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Assessment on the ecosystem report

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Author(s): Jean-Philippe Nominé, CEA
Maike Gilliot, TERATEC
Guy Lonsdale, Scapos
Valeria Bartsch, Fraunhofer/ITWM
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Authorship	**Written by:**	Jean-Philippe Nominé, CEA Maike Gilliot, TERATEC Guy Lonsdale, Scapos Valeria Bartsch, Fraunhofer/ITWM
	Contributors:	Kai Krueger, Fraunhofer/ITWM Corentin Lefèvre, NEOVIA Jean-François Lavignon, TS-JFL
	Reviewed by:	Michael Malms, ETP4HPC John Clifford, PRACE aisbl, EXDCI-2 PMO
	Approved by:	MB/TB

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List of Acronyms and Abbreviations

CfP	Call for Proposals
CoE	Centres of Excellence for Computing Applications
cPPP	Contractual Public-Private Partnership
CSA	Coordination and Support Action
D	Deliverable
DX.Y	Deliverable Number X.Y (Number Y of Work Package X)
EC	European Commission
EU	European Union
FET	Future and Emerging Technologies
FP7	Framework Programme 7
FPGA	Field Programmable Gate Array
H2020	Horizon 2020 – The EC Research and Innovation Programme in Europe
HPC	High Performance Computing
HSE	Higher and Secondary Education (organisation)
IP	Intellectual Property
ISV	Independent Software Vendor
IT	Information Technology
KPI	Key-Performance Indicator
M	Month
MOOC	Massive Open Online Courses
P4P	Private for Profit – a private company, large or small (incl. SME type)
PMR	Progress Monitoring Report
Q	Quarter
R&D	Research and Development
R&I	Research and Innovation
RO	Research Organisation
SME	Small and Medium Enterprise
SRA	Strategic Research Agenda
TRL	Technology Readiness Level
WP	Work Package

Executive Summary

This report comprises the EXDCI-2 Project Month 24 deliverable D4.4 "Assessment on the ecosystem report", in the context of Task 4 of Work Package 4, which addresses the analysis and assessment of the EU HPC ecosystem.

This activity is the direct follow-up of Work Package 7 of the previous EXDCI project, which addressed impact monitoring of the H2020 HPC activities, strongly linked to the HPC contractual Public Private Partnership strategy since its commencement in 2014. The HPC programme considered in the partnership monitoring actually encompasses R&I activities arising directly from the cPPP and also infrastructure aspects, dealt with by PRACE in particular. It corresponds essentially to the scope of what EuroHPC will now coordinate: previously handled by separate, although cooperating, entities within the H2020 programme.

The prior EXDCI WP7 deliverables reported on the motivation for the initial methodology and tool-set, on its realization, the various improvements over time, and findings up to the end of 2017, just after publication of the report on the mid-term review of all contractual Public Private Partnerships in October 2017. That mid-term review led to the redefinition of four Key Performance Indicators common to all partnerships (with a strong socio-economic flavour). The ETP4HPC methodology was adjusted to fit to these new definitions, and continuously improved, in particular to maintain the HPC-specific indicators defined in 2014. This was applied to the 2017 and 2018 Progress Monitoring Reports.

Shortly after the setup of EuroHPC in October 2018, the HPC partnership was terminated, with the intention that it should be replaced by the EuroHPC R&I Pillar. The HPC contractual Public Private Partnership was terminated at the end of 2018, after five years of operation.

This report provides the opportunity to:

- summarise the latest version of the monitoring and impact assessment methodology, after its development and application by ETP4HPC with the support of EXDCI and EXDCI-2;
- summarise the findings of the latest and final Progress Monitoring Report of the HPC Partnership, which also constitutes a testimony on the whole lifespan of the partnership and an intermediate impact assessment of the programme as defined above;
- give some hints on the current impact of the programme on the whole EU HPC ecosystem and the related value chain.

1 Introduction

The purpose of Work Package 4 Task 4 in EXDCI2 "Analysis and assessment of the EU ecosystem" is to continue the impact assessment effort set up in EXDCI [1]:

- Leveraging and improving the methodology already developed for data collection and analysis and Key Performance Indicator (KPI) tracking;
- Maintaining a regular impact assessment activity (synchronised with HPC cPPP annual progress reports)

The outcomes of this task deal with industrial competitiveness and socio-economic impact, operational aspects of the H2020 HPC programme, and its management aspects, and include an ecosystem map identifying all EU HPC stakeholders and their capabilities. The HPC programme considered in the partnership monitoring actually encompasses R&I activities arising directly from the cPPP and also infrastructure aspects, dealt with by PRACE in particular. It corresponds to the scope of what EuroHPC will now coordinate, previously handled by separate, although cooperating, entities within the H2020 programme. The cPPP activities are essentially continued in the R&I Pillar of EuroHPC (technologies targeted by the ETP4HPC SRA; applications represented in particular by the H2020 Centres of Excellence); PRACE activities will mostly be continued via the Infrastructure Pillar of EuroHPC.

As the representative of the private side of the cPPP, signed in 2014, ETP4HPC [2] was in charge of this monitoring activity – a formal obligation of the cPPP signed agreement [3] [4].

EXDCI WP7 deliverables [5][6][7][8] previously reported on the motivation for the initial methodology and tool-set, on its realization, the various improvements over time, and findings up to the end of 2017, just after publication of the report on the mid-term review of all contractual Public Private Partnerships in October 2017 [9]. That mid-term review led to the redefinition of four Key Performance Indicators common to all partnerships (with a strong socio-economic flavour). The ETP4HPC methodology was adjusted to fit to these new definitions, and continuously improved, in particular to maintain the HPC-specific KPIs defined in 2014. The new KPIs and the related adjusted methodology were used for the 2017 and 2018 Progress Monitoring Reports (PMR) [10][11].

Shortly after the setup of EuroHPC in October 2018 [12], the HPC partnership was terminated, with the intention that it should be replaced by the EuroHPC R&I Pillar. The HPC contractual Public Private Partnership was terminated at the end of 2018, after five years of operation.

The D4.4 deliverable is structured as follows:

- Chapter 2 provides a brief reminder of the genesis and history of the HPC cPPP and the transition to EuroHPC;
- Chapter 3 summarises the latest version of the monitoring and impact assessment methodology, after its development and application by ETP4HPC with the support of EXDCI and EXDCI-2, and in particular how it takes into account the new common KPIs defined for all cPPPs;
- Chapter 4 summarises the findings of the latest and final Progress Monitoring Report of the HPC Partnership (PMR 2018, published in 2019); this also constitutes a testimony on the whole lifespan of the partnership and an intermediate impact assessment of this programme;
- Chapter 5 provides indications on the current impact of the programme on the whole EU HPC ecosystem and the related value chain.

2 Brief reminder of HPC cPPP history

High-Performance Computing (HPC) is a branch of computing dealing with technologies and methodologies for large-scale compute- and data-intensive applications, including numerical simulation and/or data analytics and/or machine learning and AI, all of these being increasingly intertwined inside complex workflows. HPC mobilises densely integrated computing and storage hardware configurations, in conjunction with parallel programming.

It is now a common understanding that HPC is a key enabler and essential tool for scientific applications serving the competitiveness of research and industry, and a way to tackle many societal challenges, for the well-being of European citizens in an increasingly digitized world.

The European Commission acknowledged the strategic importance of mastering all facets of HPC already in 2012, and quickly made it a priority in the Horizon 2020 Framework Programme, which started in 2014.

The contractual Public Private Partnership (cPPP) on high-performance computing was signed at the end of 2013 between the European Commission and ETP4HPC. The Centres of Excellence subsequently participated in cPPP meetings and planning activities. The cPPP scope spanned the areas of HPC technologies and applications, while PRACE [13], created in 2010, already covered the HPC infrastructure aspects. Supported by the Commission's interactions with these two entities, the "three pillars" of the HPC value chain were acknowledged and supported by EC funding via a structured programme: technologies, infrastructures, applications.

The HPC cPPP initially planned to invest EUR 700 million from the Horizon 2020 research and innovation programme with the objective to develop a competitive European ecosystem, and exascale HPC and data infrastructures, that would serve a large spectrum of users from scientists to industry (including SMEs) and the public sector. A number of calls for HPC projects were issued within the scope of the cPPP between 2014 and 2108, and implemented under Horizon 2020 (more details are provided in Chapter 3). During this period, the cPPP was governed as initially planned, with two Partnership Board (PB) meetings held each year (a total of 10). The PB meetings participants were composed of EC and ETP4HPC representatives, and included Centres of Excellence (CoE) representatives from 2015 onwards. These latter entities were projects with a limited lifespan, and not legal entities, and were thus not in a position to formally sign the cPPP agreement; however, all nine CoEs actively took part in the PB meetings.

The ambition to strengthen the European HPC supply chain and to close the gap from research and development to the delivery and operation of exascale HPC systems, co-designed between users and suppliers, will now be continued through EuroHPC. EuroHPC will bring further resources beyond Horizon 2020, in Horizon Europe [14] and more specifically Digital Europe [15].

