White Paper

DEVELOPMENT OF A MATURITY ASSESSMENT TOOL TO IMPROVE SME HPC CAPABILITIES

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UPSCALING **SMEs** for the EMERGING EUROPEAN SUPERCOMPUTER ECOSYSTEM

EuroHPC Joint Undertaking
Funded by the European Union
TÜBİTAK ULAKBİM
EURO TRUBA

Acronyms

AI: Artificial Intelligence
BP: Base Practices
CoE: Center of Excellence
CPU: Central Processing Unit
EDIH: European Digital Innovation Hub
EuroHPC: European High-Performance Computing
EuroHPC JU: European High-Performance Computing Joint Undertaking
FAIR: Findable, Accessible, Interoperable, and Reusable
GPU: Graphics Processing Unit
HPC: High-Performance Computing
HPDA: High-Performance Data Analytics
HR: Human Resources
IEC: International Electrotechnical Commission
ISO: International Organization for Standardization
IT: Information Technology
ITU: Istanbul Technical University
ITU UHeM: Istanbul Technical University National Center for High-Performance Computing
METU: Middle East Technical University
NCC: National Competence Center
PA: Process Attribute
PoC: Proof of Concept
PRACE: Partnership for Advanced Computing in Europe
SME: Small and Medium-Sized Enterprise
SME-HPC-MM: Small and Medium-Sized Enterprise High-Performance Computing Maturity Model
SPICE: Software Process Improvement and Capability Determination
TRUBA: Turkish Science e-Infrastructure
TTO: Technology Transfer Office
TÜBİTAK: The Scientific and Technological Research Council of Türkiye
TÜBİTAK TEYDEB: Technology and Innovation Funding Programmes Directorate
TÜBİTAK ULAKBİM: Turkish Academic Network and Information Center

Table of Contents

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UPSCALING SMES FOR THE EMERGING EUROPEAN SUPERCOMPUTER ECOSYSTEM

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KEY INSIGHTS FOR SMES

- HPC helps SMEs reduce costs compared to on-premise and cloud systems.
- The EuroHPC ecosystem provides SMEs mentorship, funds, and visibility.
- The maturity model guides the improvement of SME HPC processes.
- NCC Türkiye can help SMEs bridge the gaps toward the EuroHPC ecosystem.

KEY RECOMMENDATIONS FOR NCCS AND EUROHPC

- The maturity model sets common expectations around HPC experience levels for SMEs.
- Tailored and measured services are possible following an assessment and gap analysis.
- NCCs can support HPC Champion SMEs with more resources on national infrastructures.
- EuroHPC can incentivize SMEs to become HPC Innovators based on maturity assessments.

Preface

National Competence Center (NCC) Türkiye has created the initial structure comprising national High-Performance Computing (HPC) centers, academia, and partnerships to increase Small and Medium-Sized Enterprise (SME) HPC capabilities toward the developing European HPC (EuroHPC) ecosystem. The NCC has started 29 collaborations with SMEs and produced success stories in the manufacturing, transportation, social media, and engineering sectors. NCC Türkiye has planned to upscale the HPC maturity of SMEs for emerging European supercomputers. Our experiences have shown that SMEs need a tool to comprehensively assess their current situation regarding HPC capabilities and assist them in identifying and prioritizing reasonable improvement opportunities. Hence, we have developed the SME HPC Maturity Model (SME-HPC-MM) based on our SME collaborations, EuroCC definitions, and Information Technology (IT) process assessment standards. The maturity model has a structure that supports SMEs' participation in the EuroHPC ecosystem. Furthermore, the model can improve the NCC-SME collaborations by guiding process improvements in SMEs for developing HPC capabilities.

THIS WHITE PAPER proposes a maturity model for SMEs building on NCC Türkiye's SME collaborations. We want to share our industrial collaboration experiences and prepare for the next phase of the EuroCC project, constructing a common expectations model to upscale SMEs. Section 1 explains the importance of participating in the EuroHPC ecosystem for an SME, NCC Türkiye's design to interact with SMEs and improve SME HPC capabilities, and an overview of our SME interactions. Section 2 presents our main achievements with SME collaborations and the process we have followed to interact with the SMEs. Section 3 describes the technical details of the methodology we have adopted to create the maturity model. The structure of the proposed maturity model resides in Section 4, and Section 5 demonstrates the application to evaluate usefulness and guide practitioners. Lastly, we discuss further measures on the national and European levels to establish sustainable relationships with SMEs in Section 6.

1 Introduction

The EuroHPC Joint Undertaking (EuroHPC JU) is a legal and funding entity established in 2018 to coordinate the actions of participating countries to make Europe a global supercomputing leader. In this context, the aim is to build, deploy and maintain a world-class supercomputing and data infrastructure in Europe. It encourages cutting-edge supercomputing technologies to mitigate technical reliance on foreign computing technology, extends the usage of HPC infrastructures to large numbers of public and private users, and supports the development of core HPC competencies through training activities for European science and industry. Funded by EuroHPC JU, EuroCC and CASTIEL have established a European network of 33 National HPC competence centers, described in the next section.

1.1 EuroCC and CASTIEL Projects

The EuroCC and CASTIEL projects aim to bridge HPC skill gaps while facilitating collaboration between participating institutions and communication of best practices across Europe. Each of the 33 NCCs acts as a part of the EuroCC network, working at the national level to map existing HPC competencies and determine the gaps in knowledge. These centers coordinate the development of HPC competencies and facilitate access to European HPC opportunities for a wide range of users by serving as a single national contact point.

CASTIEL encourages interaction and sharing of HPC expertise throughout the EuroCC network. The project creates a European competency map showing the resource and knowledge gaps available at all EuroCC Competence Centers. The project also facilitates potential collaborations and sharing of knowledge and expertise between countries to address and fill the gaps. These projects support scientific and innovative projects, strengthen industrial competitiveness, and ensure the technological autonomy of Europe. New supercomputers located in different parts of Europe rank among the top supercomputers. European private and public users will benefit from these new machines throughout Europe. Participating in the ecosystem is particularly critical for SMEs who lack the resources and need mentorship to realize full benefits.

1.2 Benefits of Participating in the EuroHPC Ecosystem for SMEs

Participating in the EuroHPC ecosystem offers many benefits for SMEs. First, it provides the latest technology infrastructure as a cost-effective solution for sustainability and budget-balanced use. If the SME prefers to operate on-premise resources, it must regularly upgrade its infrastructure, as resources become obsolete every five years on average. For new product development that requires physical testing, HPC helps reduce costs, design times, and time-to-market by computational simulations. Producing some products may be impossible or too costly without massively parallel computing infrastructure services.

The main benefit of the EuroHPC ecosystem is the network and collaboration opportunities shaped around cutting-edge technologies. HPC is an essential tool today for science and industry, but achieving superior performance and efficiency with supercomputers requires much expertise. When developing a product, one must develop expertise in these topics, particularly research-oriented codes. Since industrial users' main priority is getting results as quickly as possible, the HPC Centers of Excellence (CoEs) provide training and mentoring. The European Digital Innovation Hubs (EDIHs) help companies improve business processes, products, and services using digital technologies, providing financing advice, developing skills, and reproducing the NCC services locally. In short, these hubs and centers funded by European Union offer services for SMEs to adopt HPC technologies by fostering collaboration between these groups that will create an HPC culture, enabling sustainable innovation. The NCCs act as a single point of contact for SMEs, bridging the skill gaps and facilitating communication and collaboration between SMEs and these groups. The following section gives information about the structure, management, and partnerships of NCC Türkiye.

1.3 Structure of NCC Türkiye

The foundations of NCC Türkiye lean on the Turkish Science e-Infrastructure (TRUBA) 2023 project, operated by the Turkish Academic Network and Information Center (TÜBİTAK ULAKBİM). Since 2003, TRUBA has been a national computing infrastructure primarily serving academia, public institutions, and industry. TÜBİTAK ULAKBİM TRUBA is the coordinator of NCC Türkiye [1] and is responsible for managing projects as well as policy and sustainability-level activities. Middle East Technical University (METU), Sabancı University, and Istanbul Technical University National Center for HPC (ITU UHeM) support the NCC as partners towards the EuroHPC goals and furthers. The NCC structure enables the organization of successful training and workshops, industrial user acquisition, and industrial HPC Proof of Concept (PoC) case studies, presented in Section 2. Figure 1 illustrates the organization of NCC Türkiye with the highlighted perspective.

NCC Türkiye prioritizes an expandible structure to boost available services and reachable audiences. For example, the Technology and Innovation Funding Programmes Directorate (TÜBİTAK TEYDEB), part of our mother institute The Scientific and Technological Research Council of Türkiye (TÜBİTAK), provides a portfolio of companies involved in research and development activities. The technology transfer offices (TTOs) and technoparks help with increasing awareness. To further extend our services, we have collaborated with two European-funded projects, Mind4Machines and SparCity, aligned with EuroHPC goals. The collaboration with Mind4Machines aims to support the HPC infrastructure adoption in manufacturing companies toward more sustainable and resource-efficient manufacturing. The SparCity project collaboration can help maximize sparse computation performance and energy efficiency for SME PoC studies by providing algorithms and tools. Lastly, we collaborate with the NCC Czech Republic in training- and workshop-based events. More collaborations will contribute to the national and European ecosystems in the future, strengthening NCC's services and reach.

