisation and it is located on campus. Its business model is based on providing and operating academic HPC infrastructure while promoting leadership in innovation and scientific progress.

These HPC centres provide the overwhelming part of their capacities of CPU cycles to universities and research (up to 95%). Hence, from a revenue perspective, this business model results in most of their capacity being utilised, while generating none or very little revenue other than the public budget financing and grants received since, due their financing structure, most of the users from research and academia do not pay for their CPU cycles. As mentioned above, the share of commercial use is often consciously limited by the HPC centre to under 20% in order to remain eligible for public funding, in line with the framework for State aid for research and development and innovation, e.g. Horizon 2020 and other EU innovation-promoting programmes as well as national and regional eligibility criteria[34].

Repayable loans from the EIB and NPBs could potentially play a larger role. Loans from the EIB/NPBs can potentially fill public funding gaps until the final funding commitments by national governments are disbursed (bridge loans). These loans can play an important role as they enable swift and reliable financing in the event that financing from national public budgets cannot be disbursed as required. Such financing models have been successfully implemented in various Research and Technology

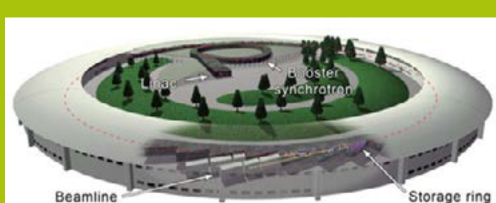
Organisations (RTOs) in Europe, e.g. the European Synchrotron Radiation Facility Project in France as specified in the textbox below.

European Synchrotron Radiation Facility (ESRF):

The European Synchrotron Research Facility (ESRF) was founded on 16 December 1988 pursuant to an international convention between 13 sovereign states. ESRF has been entrusted to a not-for-profit French société civile regulated by the French civil code, whose shareholders are public entities (or similar entities) from the sovereign states which concluded the ESRF convention. ESRF is part of the high-technology pole of the European Photon and Neutron (EPN) Science Campus in Grenoble, which also hosts the neutron source Institute Laue Langevin and the European Molecular Biology Laboratory (EMBL), both being European Research Infrastructure facilities. This campus itself is part of the GIANT (Grenoble Innovation for Advanced New Technologies) campus, which offers 6000 research jobs (generating 5,000 publications and 500 patent applications per year), 5000 student places and 5,000 industrial jobs in 40 companies in nano-sciences, cryogenics, material sciences and life sciences. The ESRF is accredited for its Scientific Excellence, producing more than 1,800 scientific articles per year, of which nearly 300 are qualified as 'high impact articles'.

Terms of the Loan

- Financed as an 'InnovFin Large Project' under Horizon 2020 Financial Instruments.
- EIB loan for EUR 65 million, signed in 2015, for upgrading purposes.
- EIB funding sourced prior to construction start.
- Specific terms and conditions linked to project implementation: amortising loan of up to 20 years with grace period of up to 6 years; or bullet loan of up to 13 years.
- Project implementation period: 2015 to 2022.
- Security/guarantee: Inside EU own risk.



Independent Institutions (RTO) Model

The Research Technology Organisation (RTO) Model is a mixed model based on the concept of shared use of HPC infrastructure between academic and commercial purposes. It aims to enhance the commercial elements of HPC centres and increase the involvement of private financing. RTOs typically finance their business through base funding from regional and/or national governments, as well as through publicly funded research and contract research with industrial partners. The core of this suggested model is the joint HPC infrastructure used by both academia and the private sector and owned by an independent RTO . This model fosters stronger cooperation between science and industry than the Public/University model. Looking at sources of revenue, the RTO model foresees equal 50% public and private shares, with half of the use allocated to academic research purposes and the other half providing revenue-generating services to industry, the latter including revenues from both sales of CPU cycles and integrated services. The advantage of the RTO is that it is, in principle, eligible for public grants and funding and is also able to make use of financial instruments, since its business model is based on the generation of long-term revenues.

