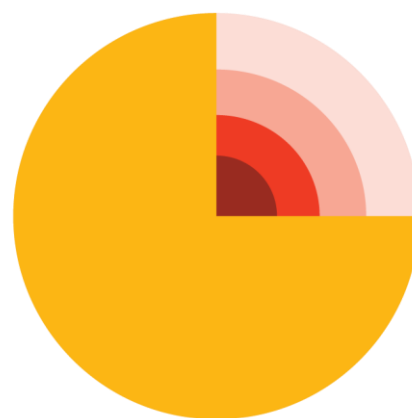




ChEESE

Deliverable D7.5 Preliminary Exploitation Plan



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ChEESE-2P Deliverable

D7.5 Preliminary Exploitation Plan

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Abstract

This Preliminary Exploitation Plan (D7.5) details the strategies for exploiting ChEESE-2P project outcomes, including a market analysis to identify key end users and early adopters. It also outlines plans for collaboration with standardisation bodies and aims to drive adoption across science, public administration, and industry sectors.

I. Copyright

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Index

1.	<i>Executive Summary</i>	4
2.	<i>Introduction</i>	4
2.1.	<i>Purpose and target groups</i>	5
2.2.	<i>Relations to other activities in the project</i>	7
3.	<i>Market analysis</i>	7
3.1.	<i>Service positioning and Stakeholder Engagement Strategy</i>	8
3.2.	<i>Targeted stakeholders: IUB(s) integration</i>	12
3.3.	<i>Stakeholder engagement: methodology</i>	14
4.	<i>Exploitable Results and Plans</i>	18
4.1	<i>Exploitation Structure: Project and Innovation Management</i>	18
4.2	<i>Exploitation strategy in a glance</i>	19
4.3	<i>Knowledge and technology transfer to industry and scientific community</i>	20
4.4	<i>Project outcomes per Pilot</i>	21
4.5	<i>Facilitating access to ChEESE Codes and Services through EPOS and other platforms</i>	Error!
	Marcador no definido.	
4.6	<i>CICD - continuous integration & continuous delivery (LUMI, Leonardo, MN-5)</i>	30
4.7	<i>Synergies with CASTIEL and CoEs (Geo-INQUIRE, DT-GEO)</i>	30
5.	<i>SWOT ANALYSIS</i>	33
6.	<i>Intellectual property management</i>	35
7.	<i>Trials/Simulation Cases</i>	37
7.1	<i>Why Trials?</i>	38
7.2	<i>Other ChEESE Channels</i>	40
7.3.	<i>Key partners</i>	40
7.4	<i>Communication and Dissemination Channels</i>	42
7.5	<i>Example of an initial Business Canvas Plan</i>	43
8.	<i>Vision and plan for Business Development at Sustainability Level</i>	44
9.	<i>Conclusions and next steps</i>	46

1. Executive Summary

This Preliminary Exploitation Plan (D7.5) outlines the strategies developed by the ChEESE-2P consortium to maximise the scientific, societal, and commercial impact of its results. It focuses on identifying key exploitable outcomes, validating them through stakeholder engagement, and building pathways for long-term adoption, with a particular emphasis on services for urgent computing, early warning, and probabilistic hazard assessment based on High-Performance Computing (HPC) simulations.

A comprehensive market analysis has been conducted, targeting civil protection agencies, the insurance sector, consultancy services, and the energy sector. The Industry and Users Board (IUB), created during the first phase of ChEESE, has grown to 24 members, actively contributing to shaping and testing services through interviews and simulation trials. Exploitable assets across nine Pilot Demonstrators are being developed towards higher Technology Readiness Levels (TRL), with many already reaching TRL 5+.

The plan also details synergies with key European initiatives such as Geo-INQUIRE, DT-GEO, CASTIEL2, and EPOS. These collaborations support data preservation, service integration, and the alignment of ChEESE-2P workflows with Digital Twin and FAIR data principles. Continuous Integration and Delivery (CI/CD) pipelines on EuroHPC infrastructures like LUMI and Leonardo further enable real-time services for geohazards.

By promoting open, interoperable, and user-driven services, ChEESE-2P aims to go beyond ChEESE-1P's legacy and ensure that its innovations persist beyond the project's end—supporting Europe's readiness for geophysical extremes through actionable, scalable HPC solutions.

2. Introduction

Work Package 7 (Dissemination, Outreach, and Capacity Building) in ChEESE-2P also covers the exploitation of project findings and the transfer of knowledge to the research community, industry, policymakers, and society at large.

The objective has been to identify the project's exploitable results and conduct a market analysis, ensuring continuity with the work carried out in ChEESE-1P and continuing to deliver impact well beyond the project's end. This task has enabled the ChEESE-2P consortium to gain a better

understanding of the market and exploitation landscape, laying a strong foundation for further actions.

The main activities included:

- Identifying the project's key outcomes.
- Analysing the exploitation context to assess the current market situation, potential target users, and early adopters.
- Building synergies with major European and global initiatives in Solid Earth sciences.

In line with its broader mission, ChEESE-2P aims to liaise, align, and create synergies with other domain-specific European projects and longer-term initiatives such as Destination Earth.

2.1. Purpose and target groups

This deliverable summarises the activities carried out under *Task 7.5 – the Sustainability Plan* – within WP7 of the ChEESE-2P project (up to Month 30, with the task continuing until the end of the project at Month 48). It provides a final overview of the exploitable innovations identified across the ongoing Pilot Demonstrators (PDs), outlining how they were selected and analysed, and highlighting those with the greatest exploitation potential.

Exploitation has been a key priority for ChEESE from the start — not only from a scientific point of view, but also in terms of societal and industrial impact. The diversity of the consortium partners already reflects this commitment. In addition, the Industry and Users Board (IUB) has played an active role by monitoring progress and offering valuable feedback throughout the project.

To maximise the project's impact beyond its lifetime, the Exploitation Team, led by the Project Innovation Manager (PIM), has focused on:

1. Identification of the project's exploitable outcomes, including both interim and final results, with emphasis on the PDs, as well as the services to be validated through the Farming Pilot Demonstrators, the Simulation Cases, and the service-enabling activities using EuroHPC infrastructures — all aimed at identifying potential commercial services and defining viable exploitation pathways.

2. Intellectual Property Rights (IPR) protection of the individual codes and toolkits developed in ChEESE. In order to ensure a smooth execution of the project, the project partners defined the details concerning the Access Rights for Exploitation to Background and Results in the Consortium Agreement (CA).

3. Identification and analysis of the target users and stakeholders: we will build on the initial user and stakeholder landscape identified during ChEESE-1P, maintaining the focus on key sectors while updating and

refining it where needed. The primary target users remain civil protection agencies, governmental organisations, (re)insurance companies, and businesses offering services in natural hazard assessment, forecasting, and geophysical explorations—particularly for the Oil & Gas industry. These groups are best positioned to benefit from the project's findings and innovations.

4. Analysis of the exploitation context and business opportunities

This task focuses on assessing the market potential and exploitation landscape of the scientific and technological developments within the project. These demonstrators tackle a range of geohazards and geoscientific challenges using extreme-scale HPC simulations, including:

- Extreme-scale modelling of seismic hazards
- Joint seismic inversion and tomography
- Global tsunami hazard and uncertainty quantification
- Complex multi-source tsunami modelling
- Ensemble-based volcanic dispersal at multiple scales
- Multiphase 3D volcanic explosion modelling
- The terrestrial dynamo model
- Geodynamics to geohazards
- Glacial outburst floods

The analysis will investigate opportunities for real-world adoption of these HPC solutions, particularly in collaboration with civil protection authorities, risk management bodies, and relevant industry sectors.

5. Assessment of the competitive environment of the project: technology readiness, integration, standardization and regulatory, policy framework at the targeted markets, and future trends at the social, business and policy levels.

6. Dissemination activities related to the exploitation of results, such as publications in international conferences and journals, and presentations of results in trade fairs, workshops and related events or press releases in technical media.

It is crucial to address strengths (benefits), weaknesses (drawbacks and prerequisites), opportunities (existing conditions suitable to promote the wide adoption of results), and threats, and will constitute the basis for planning a successful exploitation.

Contribution of partners

- BSC is the main editor of the document.
- All PD leaders provided updates on the description of their activities.

- Industry and Users Board (IUB) representatives provide direct feedback through All Hands Meetings and remote meetings, together with specific answers to a prepared survey to understand their potential interests in Pilots Demonstrators during ChEESE-1P and also ChEESE-2P.

2.2. Relations to other activities in the project

This deliverable (D7.5) is closely connected to several Work Packages within ChEESE, reflecting a cross-cutting effort to align exploitation strategies with technical development, co-design processes, and service implementation:

- **WP5 – Farming Pilot Demonstrators:** The insights gathered through interviews with PD leaders during ChEESE1 and ChEESE2 have been instrumental in shaping the initial exploitation strategy. These inputs help to identify the most promising outputs from each demonstrator and guide the selection of results with real market or societal relevance.
- **WP3 & WP4 – Co-design with European HPC Vendors and Simulation Ecosystem:** Experts from these Work Packages have contributed valuable feedback to assess the technological maturity and potential market impact of key innovations. Their evaluations have helped validate exploitable assets—such as software components, workflows, and end products—and prepare summaries suitable for dissemination to potential end users and investors.
- **WP6 – Simulation Cases and Service Enabling Using EuroHPC Infrastructures:** D7.5 has been developed in close collaboration with WP6 leadership, particularly in the planning of Simulation Cases and Trials. Special coordination has been established around Task 6.12, which focuses on enabling urgent computing services, ensuring alignment between service exploitation potential and infrastructure readiness.

3. Market analysis

This section explores the strategic positioning of ChEESE-2P's services and the project's stakeholder engagement approach. It begins by framing the market context in which ChEESE-2P operates, where the rising impact of geophysical extremes demands faster and more accurate early warning systems, probabilistic hazard assessments, and urgent computing capabilities. Sub-section 3.1 outlines how ChEESE-2P addresses these needs through HPC-enabled solutions tailored to key user sectors—including civil protection, insurance, consultancy (especially aviation), and energy.

Building on this analysis, sub-section 3.2 details the structure and role of the Industry and Users Board (IUB), which has grown into a cornerstone of stakeholder interaction. The IUB ensures that ChEESE-2P services are co-designed with real-world users, enhancing relevance and long-term sustainability. Throughout this section, the market insights serve not only to inform the project's exploitation strategy but also to align innovation with operational impacts.