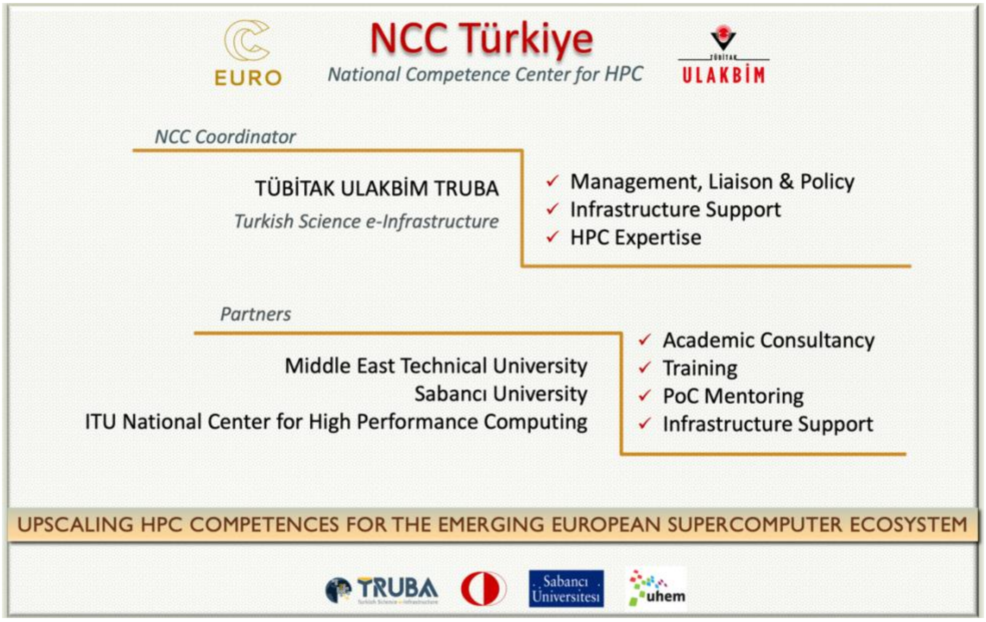

Figure 1: NCC Türkiye's organization

1.4 HPC Adoption in Turkish SMEs

More than 4,500 researchers from different disciplines in our country, regardless of university, public, and industry, are using TRUBA resources to improve innovative research, enhance scientific achievements and compete with peers at the international level. However, NCC Türkiye had limited collaboration with the industry at the infrastructure level before the EuroCC project. TRUBA signs a service agreement with SMEs' projects through the TÜBİTAK TEYDEB channel to enable HPC access. Unaware of HPC's potential benefits and insufficient human resources (HR) with HPC skills, Turkish SMEs do not approach HPC technology adoption sustainably.

The biggest obstacle encountered during the project is establishing collaborations with industrial enterprises and offering solutions to their challenges and problems that would evolve into innovative intellectual and industrial properties. To this end, the NCC was initially designed to be rooted in the most industrialized and financially developed cities (Istanbul and Ankara), enabling it to communicate with local businesses pursuing innovative results. Since TRUBA primarily serves academic researchers, it has been a significant step forward in cooperation with the industry in leveraging Sabancı University's and METU's existing industrial communication channels. Furthermore, the NCC utilizes the current industrial links of ITU UHeM, the principal partner of Türkiye in Partnership for Advanced Computing in Europe (PRACE), to extend industrial collaborations further. We present the main achievements of this structure and the NCC's industrial user acquisition and collaboration processes in Section 2.

2 EuroCC@Türkiye

NCC Türkiye has organized many activities to increase awareness in academia, the public sector, and the industry in the HPC-related fields, support collaboration between academia and industry, and facilitate and widen HPC usage, particularly in SMEs. The NCC Landscape Survey [2] showed a comprehensive picture of the HPC-related competencies across the country. This survey laid a strong base for planning the contents of the activities during the EuroCC Project.

2.1 Main Activities between September 2020 and December 2022

The expert identification form has enabled the creation of a national expert pool and the validation of national experts and competencies. This pool offers a wide range of academic and infrastructure experts in HPC, HPDA, and Artificial Intelligence (AI) to support industrial collaborations. The number and diversity of experts have increased during the project according to the requirements of planned activities.

The NCC organized winter and thematic summer schools in HPC, AI, and HPDA-related domains. Workshops, seminars, and a series of "computhons" (computation hackathons) have further supported awareness-raising activities. In addition, the NCC has organized info days to inform about the EuroHPC calls and to provide a ground for discussion and networking. NCC Türkiye has been exploring collaborations with other NCCs with twinning and mentoring perspectives, such as the High-Performance CFD event with the NCC Czech Republic. The NCC has developed an effective and collaborative platform for beginner-intermediate user documentation in Turkish. The user-oriented documents [3] comprise tutorials, how-to guides, explanations, and reference materials regarding TRUBA HPC infrastructure, following the user-oriented Diátaxis Documentation Framework [4].

Industrial case studies target problems in HPC, Big Data, and AI. A case study is a small-scale PoC project lasting between 3-12 months, which supports industrial users in HPC applications with free Central Processing Unit (CPU), Graphics Processing Unit (GPU), and storage resources on the HPC infrastructure. The goal is to initiate academic-industry collaborations and enable technology transfer. The EuroCC project helped us launch 29 industrial collaborations with SMEs and large companies, using structured processes to start and manage case studies. During these studies, academic and infrastructure experts mentor companies to overcome the challenges. For example, since industrial users are more accustomed to cloud solutions for big data and AI, the infrastructure experts work with the industrial users to run frameworks such as Spark and Dask on the HPC infrastructure, preferably using containers. We consider finalized case studies with remarkable results as success stories and publish them on the NCC website [5], providing visibility for SMEs. The NCC promoted the FF4EuroHPC second call to the companies that conducted EuroCC case studies, enabling Nanografi and ALTI DYNAMICS to find academic and HPC provider partners to apply for the second call with a successful proposal [6].

2.2 Industrial User Acquisition and Case Study Processes

Initially, NCC Türkiye tried to reach industry partners that would benefit from cost and time reductions if they used HPC in their workflows. We found these organizations mainly through the following channels:

- ⇒ We directly contacted the SMEs, inquired from TÜBİTAK TEYDEB's database, that completed the NCC Landscape Survey.
- ⇒ Our academic experts have existing academy-industry research collaborations.
- ⇒ TTOs organized project dissemination activities for technoparks.

The acquisition process (Figure 2) starts if the company has an HPC-suitable problem, determined by a high-level phone call. A meeting with the NCC experts reveals if the company needs mentorship during the case study, and the NCC can provide infrastructure and academic mentorship depending on the gaps. Experts and the company fill out the case study application form consisting of the problem definition, first suggestion, and high-level milestones of the solution. The NCC evaluates whether the problem aligns with the goals of the EuroCC project with the NCC partners using an evaluation method. As the infrastructure partners of the NCC, TRUBA or ITU UHeM allocates needed HPC resources for the case study evaluated successfully above the threshold.

During a 6-month case study process (Figure 3), we request an update for the case study report in the 3rd month. If a problem hinders the work progress, we request an update from the company to gather lessons learned before closing the case study. In the end, we close the case study after receiving the final case study report. If the company has realized business benefits, we also request the case study experts to fill out a success story form, disseminating results and providing the business visibility through the NCC website. The following section provides the results of our industrial collaborations using the industrial user acquisition and case study processes.