EuroHPC was formally established in October 2018 [16]. Its initial regulation defines a first phase of two years until the end of Horizon 2020 (then Horizon Europe and Digital Europe will take over in the context of the next Multi-annual Financial Framework). For these two initial years, the European Commission proposed to invest EUR 1 billion, jointly with the Member States, pooling resources to build a world-class European supercomputers infrastructure. EuroHPC is organized into two pillars, covering Infrastructure aspects (equipment and services) and R&I aspects (technologies, applications, development of skills) respectively.

At the time of writing this report, 31 Participating States have joined EuroHPC. Its Governing Board has been meeting regularly since November 2018 and an Interim Executive Director is in charge of its operations. In particular the calls for Expression of Interest for the selection of Hosting Entities were issued in January and February 2019 – resp. for Precursors to Exascale Supercomputers as well as for Petascale Supercomputers - then first R&I calls were issued in July 2019 [17]. The related Work Programme 2019 [18] was elaborated with input from the EuroHPC Advisory Groups (INFRAG for Infrastructures, and RIAG for R&I).

Hosting Entities selection took place in 2019 (leading to 3 consortia for Precursors to Exasclale commissioning, and 5 for Petascale), actual procurements are now being performed. R&I calls were closed in two phases (November 2019 for the widening of HPC used and skills, then January 2020 for extreme scale technologies and applications). These R&I Work Programme calls are taking over from the HPC cPPP H2020 calls (H2020 Work Programme 2019-2020 HPC calls were cancelled in mid-2018, and partly replaced by the aforementioned R&I EuroHPC calls; a subsequent Work Programme 2020 for EuroHPC R&I is planned to be published in the coming months and will complete this first phase).

The cPPP was thus formally terminated at the end of 2018, after five years of activity. As we will see in more detail in the next chapter, approximately EUR 400 million out of the provisioned EUR 700 million of the cPPP funding had been granted to R&D projects by this time. The remaining budget was intended to be used to support R&I in EuroHPC's initial two-year phase, whose contents and goals are consistent with the previous HPC work programmes implemented under the umbrella of the HPC cPPP inside H2020.

This report includes an intermediate impact assessment of the cPPP: some projects of the H2020 programme phase are still running, and their impact will have to be measured after termination; whereas the first projects launched inside the cPPP scope have terminated only recently, and some of their effects will not be measurable immediately, and will require more time.

3 Summary of monitoring and impact assessment methodology

This chapter provides a reminder of the definition of the KPIs used for the cPPP impact assessment, and summarises the latest version of the methodology progressively refined since 2014 and used for the last Progress Monitoring Report. The state of progress of the projects related to the HPC cPPP calls will give the scope of the studies and surveys performed for this PMR purpose (i.e. whether projects are included in our surveys or not, depending on their start date and thus potential impact at the date of the surveys).

3.1 Key Performance Indicators

The 2017 all-cPPP mid-term review led to the precise definition of four Key Performance Indicators common to all partnerships (with a strong socio-economic flavour). They are described in **Table 1**.

KPI / objective	Comments
Mobilised private investments *To understand and capture/show the level of industrial engagement within a given cPPP, including actual expenditure related to individual projects*	The leverage of private investments, including expenditure linked to funded projects, is one of the core reasons for the public side to agree upon a public-private partnership. Therefore, a representative approximation of the level of industrial engagement within a given cPPP is sought. An ideal estimate would encompass direct and indirect leverage effects in the following sense: • Direct leverage 1: financial and/or in-kind contributions by partners (as declared in project description and reporting) • Direct leverage 2: other investments mobilised with the initial investment from the partnership's partners in the project • Indirect leverage: public and private investment mobilised to exploit or scale-up the projects' results (beyond their lifetimes)
New skills and/or job profiles *To understand how job profiles and skills are being created and developed within the activities of the cPPP. Giving explanations on impact on job creation beyond individual projects would be a particular asset*	Jobs, profiles, and/or related skills that stem from cPPPs
Impact of a cPPP on SMEs; in Euros/Qualitative analysis *To understand the impact of the activities on SMEs*	Out of the two proposed options, the one chosen for HPC cPPP was to sample the SME community represented within the cPPP in question - instead of addressing directly the quantitative turnover question – however, some estimates of turnover evolution have been tentatively scrutinised.
Significant innovations *To understand the technological outputs of the cPPP*	This KPI concerns all developed foreground, tangible and intangible assets, that have a marketable or at least an exploitable value, including products, processes, instruments, methods, and technologies. It should involve all items directly linked to the cPPP projects as developed foreground, as well as any new foreground beyond the scope of the project that is linked to the project results (most likely through IP). Information on innovations ready to be taken to the market would be an asset given that the EU seeks opportunities to stimulate more interest by investors.

Table 1: Common Key Performance Indicators

Moreover, specific HPC KPIs were defined in 2014 (cPPP Partnership Board of November 2014), at the beginning of the cPPP, and used since then: see **Table 2** below.

Specific HPC KPI	Definition – contents / metrics
A. Indicators for Industrial Competitiveness and Socio-Economy Impact	
KPI 1 **Global market share of European HPC**	HPC systems, components and tools based on technologies developed and built in Europe, volume (in generated income) of HPC technology exported from Europe (European HPC technology developers) to the rest of the world.
KPI 2 **HPC additional investments**	The level of high-tech investment generated by the PPP, and the additional investments leveraged in the HPC value chain; relation to the investments made into European HPC companies by private investors and venture capital funds.
KPI 3 **Jobs**	Direct, sustainable jobs out of HPC research programmes recommended by the PPP, and indirect jobs in technology companies further downstream and in end-user organisations of HPC technologies and applications
KPI 4 **Innovation Environment in HPC**	• European HPC start-ups (not just those arising from H2020 projects) • Number of new SME start-up companies created out of HPC research programmes in the PPP (only successful SMEs with a sustainable business) • Unsuccessful HPC start-ups • Growth of existing European HPC start-ups
B. Indicators for the operational aspects of the programme	
KPI 5 **Research programme effectiveness and coverage**	Quality of the research programmes launched • Coverage of the R&I roadmap by calls topics • Number of co-ordinated calls launched • Number of responses to calls • Number of active research projects • Geographical coverage of project participation • Additional leverage and Impact in other related programmes (e.g. areas such as nano-electronics, photonics, microelectronics, software, storage in other parts of Horizon2020
KPI 6 **Performance of HPC technologies developed**	Technological contribution of the initiative to the next generation of HPC in terms of the affordability and usability of the technologies developed in the PPP: • Cost per petaflop/s • Cost of ownership (power, space, operation-manpower) • Percentage of HPC systems with at least 30% of European engineered componentry inside (in Europe and worldwide) • Number of European systems in Top500 and Green 500 • Range of architectures available in Europe • Number of new prototypes made available per year via the PPP

Specific HPC KPI	Definition – contents / metrics
KPI 7 **People, education, training and skills development**	Showing the on the European HPC knowledge base providing High-skilled HPC profiles and curricula developed in the PPP: • Statistics on number of days of training delivered, range of nationalities and countries of work of course attendees, gender balance of training participants • Origin of training participants: SME, large company, academia (graduate, post-graduate, engineers, developers) • New curricula and trainings created • Quality and pertinence of the trainings through feedback on evaluation forms • Number of infrastructure operators jobs in relation to the Programme • Increase of the graduate/postgraduate, PhD and post-doctoral positions related to HPC subjects, including, but not limited to, those directly related to the PPP stakeholders projects
KPI 8 **HPC use**	Use of the HPC technologies developed in academia and industry (in particular SMEs): • Growth in investment in HPC systems; • Growth in the use of external HPC services by SMEs; • Growth in the availability of application software on HPC systems • Publications crediting the use of the HPC resources (number, citation indicators, ranking of journals, etc.) • European research communities using HPC (at Tier-2, Tier-1 and Tier-0 levels) • Organisation and participation in multi-disciplinary or cross-disciplinary activities (e.g. number of workshops organised and number of participants) • Size and number of structured communities in HPC applications engaging with the PPP (disciplinary and multidisciplinary) • Co-design initiatives
KPI 9 **HPC Software ecosystem**	Impact on software ecosystem (number of applications, number of users, etc.) Large scale scientific and industrial applications adapted to the next computing generation addressing key economic areas and societal challenges • Development of next-generation software codes, libraries and algorithms. • Number of application software adapted to work with the next generation of machines • Usage of European developed codes, algorithms and libraries • Number of European codes benefiting from PPP results: open source applications, system software, ISV codes, etc. • Increase in user base of European codes • New tools of world-class interest for the research and industry communities (e.g. measured by increase in market share of tools of European origin)
KPI 10 **Patent, inventions and contributions to standards in HPC by H2020 funded projects**	Patent, direct contributions and activities leading to standardisation, and invention-submissions out of HPC research programmes recommended by the PPP

Specific HPC KPI	Definition – contents / metrics
C. Indicators for management aspects of the programme	
KPI 11 **Efficiency, openness and transparency of the PPP Consultation Process**	Monitoring the number of participants contributing to the strategy and implementation workshops Analysis of ETP4HPC members to provide evidence for representation of the HPC community Monitoring of the decision making process during the consultation
KPI 12 **Dissemination and Awareness**	Make HPC visible to the general public in Europe and to a broad range of stakeholders. Wide dissemination of information and tangible examples about how HPC solutions contribute to the day to day live of European citizens by using various communication channels like social media, print, video, etc. Awareness and information actions held for promoting the PPP activities to a broad range of stakeholders (within and beyond the ones included in ETP4HPC) – this includes events, targeted Newsletters, social media, etc.)