3.1. Service positioning and Stakeholder Engagement Strategy

3.1.1. Market context of ChEESE potential services

In recent years, the global impact of geophysical extremes has become increasingly evident. The frequency and severity of natural hazards continue to grow, further amplified by global warming and demographic shifts that place more people and critical infrastructure in vulnerable areas. In Europe alone, 40% of the population reside in coastal zones, up to 80% are potentially exposed to seismic activities depending on the country, and more than 10 million people live near active volcanoes. Globally, 1 billion people reside within 100 km of a potentially active volcano and that at least 600 million people are exposed to direct volcanic hazards worldwide. Geohazards, once considered regional or isolated phenomena, now pose systemic risks with the potential to disrupt entire sectors, from aviation and insurance to humanitarian response and civil protection.

In this context, ChEESE-2P positions itself as a key enabler of Early Warning Systems (EWSs), probabilistic hazard assessments (PHA), and urgent computing (UC) services, designed to serve both scientific and operational needs across public and private sectors. By leveraging High-Performance Computing (HPC) infrastructure and a robust portfolio of enhanced simulation codes, ChEESE-2P aims to bridge the gap between cutting-edge geophysical research and real-world applications that protect lives, economies, and ecosystems.

Traditional forecasting and decision-support tools used by key stakeholders (e.g. civil protection agencies, humanitarian actors, aviation regulators, insurers) often rely on legacy models and outdated datasets. This undermines their capacity to act quickly and efficiently in response to fast-evolving threats such as tsunamis, volcanic eruptions, or cascading multi-hazard events. For instance, global air traffic over volcanic regions remains vulnerable to ash dispersion, causing annual losses exceeding half a billion US dollars to the airline industry. Meanwhile, humanitarian responses remain reactive, incurring higher costs and delays, often at the expense of lives and livelihoods.

ChEESE-2P directly addresses these gaps by delivering services that support rapid response (e.g. urgent computing applications), strategic planning (e.g. long-term hazard maps), and cross-sectoral collaboration. A key pillar of the exploitation strategy is the co-design of services with end-users, ensuring not only technical excellence but also relevance and usability in operational environments.

For example, traditional volcanic EWSs offer limited data—often only thermal output—without incorporating real-time ash or gas dispersion models. Similarly, current tsunami warning systems rely on pre-computed scenarios, unable to reflect the full spectrum of possible event parameters in real time. ChEESE-2P takes these services to the next level by enabling probabilistic modelling and simulation workflows that are faster than real-time and adaptable to uncertainty, powered by advanced HPC platforms and containerised deployments.

In hazard assessment, ChEESE-2P embraces a next-generation probabilistic approach, moving beyond static “representative scenarios” to physics-based modelling that accounts for uncertainty across a wide range of input parameters. This evolution is essential for enabling a structured decision-making process in risk-prone regions, from megacities near explosive volcanoes (e.g. Naples) to remote but strategically located volcanoes under major air corridors (e.g. Jan Mayen).

ChEESE-2P also builds on strategic partnerships, such as with the ARISTOTLE scientific consortium, which has become a recognised service provider to the Emergency Response Coordination Centre (ERCC). The evolution of the program highlights the growing demand for 24/7, multi-hazard scientific support across the EU civil protection landscape—an area where ChEESE-2P can provide added value through its Pilot Demonstrators and Simulation Cases.

Furthermore, the project is aligned with strategic EU initiatives like Geo-INQUIRE, DT-GEO, other CoEs and Destination Earth, where geophysical extremes are now formally recognised as a key component of Earth system modelling. ChEESE-2P’s contributions—ranging from the delivery of operational services to the generation of open-access datasets—are designed to be interoperable and scalable within the broader Earth system ecosystem.

3.1.2. Market assessment

According to the presented information in sub-section 3.1.1, specific market segments are presented and analysed in this section: Civil Protection Agencies, Insurance sector and Consultancy services, and finally the Oil&Gas sector. These targeted market segments are fully aligned with the development and objectives of the Pilot Demonstrators of ChEESE.

National and EU Civil Protection Agencies

Natural catastrophes have traditionally been a topic of interest for national civil protection agencies. These agencies are particularly focused on the quantitative assessment of hazards, either to respond quickly to emergencies or to implement long-term mitigation plans. This remains a major challenge in countries with high-risk regions, such as those with active volcanoes or tectonic activity.

However, over the past ten years, with the adoption of the Sendai Framework for Disaster Risk Reduction, the transnational and multi-risk nature of natural disasters has become increasingly evident. This has driven a shift towards risk mitigation actions at the European Union scale.

The EU also invests in prevention and preparedness, supporting joint risk assessments, resilience research, and early warning tools. A strengthened UCPM now includes a strategic European reserve for crises such as chemical, biological, radiological and nuclear (CBRN) emergencies and health threats, including a stockpile of medical supplies.

Meanwhile, the global humanitarian system faces growing challenges. In 2022 international humanitarian assistance reached nearly US\$47 billion, yet funding gaps persist. Crises are becoming more frequent and more severe, but aid often arrives late and rarely supports action before disasters strike. There is a pressing need to scale up anticipatory action and innovative financing to make humanitarian response more timely and effective.

Insurance companies

Financial institutions have struggled to manage non-financial risks, such as natural disasters, with the same level of sophistication applied to financial risks. This is evident in the limitations of traditional catastrophe modeling used by insurance and reinsurance companies. The global insurance industry faces challenges in maintaining profitability amid volatile economic conditions and evolving exposures. In 2023 global insurance premiums

reached approximately USD 7.1 trillion, with non-life premiums growing by 3.9% year-over-year. The reinsurance market also saw significant growth, valued at USD 642.37 billion in 2023 and projected to reach USD 2,000.08 billion by 2034.

Consultancy services

Volcanic ash poses significant risks to aviation safety, as its abrasive particles can damage aircraft surfaces, engines, and cockpit windows, potentially leading to engine failure and impaired visibility. The 2010 Eyjafjallajökull eruption has led to more than 100,000 cancelled flights (source: IATA), causing a loss of more than US\$3.8 billion airline revenues (source: Oxford economics) and more than 10 million stranded passengers.

The aviation industry has since prioritized the development of advanced early warning systems to detect and mitigate the impact of volcanic ash clouds. High-Performance Computing (HPC) plays a crucial role in these systems by enabling rapid and accurate forecasts that align with the operational time constraints of aviation. This technological advancement aids in emergency management and reduces uncertainties in impact assessments.

The European aerospace sector remains a vital component of the global market. In 2023, the industry achieved a turnover of €290.4 billion, marking a 10.1% increase from the previous year. This sector supports over 1 million direct jobs and contributes significantly to exports. Continued innovations in aeronautical technologies not only bolster the EU economy but also enhance global aviation safety and efficiency.

Beyond aviation, other public services, such as meteorological agencies, can benefit from technologies developed to monitor atmospheric hazards. Similarly, companies operating in coastal regions may find applications for these technologies in assessing and mitigating risks related to tsunamis and seismic events, particularly concerning critical infrastructure such as energy production plants.

Oil&Gas

According to the Global Energy Perspective 2024 by McKinsey & Company, the global energy demand is expected to increase by between 11% and 18% by 2050, depending on the scenario. In the "Continued Momentum" scenario, the demand rises by 11%, while in the "Slow Evolution" scenario

it sees an 18% growth—highlighting the persistent upward pressure on global energy systems.

Despite significant progress in the deployment of renewable energy sources (RES), the energy transition has been slower than anticipated in key areas. Many critical transition levers remain immature, difficult to scale, or not yet cost-effective. Combined with constraints in scaling up renewables and the continued rise in energy consumption, this indicates that renewables alone are unlikely to fully meet the world's future energy needs across all bottom-up scenarios.

As a result, fossil fuels—including oil, natural gas, and coal—are projected to remain part of the global energy mix through 2050, albeit with a declining share. Depending on the scenario, they are expected to meet between 40% and 60% of global energy demand by mid-century, down from 78% in 2023.

3.2. Targeted stakeholders: IUB(s) integration

In ChEESE-2P, the Industry and Users Board (IUB), created in ChEESE-1P, continues to play a key role in stakeholder engagement, offering real-world feedback and supporting the project's exploitation strategy. The board includes a diverse group of institutions that represent the full value chain—from HPC providers and academia to civil protection agencies and private industry.

As of now, the IUB has grown to 24 members, with 10 institutions designated as Full Members, reflecting a higher level of engagement and commitment to the project's activities. These members contribute via interviews, surveys, and technical meetings.

The IUB facilitates a better understanding of the needs and expectations of different end-users with respect to ChEESE Pilot Demonstrators. While some stakeholders focus on a single Pilot (e.g. REPSOL), others are engaged across multiple areas. For instance, insurance companies seek tools for risk reduction and urgent computing applications, whereas academia is interested in exascale-ready training and software.

This interaction stimulates tailored follow-up actions—such as interviews and information exchange—depending on each IUB member's specific

interests. A complete overview of all members and their interest in Pilot Demonstrators is available in Appendix A.

Current IUB Members (24)

- Italian Civil Protection Department (DCP)
- Icelandic Civil Protection
- Spanish Geographic National Institute (IGN)
- European Plate Observing System (EPOS)
- Geohazard Supersites and Natural Laboratory (GEO-GSNL)
- REPSOL
- Schlumberger
- Global Parametrics
- ARM
- FAULT2SHA
- Modeling Collaboratory for Subduction (MCS)
- ARISTOTLE
- Norwegian Water Resources and Energy Directorate (NVE)
- AuScope
- National Computational Infrastructure Australia (NCI)
- International Center for Earth Simulation (ICES)
- NVIDIA
- Global Earthquake Modeling Foundation (GEMF)
- Mexican National Seismic Institute (SSN)
- The Buenos Aires Volcanic Ash Advisory Center (VAAC)
- CAT-INGV
- Centro PLINIVS
- International Association of Seismology and Physics of the Earth's Interior (IASPEI)
- International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI)

Full IUB Members (10)

- Italian Civil Protection Department (DCP)
- Spanish Geographic National Institute (IGN)
- European Plate Observing System (EPOS)
- ARISTOTLE
- AuScope
- National Computational Infrastructure Australia (NCI)
- Mexican National Seismic Institute (SSN)
- The Buenos Aires Volcanic Ash Advisory Center (VAAC)
- CAT-INGV
- Centro PLINIVS

The first meeting of the Industrial User Board (IUB) took place on 30 April 2024. During the session, project coordinator Arnau Folch, innovation manager Joan Farnós, and Tomaso Esposti Ongaro (INGV) outlined the main objectives of its second phase of ChEESE to all IUB members, including both full members and observers.