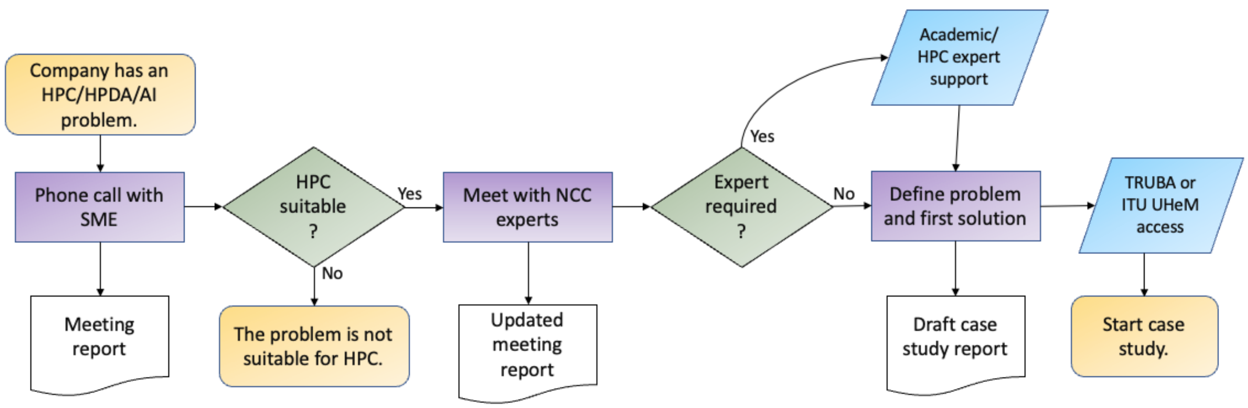

Figure 2: Industrial user acquisition process

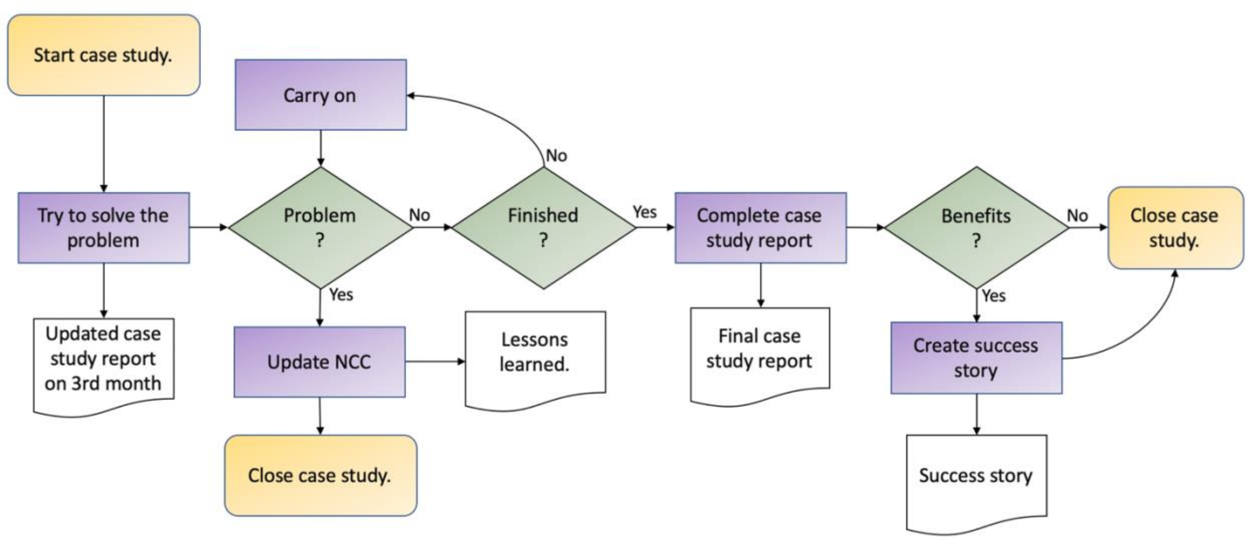

Figure 3: Industrial case study process

2.3 Results and the Main Benefits for SMEs

NCC Türkiye has initiated 29 case studies with the industry, 21 of which are SMEs (Figure 4). The NCC completed 19 case studies, with 8 success stories in HPC, HPDA, and AI domains from the manufacturing, transportation, social media, and engineering sectors as of November 2022. A success story is a complete case study with business benefits for the participating industrial organization. Many industrial success story companies experienced the HPC environment for the first time, realized cost savings, decreased computation time, and solved complex engineering problems. The industrial user acquisition (Figure 2) and case study (Figure 3) processes have enabled partnerships with the HPC Center and academia. We encouraged the partners to apply for the 2nd call of FF4EuroHPC, a European initiative that funds SMEs toward adopting HPC-related technologies. Nanografi and its case study partners were successful in the 2nd call. Figure 5 and Figure 6 show the case studies conducted by NCC Türkiye by the sector and subject domains.

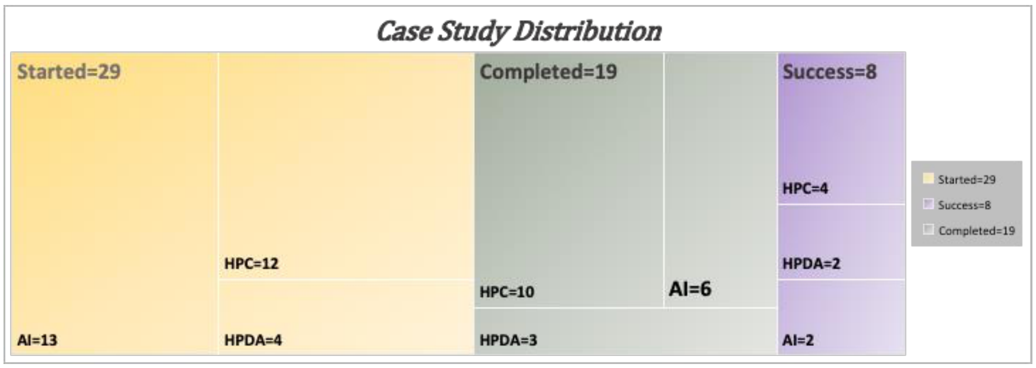

Figure 4: Distribution of industrial case studies according to HPC, HPDA/big data, and AI domains

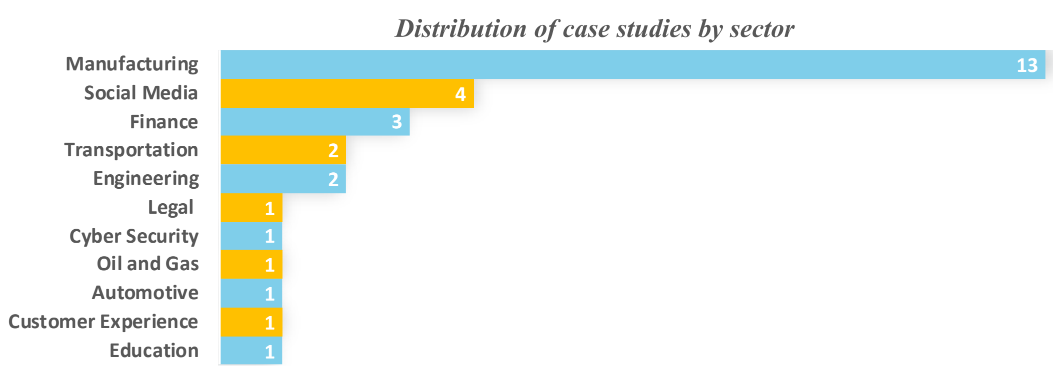

Figure 5: Distribution of industrial case studies by sector

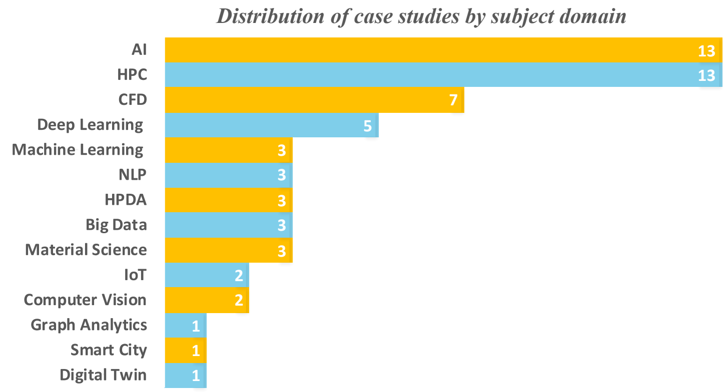

Figure 6: Distribution of industrial case studies by subject domains

2.4 Challenges and Our Solution Efforts

The NCC encountered many challenges in the industrial user acquisition, case study, and after-case study phases. We believe many of the challenges are also valid in other European countries. Therefore, this section explains our significant challenges for public and private sector organizations with our solution efforts, if applicable.

Lack of awareness about the potential benefits of HPC: SMEs are unaware that they can use HPC for competitive advantage in the fast-growing business world. We approached many SMEs with direct phone calls through the channels stated in Section 2.2 to explain the potential benefits using available success stories from Fortissimo and PRACE SHAPE. Additionally, we organized various dissemination activities, including industrial and scientific seminars, workshops, info days, conferences, and panels, to highlight the benefits of HPC for SMEs. In some events, we provided SME participants with training accounts based on a brief application form so that they could have an opportunity to run example applications on the infrastructure.

Lack of HPC strategy and vision in organizations: Many organizations don't approach HPC adoption sustainably since they don't know how HPC fits into their long-term business objectives. We believe the SMEs are trying to survive the competition and meet the demands of investors in a much shorter term, so they cannot plan HPC adoption. So, we started by contacting SMEs with employees who have used national HPC infrastructures for academic studies. These employees could convince the top management and train their colleagues to overcome the initial learning barrier.

Lack of experienced HPC personnel in SMEs and HPC has an initial learning process: Still, finding qualified personnel working in the HPC field is the main barrier for SMEs. If the SME dedicates staff to the case study who can devote a specific amount of time, NCC academic and infrastructure experts deliver training and guidance. The NCC has also prepared beginner to intermediate-level user-oriented tutorials and how-to-guides [3]. However, this matter could still be challenging when the industrial user does not allocate the necessary time.

Companies, familiar with their current resources, don't want to move their workloads to the HPC infrastructures: They also don't dedicate a person-month if they don't approach HPC adoption strategically. We tried to overcome this obstacle by providing education and skills development to the SMEs during the case study process.

Aligning academic and industrial expectations: Sometimes, the SMEs and the academy's perspectives on the problem conflict. While companies are concerned with immediate outcomes, academia expects more intellectual output. Overall, the EuroCC project has been a good initial step toward strengthening the industry-academia collaboration.

Commercial software is costly/a low tendency to use open-source codes: From a financial perspective, commercial software licenses have high costs for SMEs. Open-source software, on the other hand, is more accessible. Most of the training events we offer to SMEs focus on employing open-source software. We believe this approach drastically reduces the expenses for SMEs with low budgets.

Concern about security and data protection regulations: We could not initiate some case studies due to intellectual property, sensitive data, and data security matters. We overcame this barrier in cases where the academic expert and the company signed nondisclosure agreements. Furthermore, we encouraged companies to try the infrastructure by using open or synthetic data on the HPC infrastructure.

Large manufacturing enterprises would rather not wait in a job queue due to their limited time/deadlines. Large companies mainly prefer to use in-house systems due to commercial security, organizational investments, and qualification/verification processes. Sustainably maintaining these systems can also be incredibly challenging. Meanwhile, formerly unaware of HPC's benefits, SMEs notably enhanced performance and customizable delivery. Likewise, large companies can run their jobs effectively, accurately, and quickly in larger-scale systems, primarily using GPU-accelerated partitions. Therefore, we encouraged all industrial users by defining prioritized EuroCC project groups on the HPC infrastructure.

Companies' problems are not large-scale enough to use HPC, or they are not brave enough to increase the size of their problems: Even if some companies have large-scale problems, they delay their projects due to the lack of resources and expertise. With the support of academic and infrastructure experts of the NCC, companies can run better models in the same amount of computing time by effectively implementing the parallelization method. If the national infrastructures are insufficient, we tried to direct them toward pre-exascale supercomputer facilities in Europe.

Limited national HPC resources: TRUBA and ITU UHEM, two government-supported national HPC centers, primarily provide services and resources to academia. We envisaged that there would be a resource shortage due to the academy's intensive use of these resources and the rapid rise in industrial usage. In such scenarios, NCC Türkiye encourages companies to apply for EuroHPC calls. Companies having large-scale problems, in particular, are encouraged to apply. For this purpose, we organized info days to improve awareness about these calls, and if necessary, we can further help with the call applications. The aim is to provide information on preparing and submitting a proposal for upcoming calls and ground for networking.

Finding simulation problems that converge AI and big data to HPC are challenging: It can be difficult to find industrial use cases where the fields of big data, AI, and simulation converge. In such cases, engineers and scientists working on simulations are unfamiliar with highly adopted big data and AI frameworks. On the other hand, big data and AI engineers don't have domain expertise. We plan to initiate multidisciplinary collaborations in the upcoming phase of the EuroCC project to overcome this challenge.