Table 2: Key Performance Indicators (KPIs) for the HPC PPP

Several of these latter specific KPIs strongly overlap or intersect with the common KPIs:

- KPI 2 and KPI 3, with the first two common KPIs Leverage factor/Jobs & Skills
- KPI 7 and KPI 14 for the final two common KPIs SMEs and Innovations

This is no surprise in this 'socio-economic' category. Some of the Operational KPIs also intersect part of the common KPIs.

However, the whole set of indicators considered (common + specific) were too numerous to stay within the possibilities of the team and resources devoted to the monitoring activity – in spite of sharing part of the effort with DGCNECT, who made available a number of statistics on the calls for projects (useful for some KPIs of category B).

Most KPIs above were actually composed of several indicators, not all with a simple definition nor measurement process, sometimes having neither a clear baseline nor target.

NB: the list of specific KPIS was not revised during the lifetime of the cPPP. On the one hand, this is good since it offered a stable framework to put in perspective the evolutions. But on the other hand, too many indicators were not easily measurable nor immediately meaningful, which limited the effectiveness of the whole process.

Many indicators, mostly worth monitoring, could be left to some general and more qualitative observation process, so as to build a wider 'dashboard' of the programme impact and evolutions.

Practically, we focused most of the efforts on the common KPIs (almost equivalent to the specific HPC KPIs of category A), and developed a 'best effort' approach for the other KPIs, whenever possible. Some data were straightforwardly available (such as DGCNECT project implementation statistics), while others would have required very large scale ecosystem surveys. Socio-economic KPIs already raised a number of difficulties (well documented in EXDCI WP7 deliverables), mostly due to the reluctance of private entities to disclose business related data to an association (ETP4HPC), outside any formal, binding, legal and confidentiality framework – H2020 projects are formally linking partners together and to the EC, but not to ETP4HPC; and moreover, not all H2020 HPC projects partners are ETP4HPC members.

3.2 Data sources

Over the years, different data sources have nourished the annual progress reports; some sources provide recurrent input, other more intermittent or demand-driven input. The main sources for the latest KPIs estimates (data on 2018) were:

- data provided by the EC on the different calls (operational / implementation statistics), with also some data on directly leveraged funding (direct financial or in-kind contributions);
- ETP4HPC annual internal survey amongst ETP4HPC's Research members who benefitted from H2020 cPPP-related funding + same survey amongst extra, non-ETP-members research organisations;
- a survey addressed to the first wave of HPC Centres on Excellence funded from 2015 onwards;
- a more focussed survey for the private-for-profit (P4P) sector, outsourced to an external and independent analyst team – targeting organisations involved in cPPP projects and with an emphasis on ETP4HPC members;
- a complementary survey amongst a sample of SMEs receiving cPPP funding (for SME growth and evolution);
- PRACE KPIs (for training and HPC use).

Data provided by the EC on the different calls mostly relate to operational aspects of the programme and general statistics like categories of participants – ETP4HPC members vs. non-members); research organisation, academic organisations, industrial companies, SMEs. In addition, information was also made available concerning participants' additional contributions, declared in the project submissions and corresponding reporting (first level of direct leverage effect beyond the usual 25% indirect costs under H2020 funding rules).

Table 3 below gives on overview of the use of data sources over time for the PMRs covering the years 2014 to 2018 – "YYYY PMR" means PMR on year YYYY, or until the end of YYYY, elaborated and published in YYYY+1; for instance the 2018 PMR deals with 2018 (more generally 2014-2018) and data was collected for this purpose in Q1 of 2019.

Data source for YYYY PMR	2014	2015	2016	2017	2018
ETP4HPC internal survey	x	x	x	x	x
EXDCI survey (FETHPC+CoE projects)		x			
ETP4HPC Annual report	x	x	x	x	x
Analyst study (for profit organisations)			x	x	x
Specific extra SME interviews					x
PRACE KPIs	x	x	x	x	x
EC H2020 stats	x	x	x	x	x
Public sources (internet, other reports and public registers)	x	x	x	x	x

Table 3: Recapitulation of data sources used for the PMRs

3.3 Scope of 2018 Progress Monitoring Report

The “scoping” of the last PMR relies on an analysis of all calls for projects relating to the HPC cPPP – see **Table 4** below.

For operational statistics and implementation statistics, all projects of this table are accounted for. In contrast to that, the core (common, socio-economic) KPIs have mostly been assessed on the basis of projects started before Q4 of 2018. Projects that started in Q4 of 2018 cannot have any significant influence yet. The latter projects comprise:

- the European Processor Initiative (EPI) project (whose effective implementation and R&D activities only started in December 2018 with its first Special Grant Agreement – SGA1)
- Centres of Excellence granted in 2018 (ten 2018 CoEs + FocusCoE CSA) and started at the end of 2018
- ICT HPC and Big Data Applications 2018 call, with projects starting in the last quarter of the year 2018
  NB: for funding statistics, we have assigned 50% of these projects amounts to HPC cPPP, since the call is related to both ETP4HPC and BDVA roadmaps and under the umbrella of both HPC and Big Data cPPPs.
- In addition, the Innovation KPI was only built on the outcomes of FETHPC and CoE projects started in 2015 that are now (almost all) terminated: this allows a relatively complete, synchronous and homogenous assessment.

This means that in 2018 we mainly measured the impact of the projects starting in 2017 or before - amounting to a total of EUR 213 million out of the EUR 400 million granted (via signed Grant Agreements).

Call reference	Call title		Selected projects	Status as of the end of 2018	Taken into account for socio-economic KPIs
FETHPC-1-2014	HPC Core Technologies, Programming Environments and Algorithms for Extreme Parallelism and Extreme Data Applications	RIA	19	Most finished	Yes *
FETHPC-2-2014	HPC Ecosystem Development	CSA	2	Finished	Not in RIA funding
E-INFRA-5-2015	Centres of Excellence for computing applications	RIA	9	Most finished	Yes *
FETHPC-01-2016	Co-design of HPC systems and applications	RIA	2	Running	Yes
ICT-05-2017	Customised and low energy computing (including Low power processor technologies)	RIA	1	Running	Yes
ICT-42-2017	Framework Partnership Agreement in European low-power microprocessor technologies	FPA	1	Running but no budget	No
FETHPC-02-2017	Transition to Exascale Computing	RIA	11	Running	Yes
FETHPC-03-2017	Exascale HPC ecosystem development	CSA	2	Running	Not in RIA funding
SGA-LPMT-01-2018	Specific Grant Agreement under the Framework Partnership Agreement “EPI FPA”	RIA	1	Just starting	No
INFRAEDI-02-2018	Centres of Excellence for computing applications	RIA, CSA	9 + 1	Just starting	CSA not accounted for in RIA funding
INFRAEDI-03-2018	Support to the governance of High Performance Computing Infrastructures	CSA	1	Just starting	Not in RIA funding
ICT-11-2018-2019	HPC and Big Data enabled Large-scale Test-beds and Applications	RIA	4	Just starting	No

* *only calls taken into account for Innovation KPI analysis*

Table 4: HCP cPPP related call for projects under H2020 – global operational statistics

Since 2018 was the last year of the cPPP, and since the common KPIs had not been established at the beginning of the cPPP, we have not always distinguished precise 2018 effects from cumulative effects – this would have not been very easy nor relevant. We give in some cases hints on the observed trends.

In short, the relevant global funding figures and references for the socio-economic KPIs are summarised in **Table 5** below.
In particular, a simple simulation further estimates the fraction of H2020 funding effectively spent (used) by the projects along the years, which is lower than the granted amount, since the projects tend to progressively spend their funding over an average duration of three years – the simulation assumes a linear spending over time.

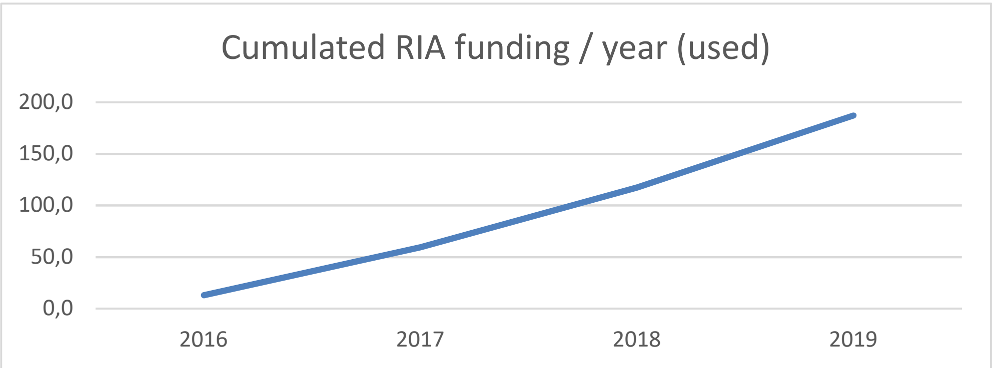
Funding granted to projects related to the cPPP from 2014 to 2018 - RIA	***400 M€***
Funding granted between 2014 and 2017 - RIA ***Reference amount for quantified, common socio-economic KPIs***	***213 M€***
Estimated RIA funding effectively used by consortia used until end of 2018  	***180 M€***
Extra funding granted via CSAs between 2014 and 2018	***11 M€***

Table 5: HCP cPPP related call for projects under H2020 – global funding statistics

3.4 Data collection and sampling methodology for the 2018 PMR

The approach taken for the last cPPP PMR (published in 2019, covering the 2014-2018 period, actually the whole lifespan of the partnership) is the continuation of the progressive refinement of our methodology. It uses the scope of the projects described in the previous section and the data sources mentioned in **Table 3**.