Following this, researchers from ChEESE and several IUB members took part in a series of meetings aimed at fostering partnerships and planning the so-called Simulation Cases. These cases will involve testing services developed under the ChEESE umbrella. Notable meetings included discussions with the Global Earthquake Model (GEM) Foundation, the Buenos Aires Volcanic Ash Advisory Centre (VAAC), the Italian Civil Protection Department (DCP), and the European Plate Observing System (EPOS), focusing on collaboration and technical support for participation in Mexico's national earthquake drill scheduled for 19 September 2025, as well as other collaborations as detailed in Section 6.

Low TRL related Scientific services

The Pilot Demonstrators (PDs) are also expected to deliver valuable low-TRL outcomes. These outputs will be particularly beneficial to the scientific community and to external users interested in adopting the workflows developed by the PD partners. Several mechanisms exist to further exploit these assets, including initiatives such as COST and EuroHPC JU, which are described below.

COST – European Cooperation in Science and Technology

COST is a funding organisation that supports the creation of research networks, known as COST Actions. These networks provide an open platform for collaboration among scientists across Europe and beyond, fostering research advancements and innovations. This mechanism can be leveraged by various ChEESE Pilot Demonstrators, which span a wide range of Technology Readiness levels and therefore require tailored exploitation pathways.

COST operates on a bottom-up principle, allowing researchers to establish networks based on their own ideas and scientific interests by submitting proposals to the COST Open Call. These proposals can be in scientific discipline. COST Actions are typically interdisciplinary and inclusive, allowing for broad participation. Researchers can join ongoing Actions at any time during their four-year funding period. These networks often

include multiple stakeholders, such as private sector actors, policymakers, and civil society organisations.

EuroHPC Joint Undertaking (EuroHPC JU)

In parallel, other initiatives are also being explored to accelerate the development of the Pilot Demonstrators. One such example is the use of computational resources provided by EuroHPC JU, specifically allocated to Centres of Excellence (CoEs). ChEESE partners have also been granted, which will be instrumental in conducting scalability studies (both weak and strong scaling). These resources will be strategically allocated to support the computational needs of the Pilot Demonstrators.

3.3. Stakeholder engagement: methodology

During the first phase of ChEESE (2018-2022), a comprehensive stakeholder engagement process has been established with the goal of collecting data, assessing key markets from the end-user perspective across various Pilot Demonstrators (PDs), and defining hazard-related exploitation strategies (e.g., insurance, oil & gas, scientific applications). Stakeholder collaboration, particularly through the Industry and Users Board (IUB), has played a critical role in identifying relevant sectoral needs and opportunities.

The ChEESE engagement methodology involves a structured, multi-step approach:

1. Initial contact with potential IUB members by the Project Manager (PM) and Project Innovation Manager (PIM).
2. Introductory teleconference involving the prospective IUB, PM, PIM, and leaders of WP4 and WP5.
3. If interest was confirmed, the PM submitted the candidate to the Project Steering Board (PSB) for approval.
4. Upon acceptance, the new IUB member received an introductory document describing the PDs.
5. The new member was asked to complete a survey assessing their technical and exploitation interests, as well as organisational capabilities.
6. Based on survey responses, the PIM defined a roadmap for interaction with specific Pilot Leaders.
7. A series of meetings were held involving the IUB members, relevant Pilot Leaders, WP4/WP5 leaders, and the PIM.
8. Follow-up iterations aimed to identify potential operational testbeds for PD validation.

This process was supported by a detailed questionnaire to capture technical and exploitation needs, and was complemented by broader engagement initiatives such as the ChEESE Industry and Scientific Days.

Questionnaire provided to all IUB members in ChEESE1-P

The PIM, together with the WP4 and WP5 leaders from the first phase of ChEESE, prepared a joint survey to understand the interest and potential added value that IUB members could bring to the development of the Pilot Demonstrators. In that sense, different types of end-users are interested in different pilots, which enriches the feedback that all leaders must consider aiming to develop a successful asset. Thus, the preparation of the questionnaires was oriented to HPC and technology providers, ISVs, Academic experts and research code developers, etc. Here the main questions that have been asked to all of them in a first wave are presented:

- i. What is the Minimum Value Product for your service? (Please describe the minimum useful outcome from this Pilot Demonstrator that can be employed for your service)
- ii. What is the current alternative you are using? (Please name a software that is currently used to solve the same case. Please indicate whether there is any limitation that you wish our Pilot Demonstrator would overcome)
- iii. What test case/s would be relevant for you? (Please indicate whether there exists a data set that can be used for testing purposes and might have been used to validate an alternative product. Is it freely available?)
- iv. Who is the Expert? (Please indicate whether there is an expert user that is in charge of using the service and/or modifying it. If possible, indicate his/her contact details)
- v. What are the typical inputs? (Which type of files, formats, repositories, etc. are used to feed the service)
- vi. What are the typical outputs? (What is the desired format of the output, or alternatively which software is used for visualization or analysis)
- vii. What is your current "operational environment"? (e.g., Virtual Access to the service, a dedicated Web Framework)
- viii. What are the required "standards"? (in terms of formats, delivery time, interfaces, etc.)
- ix. Do you have any additional requests? (Please indicate any additional information that you find important or useful regarding to the Pilot Demonstrator)

Stakeholder Engagement in ChEESE-2P

Building on the structured foundation established during ChEESE-1P, stakeholder engagement in ChEESE-2P has transitioned to a more focused

and pragmatic approach, reflecting the more advanced maturity of the project and the continued involvement of previously engaged stakeholders.

Key engagement activities now include:

- Annual meetings with IUB members to share updates, gather feedback, and align priorities.
- Targeted interactions and bilateral meetings, held when necessary, to formalise collaborative actions or to discuss specific simulation campaigns and validation trials.

This more agile and need-based engagement strategy has proven effective, as the established relationships and shared understanding developed during ChEESE-1P continue to support productive and goal-oriented collaboration in ChEESE-2P.

Table 1: Examples of the IUB-PD(s) meetings outcomes (PD1 and PD5 summary of interviews)

	<i>Breakout session</i>	<i>Outcomes of the meeting</i>
<i>PILOT 1 (SC1.3 part 3)</i>	<i>SSN (Arturo Iglesias, Carlos Villafuerte, Leonarda Esquivel)</i>	Collaboration and technical support to participate in the national earthquake drill in Mexico on September 19, 2025.
	<i>GEM (Marco Pagani and Helen Crowley)</i>	Commitment to support the test planned for the Mexican simulation as data providers and evaluators.
<i>PILOT 5</i>	<i>Buenos Aires VAAC (Soledad Osos)</i>	Commit to support and coorganise the trial. Execution estimated by Autumn 2025
	<i>EPOS (Carmela Fredda) and CINECA (Gabriela Scipione)</i>	Decision to integrate the SC5.1 simulations to the Simulation Data Lake (SDL@CIN) and a service in EPOS (TCS-VO).
<i>Pilot 6</i>	<i>Commissione Grandi Rischi (CGR - Major Risks Commission) of the Italian Dept. of Civil Protection</i>	Request by the CGR of HPC phreatic eruption simulation scenarios for Campi Flegrei, for hazard and impact assessment (estimated deliver Q3 2025)
	<i>Settore Rischio Vulcanico (SRV - Volcanic Risk Department), Italian Dept. of Civil Protection</i>	Agreement of the SRV to participate in the co-design of a ChEESE Trial for Urgent Computing and Probabilistic volcanic hazard assessment (estimated Trial Run Q1 2026)

This kind of information is highly valuable for guiding the exploitation strategy of each Pilot Demonstrator and for aligning developments with real market needs, ensuring that they deliver tangible value by the end of the

project. In addition to participating in key external events — such as AGU Meetings, the EGU Galileo Conference, those promoted by CASTIEL, the EuroHPC Joint Undertaking, and other HPC-related initiatives — further opportunities to engage with new stakeholders are being planned. These include a dedicated User Day event towards the end of the project, designed to showcase results, gather feedback, and foster collaboration with end users and industry.

4. Exploitable Results and Plans

This section outlines the potential exploitation strategy of ChEESE-2P, including a brief overview of the project's innovation and exploitation structure. It describes the initial knowledge and technology transfer approach towards industry and academia, joint exploitation strategies, Pilot Demonstrator (PD) interests, and the individual exploitation plans of the partners. These efforts aim to summarise the exploitable assets across Pilots, define expected outcomes, and outline the foundations for a future Services Portfolio and potential business models for service provision. This section complements the information developed in coordination with other WP leaders, particularly that described in Deliverable 6.1 (Simulation Cases and Trials Definition). Notably, 8 of the targeted 9 Pilot Demonstrators are being upgraded to a TRL of 5 or higher+.

A key feature of ChEESE is its integration within a wider ecosystem of European research initiatives addressing natural hazards, particularly through strategic synergies with the Geo-INQUIRE and DT-Geo projects that will be detailed in the section 4.8.

4.1 Exploitation Structure: Project and Innovation Management

The Project Innovation Manager (PIM) has the task to understand and assess innovations and innovators in a project, as well as commercialization opportunities and related strategies. For a given innovation, the PIM should identify the best place for the project partner to take it to market and provide advice on fulfilling the innovation potential.

The key task of the PIM is to gather relevant information on potential innovations and innovators by reviewing project materials and engaging in discussions with partners during the review meeting. Depending on the stage of the project, whether it has just started, is well underway, or nearing completion, the PIM assesses how well prepared the consortium or

innovator is to enter the market, and how they plan to adapt to evolving market conditions. At the same time, the interaction between the PIM and the innovators aims to raise awareness of key issues and support the development of a more effective and proactive exploitation mindset.

In order to ensure that the results of the project will not remain confined in academia or research labs but will find their route toward the market, a proper innovation management is of paramount importance. The Innovation Manager will work closely with the Project Coordinator and the consortium exploitation team to ensure a proper exploitation path. Innovation management processes include both day-to-day management of knowledge and IPR issues and the iterative creation of exploitation plan and technology roadmaps. More concretely, it will include the following actions:

- i. Facilitate any related conflict resolution.
- ii. Facilitate the creation of commercial agreements between partners leading to joint exploitation after the end of the project.
- iii. Monitor the project to guarantee the consistency between technical and marketing choices.
- iv. Monitor the market during the whole duration of the project, particularly concerning the evolution of the technology, potential customers, and existing and emerging competitors.
- v. Plan initiatives that combine technical and exploitation objectives to create business models for defining and exploitation path of most relevant innovations within the project.