Initiating case studies with the public administrations: Public administrations prefer to utilize on-premise systems and have concerns about data security. NCC is still having issues interacting with the public administrations and integrating HPC into their workflows.

Newly developing national EDIH & CoE ecosystem for HPC: We have limited participation from our national centers to the European initiatives for HPC. We have tried to beat this challenge by organizing info days and transferring knowledge from CASTIEL to the public sector and academic contact points.

These obstacles lead to the final challenge of initiating sustainable and mutually beneficial collaborations with SMEs. In the next phase of the EuroCC project, we want to be able to assess the SMEs' as-is situation regarding HPC capabilities, tailor our services for varying SME needs, and measure the effectiveness of our services. Therefore, we have developed a maturity model by following a well-defined methodology explained in the following section to answer the following questions:

- How to decide if we can create a sustainable relationship with an SME?
- How to agree on expectations from each EuroCC HPC experience level [7]?
- How to assess an SME's as-is situation regarding HPC capabilities?
- How to tailor-make our services for varying needs?
- How to measure the effectiveness of our industrial collaborations?

3 Maturity Model Development Methodology

The methodology of this white paper builds on many SME collaboration experiences and interdisciplinary research expertise to help SMEs increase their HPC capabilities by assessing the current situation, identifying the gaps, and examining reasonable improvements. We have adopted the maturity model approach since such models have proved their importance in IT management [8]–[10]. Maturity models assess an organization's as-is situation regarding its IT capabilities, derive and prioritize improvement measures, and control implementation progress [10]. We followed a well-defined procedure based on [8]–[10] to develop the maturity model, illustrated in Figure 7. The following paragraphs elaborate on each step of the procedure.

The first step is determining the model development approach. We decided to use capability maturity models, which provide means to improve processes to achieve higher quality across a project, a division, or an entire organization [8], [11]. Hundreds of organizations worldwide have utilized these models because research studies consistently demonstrate results regarding significant advantages in productivity and quality [11], [12].

The proposed SME HPC Maturity Model (SME-HPC-MM) has embraced the EuroCC experience level definitions [7] as organizational maturity levels. Since the focus is on increasing HPC capabilities, we adopted the ISO/IEC 330xx family standards [13]–[16] for process assessment, also known as software process improvement and capability determination (SPICE). SPICE consists of a set of technical standards and documents jointly developed by the International Organization for Standardization (ISO) and the International Electrical Commission (IEC). Multiple studies have customized SPICE for disciplines such as automotive [17], digital transformation [8], data science [9], and information security [18] since the capability dimension of SPICE applies to all processes across all domains [8]. Therefore, we used the technical standards to evaluate SME HPC capabilities exhaustively, customizing the process definitions according to HPC.

We formed an expert panel to identify the SME HPC processes. The experts were interdisciplinary researchers in senior and principal positions in NCC Türkiye, specializing in project management, mathematics, chemistry, physics, HPC, data science, big data, and information systems. They follow all SME case studies from the contact phase to the end and provide technical expertise when required. After iteratively developing and agreeing on the definitions, the expert panel assigned processes to maturity levels and established the relationship between capability and maturity levels. The set of processes for each maturity level determines the organizational SME HPC maturity level (Figure 10). A demo assessment followed by a demonstration in an SME with domain experts and practitioners provided data to improve the maturity model further and evaluate its usefulness. Figure 7 maps each development stage to the subsequent sections in the white paper.

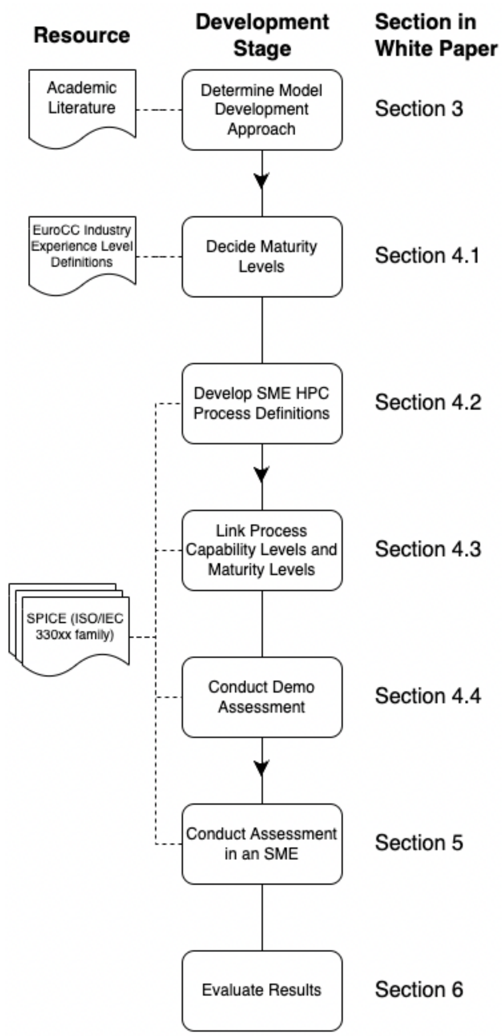

Figure 7: SME-HPC-MM development methodology (based on [8]–[10])

4 The SME HPC Maturity Model

This section explains the SME-HPC-MM, the maturity level definitions, the process and capability dimensions, and the relationships between maturity and capability levels. We have tried to keep the maturity model reasonable, lean, practical, and valuable following our SME collaborations. Still, an SME might not understand how to use the maturity model at first glance. In that case, our NCC can work with the SME, and our experts will help assess the current situation regarding SME's HPC capabilities, identify the gaps, and prioritize improvement opportunities.

4.1 Maturity Levels

The SME-HPC-MM adopts the definitions of EuroCC HPC experience levels as organizational SME HPC maturity levels [7] (Figure 8), adding the *HPC Innovator* level to the top. *Digitalization-needed* SMEs have not digitalized their processes yet. *Digitally ready* SMEs have digitalized some of their operations, but they are unaware of the benefits of using HPC or associated technologies. *HPC-ready* firms are potential HPC users but haven't used HPC before. *HPC users* take advantage of HPC-related technologies from beginner to intermediate levels. While the *HPC champions* are the experts in HPC technologies, *HPC Innovators* may contribute to the ecosystem by developing their solutions. Our proposed maturity model starts by assessing the HPC-ready level since we evaluate the SME from the HPC perspective, not the digital transformation perspective. For example, an EDIH can use the digital maturity assessment tool linked with the Digital Europe program [19] to help a digitalization-needed SME become digitally ready.

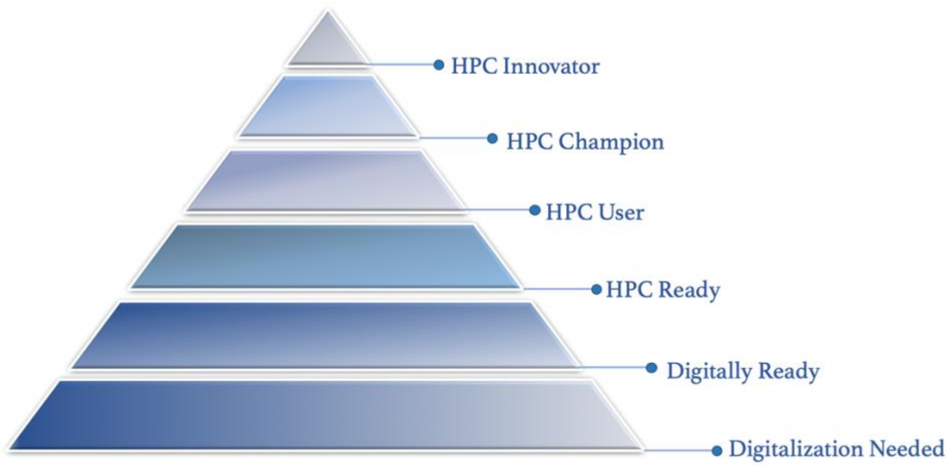

Figure 8: SME HPC maturity levels (based on [7])

4.2 Process Dimension

Sustainable benefits from HPC technologies depend on comprehensive strategic, executive, and technical process management. Accordingly, SME-HPC-MM classifies the processes under strategy management, data management, technology management, distributed and parallel application development, and supporting processes. We define each process from the *SME HPC utilization perspective*, using ISO/IEC 33004 [14], which states a process definition that covers the process name, purpose, outcomes, base practices (BPs), and output work products. Figure 9 depicts the processes that fall into each category, and **Appendix A – Process Definitions** provides the process definitions. In addition to the NCC's industrial collaboration experiences, the process definitions utilize additional resources to support data management [20]–[22], innovation management [23], and project management [24].

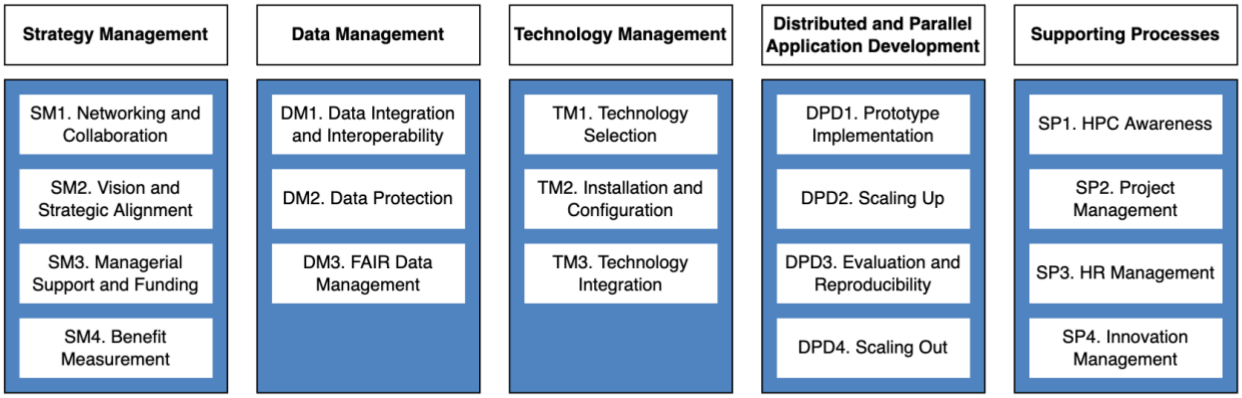

Figure 9: SME-HPC-MM process categories and processes

4.3 Capability Dimension and Organizational SME HPC Maturity

The SME-HPC-MM adopts the capability levels from [9], in which the process attributes (PAs) ratings define each capability level [8]. A PA is a measurable property of the process capability [9]. A Capability Level 1 process assessment checks the BPs described in the SME HPC process definitions to derive PAs, while Level 2-to-5 process assessments examine the generic practices described in SPICE. The SME-HPC-MM considers capability levels up to level 2 since our industrial collaboration experiences show it is challenging for SMEs to allocate resources beyond this capability level regarding HPC-related processes. Table 1 depicts the capability levels and associated PAs and ratings.