An "educated sampling" approach has been applied for specific surveys and studies. The idea was to reach the best possible "representativity vs. effort" ratios, carefully targeting subgroups of entities or organisations, with an expected high return rate – the size of the samples were such that it sometimes allowed some direct interaction and interviews if needed, and in any case manageable customised contacts and reminders. Our methodology relied also upon complementary, weakly overlapping sources (mostly non-overlapping). For instance, skills/training data use PRACE and Centres of Excellence independent – although mutually known and sometimes coordinated - activities statistics. The jobs KPI builds from a questionnaire to research organisations and from a series of interviews with a sample of companies. The innovation KPI uses an exhaustive interrogation of all FETHPC and CoE projects starting in 2015, each project coordinating an answer for its consortium.

The following data collection processes used such a sampling approach:

- **ETP4HPC research survey**: the ETP4HPC annual internal survey was sent to 20 ETP members from research organisations, with questions on leverage factor, jobs, patents – 9 full answers were received out of a total of 15. In 2019 (for the 2018 PMR), the ETP4HPC survey was restricted to research organisations receiving cPPP-related funding (a representative sample of both ETP members + a few non-ETP members; receiving in total 30% of the funding going to research organisations for those who answered)
- **CoE survey**: Centres of Excellence (all nine CoEs funded in the first round in 2015-2016) were reached with a questionnaire via FocusCoE CSA [22], on jobs, innovations, and training efforts;
- **Analyst study (for profit organisations)**: for the "private for profit" (P4P) sector, data was collected again by a contractor, as in 2017 and 2018, via interviews aligned with a pre-submitted questionnaire. Private companies mostly would not share any operational or commercial data with ETP4HPC, the confidentiality constraints were managed by the contracted analyst, using a well-established protocol and non-disclosure agreement approach that was widely accepted by the interviewed organizations. Only aggregated and anonymised data were shared with ETP4HPC for the PMR. For most of the companies interviewed this was the third such interview and the process was smooth, providing data on leverage factor, jobs, patents, innovations, SMEs.
  In order to get representative and focused input regarding the KPIs, 11 companies participating in FETHPC and projects were selected.
  This sample represents the main industrial beneficiaries of the cPPP, amounting to 55% of the funding going to the P4P industry sector, including SMEs. SMEs receive 50% of that share. The P4P sector in total receives ca. 24 % of the whole cPPP-related R&I funding - the interviewed industry participants reported that together they received EUR 26 million in funding under the H2020 HPC programme. The organisations interviewed are a mixture of SMEs and larger European or international companies; most are involved in more than one project. The aggregated staff of the large companies interviewed is above 460 000 – a minor fraction of this, not estimated, being related to HPC (although we can ensure that this is several thousands). The aggregated staff of the interviewed SMEs is 220 (out of which ca. 100 in HPC activities).
  Private investment and skills/jobs KPI estimates primarily stem from this study; other sources were also used to elaborate SME and Innovation KPIs.
- **Specific extra SME interviews**: another sample of SMEs was interviewed by the ETP4HPC/EXDCI-2 KPI team to collect extra information on their evolution and growth, how it related to H2020 funding, and some success stories – this is another sample of 10 SMEs, weighting 60% of the funding going to SMEs which we included in our scope.

The "representativity" of the surveyed or interviewed samples can thus be summarised as follows in **Table 6**.

Survey or questionnaire	Targeted data for socio-economic KPIs	Representativity of the sample NB: scope = EUR 213 million of 2014-2017 project
ETP4HPC research survey	Leverage factor, jobs, patents	30% of the funding going to research organisations
CoE survey	Jobs creation & training, innovations	100% (of 2015 CoEs)
Analyst study (for profit organisations)	Leverage factor, jobs, patents, innovations, SMEs evolution	55% of the funding going to P4P industry sector (out of which 50% for large companies and 50% for SMEs)
Extra SME interviews	SMEs evolution	60% of the funding going to SMES

Table 6: Representativity of samples in the different surveys and interviews

Other sources used (existing reports or publicly available data) were:

- **ETP4HPC Annual report:** various data on ecosystem evolution, dissemination, outcomes of projects;
- **PRACE KPIs and annual reports:** usual updated PRACE KPIs were used [19] [20] for training statistics and data on HPC use;
- **Public sources (internet, other reports and public registers):** public sources were eventually compiled (web intelligence mainly) to consolidate some extra data on dissemination or HPC specific KPIs – such as market data, but also for cPPP-related publication and press/media releases;
- **EC H2020 statistics:** for the number of projects and funding granted in the HPC calls – provided by DGCNECT as anonymised data; a compilation of public project factsheets [21] was also used.

4 Main findings at the end of the cPPP

4.1 Introduction and general facts

The build-up and creation of the Partnership gave new momentum to European HPC. The growing number of organizations joining ETP4HPC, as well as the good response to calls for proposals (CfP) run between 2014 and 2018 are probably linked (at least in part) to the visibility and structuring of the HPC subject via the cPPP. As a result of those CfPs, EUR EUR 400 million in funding was allocated to 56 technical projects targeting technological blocks related to the Exascale goal - with the selected FETHPC projects mostly covering ETP4HPC SRA topics and vision – plus a further EUR 11 million funding for 5 coordination and support action.

The initial momentum of the HPC cPPP has been maintained and even amplified. Several FETHPC and two CoE calls led to many projects, between 2014 and 2018. The remainder of the CfPs initially planned in 2018-2020 were postponed to be re-organised under the umbrella of EuroHPC (continuation of FETHPC), but are following the envisioned trajectory. In the meantime, the European Processor Initiative has been added to the programme, while an extra call addressing the combination of HPC and Big Data was launched in 2018.

This funding engaged in the updated cPPP scope is about 60% of the total amount initially planned for the HPC cPPP in the 2014-2020 period (EUR 400 million out of EUR 700 million). The EU budget not spent under H2020 and the cPPP will be shifted to the EuroHPC R&I Pillar funding and complemented by national funding, reaching an estimated additional EUR 392 million for the years 2019 and 2020. It must be noted however that the initial scope of the cPPP did not encompass the more recent effort towards the European processor and its prequels (3 ICT projects amounting to 90 M€, in particular the large EPI project – FPA/SGA1).

In the following sections of this chapter, we give brief summaries of the main findings fully documented in the 2018 PMR [10].

4.2 Common KPIs

4.2.1 *Mobilised private investments*

In the 2019 study with industrial companies, more than half (55%) of the projects they were involved in had been completed, and the rest were due to end within 24 months. As in the 2018 study, a large majority of industry participants (73%) rated the H2020 funding as "extremely important for our future," and this was uniformly true for the SMEs. The three other participants (27%) rating the funding as only "somewhat important" were large corporations who viewed the funding as indispensable but small compared with their employers' substantial R&D budgets. Without the H2020 funding, all the industry participants would either not have pursued this important research (14%) or would have been forced to pursue it on a more limited basis (86%). The participants agreed unanimously (100%) that it is "very important" for funding of this kind to remain available to European industry.
Direct leverage 1: in-kind (unfunded) contributions by partners declared in the projects is less than 0.5% of total funding of the projects assessed. In essence, all 2014-2018 cPPP-related projects started before the end of Q42018 are RIA (Research and Innovation Actions), with 100% funded for all partners.

Direct leverage 2: the industry participants receive approximately one quarter of the projects' total funding; during the projects lifetime, they add an estimated 40% in-kind contribution to the EU funding. Higher and Secondary Education (HSE) and research Organisation (RO) institutes, get ca. 76% of the cPPP-related funding, and thus form the majority of the so-called 'private' side of the cPPP, in terms of funding. In addition to the 100% funding rate under H2020 rules (for RIA actions), we estimate the extra in-kind contribution to be at least 25% of the total funded personnel cost (mostly related to higher indirect costs than the standard H2020 25% rate), with also some other in-kind equipment or other resource usage.
Indirect leverage: the leverage factor estimated is in the order of 4.6; industrials would invest 4.6 euros for each EU euro, to turn the project innovations into commercial products.
In total, an extrapolated global leverage factor of all 3 levels combined would be close to 5.