Finally, the exploitation strategy is divided in different main topics which involve different specific steps:

1. Definition of ChEESE as a service provider (Pilot to Product: P2P). Service development strategy is explained in D5.1.
2. Industry, Public Authorities and Entities Engagement (IUB participation)
3. Sustainability strategy (ChEESE Engagement in EC COEs sustainability roadmap and decision pools)

4.2 Exploitation strategy in a glance

Exploitation efforts in ChEESE-2P continue to focus on engaging with the Industry and Users Board (IUB), which currently includes 24 organisations. The main activities performed are the following:

- IUB members have been informed about the Pilot Demonstrators (PDs) planned in the project and have indicated which ones they are most interested in following closely.
- Interviews have been conducted with most of the IUB members to understand their evolving needs and expectations during ChEESE1.
- Other organisations related to ChEESE activities have been identified and invited to join the IUB (as detailed in the previous sub-section).
- ChEESE-2P is strengthening collaboration and knowledge exchange with other EU-funded initiatives such as DT-Geo and Geo-INQUIRE. These synergies aim to foster co-design and joint exploitation of services, tools, and data across projects dealing with Digital Twins and the Solid Earth community.
- ChEESE has also been working closely with CASTIEL2, actively contributing to the CoEs Task Force on Commercial Services. This collaboration has led to discussions on different exploitation approaches and the co-authorship of strategic documents such as the White Paper – Best practices for provision of commercial services by CoEs, which supports a common vision on service sustainability and industrial engagement across Centres of Excellence.
- A sustainability approach continues to be developed at three levels: Pilot Demonstrator, Partner, and ChEESE as a whole, to ensure long-term impact and uptake of results beyond the project's duration.

4.3 Knowledge and technology transfer to industry and scientific community

The **Exploitation Strategy of ChEESE-2P**, outlined in accordance with the project's progress at M30, has evolved to reflect a more integrated and collaborative vision. It remains a living document that will continue to be refined as the project advances. The current strategy builds upon three core pillars:

- **Joint exploitation within the ChEESE ecosystem:** ChEESE partners are committed to exploring joint exploitation opportunities by consolidating an ecosystem that supports technical services, business development, training, and consultancy based on the project's results. This ecosystem will facilitate the transfer of cutting-edge HPC-based solutions for Solid Earth applications to both industry and the scientific community.
- **Exploitation of the Pilot Demonstrators (PDs):** The PDs serve as tangible validation tools for the project's technologies and services,

representing a key channel for future business opportunities. Through close collaboration with the Industry and Users Board (IUB), PDs provide real-world testing environments that demonstrate the value of ChEESE innovations, paving the way for scalable services aligned with user needs.

- **Individual exploitation plans of partners:** As detailed in Section 4.5, most ChEESE partners are already active in HPC-related markets or research domains. The project enables them to reinforce their offerings, and access to new market segments, and enhance their innovation capacity through the adoption and co-development of project results.

The knowledge and technology transfer activities are closely tied to the IUB, whose members are key stakeholders in the validation of project results. Their engagement includes:

- i. Providing continuous feedback on the relevance and applicability of Pilot Demonstrators.
- ii. Testing pre-operational services in real environments to support broader adoption.
- iii. Participating in market and user-needs analysis to shape service development.
- iv. Collaborating actively with Pilot Leaders to ensure alignment between service implementation and real-world operational needs.

This integrated and multi-layered exploitation strategy aims to ensure the long-term impact, visibility, and usability of ChEESE results within and beyond the duration of the project.

4.4 Project outcomes per Pilot

The Pilot Demonstrators (PDs) serve as proofs of concept to test selected codes and workflows on Exascale hardware prototypes. A total of 9 PDs have been defined to support the development and validation of the project's eleven flagship codes. Pilots that reach a Technology Readiness Level (TRL) above 4 are expected to evolve into operational services over the course of the project.

Objectives:

- i. Increase TRL of all PDs by at least 2 points
- ii. Increase TRL to ≥ 5 for 8 PDs (8 potential Services)

The initial expected knowledge and technology transfer to industry per Pilot Demonstrator is the following:

Table 2: Services related to Pilot Demonstrator(s)

N o	Pilot Demonst rator name	Are a	Flagsh ip Code	INSTITUT ION	Rela ted ECC	Initi al TRL	Targ et TRL	Relate d servic e
1	Extreme-scale modeling of seismic hazards	CS	All CS codes	All	ECC2 ,ECC3	5	7	N/A
2	Joint seismic inversion and tomography	CS	SPECFE M3D	CNRS+INGV	ECC1	4	6	N/A
3	Global tsunami hazard and uncertainty quantification	T	HySEA	INGV	ECC6	7	8-9	Hazard assessment
4	Complex multi-source tsunami modeling	T	HySEA, ExaHyPE, SeisSol	NGI	ECC4 , ECC5	3	5	Hazard assessment, urgent computing
5	Ensemble-based volcanic dispersal at multiple scales	V	FALL3D	CSIC	ECC7 , ECC9	5	7-8	UC service on volcanic ash forecasts ; European Tephra HAZard Map integrat

								ed in EPOS
6	Multiphase 3D volcanic explosion modeling	V	OpenPD AC	INGV	ECC8	4	7	Physics based simulation of explosive volcanic eruptions: 1) Urgent Computing ; 2) PVHA
7	The Earth's dynamo model	MHD	xSHELLS	CNRS+IPGP	ECC10	3	5	N/A
8	Geodynamics to geohazards	GD	LaMEM, pTatin3D	UM, CNRS, CSIC, LMU	ECC11, ECC12	3	5	Hazard assessment, urgent computing
9	Glacial outburst floods	GL	Elmer/Ice	CSC	None	2	4	Hazard related simulations of rapidly rising GLOFs

Additionally, a summary of Pilot services and expected outcomes are presented in Appendix B. The Pilot Service scheme follows the next table format:

Table 3: Pilot Demonstrator service summary

Asset title	'Business' name for the asset
Lead partner(s)	Lead (point of reference) partner for the asset
TRL initial	
TRL target	
Description	A description of the asset: Focus on main value proposition(s), selling points
Objectives	
ChEESE results and components involved	One or more of the other assets involved or linked to this asset.

Type(s) of asset	Examples (multiple possible): Product, Service, Demonstrator,
Relevant stakeholders	Stakeholders involved in the use of the asset. It should include parties already contacted/involved in CHEESE and exploitation, for example by direct contact, presentation, take-up of the component. Example: direct customers, direct suppliers, suppliers of complementary products
Exploitation channel(s)	The main exploitation channels for the asset, e.g. Support, Training, Consulting, Extension/Customization. More than one channel is possible for an asset also depending on the partners involved
Possible competitors	Possible competitors in the market offering similar/competing value propositions
Replicability in other domains and ecosystems	Replication capabilities in different domains. They should be as much as possible concrete and based on the bottom-up capability of the partners.
Action plan / status	Concrete action (plans) for pushing the asset to the market: i.e. so that it is concrete and not just theory.
Other relevant information	Risk, initial expected revenue streams, IP issues, etc.

On the other hand, each partner, further than their responsibilities assumed in the Pilot demonstrator development, has their own initial exploitation strategy, briefly described in the next table.

Table 4: Initial exploitation strategy per Partner

Partner	Initial exploitation strategy
BSC	BSC will use the results of this project to improve its internal research lines in Exascale computing with a particular focus on fast simulations of earthquakes and tsunamis as well as their associated workflows. The benefit will be an updated AI-based model to infer seismic motion in seconds with high precision. The model will be suitable for areas with few records of strong earthquakes as it harnesses the potential of physics-based simulations to bridge the gap between observations and accuracy. Our testbed will be Iceland. Future developments are likely to be transferred to initiatives within the framework of the Destination Earth initiative and stakeholders such as the Unidad Militar de Emergencias in Spain.
CINECA	CINECA will use the working methodology developed in WP2 to continue advancing the ecosystem of codes and mini-apps towards exascale. Furthermore, it will contribute to the development of technical solutions and a methodology aimed at interactive and urgent computing, particularly on the Leonardo pre-exascale architecture and from a service-oriented perspective.
CNRS	CNRS will integrate all software developments and performance improvements achieved within the ChEESE-2P Centre of Excellence into the open-source SPECfem3D package, enhancing its capabilities for high-frequency, high-resolution seismic wave and noise

	modeling. These enhancements—including advanced I/O handling, GPU optimizations, and multiphysics extensions—will directly benefit the broader geophysical and computational seismology communities who rely on SPECFEM for both academic and applied research. In parallel, ongoing developments funded by a French National Research Agency (ANR) project will be synergistically combined with CoE contributions to further extend the code’s utility for open science.
CSC	CSC instantly publishes new code in Elmer on its public GitHub repository. Methods used within the CoE to compute rapidly rising GLOFs will be communicated to the scientific peers and made available in form of published papers and made available for reproduction on platforms, such as Zenodo. This will be in form of Elmer-specific solver input files (sif) and also in a more general form in terms of providing workflows.
CSIC	CSIC will use the results of this project to improve its internal research lines in volcanic ash modelling. The pilot demonstrator on volcanic plume modelling at scale, and its different applications (long-term hazard mapping – SC5.1, and short-term operational forecasts – SC5.2), could lead to commercial and/or governmental services, and also has potential to be integrated into DestinE. Finally, the improved performance portability and time-to-solution of the FALL3D code will benefit its community of users.
E4 Analytics	E4 Analytics will contribute to the development and configuration of a specific working environment for interactive computing services based on the Jupyter ecosystem on pre-exascale systems, adhering to the needs of the Cheese-2P scientific partners and, more generally, for the Earth sciences domain.
Eviden	Eviden will leverage the knowledge gained through collaborations on the Solid Earth European flagship applications and mini-apps to strengthen the competitiveness of its offerings, particularly its service portfolio. Additionally, the results obtained may be used for further dissemination or publication, for instance, to demonstrate CEPP’s expertise.
IMO	IMO will use the results of this project to improve its internal hazard research on earthquakes, volcanic ash dispersal, and subglacial floods. The CyberShake results will form the building blocks for a reliable physics-based long-term (i.e., PSHA) and short-term (i.e., urgent seismic computing) hazard assessment for the Southwest Iceland bookshelf system. The Tandem results will be the first attempt at establishing a seismic cycle model of the bookshelf system that would facilitate intermediate-term seismic hazard assessment. The results of Elmer/Ice simulations will improve internal