After establishing the process dimension and capability dimension, the expert panel identified processes that fall into the maturity levels and set the relationships between maturity levels and capability levels based on their expectations of SMEs that fall into each maturity level. Figure 10 illustrates the relationships between maturity levels and capability levels and the processes associated with each maturity level.

Table 1: Capability Levels and PAs (adopted from [9], [15])

Capability Level	Process Attributes	Rating	Achievement
Level 0 Incomplete	Not Applicable	Not Applicable	There is no initiative to implement the process.
Level 1 Performed	PA-1.1: Process Performance	Largely Achieved	The BPs are performed in an ad-hoc manner.
Level 2 Managed	PA-1.1: Process Performance	Fully Achieved	The process is implemented, planned, and monitored. In addition, the output work products are established, controlled, and maintained.
	PA-2.1: Work Product Management	Largely Achieved	
	PA-2.2: Performance Management	Largely Achieved	

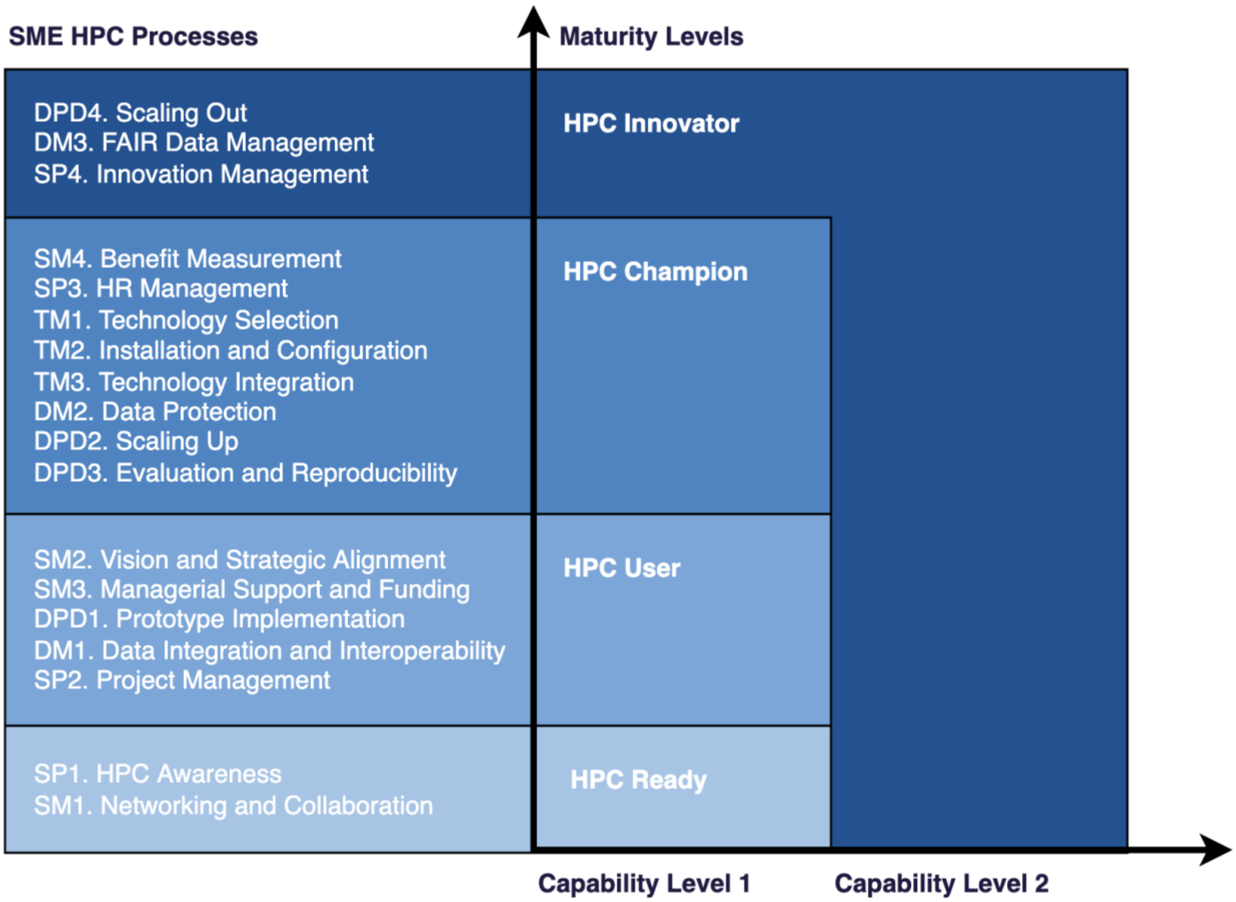

Figure 10: The relationships between maturity levels and capability levels and the processes associated with each maturity level (based on [7]–[9])

4.4 Demo Assessment

Following the identification of initial maturity levels and corresponding process capability levels, the expert panel performed a demo assessment in a three-hour-long meeting. Two people who helped the SME run simulations in the HPC infrastructure simulated the SME. Two people played the assessor role, and two facilitated and observed the assessment process. The demo assessment revealed the unclear and ambiguous definitions in process definitions. The team agreed on changing several linkages between process capability and maturity levels. The expert panel suggested that a questionnaire for the updated process definitions can help with the maturity assessment. The last discussion was about preventing the SME participants from feeling frustrated and discouraged. The expert panel conceded that assessors and the SME could first determine a target level and begin the evaluation by asking questions corresponding to the lowest maturity level. The assessment would end at the target level or if the SME does not implement many processes at the current maturity level.

5 Demonstration of SME HPC Maturity Model

As part of the model development, we conducted an exploratory study in an SME that utilizes HPC for AI before finalizing the SME-HPC-MM. This demonstration enabled the model design team to evaluate the maturity model's usefulness. Furthermore, we intend this demonstration to guide practitioners in further applications of SME-HPC-MM. The target SME has provided worldwide machine learning consultancy and customized AI software development services for over ten years. NCC Türkiye and the SME have collaborated on a EuroCC case study, where the SME has used HPC services for AI for the first time. During the maturity assessment, we collected data by performing semi-structured interviews with the people from the case study SME and observing outputs, such as documents, plans, tools, and experiences. NCC experts (three evaluators and two observers) met with the Chief Executive Officer and Chief Operating Officer on August 22, 2022, for one hour to conduct the assessment.

5.1 SME HPC Maturity Level Determination

In this exploratory study, we performed a Capability Level 1 process assessment by rating the process BPs. The four-point rating scale used for rating BPs shows the extent of the achievement according to [16]:

Not Achieved: The achievement level is between 0% and 15%.
Partially Achieved: The achievement level is between 16% and 50%.
Largely Achieved: The achievement level is between 51% and 85%.
Fully Achieved: The achievement level is between 86% and 100%.

expert panel derives the PA rating for all processes based on their BP ratings. The PA rating determines the process capability level. A process capability level will be Level 1 if the process' PA 1.1 rating is at least largely achieved (Table 1). The organizational maturity level depends on the process capability levels, as depicted in Figure 10. Based on a single-round Delphi technique for reaching group consensus [25], each evaluator derives the process PA ratings based on BP ratings individually. They send their ratings to a facilitator, who provides a summary, pointing out the significant differences in judgments. Then the evaluators can revise their PA ratings to reach a group decision or consensus. shows the capability level assessments of the SME. Table 2 shows PA ratings with corresponding capability levels for two example processes, and Table 3 shows the capability level assessments of the SME.

5.2 Gap Analysis, Improvement Opportunities, and Assessment Report

The assessment reveals the gaps regarding missing HPC processes in the SME. A gap analysis shows the lacking processes in the case study SME that prevents the SME reach the next maturity level. For example, the SME under evaluation is an HPC User and needs to implement data protection, scaling up, and HR management processes to reach the HPC Champion level (Figure 11). In return, Table 4 exhibits the prioritized reasonable capability improvement opportunities.

The assessment report comprises brief information about the maturity model, assessment results, prioritized improvement opportunities, and an executive summary. Most importantly, the report should reveal an action plan for reasonable improvement opportunities, the business benefits that incentivize the SME to reach the next level, and how the NCC can help bridge the gaps.