4.2.2 *New skills and/or job profiles*

<u>*Skill development and training*</u>
Many training events/sessions/material have been developed and delivered via PRACE since 2010, followed by the Centres of Excellence for Computing Applications from 2015 onwards (and to a lesser extent FETHPC projects). This is an estimated 20000+ person-days of training in the period 2014-2018, mostly in the form of short sessions or events (1/2 to several days) often for young practitioners (researchers, engineers, ...) but also for more advanced professionals both from research organisations and industry. Basic as well as advanced levels were covered, regarding the use of HPC (tier0 or tier1 resources), programming, but also more application specific topics with scientific communities. Several MOOCs (Massive Open Online Courses) have also been developed by PRACE. Let us mention other organisations which are very active in IT and advanced computing training, like HiPEAC[45]. HiPEAC is not formally part of the HPC programme but has active links with ETP4HPC.

<u>*Jobs*</u>
By the end of 2018, at least 100 direct jobs were created during the lifetimes of the projects in the s/w and h/w industry (hardware, system, application development, and more than 250 direct jobs in research (in part, temporary jobs). It is estimated that 50% of the industrial jobs created would become permanent, the largest likely category being developers of system software—a broad category that could refer to any part of the software stack between the operating system and the application kernel, followed by developers of hardware and applications. Many of the applications developers were engaged in scaling and optimizing existing application codes. Mid-term impact on jobs in the public research and academic area is more difficult to measure.

4.2.3 *Impact on SMEs*

Since the start of the FP7 Framework Programme, and then continued in H2020, the share of SME participation in HPC EU funded projects has significantly improved. SMEs have not only increased their participation in general, but also today consider H2020 projects as a building block of their R&I strategy: as of today, four of the "Top10" industrial beneficiaries in cPPP related calls are SMEs. SMEs get a total funding of EUR 25 million in the FETHPC programme (out of the 213 M€ considered here).
The strategic importance of H2020 for SMEs is also confirmed by interviews: all SMEs consider H2020 funding as "extremely important for our future". In particular working less in

isolation and getting into the habit of collaborating closely in the area of advanced technologies is considered of utmost importance.
Some quantitative but limited and specific findings could be derived from specific direct interviews of 10 SMEs.
Turnover: the H2020 funding had a positive contribution to the increased turnover/business for 6 of them (though exact quantification of the contribution is not possible). It is too early to tell about any influence or correlation for 3 others (too recent projects). One company spun-off a new HPC activity, still operational but no longer in the HPC sector.
For the 2 smallest/youngest companies (staff still under 10), H2020 funding was instrumental – weighting up to 25% of operational costs and 50% of staff increase over the last 3-4 years.

General benefits: for 3 companies, the main perceived and reported benefits are enhanced reputation, networking, increased collaborations, and better ecosystem role (fostering dissemination, gaining new projects or activities and partners, or potential future improved products and services)**.**
For 3 other companies, new contracts or customers or business stemmed from H2020 funding (H2020 supported skills/staff increase and new activities, which in turn helped get new business).
For 2 companies, it is still too early to tell, but one of them already modified its roadmap in the light of new needs in the HPC area (not technical aspects but other IT/management aspects).
A start-up boosted its growth and is on its way to turning what were initially academic developments into implemented/productised solutions.
The company which created a spin-off which eventually stopped HPC activities - but still exists and continues in other areas with the spun-off know-how – considers experience within the projects positively.

4.2.4 *Significant innovations*

Two different subsets of projects could be scrutinised for this KPI: the FETPHC and CoE projects that started in 2015. Let us note that many partner organisations participate in more than one project, and often in both of the two categories.

Overall, we observe a rich portfolio of innovations, not easily summarised nor quantified in a short list or mere figure, mainly in the following categories:

- Hardware and software building blocks for ‘supercomputing’ solutions
- Different prototypes of full systems with innovative architectures or features
- Important evolution or optimisation of community application codes
- New models, or methodologies, or software components useful for application scale-up and improved performance towards exascale
- New application features, and new or better modes of exploitation of applications

FET-HPC 2015 projects (study conducted by the EXDCI-2 project, Work Package 2)

Most of the FET-HPC projects related to the September 2015 call are now finished. The end of 2018 was a good time to analyse the outcomes of these projects - and what could be suggested for maximizing the impact of these projects.

NB: Handbooks listing all FETHPC (and CoE) projects mentioned below can be found on the ETP4HPC website [23]. It contains in particular links to the projects’ websites and complete lists of their partners.

The most relevant so-called IP (Intellectual Property) elements generated by the projects have been identified. A first quantitative analysis shows that most of the results are in the field of software. Out of the 171 IP elements listed, two thirds are software and 20 are hardware related. The other types of results are APIs, applications optimizations, benchmark suites, trainings and demonstrators.

It is interesting to note that most of the IP elements could already have some exploitation, being mature enough. FET HPC 2014 projects (started in 2015) have generated many IP elements that can be useful for end users and application developers. Some of them target HPC system providers, and computing centres or could be good inputs for integration projects (advanced demonstrators).

At a qualitative level, starting with the hardware side, we see the development of several processor or FPGA boards, active interposer technology, interconnect technologies (one using photonics) and cooling technology.

The system-oriented projects have developed 8 demonstrators, most of them being open to experiment by external teams. The larger ones in terms of computing power come from ExaNest-EcoScale, Mont-Blanc and Mango. IO (Input/Output) related projects, Sage and NextGenIO have also demonstrators that can be useful for testing new storage hierarchy or object file system.

Some APIs have been proposed by the projects in domains like FPGA management, object file systems, energy efficiency and interaction between runtimes.

On the software side, besides the enhancement of several applications or application kernels, we see results in domains such as FPGA programming, file systems, runtime, energy efficiency, time constrained computing, and tuning/debugging tools.

The complete set of results is very rich and for the exploitation of this basis, we have new FET-HPC 2017 or other projects that will continue some of these efforts (EuroExa, Mont-Blanc 2020, Sage2, Escape-2 or Recipe).

CoE 2015 projects

In addition to the very important contribution of CoE projects to skill development and training reported above, the CoEs were questioned about their main self-assessed achievements/innovations. The following table does not pretend to map and classify all CoE activities, but to identify the self-perceived most salient and/or innovative ones. For example, having only one CoE mentioning ISV interaction does not mean the others had none, but rather that they highlight other achievements first.

Kind of self-assessed innovation or achievements by Centres of Excellence	# of CoEs mentioning this
Community code scaling, porting, or performance optimisation	6*
Other kinds of s/w environment improvement: cloud access mode, workflow management, data services	3
Various new pieces of software developed (components, DSL…)	3
New model or method	2
Patent	1
Start-up	1
Spun-out activity	1
New skills/competences and/or related material, dissemination	4
Community structuration	1
New collaborations, networking and ecosystem effects	2
ISV interaction	1

Table 7: Centres of Excellence innovations or achievementss

4.3 Specific KPIs

This section selects some extra information related to HPC specific KPIs (from Annex 5.6 of PMR 2018 [24]).

Global market share of European HPC
From IDC's and then Hyperion Research's (IDC HPC division spin-off [25]) recurring studies of the worldwide HPC market, the estimates of EU suppliers' share of the EU HPC server market are as follows:

- 2014 = 4.1%
- 2015 = 4.6%
- 2016 = 4.9%
- 2018 = 5.0%

This positive trend cannot, however, be easily related to direct cPPP effects: should there be a causality regarding this moderate but positive trend, it cannot be proven easily nor quantified (i.e. which fraction could be explained by cPPP impact). Some technology related to cPPP projects started to be productized and available in 2018 only. An acceleration of this trend is expected when more cPPP-related new IP hits the market and intersects European bids.

Research programme effectiveness and coverage
The 2014-2018 calls reflect the ETP4HPC SRA topics, from the different SRA versions since 2013 [26]; the SRA is directly mentioned in the calls as a detailed technical reference.
All EU Members States had organisations participating in the pool of 63 projects granted (1 FPA, 56 RIA, 6 CSA) from 9 calls, except Estonia, Lithuania, and Latvia.

Performance of HPC technologies developed
Several 'hardware' projects produced and deployed prototypes of systems or subsystems: NextGenIO, SAGE, Mango, Mont-Blanc, DEEP-EST, and EuroEXA (see [23] for the complete list of projects and their websites).

<u>Patent, inventions and contributions to standards in HPC by H2020 funded projects</u>
It is important to highlight that the focus of FETHPC projects is on pre-competitive, open research. This implies that most patents deriving from this research will occur after the completion of the projects. CoE projects, on their side, are oriented toward scientific applications. Nevertheless, at least 11 patents filed during the lifetime of FETHPC projects were reported by industrial participants, plus one from a CoE project partner.

Questioning ETP4HPC member organisations (from industry as well as from research), it also appears that a number of them are represented and active in standard bodies - all of them being involved in FETHPC and/or CoE projects. These standard bodies are essentially concerned with parallel programming models or languages (MPI Forum, GASPI Forum, FORTRAN standardization committee, and OpenMP ARB), software frameworks for HPC (OpenHPC), file systems (EOFS and Lustre Centre of Excellence).