	simulations of subglacial floods (GLOFs) at the IMO. FALL3D transport model applied to three icelandic volcanoes will produce footprint for the first European tephra hazard map.
INGV	INGV will take advantage of activities carried out in the CoE to consolidate its cross-disciplinary expertise in HPC and to enlarge the number of HPC users and applications within its community. New physical modules or numerical models and codes (OpenPDAC, Multilayer HySEA, Specfem3D) will be brought at higher performances (towards Exascale) strengthening its capability to envisage scientific grand-challenges in the field of SE research (seismology, volcanology, tsunami science). INGV will finally improve the quality, reliability and accuracy of services provided by the volcano Observatories and the National Seismic Networks towards Italian Civil Protection and National Institutions, especially for what concerns Probabilistic Hazard Assessment and Urgent Computing in case of natural catastrophes, as well as towards TEWS (Tsunami Early Warning Systems) end-users.
IPGP	IPGP will integrate software developments developed with the CoE into the open-source code XSHELLS and will release the JAX-based subgrid-scale modelling demonstrator for quasi-geostrophic turbulence. Results of the EuroHPC campaign will be made available to the scientific community for research on subgrid-scale modelling of magnetohydrodynamic turbulence.
HLRS/USTUTT	The knowledge gained from code and workflow audits on EuroHPC Tier-0 systems is already being actively applied to enhance the software environment of the new HLRS Hunter supercomputer. For example, improvements to the Spack configuration are contributing to a more efficient and flexible handling of the software stack, directly benefiting HLRS services. Additionally, ChEESE-2P provides HLRS with valuable insights into advanced and complex workflows that are not yet common among its user base. This exposure enables HLRS to anticipate future user needs, broaden its expertise in this area, and proactively plan for future services. Insights from CI/CD integration efforts have delivered important feedback, which will inform the setup of future CI/CD services at HLRS, ensuring modern and automated software development and deployment support as well as improved service quality. Finally, the lightweight performance analysis tool "TALP" developed within the project enriches HLRS's toolset to analyze, understand, and optimize customer codes. Its capabilities will be especially helpful for improving code efficiency on the new APU-based Hunter system.

LMU	LMU will link all developed software, workflows and pre- and postprocessing tools into on-going international research activities in computational seismology and earthquake source physics. Specifically, the EU projects DT-GEO, GEO-Inquire, TREAD and SPIN, the German Research Foundation project DEFORM, and the NSF US funded projects MTMOD, Quakeworx, LCCF-CSA, CRESCENT, SCEC and SZ4D. These developments will be used for physics-based seismic hazard assessment for small and large earthquakes. ChEESE-2P will enable LMU to go well beyond scenario-based multi-physics simulations and establish excellency for physics-based PSHA. All developed scenarios and software will be made publically available via the open-source repositories of SeisSol and Tandem.
NGI	NGI will exploit the present project to improve our operational research capabilities in terms of providing fast high resolution coupled landslide-tsunami computations. In particular, the present project will enable us to make a leap in terms of quantifying uncertainties in tsunami generation due to differences in landslide physics; from present rudimentary analysis, to future exploration of the full uncertainty space. The latter has previously been unfeasible due to limited computational capabilities.
RBI	RBI will take advantage of the CoE to integrate a new tsunami source - meteo-tsunamis which are driven by either local or glabal atmospheric disturbances - within the flagship code HySEA and to improve the research on planetary acoustic meteo-tsunamis driven by volcanic explosions like the Hunga Tonga - Hunga Ha'apai event which took place in January 2022.
TUM	TUM will integrate all software improvements developed within the CoE into the open-source software packages SeisSol (www.seissol.org) and ExaHyPE (www.exahype.org). Simulation scenarios with SeisSol will be integrated into its reproducible research collection (https://seissol.readthedocs.io/en/latest/reproducible-research.html). ExaHyPE scenarios, in particular the new landslide model, will be distributed as part of the code repository. SeisSol and ExaHyPE are increasingly adopted by the geoscience community, also as part of activities such as the EU projects GeoInquire and DT-GEO. Software components of SeisSol and ExaHyPE, such as the YATeTo toolkit (DSL and code generator) for tensor operations (also used by the flagship code tandem), the code generators GemmForge, ChainForge and TensorForge, for batched matrix and tensor operations on GPUs, or the easi library for easy Initialization of model parameters, are part of the SeisSol repository (https://github.com/SeisSol/) and are provided as reusable software components.

UM	UM will exploit the working methodologies developed in WP2 (e.g., performance audits) and advancements in WP5 to integrate novel features into LaMEM, advancing its readiness for exascale computing. Improved scalability on EuroHPC systems—particularly LUMI—is expected to significantly enhance LaMEM’s ability to simulate geohazards at high resolution and in realistic 3D configurations. These developments will be showcased in Pilot Demonstrator 8 (PD8), specifically simulation case 8.1, “Magmatic systems and induced landslides: the Etna case.” This case will deliver the first high-resolution 3D viscoelasto-plastic model of ongoing deformation at Mt. Etna, enabling identification of potential sliding planes driving surface instability. Furthermore, UM will contribute to the development of scalable computational strategies for interactive and urgent geohazard modeling, with a focus on deployment on EuroHPC pre-exascale platforms from a service-oriented perspective. The resulting improvements in LaMEM’s parallel performance, numerical robustness, and workflow automation will benefit the broader geoscience modeling community and support time-critical applications such as early warning systems and real-time hazard assessment.
UMA	The results of the present project will have a direct and straightforward application in the improvement of the numerical tools used for tsunami modeling by our community. The improvements in the different codes, for earthquake-generated tsunamis, landslide-generated tsunamis and meteo-tsunamis are a direct output of the projects. Dispersion, coupling between models and richer vertical structures for the computed solutions are part of the achievements. Some of these features can be directly included in TEWS around the world wishing to use direct tsunami computations in their systems. A direct output from the project will be the improvement of the capabilities of the operational model currently used in TEWS. The project will also provide an efficient tool for the construction of the GTM Hazard Map. The contribution to multi-source local high-resolution scenarios, but also including global impact must be emphasized.

4.5 Facilitating access to ChEESE Codes and Services through EPOS and other platforms

As part of ChEESE-2P's commitment to scientific and industrial exploitation, significant efforts have been made to streamline access to the project's codes and services via established research infrastructures such as EPOS

(European Plate Observing System) and other emerging initiatives. EPOS is a long-term, multidisciplinary European research infrastructure that integrates data, data products, and services from the solid Earth science community. In alignment with Task T1.5, a Data Management Plan is being implemented to ensure the use of EPOS-enabled metadata descriptors, facilitating full interoperability with the EPOS service catalogue. This foundational work supports the broader objective of offering FAIR (Findable, Accessible, Interoperable and Reusable) datasets to the solid Earth science community.

We have also initiated dedicated **collaboration with EPOS** in the development of the ICS-D (Integrated Core Services – Data), enabling cross-disciplinary access to ChEESE simulation workflows, numerical codes, and high-performance computing (HPC) services. This effort paves the way for long-term integration of high-TRL services, including those for tsunami early warning systems (TEWS), operational forecasting of geohazards, and the modelling of surface deformation related to geo-resource exploitation.

The publication of **dedicated pages for each of the flagship codes** has begun on the ChEESE-2P website. These pages feature detailed descriptions, access links, explanatory videos, KPIs, and visual data on document downloads by country. This structured online presence enhances the visibility and usability of the services, while strengthening engagement with academic, industrial, and civil protection stakeholders. The data-rich format also supports continuous monitoring of uptake and impact throughout the project lifecycle.

ChEESE is also actively participating in discussions with other Centres of Excellence and initiatives coordinated through CASTIEL2 to explore joint solutions for greater service visibility. These include collaborations with platforms such as the EuroHPC Portal, Waldur, and the Simulation Data Lake (SDL) — a platform developed by Cineca for storing and accessing simulation datasets, promoting data discoverability and reuse, as well as experiment repeatability in the context of the Geo-INQUIRE project and beyond. Through regular liaison meetings and joint events, we aim to avoid fragmentation, ensure alignment of technical interfaces, and co-develop sustainable pathways for service publication and integration.

As the project enters its final phase, the focus will shift towards consolidating ongoing efforts. Plans include the expansion of code documentation, improved service discoverability, and the reinforcement of

links with EPOS TCSs, Geo-INQUIRE, and other Horizon Europe-funded initiatives. These actions aim to ensure that ChEESE codes and services remain visible, accessible, and impactful beyond the project's duration.

4.6 CICD - Continuous Integration & Continuous Delivery (LUMI, Leonardo, MareNostrum-5)

To maximise the scientific and operational impact of its geohazard modelling tools, ChEESE-2P is intensifying efforts to ensure seamless deployment and integration of its codes across major EuroHPC pre-exascale systems such as LUMI (Finland), Leonardo (Italy), and MareNostrum 5 (Spain). These actions aim to enhance performance portability and enable continuous integration and delivery (CI/CD) practices that support the delivery of urgent computing services in geohazards. Through this work, ChEESE-2P ensures that its flagship codes can fully exploit the computational capacity of Europe's most advanced HPC infrastructures.

In alignment with Task T6.4, ChEESE-2P is enabling four urgent computing services on these Tier-0 EuroHPC platforms. By optimising code configurations for reduced time-to-solution, the project assesses their operational relevance in real-time emergency response contexts. This work is carried out in collaboration with the EuroHPC Infrastructure Advisory Group (INFRAG) to define technical requirements and policies for EU-level urgent access to HPC.

4.7 Synergies with CASTIEL and CoEs

ChEESE-2P has been actively collaborating with CASTIEL2, National Competence Centres (NCCs), and other EuroHPC Centres of Excellence (CoEs) across multiple domains. This includes co-leading events such as the workshop "How European projects are developing HPC-based software and services to address natural hazards" in December 2024, alongside EoCoE-III, ESiWACE3, and other initiatives.