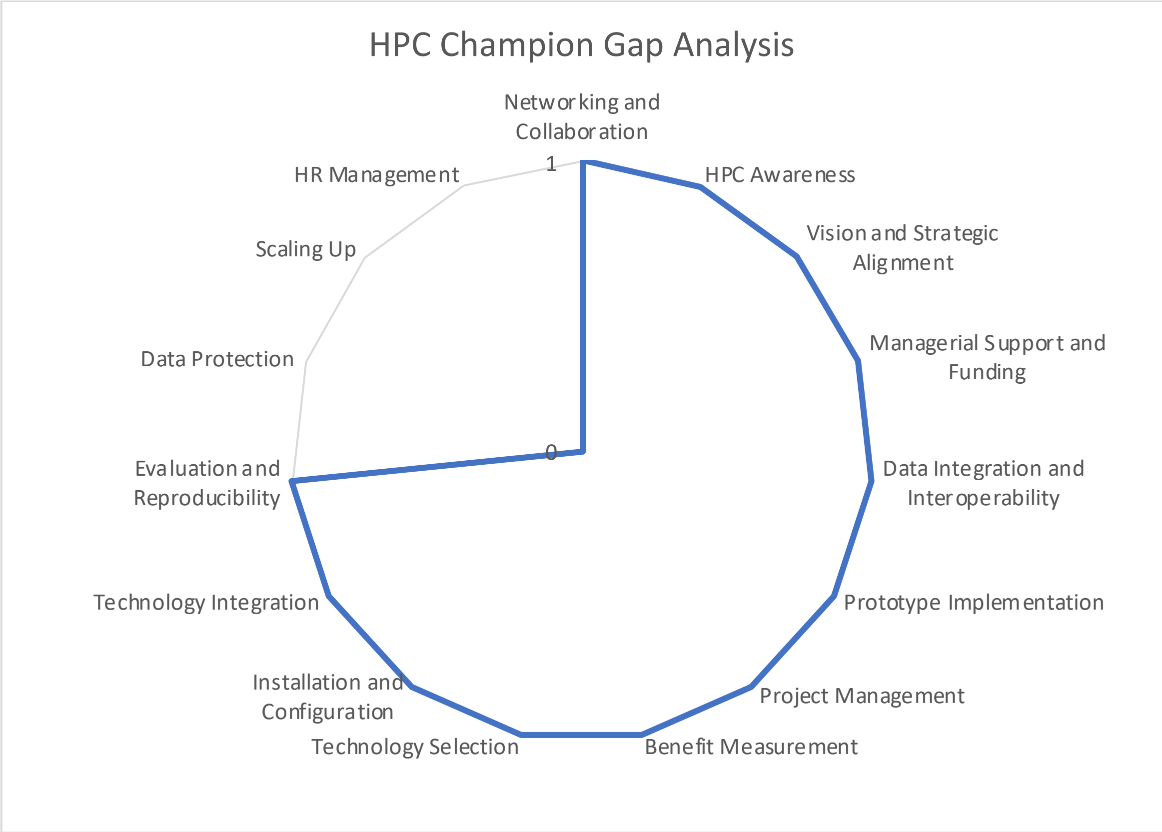

Figure 11: HPC Champion gap analysis for the SME

Table 2: PA ratings with corresponding capability levels for two example processes. While the evaluators don't need to change their PA rating for SM3, they need to reach a consensus for DPD2 since the largely achieved PA rating indicates a process capability of level 1.

Process ID	Process Name	Process Area	Evaluator 1 – PA Rating	Evaluator 2 – PA Rating	Evaluator 3 – PA Rating	Process Capability Level – Consensus
SM3	Managerial Support and Funding	Strategy Management	Fully Achieved	Largely Achieved	Largely Achieved	1
DPD2	Scaling Up	Distributed and Parallel Application Development	Not Achieved	Largely Achieved	Partially Achieved	0

Table 3: Capability level assessments of the SME (based on [8], [9])

Maturity Level	Process ID	Process Name	Process Area	Process Capability Level	HPC Champion Capability Level Requirement
HPC Ready	SM1	Networking and Collaboration	Strategy Management	1	1
	SP1	HPC Awareness	Supporting Processes	1	1
HPC User	SM2	Vision and Strategic Alignment	Strategy Management	1	1
	SM3	Managerial Support and Funding	Strategy Management	1	1
	DM1	Data Integration and Interoperability	Data Management	1	1
	DPD1	Prototype Implementation	Distributed and Parallel Application Development	1	1
	SP2	Project Management	Supporting Processes	1	1

HPC Champion	SM4	Benefit Measurement	Strategy Management	1	1
	TM1	Technology Selection	Technology Management	1	1
	TM2	Installation and Configuration	Technology Management	1	1
	TM3	Technology Integration	Technology Management	1	1
	DPD3	Evaluation and Reproducibility	Distributed and Parallel Application Development	1	1
	DM2	Data Protection	Data Management	0	1
	DPD2	Scaling Up	Distributed and Parallel Application Development	0	1
	SP3	HR Management	Supporting Processes	0	1
HPC Innovator	DM3	FAIR Data Management	Data Management	0	0
	DPD4	Scaling Out	Distributed and Parallel Application Development	0	0
	SP4	Innovation Management	Supporting Processes	0	0

Table 4: The prioritized capability improvement opportunities for the case study SME

SME HPC Process	Current Capability	Capability Improvement Opportunities	Priority
HR Management	Part-time personnel help with technical tasks and most team members have academic and sectoral experience. They know TRUBA HPC System because of their academic studies. The SME is actively searching for new people to work on the technical side. However, there is no initiative for obtaining HPC-related skills through training or job posting.	The company can prepare a training checklist for new technical recruits to overcome the initial learning curve for using the GPU resources on HPC systems.	High
		The SME can apply for European project grants to acquire funding for new employees. The recruits can pick up the HPC skills following the training checklist.	Medium
Data Protection	The company identifies the HPC-related commercially sensitive datasets, knows the regulations applicable to these datasets, and broadly understands the data protection requirements. However, a comprehensive data management plan that defines the standards and regulations together with data sharing, archiving, and preservation policies partially exists. The SME has not implemented data protection for HPC-related datasets.	The SME should prepare a data management plan, defining the HPC-related datasets with applicable standards and regulations. The data management plan should also describe the data sharing, archiving, and preservation policies.	High
		The SME should select and apply an appropriate technique to implement data protection.	Medium
Scaling Up	The SME has run AI applications on the national HPC infrastructure using multiple GPUs on a single node. However, they don't define the performance metrics that should improve with more GPU resources on a single node.	The SME can define a performance metric that should improve by using more resources on a single node.	Medium
		The company can use the HPC infrastructure to implement benchmarks on the same node, visualizing the results.	Low

6 Discussion and Conclusion

The industrial success stories demonstrate that SMEs can decrease the design times while increasing the performance of the designs using the HPC system with reduced costs compared to on-premise and cloud systems. Moreover, they increase networking and collaboration with NCC, HPC centers, and academia. These collaborations lead to mentorship, computation time, funds, and increased visibility through case studies and success stories. The SME-HPC-MM can further support the SMEs' participation in the EuroHPC ecosystem by setting common expectations around HPC experience levels. The model enables the assessment and prioritization of the gaps in SMEs regarding HPC capabilities. Then the NCC can derive an action plan and offer tailored services to bridge the gaps.

The NCCs can also apprehend how sustainable an SME approaches HPC adoption using the assessment model. Nevertheless, the model will not be the silver bullet for overcoming all the challenges behind upscaling SMEs toward the EuroHPC ecosystem and establishing sustainable relationships with them. Additional measures are necessary both on the national and European levels. For example, the NCCs can support the HPC Champion SMEs with more resources on the national infrastructures, and the EuroHPC can devise mechanisms on the European supercomputers to incentivize becoming an HPC Innovator SME based on concrete, objective, and transparent assessments. Still, an SME cannot readily scale its application from national HPC systems to a European-level supercomputer, select the best system, and adapt application codes between systems. A new technology management task force can help bridge this gap by guiding SMEs and providing feedback to HPC providers.

In the next step, NCC Türkiye plans to tailor and measure our services for SMEs employing SME-HPC-MM, encouraging academic and infrastructure-level collaborations in a more structured fashion. Our NCC can collaborate with EDIHs on the national level for dispersing to different strategic cities of Türkiye for more effective knowledge transfer between academia and industry. The model can also assist SMEs participating in the EuroHPC ecosystem in other countries. We provide the methodology and detailed process definitions for developing SME-HPC-MM. Therefore, NCCs can tailor-make the model according to their circumstances or reach a consensus on one common expectations model across NCCs. NCC Türkiye foresees extending the model to assess HPC capabilities for large organizations, public bodies, and academia, depending on the success of the applied SME-HPC-MM.

CRediT Authorship Contribution Statement

Kerem Kayabay: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization, Project Administration **Ozlem Sari:** Formal Analysis, Investigation, Validation, Writing – Original Draft, Writing – Review & Editing, Visualization **Merve Demirtas:** Formal Analysis, Investigation, Validation, Writing – Original Draft, Writing – Review & Editing, Visualization **Sezen Bostan:** Validation, Writing – Original Draft, Writing – Review & Editing **Burcu Ortakaya:** Conceptualization, Validation, Writing – Review & Editing, Supervision, Project Administration

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Appendices

Appendix A – Process Definitions

Table 5: Process definition for Networking and Collaboration

Process Reference	**ID**	SM1
	Name	Networking and Collaboration
	Purpose	To collaborate with other SMEs, HPC Centers, NCCs, EDIHs, or academia who can support the SME for prototype implementation, skill development, and funding towards successful HPC adoption.
	Outcomes	1. Contacts in the HPC ecosystem such as technology providers, HPC centers, academia, experts, and funding mechanisms are found. 2. Channels (e.g., web page forms, surveys, user forums, phone call) to create new contacts are used. 3. Collaborations in experiments, projects, funding opportunities, and infrastructure access are created.
Process Performance Indicators	**Base Practices**	**SM1.BP1:** Identify national and European-level stakeholders participating in the HPC ecosystem. → [Outcome: 1] **SM1.BP2:** Identify and use channels to reach the stakeholders such as NCCs and EDIHs, and HPC infrastructure providers. → [Outcome: 2] **SM1.BP3:** Create collaborations through projects (e.g., case studies, use cases, pilots, experiments) and funding applications (e.g., FF4EuroHPC, Mind4Machines). → [Outcome: 2, 3] **SM1.BP4:** Share collaboration experiences through suitable channels. → [Outcome: 3]
	Output Work Products	Emails and meeting minutes with stakeholders participating in the HPC ecosystem → [Outcomes: 1,2] Collaboration outputs published by the SME such as social media posts, position paper, white paper, magazine article, success story, blog post, case study report, academic publications → [Outcome: 3]