<u>Efficiency, openness and transparency of the PPP consultation process</u>
ETP4HPC had grown to 96 members by the end of 2018, incl. 1/3 of EU SMEs; members are technology suppliers but also application owners, service providers, ISVs…Each ETP4HPC SRA elaboration involved 100 to 200 experts from ETP4HPC members as well as from PRACE, Centres of Excellence, and BDVA (Big Data Value Association [27]).

4.4 Evolution over time and other comments

In Section 4.2 on common KPIs, the analyses took the scope of projects started before the second half of 2018, in order to have some measurable internal dynamics or external effects as of the end of 2018.

Taking the wider perspective of total funding granted over all projects (including the latest ones started later in 2018) can cast light on other aspects of the HPC cPPP momentum across the whole ecosystem. This is the perspective taken in this section.

Overall funding granted to industry (P4P), including SMEs, increased its share from 25.5% to 32.8%: mostly driven by the EPI and the testbeds projects. Funding to research organisations (RO) remained stable in 2018 and funding to Higher and Secondary Education (HSE) grew more slowly, decreasing its share by almost 5% to 27%. Participations by type of organization in the funded projects broadly reflects the allocation of funding with small deviations in one direction or another (**Figure 1**).

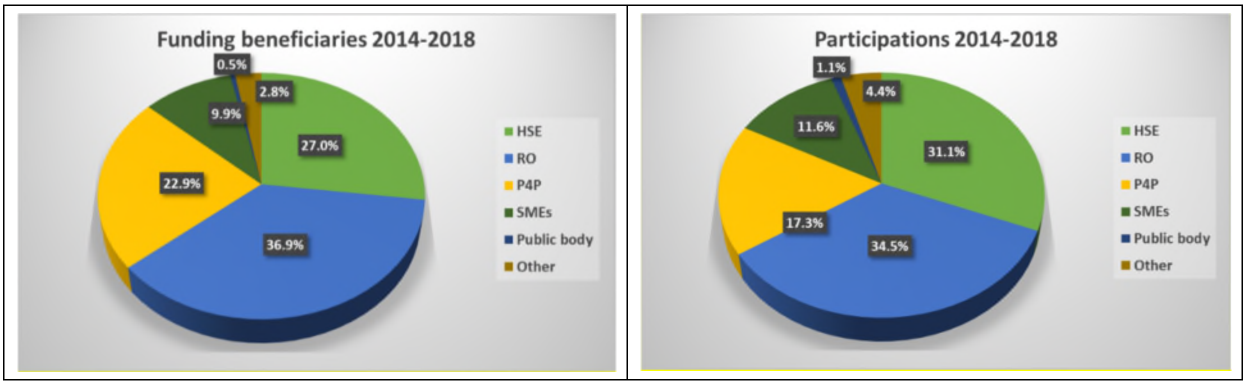


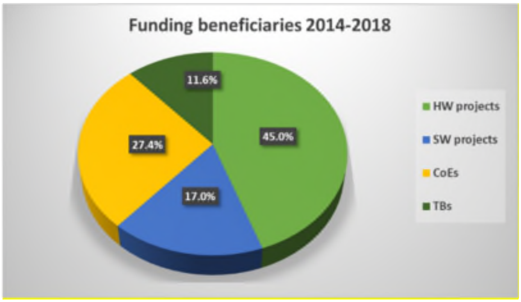
Figure 1: Analysis of 2014-2018 HPC cPPP beneficiaries by funding and by participants

The projects related to the cPPP in the period 2014-2018 can be broken down into four different classes based on the type of projects funded. We distinguish between hardware projects (HW), software projects (SW), Centres of Excellence (CoE) and Testbeds (TB). Hardware projects typically also have considerable activities on software development. However, in the first instance it allows us to break down the funding in the different areas, as this is an important aspect of the implementation of the HPC strategy.

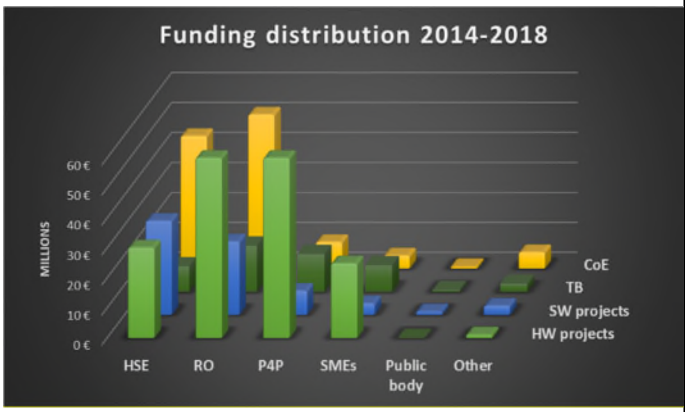
Two of the three calls in 2018 were application oriented, providing a second round of funding to CoEs and starting the activities on HPC and Big Data enabled testbeds, the third call being for the EPI project. The picture that emerges is one where funding in HW on one side and SW + CoE + TB topics on the other side remains balanced, with a slight increase for software and application-oriented projects. According to preliminary planning for the years 2019 and 2020, this trend is expected to be maintained in EuroHPC.

A more detailed picture of the funding distribution emerges, when it is broken down per type of organizations (**Figure 2**, right column). For HW projects, the funding is almost evenly split between public and private for profit organizations, oriented towards creating innovations in this area, in line with the HPC strategy of strengthening the European industrial supply chain. A similar situation is also encountered for the projects developing HPC and Big Data testbeds that are more oriented towards applications with industrial impact.

Higher or Secondary Establishments (HSE) and Research Organisations (RO) are clearly receiving a large share of the funding in projects developing solutions for the HPC software stack (SW) and for Centres of Excellence in HPC Applications (CoEs), highlighting the collaborative nature of the software development work in these areas. The chart at the bottom right of **Figure 2** presents the breakdown of participations in the different types of projects. Compared to the same type of chart pictured above, the trends are the same. One highlight is that HW projects, while absorbing almost half of the funding in the period 2014-2018, are characterised by a smaller number of participants.



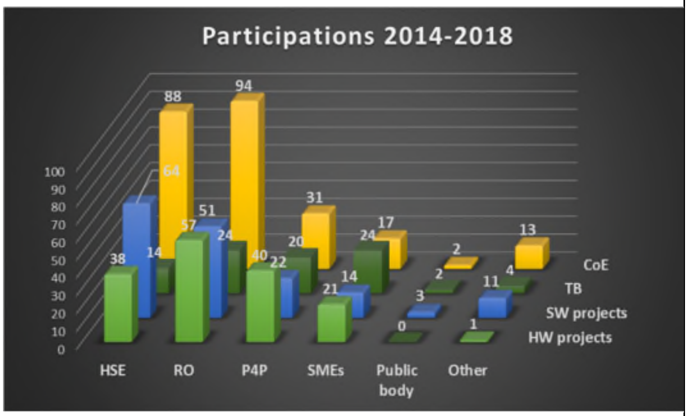
Global Funding / projects types



Funding broken down by category of beneficiary

Caption for project types

- HW = hardware project (not excluding significant software i.e. system stack, benchmarks, pilot applications) – category encompassing EPI project
- SW = pure software project (system stack and/or solutions/application elements
- CoE = Centre of Excellence (applications)
- TB = TrstBed in HPC/Big Data (mostly industrial applications)



Participations broken down by category of beneficiary

Figure 2: Analysis of 2014-2018 HPC cPPP beneficiaries by project types

European industrial platforms play an important role in organizing the community around strategic priorities and European roadmaps. However, their work should represent not only the interests of their members, but reflect the reality of the wider community. It is therefore important to monitor how H2020 funding is distributed among ETP4HPC members and non-members. Implementation statistics show that a majority of the beneficiaries (59%) are not members of ETP4HPC. The funding instead shows the opposite: while until last year it was evenly split between ETP members and non-members, the new projects funded in 2018 broke that balance in favour of ETP members, who now receive a majority of funding (56.5 %). This can be partly explained by the fact that of the 14 new projects granted in 2018, 9 of them were coordinated by ETP members. In addition, a large share of the funding to the EPI SGA1 project went to ETP members.

5 An overview of the EU HPC ecosystem

This chapter gives an overview of the European players in relation to the HPC cPPP activities, and of their contributions to the European HPC ecosystem development when relevant. This analysis is based on the findings of EXDCI-2 Task 4.4, as well as other work performed in the framework of the EXDCI projects [29][30][31], and of PRACE 5IP project [28]. PRACE's cartography is a very complete breakdown of all possible local (EU) or non-local (international) stakeholders, whereas [31] takes the perspective of a value chain analysis – from technologies to applications, via infrastructure and related "service providers". The facets below borrow from both visions in order to show in which domains the cPPP contributed to the ecosystem development, to understand other ongoing European activities, and to map this onto the future plans of EuroHPC - as know by us at the time of writing this report.

The European HPC ecosystem can be divided into different facets We will first provide an overview of the main activities/projects within each facet (Section 5.1), and in a second step (the subsequent sections of this chapter) we will give some more details on the main European players and their activities in each facet of the ecosystem.

This analysis started with cPPP-related projects and their participants, though other companies working on the identified topics not participating in any project will also be mentioned in this report. Although the cPPP-related projects involved an important part of EU players in many areas, there is still plenty of room for inclusion of more EU organisations in future EuroHPC CfPs.