ChEESE also contributes to several CASTIEL2 task forces, most notably the Task Force on Commercial Services, where it has played a key role in shaping strategic discussions on exploitation. These efforts have led to the co-authorship of the White Paper – Best practices for provision of commercial services by CoEs, promoting a unified vision of sustainability and industrial engagement.

In addition, ChEESE participates in the Thematic Application Cluster on Environmental Simulation – Natural Hazards Risk Management, working to raise awareness of CoE-developed codes and services, while targeting specific user groups to expand use cases and proof-of-concepts (PoCs) with private companies.

These combined efforts are reinforced by regular cross-CoE meetings on exploitation, training, and platform integration, helping to build a more cohesive and collaborative European HPC ecosystem.

Integration with Geo-INQUIRE project

ChEESE2-P contributes to Geo-INQUIRE's long-term vision by enabling the reuse and preservation of simulated data produced by its workflows and to give (Virtual and Trans-National) access to high-TRL HPC software and workflows to a broader scientific community. Discussions are ongoing regarding the level of integration of simulation outputs in the Simulation Data Lake (SDL) developed by Geo-INQUIRE, which aims to ensure long-term accessibility and reproducibility. This infrastructure facilitates not only academic reuse but also might support civil protection and insurance sectors in assessing hazard-related risks based on high-fidelity simulation data. Moreover, ChEESE workflows, initially developed under ChEESE-1P, are becoming standardised services offered within Geo-INQUIRE's virtual access portfolio, in line with the EU Commission's vision of open, FAIR-compliant services for the geoscience community. These workflows contribute to Geo-INQUIRE's Work Package 5, which focuses on computational geoscience services.

Common partners	9	CSIC, BSC, INVG, IMO, CIN, LMU, UMA, NGI, CNRS
Coordination	ChEESE-2P (CSIC); Geo-INQUIRE (GFZ)	
Main concept	ChEESE-2P is about codes, Geo-INQUIRE is about access to existing products	
Objectives	ChEESE-2P	Code preparation and deployment, service enabling, research
	Geo-INQUIRE	Portfolio of Virtual Access (VA) and Transnational Access (TA)
Synergies	- ChEESE-CoE services (SaaS and WaaS based on ChEESE-1P) 4 codes shared (SeisSol, ExaHyPE, HySEA, FALL3D) 1-way feedback: ChEESE-1P code developments transferred to Geo-INQUIRE for SaaS (VA4/TA2-531). Also, some ChEESE-1P PDs (workflows) transferred for WaaS (TA2-541)	
Common goals	Same Community and long-term ambition (EPOS TCS and ICS)	
EPOS	ChEESE-2P	Enabling of 2 services (TCS-TSU and TCS-VO)
	Geo-INQUIRE	Deployment and interoperability of datasets/products of the RIs EPOS-ERIC

Figure 1: ChEESE-2P and Geo-INQUIRE

Contribution to DT-Geo and the Digital Twin paradigm

ChEESE also contributes to the advancement of Digital Twins for geohazards through its integration with DT-Geo. While ChEESE focuses on code preparation, deployment, and service enabling for geohazard modelling, DT-GEO concentrates on developing workflows and deploying a pre-operational Digital Twin (DT) for Solid Earth. The two projects share nine common partners and align their efforts to advance simulation-based forecasting tools within the European Destination Earth programme. In this sense, ChEESE acts as a provider of workflows and modelling capabilities that can be modularly integrated within the DT-Geo infrastructure, fostering cross-project technical alignment and resource reuse.



ChEESE-2P and DT-GEO



Common partners	9	CSIC, BSC, INVG, IMO, CIN, LMU, UMA, NGI, CNRS
Coordination	ChEESE-2P (CSIC); DT-GEO (CSIC)	
Main concept	ChEESE-2P is about codes, DT-GEO is about workflows	
Objectives	ChEESE-2P	Code preparation and deployment, service enabling, research
	DT-GEO	Deploy a pre-operational DT (model-data fusion)
Synergies	5 codes shared (SeisSol, SPECfem3D, ExaHyPE, HySEA, FALL3D) 2-way feedback: ChEESE-2P code developments can be transferred to DT-GEO and DT-GEO workflows can benefit some ChEESE-2P PDs (PD1 to PD5) - No overlap between the DT-GEO Site Demonstrators (SDs) and the ChEESE-2P Simulation Cases (SCs)	
Common goals	Same Community and long-term ambition (DestinE)	
EPOS	ChEESE-2P	Enabling of 2 services (TCS-TSU and TCS-VO)
	DT-GEO	Integration of DT-GEO components in ICS-D

Figure 2: ChEESE-2P and DT-GEO.

Together, these collaborations ensure that the assets developed in ChEESE-2P—such as software tools, simulation workflows, and datasets—are not only upgraded in terms of TRL and usability, but also embedded into a broader European service ecosystem, enhancing their exploitation potential.

Further partner-specific exploitation plans will be elaborated individually, identifying concrete actions for each exploitable asset and service component developed under the project.

5. SWOT ANALYSIS

The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis for ChEESE-2P provides a strategic overview of the internal and external factors that may influence the project's exploitation potential. This will be updated throughout the project's lifecycle in alignment with progress on the business plan, stakeholder engagement, and EuroHPC JU priorities.

Strengths (*Internal characteristics that give ChEESE-2P an advantage*)

- **European Scientific Leadership:** ChEESE-2P builds on the legacy of ChEESE by uniting Europe's top HPC centres and scientific institutions with proven experience in urgent computing for natural hazards. It benefits from close collaborations with EPOS ERIC, national monitoring agencies, and global scientific networks.
- **Scope and Ambition:** The project's focus on 11 community flagship codes addressing 12 Exascale Computational Challenges (ECCs), and the development of 9 state-of-the-art Pilot Demonstrators (PDs) for 15 high-impact Simulation Cases (SCs), reflects a clear scientific and technological ambition. The inclusion of new domains (geodynamics, glacier hazards) strengthens the project's interdisciplinary relevance.
- **Technical Excellence in Code Optimisation:** ChEESE-2P places strong emphasis on co-design, performance portability, and scalability across evolving EuroHPC architectures, including containerisation, accelerators, and continuous performance monitoring. This enhances the long-term sustainability and reusability of outcomes.
- **Institutional and Operational Relevance:** The project directly targets European institutions responsible for operational monitoring, ensuring practical uptake of early warning and hazard forecast tools. This makes ChEESE-2P not just scientifically relevant but operationally useful.
- **Visibility and Neutrality:** As CoE, ChEESE-2P maintains a neutral stance attractive to both industry and public institutions. This enables unbiased collaboration and fosters trust, especially when compared with proprietary solutions offered by commercial vendors.

Weaknesses (*Internal characteristics that place CHEESE at a disadvantage relative to others*)

- It is difficult to reuse solutions adopted for a specific use case to others, in order to generate specific services.
- Maintain a proper balance between excellent fundamental science and deriving applications.
- Lack of driving commercial/legal entity makes it difficult to adapt to market evolving needs.
- A business plan is difficult to build, since no exascale systems are already available and therefore the present market is limited to test business opportunities and models.
- The diversity of target users (scientists, public authorities, hardware developers, industry) increases communication complexity. Tailoring exploitation strategies to such different audiences can dilute focus and stretch resources.

Opportunities (*External elements that ChEESE could exploit to its advantage*)

- European industry, including SMEs and consultancy firms (e.g. Mitiga Solutions), increasingly requires access to high-fidelity simulations for competitiveness. ChEESE-2P's expertise in code optimisation and performance engineering offers a concrete value proposition.
- By developing recommendations for EuroHPC emergency access for geohazard scenarios, ChEESE-2P can shape future HPC access policies and position itself as a reference initiative for societal-relevant supercomputing applications.

Threats (*External elements in the environment that could cause trouble for ChEESE*)

- Competing initiatives in the US, Japan, and China may develop alternative flagship codes and services that become de facto standards, limiting European influence.
- The shortage of young HPC experts, especially in academia and public research centres, threatens the sustainability of ChEESE-2P's scientific and technical capacity beyond the project's duration.
- The Simulation Cases are expected to produce massive datasets, raising concerns about storage, analysis, FAIR compliance, and integration into EOSC. Delays or underperformance here may undermine uptake.
- Despite clear scientific and societal relevance, converting the results into viable services or products for a broader market may face obstacles due to lack of business incentives or readiness from public institutions.
- Without a clear legal/commercial entity or long-term support mechanism, exploitation and maintenance of PDs and urgent computing services after ChEESE-2P could be at risk.

6. Intellectual property management

For an effective exploitation of the project results it is necessary to establish the main aspects of the methodology that we will further develop on Intellectual Property Rights (IPRs). IPR Management for ChEESE-2P is based on the following principles:

1. Background knowledge and Access Rights. Each partner will own the background that it brings to the project. In order to ensure a smooth execution of the project, the project partners will define the details

concerning Access Rights for Exploitation to Background and Results in the Consortium Agreement.

2. **Patents.** In case that a partner wants to submit a patent application, they will communicate to the Project Coordinator (PC) and the Project Innovation Manager (PIM) will have to determine whether it is a joint foreground or not and initiate if deemed, the appropriate study. All required measures will be taken to guarantee that there is no disclosure that can undermine the patent possibility. Therefore, all partners will be communicated and special measures of confidentiality will be taken. Information of patent applications will be made available to the EU through regular management reports. The costs of the patent applications will be covered by the submitters.

3. **Foreground knowledge and IP ownership.** Results will be owned by the project partner carrying out the work leading to such results, independently of whether they can be protected or not. If any results are created jointly by at least two project partners and it is not possible to distinguish between the contributions of each of the project partners, such results, including inventions and all related patent applications and patents, will be jointly owned by the contributing project partners. Each partner may use the results and material produced within the project for project purposes provided that such use does not come into conflict with the terms of the project Grant Agreement or the European legislation. Further details concerning jointly owned results, joint inventions and joint patent applications will be addressed in the Consortium Agreement.

4. **IPR log:** An IPR log has been set up to keep track of the services developed by the project partners. As new services are created, they're continuously added to this log, helping to safeguard everyone's contributions and ensure transparency when it comes to ownership and the origin of each asset. This shared record makes it easier for partners to collaborate on future developments. All intellectual properties (IPs) generated in the project—whether it's software, a workflow, methodology, dataset, invention, or design—must be reported at least twice during the project. The IPR log will be a key tool during the exploitation phase, as it helps identify which pieces of IP are involved in a given ChEESE service and which partners need to agree on how that service can be used or commercialised.