Table 6: Process definition for Vision and Strategic Alignment

Process Reference	**ID**	SM2
	Name	Vision and Strategic Alignment
	Purpose	To determine how HPC systems provide competitive advantage to the SME and how to sustain return on investments for HPC systems
	Outcomes	1. Computation or data-intensive HPC-suitable problems are defined. 2. Business benefits of the solution, such as customers willing to buy the solution, are discussed. 3. SME's business objectives by adopting HPC technology are established. 4. HPC vision and strategy that explain the linkages between HPC resources and business objectives are created.
Process Performance Indicators	**Base Practices**	**SM2.BP1:** Define HPC-suitable problem(s). → [Outcome: 1] **SM2.BP2:** Identify business benefits (e.g., reduction in cost or design time) for the SME. → [Outcomes: 2, 3] **SM2.BP3:** Establish HPC vision and strategy. → [Outcome: 4]
	Output Work Products	Problem definition suitable for a pilot study on an HPC system → [Outcome: 1] A brief statement in any document explaining the linkages between HPC resources and business goals and priorities (e.g., sustainability) [Outcomes: 2,3,4]

Table 7: Process definition for Managerial Support and Funding

<table>
<tr><td rowspan="4">Process Reference</td><td>ID</td><td>SM3</td></tr>
<tr><td>Name</td><td>Managerial Support and Funding</td></tr>
<tr><td>Purpose</td><td>To find and allocate resources to access and use HPC systems effectively and sustainably.</td></tr>
<tr><td>Outcomes</td><td>1. Available access modes and calls to use HPC system are identified.
2. Submissions to call applications are made.
3. HPC system access is granted.
4. Funding in terms of compute time, budget, and person-hour to effectively use the HPC system is established.
5. Employee commitment is monitored.</td></tr>
<tr><td rowspan="2">Process Performance Indicators</td><td>Base Practices</td><td>SM3.BP1: Assign person-hours to follow through all the processes and effectively integrate the HPC system to business processes. Monitor and encourage employee commitment. → [Outcomes: 4,5]
SM3.BP2: Research and select an HPC access mode and prepare application with your partners. → [Outcome: 1,2,3]
NOTE 1: Identification of available and adequate HPC systems belongs to the Technology Selection process.
NOTE 2: Finding partners belongs to the Networking and Collaboration process.
NOTE 3: Measuring business value belongs to the Benefit Measurement process.
NOTE 4: A reward system based on the quantifiable metrics belongs to the HR Management process.</td></tr>
<tr><td>Output Work Products</td><td>Summary of access modes, calls, and deadlines → [Outcome: 1]
Application documents → [Outcome: 2]
Username(s) and associated compute time and storage quota for the HPC system → [Outcomes: 3,4]
Responsible employee(s) → [Outcome: 4]
Meeting minutes for periodic meetings to monitor commitment → [Outcome: 5]</td></tr>
</table>

Table 8: Process definition for Benefit Measurement

<table>
<tr><td rowspan="4">Process Reference</td><td>ID</td><td>SM4</td></tr>
<tr><td>Name</td><td>Benefit Measurement</td></tr>
<tr><td>Purpose</td><td>To ensure the organization is effectively achieving its HPC-related business objectives</td></tr>
<tr><td>Outcomes</td><td>1. A system to define and monitor quantifiable performance and result metrics is established.</td></tr>
<tr><td rowspan="2">Process Performance Indicators</td><td>Base Practices</td><td>SM4.BP1: Define quantifiable metrics for the HPC-related projects. → [Outcome: 1]
NOTE 1: Identification of the business objectives belongs to the Vision and Strategic Alignment process.
SM4.BP2: Follow up the progress and update the metrics if necessary. → [Outcome: 1]
NOTE 2: A reward system based on the quantifiable metrics belongs to the HR Management process.</td></tr>
<tr><td>Output Work Products</td><td>Metrics defined in a suitable interface such as excel or web page → [Outcome: 1]
Meeting minutes for periodic meetings to monitor the progress on metrics → [Outcome: 1]</td></tr>
</table>

Table 9: Process definition for Data Integration and Interoperability

Process Reference	**ID**	DM1
	Name	Data Integration and Interoperability
	Purpose	To make data accessible and interoperable on heterogeneous infrastructure, hardware, software, and services using common communication protocol and data model
	Outcomes	1. Data transfer, storage, processing, and reusability requirements on the HPC system are identified. 2. Data transfer interface for HPC system is devised. 3. Data is transformed into a standard format to be stored and processed on the HPC system.
Process Performance Indicators	**Base Practices**	**DM1.BP1:** Identify data storage, processing, and reusability requirements (e.g., storage space) for the HPC system. → [Outcome: 1] **DM1.BP2:** Devise a data transfer interface (e.g., the SCP command) for the HPC system. → [Outcome: 2] **DM1.BP3:** Transform data into a standard format according to storage, processing, and reusability requirements. → [Outcome: 3]
	Output Work Products	Data integration and interoperability requirements specification → [Outcome: 1] Data sharing interface → [Outcome: 2] Data in standard format → [Outcome: 3]

Table 10: Process definition for Data Protection

Process Reference	**ID**	DM2
	Name	Data Protection
	Purpose	To protect HPC-related commercially sensitive or personal data during ingestion, storage and processing for privacy, confidentiality, and security
	Outcomes	1. Policies that control data access, usage, and sharing are created. 2. Data protection requirements are understood. 3. Techniques to protect sensitive or personal data are devised.
Process Performance Indicators	**Base Practices**	**DM2.BP1:** Identify and describe HPC-related commercially sensitive or personal datasets. → [Outcome: 1] **DM2.BP2:** Identify and describe standards and regulations. → [Outcome: 1] **NOTE 1:** The SMEs and large companies may have different obligations[1]. **DM2.BP3:** Establish data sharing policy. → [Outcome: 1] **DM2.BP4:** Establish data archiving and preservation policy. → [Outcome: 1] **DM2.BP5:** Create a data management plan. → [Outcome: 1] **DM2.BP6:** Identify data protection requirements. → [Outcome: 2] **DM2.BP7:** Implement data protection. → [Outcome: 3]
	Output Work Products	Data management plan → [Outcome: 1] Data protection requirement specification → [Outcome: 2] Models trained on synthetic data → [Outcome: 3] Models trained on open data → [Outcome: 3] Non-reversible transformation technique → [Outcome: 3] Encryption and decryption technique → [Outcome: 3]

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Table 11: Process definition for Data Integration and Interoperability

Process Reference	**ID**	DM3
	Name	Findable, Accessible, Interoperable, and Reusable (FAIR) Data Management
	Purpose	To make sure internal or external employees and computational systems can find, access, interoperate, and reuse HPC-related data with zero or minimal effort.
	Outcomes	1. The implications and benefits of FAIR guiding principles to SME's data management policies and implementation are understood. 2. Dataset-specific requirements are identified according to FAIR principles. 3. Technologies that implement FAIR data management such as repositories and architectures are adopted. 4. Data management plan is updated periodically to reflect the FAIR principles and implementation.
Process Performance Indicators	**Base Practices**	**DM3.BP1:** Identify the implications and benefits of using FAIR guiding principles. → [Outcome: 1] **DM3.BP2:** Identify dataset-specific requirements such as repositories, policies, and standards. → [Outcome: 2] **DM3.BP3:** Implement FAIR data management using technologies that meet the dataset-specific requirements. → [Outcome: 3] **NOTE 1:** Selecting the appropriate set of technologies belongs to the Technology Selection process. **DM3.BP4:** Set up periodic meetings to update the data management plan according to the FAIR principles and implementation. → [Outcome: 4]
	Output Work Products	FAIR data management requirements specification → [Outcomes: 1,2] Data management technologies implement FAIR data management → [Outcome: 3] Data management plan reflects the FAIR principles and implementation → [Outcomes: 1,4] Meeting minutes for periodic meetings to update the data management plan → [Outcome: 4]

Table 12: Process definition for Technology Selection

Process Reference	**ID**	TM1
	Name	Technology Selection
	Purpose	To find the suitable set of technologies that satisfy HPC-related processes considering the requirements for each technology category and SME's technology vision.
	Outcomes	1. The technology categories for the HPC-related processes are identified. 2. An HPC technology vision is created. 3. A decision-making or assessment approach to select suitable technologies according to SME's technology vision and requirements is devised. 4. Technologies are selected using the decision-making approach
Process Performance Indicators	**Base Practices**	**TM1.BP1:** Identify the technology categories for HPC-related processes such as HPC systems, data sharing, and programming languages. → [Outcome: 1] **TM1.BP2:** Create a technology vision statement (e.g., open-source) considering the organizational, technical, and environmental components for HPC-related technologies. → [Outcome: 2] **TM1.BP3:** Establish a decision-making or an assessment approach that takes into account the HPC technology vision statement and requirements. → [Outcome: 3] **NOTE 1:** Determination of requirements for each technology category belongs to dedicated processes.

		TM1.BP4: Apply the decision-making approach to determine the suitable set of technologies. → [Outcome: 4]
	Output Work Products	HPC technology categories for the HPC-related processes → [Outcome: 1] HPC technology vision statement published on a web page or strategy document → [Outcome: 2] Decision-making or assessment approach for technology selection → [Outcome: 3] The decision-making or assessment approach is applied to determine: → [Outcome: 4] - Available and adequate HPC systems - Data management technologies - Distributed and parallel application development technologies

Table 13: Process definition for Installation and Configuration

Process Reference	**ID**	TM2
	Name	Installation and Configuration
	Purpose	To set up the technologies with proper software settings to achieve the objectives.
	Outcomes	1. Installation is planned and documented. 2. Installation and configuration steps are completed. 3. Tests are devised and performed.
Process Performance Indicators	**Base Practices**	**TM2.BP1:** Plan the installation considering compatible packages, installation method, and target system specifications. Carry out the installation plan. → [Outcomes: 1,2] **TM2.BP2:** Adjust settings to make sure the technologies perform as intended on the target system. → [Outcome: 2] **TM2.BP3:** Devise and perform tests to make sure the technologies are working properly. → [Outcome: 3]
	Output Work Products	Installation and configuration how-to guide → [Outcomes: 1,2,3] Software files installed and configured on the target system → [Outcome: 2] Test results → [Outcome: 3]

Table 14: Process definition for Technology Integration

Process Reference	**ID**	TM3
	Name	Technology Integration
	Purpose	To blend HPC with SME's hardware and software systems to coordinate the consumption of inputs by HPC systems and HPC outputs by intended technologies.
	Outcomes	1. Use cases that require HPC systems are defined. 2. HPC-integrated application workflows are created. 3. Technologies that run the application workflows are implemented.
Process Performance Indicators	**Base Practices**	**TM3.BP1:** Define use cases that require HPC systems. **TM3.BP2:** For the use cases that require HPC systems, devise the HPC-integrated application workflows for the use cases considering heterogeneous hardware and software systems and data flow between the components. → [Outcomes: 1,2] **NOTE 1:** Selection of hardware and software components belongs to the Technology Selection process. **TM3.BP3:** Implement the technologies (e.g., shell scripts, workflow management tools) that run the application workflows. → [Outcome: 3] **NOTE 2:** Reproducibility of the application workflow results belongs to Evaluation and Reproducibility process.