In our example, we assume a financing need of EUR 250 300 million for a new centre. This includes the additional financing requirements resulting from the new infrastructure to be built:

Example of an RTO model

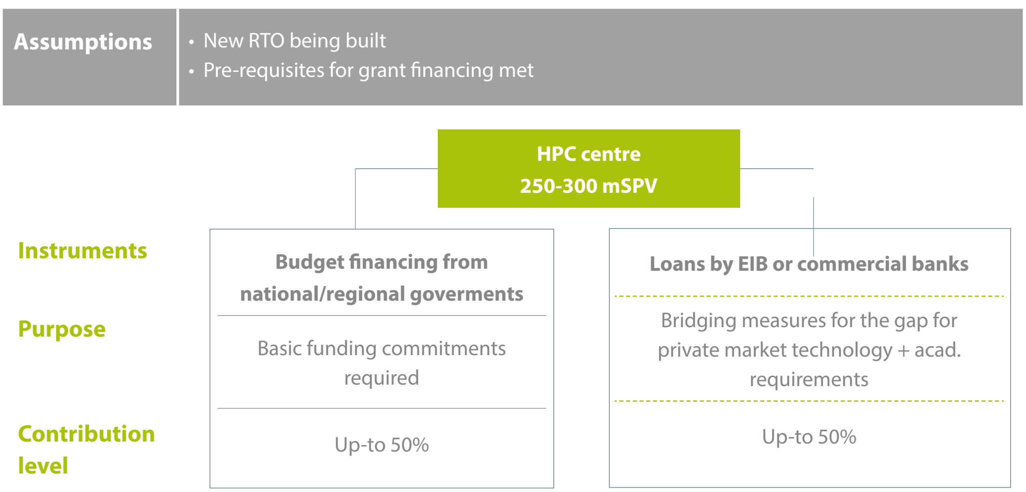


Figure 31: Example of an RTO model

The PPP Model

It is recommended to further pursue mixed PPP models to better integrate scientific work while increasingly opening up HPC centres to commercial clients.

The objective of the **Private-Public Partnership (PPP) Model** is to integrate the use of HPC for research and science, while increasingly opening up HPC centres for commercial use. The PPP HPC centre model aims to combining the strengths of the university (purely public) and the private (purely commercial) model. In the PPP model, a part of the business builds on the capacity used by reliable scientific university activities (i.e. with a steady revenue stream through public budgets), while the other part engages commercial clients to a large extent. The capacity use can be evenly split, 50/50 or in various other combinations. However, the commercial part can be significantly higher than in a purely science-oriented model, which is limited to roughly 20% in the University Model. In this model, the HPC Centre can be located on a University Campus while being owned, run and operated by a private sector stakeholder or government-owned enterprise, potentially a telecommunications (telco) provider. The ownership by an enterprise is a distinguishing feature of the PPP model. The centre therefore benefits from commercial and industry expertise, as well as a broader network of prospective clients, and may potentially leverage the balance sheet of the private sector partner.

For our example, we assume that a private operator establishes and runs an HPC centre on a university campus. We assume a financing need of approximately EUR 100 150 million to acquire new HPC machines. We assume the building is rented from the university. Given the 100% ownership of the centre by the private partner, the financing would be provided to the HPC owning entity (i.e. private entity). Hence, the model is similar to the purely commercial financing model depicted below. In this PPP model, the benefits of ownership by the private partner could enhance bankability in the early stage of the project by relying on the balance sheet of the well-established private partner (e.g. telco provider).