Table 5: IP log register example.

DAT E	Mo nth	Item	Descrip tion of the IP item	Type	Tentati ve IP protecti on	Tentativ e IP protecti on details	Dev elop er(s)	Stat us
April 2025	M28	FALL3D -9.1	Code version 9.1	Software	License / Copyright	GNU GPL v3	BSC/INGV	Released
April 2025	M28	MetPre p	Code version 1.0	Software	License / Copyright	GNU GPL v3	BSC	On-going
April 2025	M28	Elmer	Code version 9.0	Software	License / Copyright	GNU GPL v2 or later	CSC	On-going
April 2025	M28	MLESmap workflow	Code version 1.0	Software	License / Copyright	TBD	BSC	On-going
April 2025	M28	LaMEM	Code version 2.1.4	Software	License / Copyright	MIT	UM	On-going
July 2024	M18	OpenP DAC 12	Code version 12	Software	License / Copyright	GNU GPL v3	INGV	Released
April 2025	M28	Tsunami-HySEAMC	Code version 4.1.5	Software	License / Copyright	GNU GPL v2	UMA	Released
April 2025	M28	Meteo-HySEA	Code version 1.0.1	Software	License / Copyright	GNU GPL v2	UMA	Released

7. Trials/Simulations Cases

One of the objectives of ChEESE-2P is to conduct Simulation Cases using the Pilot Demonstrators, codes, and services developed within the project. As part of its mission to advance the operational readiness of these Pilot Demonstrators (PDs), ChEESE-2P is organising a series of Trials and Simulation Cases to test the applicability of its HPC-based services in real-world conditions. These activities are planned for the second half of the project and are currently undergoing internal discussions and coordination with relevant stakeholders. They are being developed within the framework of Work Packages 6 and 7, which have produced an internal document titled *Trial Guidelines*. This document outlines a structured methodology and provides a template to support the co-design, preparation, and execution of the Trials. Each Trial is co-designed by the ChEESE researchers in close collaboration with stakeholders and members of the Industry and Users Board.

7.1 Why Trials?

ChEESE-2P Trials are more than just technical exercises — they are a strategic step forward to evaluate the real-world impacts of new technologies and methodologies developed in the project. Their purpose spans across three stakeholder groups:

- **For developers:** Trials provide an opportunity to test new technological solutions, collect user feedback, and identify areas for improvement.
- **For scientific experts:** They help highlight new research challenges and foster collaboration within an Open Science framework.
- **For practitioners:** Trials are a means to connect innovations with day-to-day operational problems, providing a realistic context to assess potential solutions.

To guarantee the consistency and quality of the Trials, ChEESE-2P adopts a structured, user-centred approach inspired by the methodology formalised in the EU DRIVER+ project, originally designed to support innovation in crisis management. This methodology ensures that user needs guide the development and evaluation of solutions, reinforcing the co-design principles at the core of ChEESE-2P.

The first confirmed simulation case of ChEESE-2P will take place on 19 September 2025, as part of the National Seismic Drill of Mexico. This annual large-scale drill, organised by the Mexican government, aims to raise public awareness and improve emergency response readiness in the face of potential seismic events. It mobilises institutions across the country and includes real-time scenarios to test alert systems and crisis protocols.

Mexico is a seismically active region due to its location at the convergence of several major tectonic plates: the North American Plate, the Pacific Plate, the Cocos Plate, and the smaller Rivera and Caribbean Plates. This tectonic complexity leads to frequent earthquakes, particularly along the western coast and southern regions. The primary source of seismic activity is the subduction of the Cocos and Rivera Plates beneath the North American Plate along the Middle America Trench.

In this context, ChEESE, in collaboration with the Mexican National Seismological Service (SSN)—a member of the project's Industry and Users Board—will simulate an operational urgent computing service for earthquake impact forecasting. The trial will demonstrate the capabilities of two HPC-based workflows developed at the Barcelona Supercomputing Center under ChEESE-2P, as well as through synergies with the DT-GEO and Geo-INQUIRE projects. These efforts are closely aligned with the project's exploitation and sustainability strategy, aiming to showcase the real-world applicability of its services and foster long-term collaborations beyond Europe.

Notably, this year marks the 40th anniversary of the devastating 1985 Michoacán earthquake, which destroyed large parts of Mexico City, causing thousands of deaths, and remains a somber reminder of the region's seismic vulnerability.

Beyond the Mexico drill, ChEESE-2P is driving other impactful Simulation Cases. Pilot 5 is collaborating with the Buenos Aires Volcanic Ash Advisory Centre (VAAC) to co-organize and execute a trial focused on volcanic ash, estimated for Autumn 2025. This pilot, along with EPOS and CINECA, is also integrating SC5.1 simulations into the Simulation Data Lake (SDL@CIN) and an EPOS service (TCS-VO), streamlining data accessibility and service provision.

Meanwhile, Pilot 6 is actively engaging with the Italian Civil Protection Department. Specifically, the Commissione Grandi Rischi (CGR) has requested HPC phreatic eruption simulation scenarios for Campi Flegrei for hazard and impact assessment, expected by 2025. Additionally, the Settore Rischio Vulcanico (SRV) has agreed to co-design a ChEESE trial for urgent computing and probabilistic volcanic hazard assessment, with a trial run estimated for 2026.

7.2. Other ChEESE Services

Other services that ChEESE CoE may offer to the community are also here itemized:

- i. Repository: Various tools provided, including user-friendly and efficient systems for workflow executions and data processing (<https://cheese2.eu/codes/>)
- ii. Events (<https://cheese2.eu/all-events/>)
- iii. Training and webinars (<https://cheese2.eu/trainings/>)
- iv. Webinars and code videos (<https://www.youtube.com/@ChEESECoE/videos>)

7.3. Key partners

In the ChEESE-2P, the Innovation and User Board (IUB) continues to play a key role in connecting the project to relevant stakeholders and end-users. Unlike in ChEESE-1P, where new IUB members were gradually integrated throughout the project, ChEESE-2P builds upon an already established structure, focusing on reinforcing existing collaborations and ensuring continuity in the stakeholder ecosystem.

The sectors engaged in ChEESE-2P include public authorities and civil protection institutions, scientific organisations, HPC infrastructure providers, and international geoscience networks. Rather than a strong emphasis on industrial end-users as in ChEESE-1P, the current project focuses more on operational agencies and public bodies that can provide valuable feedback and real-world use cases for the Pilot Demonstrators.

Beyond the IUB, ChEESE-2P continues engaging with a broad ecosystem of strategic players:

- HPC Resource Providers, such as Barcelona Supercomputing Center (BSC) with MareNostrum 5 and CINECA with Leonardo, two EuroHPC pre-exascale systems. These organisations provide and maintain the physical infrastructure, user support, and resource allocation mechanisms essential to execute large-scale simulations.
- Technology Providers and Co-design Experts, involved in the development and optimisation of software and hardware interactions for exascale readiness (e.g. via EuroHPC JU initiatives and the European Processor Initiative (EPI)).

- Research Code Developers, from both academia and industry, such as Mitiga Solutions, contributing scientific models and numerical codes central to the PDs.
- Independent Software Vendors (ISVs), developing market-specific tools for seismic and volcanic risk management, including the Global Earthquake Model Foundation and other hazard analytics providers.
- Open Source and Scientific Communities, such as EPOS and INGV, that maintain strong networks of researchers, developers, and users and contribute to dissemination, validation, and potential uptake of ChEESE results.
- Solid Earth and Hazard Communities, such as ICES Foundation, VECMA and ARISTOTLE, which act as multipliers of technical know-how and facilitate cross-pollination between research, operations, and policy.
- Other Centres of Excellence, such as EoCoE-III, Hidalgo2, and ESiWACE3.
- Other related European Commission initiatives, including projects funded under Horizon Europe and EuroHPC JU calls, which provide synergy opportunities and visibility across European HPC and risk management ecosystems.
- This diverse stakeholder network ensures that ChEESE-2P continues to address both scientific and operational challenges in natural hazard prediction and contributes actively to the European HPC and disaster risk reduction agendas.

7.4. Communication and Dissemination Channels

ChEESE-2P continues to rely on a broad range of communication and exploitation channels to maximise the impact and visibility of the services and tools developed within the project. These include: web presence, social media platforms, members' institutional networks, scientific events, training activities, and collaborations with key stakeholders such as ARISTOTLE.

A new website was launched (<https://cheese2.eu/>) to reflect the beginning of the second phase of the project, with updated information, structure and branding tailored to the current scope of activities. In parallel, ChEESE maintains its presence on LinkedIn and X (formerly Twitter), and has recently expanded its outreach to BlueSky, strengthening its visibility in alternative scientific and tech-focused online communities.

In addition to traditional dissemination formats (e.g. conferences, workshops, webinars, including the EuroHPC User Day, the European Geosciences Union (EGU) General Assembly, the SimTech Conference, and the International Conference on Uncertainty in Atmosphere-Ocean Modelling (ICUA), several internal discussions and strategic meetings have taken place to explore new digital channels where the project's codes and services can be made accessible and visible. These include platforms like Waldur, the EuroHPC portal, and other evolving online environments that cater to HPC, scientific workflows, and service provisioning.

One particularly important dissemination and integration channel remains ARISTOTLE, with which ChEESE maintains an active and strategic relationship. Project management and innovation teams have been in contact with ARISTOTLE leadership to explore how the Pilot Demonstrators (PDs) developed in ChEESE-2P can complement or extend ARISTOTLE's operational environment — particularly by incorporating High-Performance Computing components into multi-hazard services such as tsunami early warning, earthquake risk, and volcanic activity forecasting.

ARISTOTLE's multi-hazard approach — covering earthquakes, tsunamis, floods, volcanic activities, wildfires, and severe weather events — aligns closely with the hazards addressed in ChEESE's Pilot Demonstrators. In addition, the project is attentive to other risk types listed in the Commission Staff Working Document on EU disaster risk, such as droughts, landslides, space weather, and so-called Natech events (technological disasters triggered by natural hazards), and will explore how the developed services may contribute to those domains.