5.1 Overview of European HPC-related activities

The cPPP contributed srongly to the development of HPC system hardware, the application development tools, and to the application development itself. Transversal topics, such as the connection to the ecosystem, the link to the upstream technologies and the international collaboration have been handled either via the coordination and support actions EXDCI. or directly by ETP4HPC or PRACE organisations. Other topics, such as support for SMEs, or skill development have benefitted more from non-cPPP funded actions. This gap has been identified and will be addressed in the framework of EuroHPC.

Figure 3 and **Table 8** describe the facets and kinds of players we have considered in the ecosystem.

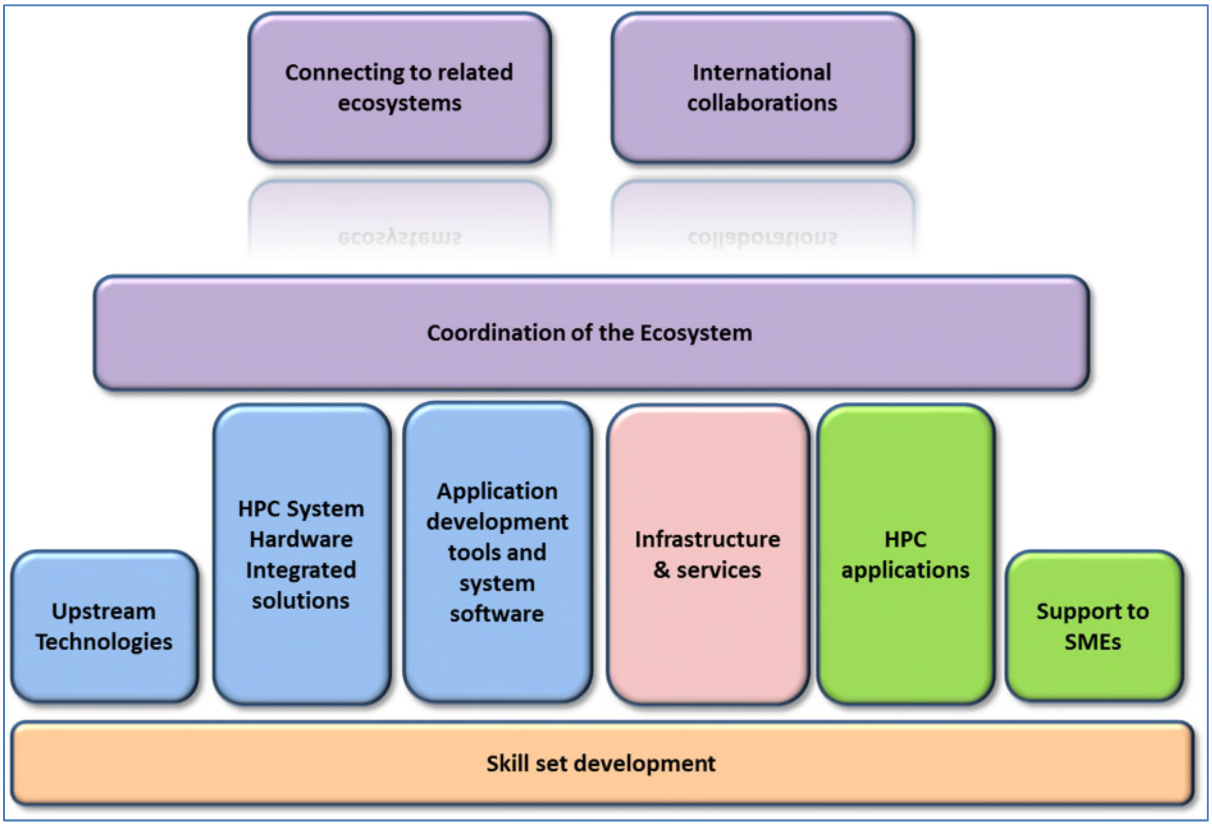


Figure 3: Facets and players in the EU HPC ecosystem

Ecosystem facet	cPPP Actions	Other European activities	Planned actions in the framework of EuroHPC JU
HPC System Hardware Integrated solutions	• FETHPC-1-2014: HPC Core Technologies • FETHPC-01-2016: Co-design of HPC systems and applications • EPI	• PCP: Pre-commercial procurement in HPC (PRACE 3I project) • PPI: Public procurement of innovative HPC Systems (PPI4HPC project) • Federated ENgine for Information eXchange (FENIX)	• Also supported via the procurement of 5 petascale and 3 pre-exascale systems.
Infrastructure & services		• ICEI / HBP SGAs (FENIX) • EOSC and EUDAT	• Also supported via the future operations of 5 petascale and 3 pre-exascale systems.
Application development tools and system software	• FETHPC-1-2014: Programming Environments and Algorithms for Extreme Parallelism and Extreme Data Applications • FETHPC-02-2017: Transition to Exascale		• EuroHPC-1-2019 • EuroHPC-2-2019

Ecosystem facet	cPPP Actions	Other European activities	Planned actions in the framework of EuroHPC JU
HPC applications	• INFRA-5-2015 and INFRAEDI-02-2018: Centres of Excellence • INFRAIA-01-2016-2017: HPCEuropa3	• PRACE High Level Support Teams (HLSTs)	• EuroHPC-04-2019 (RIA) • EuroHPC-3-2019
Support to SMEs	• Eurolab4HPC open calls • EXDCI-2: Spin-off Initiative	• PRACE Shape, • fortissimo projects • Tetramax project	• EuroHPC-04-2019 (RIA) • EuroHPC-05-2019
Skill set development	• FocusCoE: Stakeholder workshop on training • Via the CoEs: large range of training activites deployed	• PRACE Training portal • PRACE Summer School	• EuroHPC-04-2019 (RIA) • EuroHPC-05-2019
Upstream Technologies	• EXDCI2: dedicated task	• FETFLAGSHIP on Quantum Computing (part of EU Quantum Flagship) • FETFLAGSHIP Human Brain Project (neuromorphic computing) • Horizon2020 ICT and FET electronics and photonics calls	
Connecting to related ecosystems	• EXDCI and EXCDI-2: connecting to BDVA, HiPEAC, EOSC, AIOTI	• ETP4HPC specific actions	
International collaborations	• FETHPC-1-2018: international collaborations • EXDCI and EXDCI-2: collaboration with BDEC	• ETP4HPC specific actions	
Coordination of the Ecosystem	• FETHPC-2-2014 and FETHPC-03-2017: EXDCI and EXDCI-2 Eurolab4HPC • INFRAEDI-02-2018: FocusCoE	• PRACE	• EuroHPC JU • EuroHPC-04-2019

Table 8: Ecosystem facets and their links to the HPC cPPP and other activities

5.2 European players developing HPC System Hardware and Solutions

The analysis based on the findings of [31] shows that the industrial and academic players in Europe developing HPC system hardware make up a healthy ecosystem in the areas of the integration, installation and operation of HPC systems and the integration on chips, boards and for the use of FPGAs in HPC. The integration of HPC systems, innovative cooling systems, and container-based solutions for HPC are tackled by a variety of players. However, there is a lack at the basic hardware level. There is no known European player concerning the foundry of chips and memory, and only one company (Seagate) which does research in Europe on Storage systems. Via the EPI initiative, Europe is eager to gain in autonomy, commencing with core “compute” technology.
Note that vendors integrating and sometimes designing supercomputers often provide services for operation of full solutions. Solutions and service providers (such as for HPC in the cloud) have also been included in **Table 9** below.

System Component	**European Players**
Foundry of chips	
Design of HPC Chips	EPI
FPGAs	Kalray, Graphcore, Maxeler
Interconnect	Atos, Extoll
Memory	
Integration of chips	IMEC, CEA, Fraunhofer
Integration at board level and server level	ATOS, E4, 2CRSI
Integration of FPGAs	ProDesign, PLDA, Reflex
Integration of HPC Systems	Megware, E4, 2CRSI
Cooling Technology	Asetek, Iceotope, Submer
Storage Systems (research in Europe)	Seagate
Data center installation	Saiver, Schneider Electrics
Containers	ATOS, Iceotope
Operation of HPC systems	FZJ/JSC, EPCC, STFC, CEA, CINES, IDRIS…
HPC on demand	OVHCloud, Arctur, T-systems, ATOS-Extreme Factory, Gompute

Table 9: European players developing HPC System Hardware and Solutions

5.3 European players developing tools for parallel application development and system software

Interestingly, most players in Europe working on application development tools and on system software are from research and academia - and HPC centres, sometimes in a co-design approach with EU vendors. In general, it is difficult to build a business model around the licensing of tools and system software when a large part of the user community is used to such things being free of charge (e.g. developed and/or adapted by the hardware vendor and delivered with the hardware, or managed by a computing centre). In addition, in this domain, much relies on open source software and the underlying community (as for example for the European MPI or LUSTRE efforts).