Example for a PPP Model

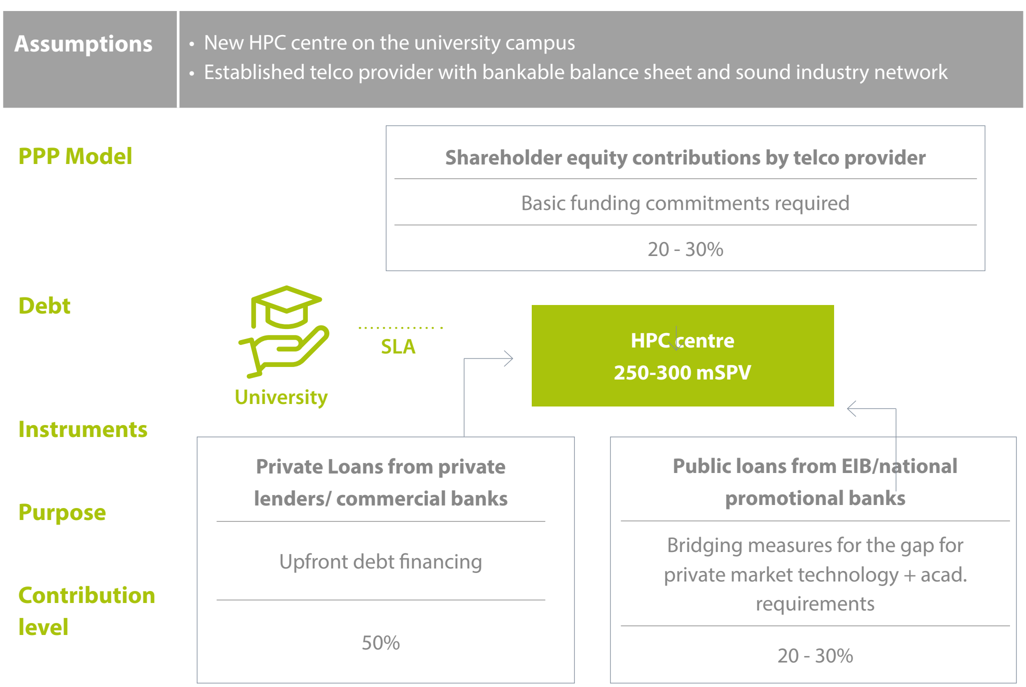


Figure 32: Example for the PPP model

The Private Sector Model

The **Private Sector Model**, which currently represents a niche market in Europe, is implemented by a small number of purely commercial HPC centres. Commercial HPC centres mostly operate at a smaller capacity and are, therefore, less costly to finance and operate. However, purely commercially oriented HPC centres try to focus their activities on providing HPC infrastructure and services to large corporations (in order to secure long-term revenues through large ticket items) and thus do not play an important role in supporting the use of commercial HPC applications among SMEs.

For our financing model example, we assume a financing need of approximately EUR 50 million for the purchase of a new machine. For simplicity's sake, we assume that buildings already exist (or that the centre can use the existing buildings of the commercial owner). Financing is based on collateral from the infrastructure and the track record of the operator. It can be corporate finance or project finance-based. The latter model is more convenient if numerous owners establish a Special Purpose Vehicle (SPV) jointly.

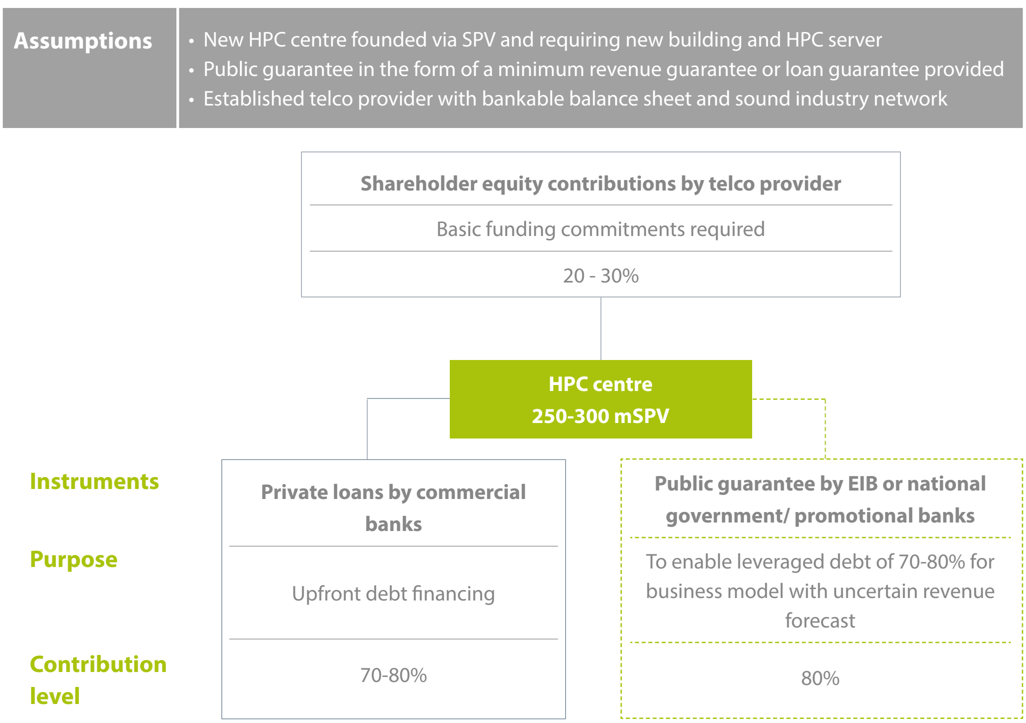


Figure 33: Example of a commercial model

DEDICATED FINANCIAL INSTRUMENTS AND FINANCIAL ADVISORY SERVICES:

Recommendation 4: Adapt existing financial instruments and explore the development of more dedicated financial instruments and blended instruments for the financing of HPC centres and to support the digitalisation of companies including HPC development and deployment.