	Output Work Products	Documentation that depicts use cases that require HPC systems and corresponding HPC-integrated application workflows → [Outcomes: 1,2] Technology implementations to run the application workflows → [Outcome: 3]

Table 15: Process definition for Prototype Implementation

Process Reference	**ID**	DPD1
	Name	Prototype Implementation
	Purpose	To demonstrate the benefits of HPC infrastructure for a suitable problem in a pilot study.
	Outcomes	1. Technical and/or scientific challenges are defined. 2. Solution stages are devised and implemented on the HPC infrastructure. 3. Business, scientific, and/or societal impacts are discussed.
Process Performance Indicators	**Base Practices**	**DPD1.BP1:** Create a pilot study document defining the technical and scientific challenges for an HPC-suitable problem. → [Outcome: 1] **NOTE 1:** HPC-suitable problem definition belongs to Vision and Strategic Alignment Process. **DPD1.BP2:** Use the HPC infrastructure to implement the solution stages. → [Outcome: 2] **NOTE 2:** There are dedicated processes for Technology Selection and Installation and Configuration under the Technology Management process area. **NOTE 3:** Defining milestones and iterating through solution stages belongs to Project Management Process. **DPD1.BP3:** Discuss the business, scientific, and/or societal impacts in the pilot study document. → [Outcome: 3]
	Output Work Products	Pilot study document → [Outcome: 1,3] Application codes → [Outcome: 2]

Table 16: Process definition for Scale Up

Process Reference	**ID**	DPD2
	Name	Scaling Up
	Purpose	To understand how the application code scales on the same node using more processing resources.
	Outcomes	1. Performance metric(s) are defined. 2. Benchmarks are implemented for the same node. 3. Benchmark results are obtained for the same node.
Process Performance Indicators	**Base Practices**	**DPD2.BP1:** Define performance metric(s) (e.g., runtime, accuracy) that should improve with more resource on a single node. → [Outcome: 1] **NOTE 1:** The metric(s) are a subset of the metric(s) defined in Evaluation and Reproducibility process. Research for the metric(s) belongs to the Evaluation and Reproducibility process. **DPD2.BP2:** Use the HPC infrastructure to implement benchmarks on the same node and obtain results. → [Outcomes: 2,3] **DPD2.BP3:** Visualize the benchmark results. → [Outcome: 3]
	Output Work Products	Performance metric(s) → [Outcome: 1] Benchmark codes → [Outcome: 2] Benchmark visualization → [Outcome: 3]

Table 17: Process definition for Evaluation and Reproducibility

Process Reference	**ID**	DPD3
	Name	Evaluation and Reproducibility
	Purpose	To interpret the performance of the application with regards to standard metrics or benchmarks and use techniques for other people to easily repeat the experiments and obtain the same results.
	Outcomes	1. Benchmark tasks and performance metrics are defined. 2. The environment to run the application and dataset access mechanisms for reproducibility are created. 3. Experiments are devised considering relevant variables (e.g., features, hyperparameters, neural architectures, ML modelling approaches) 4. The application is run for multiple experiments and results for all experiments are obtained. 5. All of the results are reported along with the experiment configurations, application code, scripts, instructions on how to install and configure the runtime environment, and instructions on how to access the dataset(s) to reproduce the results. 6. Conclusions are obtained based on interpretations of the results.
Process Performance Indicators	**Base Practices**	**DPD3.BP1:** Research and define benchmark tasks and performance metrics for evaluating and comparing your application. → [Outcome: 1] **NOTE 1:** These benchmarks and metrics extend the benchmark and metric(s) defined in Scale Up process. **DPD3.BP2:** Create the environment to run the application and dataset access mechanisms for other people (e.g., internal, external) to easily repeat the experiments/simulations. → [Outcome: 2, 5] **DPD3.BP3:** Devise and run the experiments considering the relevant variables. → [Outcomes: 3,4] **DPD3.BP4:** Report the results, drawing conclusions based on interpretations of the results. → [Outcomes: 5,6]
	Output Work Products	Benchmark tasks and performance metrics are defined. → [Outcome: 1] Environment to run the application → [Outcome: 2] Data set access mechanism → [Outcome: 2] Technical report or publication describing the code repository, experiments, benchmark tasks, performance metrics, and conclusions → [Outcome: 3, 6] Code to run the application for multiple experiments → [Outcome: 4] Code shared in a suitable repository (e.g., Zenodo, GitHub) with README file explaining how to install and configure the runtime environment, and instructions on how to access the dataset(s) to reproduce the results → [Outcome: 5]

Table 18: Process definition for Scale Out

Process Reference	**ID**	DPD4
	Name	Scaling Out
	Purpose	To understand how the application code scales on multiple nodes using more processing resources.
	Outcomes	1. Benchmarks are implemented for multiple nodes. 2. Benchmark results are obtained for multiple nodes.
Process Performance Indicators	**Base Practices**	**DPD2.BP1:** Use the HPC infrastructure to implement benchmarks on multiple nodes and obtain results. → [Outcomes: 1,2] **NOTE 1:** Definition of performance metrics belongs to Scaling Up process. **DPD2.BP2:** Visualize the benchmark results. → [Outcome: 2]

	Output Work Products	Benchmark codes → [Outcome: 1] Benchmark visualization → [Outcome: 2]

Table 19: Process definition for HR Management

Process Reference	**ID**	SP1
	Name	HPC Awareness
	Purpose	To raise awareness for HPC systems through attending events.
	Outcomes	1. National and global HPC events such as trainings, webinars, seminars, and hackathons are identified. 2. HPC events are attended. 3. HPC ecosystem content is disseminated.
Process Performance Indicators	**Base Practices**	**SP1.BP1:** Identify HPC events. → [Outcome: 1] **SP1.BP2:** Be present at HPC events. → [Outcome: 2] **SP1.BP3:** Repost content from HPC ecosystem through suitable channels such as social media. → [Outcome: 3]
	Output Work Products	Certificates of attendance or presentation for events → [Outcome: 1, 2] Blog post, news article, social media reposts → [Outcome: 3]

Table 20: Process definition for Project Management

Process Reference	**ID**	SP2
	Name	Project Management
	Purpose	To oversee HPC-related projects (e.g., HPC pilot study, HPC technology integration) towards successful completion.
	Outcomes	1. A suitable approach is adopted since HPC-related projects may involve evolving requirements, high risk, and significant uncertainty. 2. HPC documents that define scope, milestones, and risks are initiated.
Process Performance Indicators	**Base Practices**	**SP3.BP1:** Discuss and adopt a suitable project management approach. → [Outcome: 1] **SP3.BP2:** Create the initial versions of the HPC documents that define scope, milestones, and risks. → [Outcome: 2]
	Output Work Products	Backlog → [Outcome: 1] Project documents → [Outcome: 2]

Table 21: Process definition for HR Management

Process Reference	**ID**	SP3
	Name	HR Management
	Purpose	To strategically recruit, train, and retain personnel focusing on HPC-related skills.
	Outcomes	1. HPC-related skills, certifications, trainings, and competitive salaries are identified. 2. HPC-related job postings are made. 3. HPC-related skills are obtained through trainings and recruitment. 4. A reward system is created.
Process Performance Indicators	**Base Practices**	**SP3.BP1:** Research HPC-related skills, certifications, trainings, and competitive salaries. → [Outcome: 1] **SP3.BP2:** Create and distribute job postings looking for HPC-related skills. → [Outcome: 2]

		SP3.BP3: Pick up HPC-related skills through training and recruitment. → [Outcome: 2] **SP3.BP4:** Establish a reward system based on criteria such as certification and quantifiable metrics that measure business value. → [Outcome: 4] **NOTE 1:** Measuring business value based on quantifiable metrics belongs to the Benefit Measurement process.
	Output Work Products	Job postings looking for HPC-related skills → [Outcomes: 1,2] Employees with HPC-related skills and certifications → [Outcome: 3] Employee benefits → [Outcome: 4]

Table 22: Process definition for Innovation Management

Process Reference	**ID**	SP4
	Name	Innovation Management
	Purpose	To explore and create new business models, processes, services, or products using HPC technology.
	Outcomes	1. Literature review is performed. 2. Market research is conducted. 3. Intellectual properties are protected. 4. An organizational change plan is prepared.
Process Performance Indicators	**Base Practices**	**SP4.BP1:** Perform literature review to analyze the technologies to transfer from academia. → [Outcome: 1] **SP4.BP2:** Conduct market research, identifying the competitors that use HPC. → [Outcome: 2] **SP4.BP3:** Prevent people from copying through suitable mechanisms. → [Outcome: 3] **SP4.BP4:** Develop roadmap to plan the (partial) organizational change to incorporate HPC into business processes. → [Outcome: 4]
	Output Work Products	Literature review report → [Outcome: 1] Market research report → [Outcome: 2] Trademark(s), patent(s) → [Outcome: 3] Organizational change roadmap → [Outcome: 4]