Type of system software	European Players
Interconnect Management	FabriScale
Resource Management	
File Systems	ThinkParQ, Fraunhofer, EOFS, community-effort
Data Management	Grau Data; OpenIO
Compiler	NAG
Scientific Libraries	NAG
Parallel Programming Models	Fraunhofer, BSC, CEA, community effort
Runtimes	BSC, INRIA, CEA, Fraunhofer
Performance Analysis Tools	Dresden, BSC, FZ Jülich, TUM

Table 10: European players developing application, programming tools and system software

5.4 European Players in the HPC application landscape

The success of exascale in Europe will strongly depend on the ability of HPC applications to use, in particular, EuroHPC's future machines in an efficient way. The set of HPC Centers of Excellence (CoEs) constitutes well-structured efforts addressing multiple user communities, by bringing together their stakeholders and by pushing the main application codes of those communities towards the exascale. Support for application developers is provided by PRACE's High Level Support Teams (HLST) as well.

The efforts to support the application developers will be pursued within EuroHPC via the national Competence Centres (EuroHPC-4-2019) and the call on "Industrial software codes for extreme scale computing environments and applications" (EuroHPC-3-2019). The goal of this latter call is to improve industrial software and codes for industrial users, so that they may fully exploit the new capabilities of extreme performance HPC environments.

The effort towards industrial application codes should be pursued and strengthened, as we have in Europe strong industries developing their own application codes in-house, as well as strong ISVs, which is a key to industrial competitiveness at a global scale. In-house development can be seen, for example, in the chemical (BASF), aviation (Airbus) and oil&gas sectors (CGG, Total). The ESI Group, as an ISV in the area of virtual prototyping, and Dassault Systèmes, which purchased Simulia, are large European companies and global players. In addition, there are many skilled, smaller and more specialised ISVs in Europe.

5.5 European effort in supporting SMEs

In the framework of the cPPP, support for SMEs was provided via dedicated tasks in EXDCI and Eurolab4HPC projects, with the goal to allow SMEs more easily to integrate IP and knowhow coming from research. In the framework of EXDCI-2, this happens via the Proof-of-concept implementation of the “Project Spin off” Idea, focussing on consortia from already existing R&I projects [38], while Eurolab4HPC’s concept is based on open calls for funding short exchanges or business protoyping activities beyond collaboration in R&I projects [35].

Substantial support for SMEs was provided by the Fortissimo projects, as part of the I4MS programme [36]. Fortissimo allowed companies to engage with HPC specialists (either from HPC Centres or from a service provider) to support the companies in using HPC technology successfully to the benefit of their businesses. A very similar follow-up activity is planned in EuroHPC JU (call EuroHPC-4-2019). Moreover, the national Competence Centres to come (call EuroHPC-5-2019) will also act as competence hubs for SMEs in their country. Both projects are expected to push the uptake of HPC for numerical simulation, data analytics and machine learning amongst European SMEs from a wide variety of domains.

5.6 European activities on training and skill development

Under the cPPP umbrella, the Centres of Excellence organise a variety of training activities. These target researchers as well as company’ specialists, ranging from webinars or online courses to workshops of several days. They address more general HPC-related topics (such as “dynamic load balancing”), as well as domain or application specific training activities (see for example [39]).

PRACE is also very active in training, offering via its HPC centres a wide and diverse range of events [40] [41].

Efforts in building an overview of the existing offer and in identifying gaps are pushed by the EC. This led to a first workshop held in October 2019 in Brussels, organised by FocusCoE with the support of the Commission. The national Competence Centres (call EuroHPC-4-2019) are expected to expand the European offer on training and skills development, in particular for SMEs and companies.

5.7 Connection to-European upstream technologies

Within EXDCI2 there is a dedicated task addressing the establishment of connections between future HPC developments and upstream technologies. By upstream technologies, we mean existing leading edge research and developments in areas that would potentially have impact on future HPC systems, such as photonics and nano-electronics.

After informal discussions between experts in EXDCI-2 and expert representatives from the R&D communities developing such upstream technologies, a joint workshop took place in November 2019 in Brussels. The theme of this workshop was "New technological paths for high performance chips targeting HPC and edge". The event gathered about 40 experts from the HPC, photonics and electronics ecosystems, among others, coming from both academia and industry, in order to discuss potential paths to be explored in the future, in terms of HPC and edge systems.

The objective of this workshop was to address the challenges of increasing demand for performance in regards to chips and HPC systems. These discussions will be continued during the 2020 edition of the EuroHPC Summit Week, with the intention to pave the way for adequate research calls on these topics in EuroHPC and in the Horizon Europe framework.

5.8 Connection to HPC-related ecosystems

As part of the EXDCI projects' activities on the Strategic Research Agenda (SRA), ETP4HPC engaged in discussions with partners of other ecosystems having a link with, or interest in, HPC:

- With the Big Data Value Assoication (BDVA [27]), who contributed to the SRA, in particular on topics such as "AI everywhere".
- The association AIOTI (Association of the Internet of Things Initiative [42]) provided input and real-life examples for the use cases presented in the document.
- With the cPPP on Cybersecurity and its private member ECSO [43], ETP4HPC worked on open questions on security, which is becoming increasingly important, as the HPC systems become part of more global and complex workflows.
- Another issue gaining importance in HPC in center-to-edge scenarios is connectivity, represented by the PPP on 5G [44].

In Horizon 2020, some calls have already covered data and HPC-related aspects (ICT-11-2018 or ICT-51-2020 for example). The goal is to strengthen the collaboration between the concerned European players in these areas, via more joint CfPs in EuroHPC, as well as in Horizon Europe.

5.9 Connection to international activities

Via the FETHPC-1-2018 call, two FET research projects were funded, bringing together European and Mexican and Brazilian partners, respectively.

European partners also contributed (via EXDCI projects) to the Big Data and Extreme-scale Computing Initiative (BDEC) [32]. Bringing together researchers from the United States, the European Union, Japan and China, BDEC has staged a series of workshops that have endeavoured to map out how Big Data intersects with achieving exascale computing. BDEC has developed a wider and longer-term vision for a potential convergence of software layers underlying HPC and data-intensive infrastructures and services. The next workshop will take place in Porto in March 2020 as part of the EuroHPC Summit Week 2020.

6 Conclusion

The EuroHPC Joint Undertaking is now in place and developing activities on infrastructures as well as on R&I aspects of HPC. The HPC cPPP is formally terminated (exchange of letters between ETP4HPC and Commissioner Gabriel in March/April 2019). After dealing with the call for Hosting Entities for both Precursors to Exascale (formerly: Pre Exascale) and Petascale systems in April 2019, EuroHPC published its first calls for R&I projects, replacing the H2020 cPPP calls, on July 25, 2019. The related submission periods closed in November 2019, and then in January 2020 for two different subsets of proposals. This implements an effective junction with the former HPC cPPP, the underlying Work Programme 2019 of EuroHPC replacing the previous H2020 one, with some updates but a strong continuity in terms of contents and objectives. In particular the European Processor Initiative is now fully integrated in EutoHPC R&I activity.

Several calls for proposals related to the HPC strategy were implemented during 2018. Many were in the area of HPC applications such as the call for proposals for HPC Centres of Excellence, and HPC and Big Data enabled Large-scale Test-beds and Application. The consortium for the European Processor Initiative (EPI) also started in December 2018. These different projects did not contribute to the data of this report. EuroHPC will certainly take over for the monitoring and impact assessment of these efforts, together with the projects to be launched in 2019-2020.

The data collection process and methodology set up in 2014 was refined and adapted until 2019 for the last PMR, optimising efforts and focusing on the most productive actions for the core, common KPIs and some others, now better understood by experience. The well-known and persistent shortcomings remain: the variable return rates of surveys and questionnaires; the difficulty of sensitive data collection especially from private companies; and limited amount and history of funding in the cPPP. However, time was on our side for this latter point, with a significant number of projects now completed – although still quite recently – and almost one-half of the initially committed cPPP funding granted. To address the very variable return rate of surveys, we used our precise knowledge of the ecosystem, projects and players to define target samples of reduced size that could be reached by adjusted questionnaires or interviews, while being quantitatvely representative of a significant fraction of the activities.

This 2018 report can be seen as an intermediate one and a first testimony after five years of cPPP operations – with already significant innovations visible in both technology and application areas. The continuous increase (since FP7) of industry participation in the programme can be seen as positive, although still limited. On the one hand having SMEs accounting for half of the industrial participation is good. On the other hand, the global private (P4P) side participation could be higher, and above all, the coordination of the whole programme towards stronger industrial outcomes could be improved, with two benefits: making solutions for applications faster and better developed and so increasing the economical and societal benefit of the HPC programme for Europe; and making excellent public research better and faster exploited by technology suppliers and vendors. A possible accelerator of such effects could have been the concept of Extreme Scale Demonstrators proposed by ETP4HPC, meant for the second part of the cPPP, after a first phase devoted to developing hardware and software building blocks and some prototypes of limited scope or size.

Although the cPPP will not directly be continued as such, EuroHPC will take over and is meant to amplify and better integrate efforts. A strong continuity in both implementation and impact assessment of the European HPC R&I is thus expected, together with a stronger link and coordination with computing and data infrastructures - their funding, their technological equipment options and their relevance and usefulness for applications.