As more established commercially oriented business models emerge, the study recommends adapting existing financial instruments and exploring the use of more dedicated financial instruments to support the financing of HPC infrastructure and digitalisation of companies including supporting the adoption of digital technologies by companies including the use of HPC as a service. Examples of potential actions that could be considered in this area are the following:

4.1 Adapt existing financial instruments and strengthen their use and uptake.
It is recommended to adapt existing financial instruments to strengthen financial support for HPC programmes from both the private and public sector. There exists a diverse and rich offering of financial instruments, such as InnovFin and EFSI. Both InnovFin Science and EFSI could be used to fund the capital needs of HPC centres, once more commercially oriented business models emerge. The study recommends reviewing the existing eligibility criteria of these instruments with the objective of increasing investments in the sector.

4.2 Explore the set-up of dedicated financial instruments for the take up of digital services including HPC as a service. There are two main areas:
(i) The digitalisation of traditional companies often involves a change in business model, moving from buying equipment and hardware (capex) to buying access to digital applications and equipment (opex) such as using HPC services provided by an HPC centre via computer cloud. Such a change in business model is seen as high risk by private investors (in particular banks) due to the uncertainty of the benefits (in terms of speed to market, for new products, reduction in R&D) and migration toward an asset-light approach (lack of collateral). In this context, the study recommends exploring the need for the setting-up of dedicated financial instruments to support the digitalisation of companies, including the development and deployment of HPC. This could include risk sharing instruments with a first loss piece (from EFSI or InnovFin) covering risks on loans provided by banks and financial intermediaries for digitalisation projects.

(ii) There is growing and potential demand for digital services including HPC services arising from innovative start-ups developing applications with high computing capacity requirements (such as

Artificial Intelligence). To support this emerging demand, the study recommends exploring the need for setting up dedicated financial instruments (mainly equity) to invest in these companies. By including a higher-risk tranche from the public sector, this instrument could attract private investors into considering more risky ventures such as start-ups in IoT or AI.

4. 3 Consider the use of blended instruments (i.e. combining private and public funding) for financing HPC centres.

Most public HPC centres are currently financed by public grants. However, blended grants combining public and private funding in a single instrument could provide some financial relief for strained public budgets and, thus, enable the establishment and/or upgrading of HPC centres. Hence, the study recommends considering the use of blended financial instruments to address the financing needs related to the establishment of HPC centres. In particular, the study recommends exploring the feasibility of a blended instrument such as a dedicated HPC infrastructure fund. Such a fund could include a higher-risk taking tranche from public sources (as in the case of the broadband fund, which includes a first loss piece from the CEF).

Recommendation 5: Improve knowledge of, and access to, public financing instruments and financial advisory services for HPC stakeholders.

The study identified that there is a lack of knowledge and awareness of existing financial instruments among HPC stakeholders, and a perception that the application process for these instruments is lengthy and cumbersome. A key objective is to increase the use and uptake of existing financial instruments by HPC stakeholders.

The study found that financial advisory services can play an important role supporting HPC project promoters to develop new approaches that are based on strong public value and an enhanced return orientation for public investments.

Therefore, the study recommends strengthening financial advisory services in order to: (i) support the development of HPC programmes that are based on more commercially oriented business models; (ii) promote knowledge on the developing suite of financing mechanisms for HPC stakeholders; and (iii) enhance the bankability of HPC projects that are already more commercially oriented.

Annex

List of figures

List of abbreviations

Acronym	Definition
ACM	Association for Computing Machinery
APER	Agency for the Promotion of European Research
ASCS	Automotive Simulation Centre Stuttgart
AWS	Amazon Web Services
BSC	Barcelona Supercomputing Centre
CAE	Computer-Aided Engineering
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CC	Cloud Computing
CEO	Chief Executive Officer
CFD	Computational Fluid Dynamics
CFO	Chief Financial Officer
CoE	Centre of Excellence
cPPP	Contractual Public Private Partnership
CPU	Central Processing Unit
CSCS	Centro Svizzero di Calcolo Scientifico (Swiss National Supercomputing Centre)
DG	Directorate General
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortisation
EC	European Commission
ECP	Exascale Computing Project
EDA	Electronic Design Automation
EFSI	European Fund for Strategic Investments
EIF	European Investment Fund
EMEA	Europe, the Middle East and Africa
Ensoc	Energy Solution Centre e.V.
EOSC	European Open Science Cloud

Acronym	Definition
EPCC	Edinburgh Parallel Computing Centre
ERP	European Recovery Programme
ETP4HPC	European Technology Platform for High Performance Computing
ExaNeSt	European Exascale System Interconnect and Storage
Fraunhofer SCAI	Fraunhofer Institute for Algorithms and Scientific Computing
FTE	Full Time Equivalent
GBP	British pound
GSC	Gauss Centre for Supercomputing
HLEG EOSC	High Level Expert Group on the European Open Science Cloud
HPC	High Performance Computing
HPCS/HLRS	High Performance Computing Centre Stuttgart (Höchstleistungsrechenzentrum Stuttgart) ICT Innovation for Manufacturing SMEs
I4MS	ICT Innovation for Manufacturing SMEs
IaaS	Infrastructure-as-a-Service
IEEE	Institute of Electrical and Electronics Engineers
InnovFin	EU Finance for Innovators programme
IP	Intellectual Property
IPCEI	Important Project of Common European Interest
IRENA	The International Renewable Energy Agency
ISV	Independent Software Vendor
KfW	Kreditanstalt für Wiederaufbau
KfW IPEX	KfW international project and export finance
KIC	Knowledge and Innovation Community
KPI	Key Performance Indicator
LRZ	Leibniz Supercomputing Centre (Leibniz Rechenzentrum)
NATO	North Atlantic Treaty Organisation
NSCI	National Strategic Computing Initiative

Acronym	Definition
OEM	Original Equipment Manufacturer
OPEX	Operating Expenditures
P&L	Profit and Loss Statement
PaaS	Platform-as-a-Service
PCP	Pre-Commercial Procurement
PE	Private Equity
PPP	Public-Private Partnership
PRACE	Partnership for Advanced Computing in Europe
R&D	Research and Development
RE	Renewable Energy
RTO	Research Technology Organisation
SaaS	Software-as-a-Service
SME	Small and Medium-Sized Enterprise
STFC	Science and Technology Facilities Council
TCO	Total Cost of Ownership
TTO	Technology Transfer Office
TWT	Technical/scientific transfer (Technisch-Wissenschaftlicher Transfer)
US	United States of America
VC	Venture Capital

References

1. European Commission, "ICT Innovation in Horizon 2020", available at: *https://ec.europa.eu/digital-single-market/en/ict-innovation-horizon-2020* (last accessed 31 May 2017).
2. Fortissimo is a collaborative project that enables European SMEs to be more competitive globally through the use of simulation services running on a High Performance Computing cloud infrastructure. The project is coordinated by the University of Edinburgh and involves 123 partners including Manufacturing Companies, Application Developers, Domain Experts, IT Solution Providers and HPC Cloud Service Providers from 14 countries. These partners are engaged in 53 experiments (case studies) where business relevant simulations of industrial processes are implemented and evaluated. The project is funded by the European Commission within the 7th Framework Programme and is part of the I4MS Initiative. See more details at https://www.fortissimo-project.eu/
3. European Commission, "High Performance Computing in the EU: Progress on the Implementation of the European HPC Strategy", IDC Study, 2015.
4. European Commission, "High Performance Computing in the EU: Progress on the Implementation of the European HPC Strategy", IDC Study, 2015.
5. Saywer and Parsons 2011 *https://ec.europa.eu/digital-single-market/en/news/eu-ministers-commit-digitising-europe-high-performance-computing-power.*
6. Eurostat, "Manufacturing statistics - NACE Rev. 2", available at: *http://ec.europa.eu/eurostat/statistics-explained/index.php/Manufacturing_statistics_-_NACE_Rev._2* (last accessed 31 May 2017).
7. European Commission, "High Performance Computing in the EU: Progress on the Implementation of the European HPC Strategy", IDC Study, 2015.
8. Osseyran & Giles, "Industrial Applications of High-Performance Computing: Best Global Practices", Chapman & Hall/CRC Computational Science (25), Chapman and Hall/CRC, 2015.

09. The Pharmaceutical Industry and Global Health, available at: https://www.ifpma.org/wp-content/uploads/2017/02/IFPMA-Facts-And-Figures-2017.pdf (last accessed 6 June 2017).

10. The Pharmaceutical Industry and Global Health, available at: https://www.ifpma.org/wp-content/uploads/2017/02/IFPMA-Facts-And-Figures-2017.pdf (last accessed 6 June 2017).
11. European Commission, "High Performance Computing in the EU: Progress on the Implementation of the European HPC Strategy", IDC Study, 2015.
12. Eurostat, "Renewable energy statistics", available at: *http://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics* (last accessed 9 February 2017).

13. "Renewable Energy Benefits: Measuring the Success", available at *http://www.irena.org/DocumentDownloads/Publications/IRENA_Measuring-the-Economics_2016.pdf* (last accessed 9 February 2017).

14. European Commission, "High Performance Computing in the EU: Progress on the Implementation of the European HPC Strategy", IDC Study, 2015.

15. European Commission, "High Performance Computing in the EU: Progress on the Implementation of the European HPC Strategy", IDC Study, 2015.

16. Research Fraunhofer SCAI.

17. A total of 159 organisations were approached for expert interviews. A total of 45 interviews were conducted, resulting in a good overall response rate of nearly 30%.

18. Business Dictionary, "Corporate Venturing", available at *http://www.businessdictionary.com/definition/corporate-venturing.html* (last accessed 6 June 2017).

19. European Commission, "Working together for jobs and growth: The role of National Promotional Banks (NPBs) in supporting the Investment Plan for Europe", available at: *http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52015DC0361* (last accessed 6 June 2017)

20. KfW, "Minimum expected return of private equity companies: Claims become more modest", available at: *https://www.kfw.de/PDF/Download-Center/Konzernthemen/Research/Research-englisch/PDF-Dateien-Paper-and-Proceedings/Mindestrenditeerwartung-KF_EN.pdf*(last accessed 7 February 2017)

21. Deutsche Bank Research, "Investitionen und Wachstum stärken: Die Rolle der Förderbanken in Europa", available at: *https://www.dbresearch.de/PROD/DBR_INTERNET_DE-PROD/PROD0000000000402333/Investitionen_und_Wachstum_st%C3%A4rken%3A_Die_Rolle_der_.pdf* (last accessed 7 February 2017).

22. IDC, "Council of Competitiveness Study of ISVs Serving the High Performance Computing Market: Part A – Current Market Dynamics", available at: *http://www.compete.org/storage/images/uploads/File/PDF%20Files/ISV_Study_Part_A_2005.pdf* (last accessed 6 June 2017).

23. European Commission, "Implementation of the Action Plan for the European High-Performance Computing strategy", available at: *https://www.kowi.de/Portaldata/2/Resources/fp/2016-SWD-EU-HPC-Strategy.pdf* (last accessed 6 June 2017).

24. Top 500 – The List, "November 2016", available at: *https://www.top500.org/lists/2016/11/* (last accessed 6 June 2017).

25. */www.kowi.de/Portaldata/2/Resources/fp/2016-SWD-EU-HPC-Strategy.pdf* (last accessed 6 June 2017).

26. Theis and Wong (2017): "The End of Moore's Law: A New Beginning for Information Technology". Computing in Science and Engineering, Volume: 19, Issue: 2.

27. HPC Userforum, "Update on HLRS", available at: *https://hpcuserforum.com/presentations/stuttgart2017/HLRS_Update.pdf* (last accessed 6 June 2017).

28. HPC Userforum, "Update on HLRS", available at: *https://hpcuserforum.com/presentations/stuttgart2017/HLRS_Update.pdf* (last accessed 6 June 2017).

29. Daimler, "Das Geschäftsjahr 1987", available at: *https://www.daimler.com/dokumente/investoren/berichte/geschaeftsberichte/daimler-benz/daimler-ir-geschaeftsbericht-1987.pdf* (last accessed 6 June 2017).

30. "HPC Helping SME Manufacturers Expand Simulation Capabilities", available at: *https://www.hpcwire.com/solution_content/hpe/manufacturing-engineering/hpc-helping-sme-manufacturers-expand-simulation-capabilities/* (last accessed 6 June 2017).

31. HPC Userforum, "HPC and Industry in Europe", available at: *https://hpcuserforum.com/presentations/stuttgart2017/ParsonsIDCForum280217.pdf* (last accessed 6 June 2017).

32. HPC Userforum, "HPC and Industry in Europe", available at: *https://hpcuserforum.com/presentations/stuttgart2017/ParsonsIDCForum280217.pdf* (last accessed 6 June 2017).

33. European Commission " Realising the European Open Science Cloud", available at *https://ec.europa.eu/research/openscience/pdf/realising_the_european_open_science_cloud_2016.pdf#view=fit&pagemode=none* (last accessed 6 June 2017)

34. European Commission, "Framework for State aid for research and development and innovation", available at: *http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014XC0627(01)&from=EN* (last accessed 6 June 2017).

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