7.5. Example of an initial Business Canvas Plan

Key Partners	Key activities	Value proposition	Customer relationships	Customer segments
Industrial End Users	Improve and develop Simulation Codes	Code improvement towards Exascale	Code Developer oriented	Code developers (commercial and non-commercial/research)
HPC resource providers	Improve data management and analytic tools, expertise	Keep and Develop European Competitiveness	Fair and neutral, competence-oriented	HPC technology providers
Research code developers		Expertise exchange platform	Community oriented	HPC resource providers
Academia and Scientific community	Key Resources	Provides project management and consultancy services	Channels	HPC and simulation expertise consultants
Scalability Experts and consultants	Portal Resources	Provides Training	Web presence	Industrial End Users
Services providers	- Homepage (Website) - Knowledge base: use cases, whitepapers, webinar, films - Services offering	Provides tools from Pilot Demonstrators	Social media	Academics and Scientifics
Open Source Groups			Members, sponsors and advertisers	Associate actors
Industry sector trade organizations			Industry events, seminars and conferences, Clusters	EU

Insurance and reinsurance players	from partners /vendors	Provides assets regarding workflows	Direct Marketing and sales Campaign	Local and national Government
Centres of Excellence (Including FocusCOE and HPC3)	Service provider resources	Solid Earth Leadership at EU level	Marketing activities of Stakeholders	Local and national Public Institutions (Civil protection)
Public institutions	• Services ready to use • Services planned • Services on Demand	Advertising Platform	Trade groups	Local, national and international organizations (e.g. emergency, NGOs, social care, etc.)
	HPC Centre resources			CoEs council (HPC3)
	Access to HPC infrastructure (software oriented to exascale)			
Costs • HPC-related human resources (HPC and code experts, consultants, training experts) • Administration (public relations, community support, sales & marketing, management) • Office space • IT expertise for Website			Revenue streams • Membership fee • Sponsorship fee • Advertising fee • Training revenues • 3rd-party funding • HPC3	

8. Vision and plan for Business Development at Sustainability Level

As in the previous phase, ChEESE-2P addresses its sustainability along three complementary axes:

- a) the Pilot Demonstrators (PDs),
- b) the strategic interests of the partner institutions, and
- c) the Centre of Excellence (CoE) as a whole.

All developments and foregrounds generated within ChEESE-2P are guided by exploitation strategies designed to align these three perspectives and ensure long-term relevance and continuity.

ChEESE as a central actor in the European Geohazard Ecosystem

ChEESE-2P sits at the centre of a growing ecosystem of interrelated European projects and infrastructures aiming to deliver operational services and digital frameworks for geohazard modelling and risk mitigation. The codes, workflows, and services developed in ChEESE-2P are positioned to contribute not only to scientific innovation but also to the creation of long-term (2027–2030) digital infrastructure, particularly in the context of Digital Twins for geophysical extremes.

The project aligns closely with initiatives such as DT-GEO, Geo-Inquire, GET-IT, and other digital twin efforts focused on earthquakes, tsunamis, and related natural hazards. Its contributions — including simulation codes, validated workflows, and operational use cases — act as bridges between low-TRL research outputs and high-TRL services accessible through platforms like EPOS-ERIC and EuroHPC.

Furthermore, ChEESE-2P is strategically positioned to contribute to the broader vision of the Destination Earth (DestinE) initiative, particularly through the Digital Twin on Natural Hazards. By developing scalable and HPC-optimised components that simulate complex geophysical phenomena, ChEESE supports DestinE's goal of building an accurate, interactive, and high-resolution digital replica of Earth. Its outputs can serve as foundational modules or plug-in components for hazard-specific layers within DestinE, enhancing Europe's capacity to anticipate, prepare for, and respond to natural disasters with unprecedented precision.

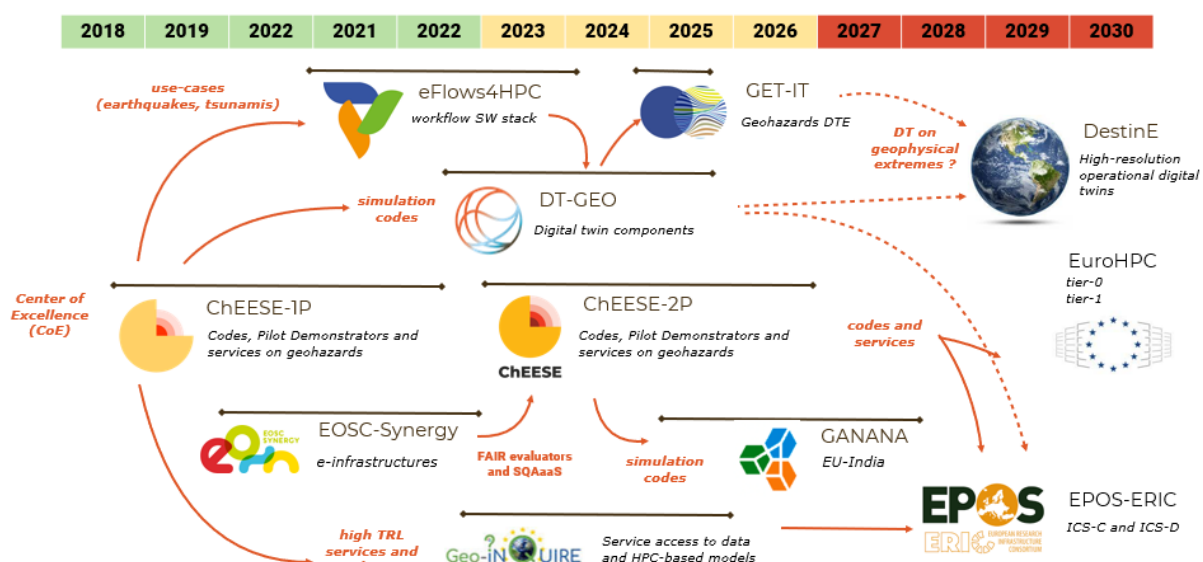


Figure 1: An ecosystem of interrelated projects with long-term (2027-2030) ambitions.

9. Conclusions and next steps

With the second phase of ChEESE underway, the project is consolidating its path towards a sustainable exploitation of results, building upon the lessons learned during ChEESE-1P. The definition and refinement of the service portfolio — including the Pilot Demonstrators (PDs), standardised workflows, and computational services — will be a cornerstone for confirming the business model outlined in the previous sections.

The preliminary market assessment, now focused on services with increasing maturity and community interest, will be critical for validating the value proposition of ChEESE as a Centre of Excellence. Engaging closely with the Industry and Users Board, as well as with initiatives such as DT-GEO, Geo-INQUIRE, EPOS, and others already mentioned in Section 4.8, will help align exploitation paths with the real needs of stakeholders in science, civil protection, and industry.

In the coming period, exploitation efforts will focus on the following key actions:

- Monitor and document Intellectual Property (IP) generated within the project, ensuring proper attribution and alignment with future exploitation scenarios.

- Support the maturation of PDs with higher Technology Readiness Levels (TRLs), especially those closer to pre-operational or operational status.
- Work closely with WP5 leaders and the PM team to evaluate integration options for ChEESE services within broader European digital research infrastructures.
- Start drafting a sustainability and business development strategy for the CoE beyond the project's duration, exploring possible synergies with EuroHPC's HPC3 programme and emerging European frameworks.
- Facilitate the coordination between communication, training, and exploitation tasks to reinforce the visibility and usability of ChEESE services.

Appendix A: Industry and Users Board description

In the next table all currently IUB members are briefly described (May 2025).

Table 6: Description of IUB Full members

Nº order	Institution / Type	Description
1	<u>ARISTOTLE / EC DG-ECHO Project</u>	All Risk Integrated System TOWards Trans-boundary hoListic Early-warning - European Natural Hazards Scientific Partnership (ARISTOTLE-ENHSP) is a project financed by the EC DG-ECHO that delivers world-leading multi-hazard advice capability to the Emergency Response Coordination Centre (ERCC). ARISTOTLE-ENHSP has been designed to offer a flexible and scalable system that can provide new hazard-related services to the ERCC and to create a pool of experts in the field of Meteorology and Geophysics of Europe that can support the ERCC about situation assessments in crises. The 24*7 services system is set up in a way that it builds upon and adds value to existing information systems and sources, and that it fully respects national and regional responsibilities. As required, a multi-hazard scientific partnership and its governance will be created to ensure the holistic understanding of crisis management in natural disasters with interrelated consequences and cascade & linked effects, which may lead to an unforeseen chain of events. Within ARISTOTLE-ENHSP, a collaborative network of scientific and operational experts has been established across Europe to exploit the available scientific and technological expertise and to assure mutual learning and improved coordination based on a multi-hazard

		approach, including the definition and implementation of the required prevention countermeasures, enhancing the information provided to the ERCC and, through the governance structure, ensuring a collaborative dialogue with the national mandated civil protection authorities. http://pilot.aristotle.ingv.it/ and http://aristotle.ingv.it/tiki-index.php
2	<u>AuScope / Government organization</u>	AuScope provides geoscientists with world-class research 'toolkit' to help tackle Australia's key geoscience challenges, and improve Australian life and the environment. At our core, we are a group of eminent geoscientists from federal and state government agencies and universities across Australia. We run eight programs that link diverse branches of geoscience like geodesy, geophysics, geochemistry and geodynamics with computation, and put research tools, data, services and analytics at the fingertips of geoscientists. https://www.auscope.org.au/
3	<u>CAT-INGV</u>	There are two main tasks of the Tsunami Alert Centre of the National Institute of Geophysics and Volcanology (CAT-INGV): issuing alerts in the event of earthquakes that could potentially generate tsunamis, and conducting studies to assess, on a probabilistic basis, the tsunami hazard for the Italian coasts—starting with those of seismic origin (Seismic Probabilistic Tsunami Hazard Analysis, SPTHA).
4	<u>European Plate Observing System (EPOS)</u>	The European Plate Observing System (EPOS; https://www.epos-ip.org) is an European Research Infrastructure Consortium (ERIC), a long-term plan aimed at creating a pan-European infrastructure for Solid Earth science to support a safe and sustainable society. The EPOS mission is to integrate the diverse and advanced European research infrastructure for solid Earth Science relying on new e-science opportunities to monitor and unravel the dynamic and complex Earth system. The EPOS ultimate goal is to enable innovative multidisciplinary research for a better understanding of the Earth's physical processes that control earthquakes, volcanic eruptions, ground instability, tsunami, and all those processes driving tectonics and Earth surface dynamics. EPOS integrates those research infrastructures provided and supported by national organisations, and aims at providing an interoperable platform where specific scientific services can be presented in a uniform and harmonized manner, facilitating cross- disciplinary access and utilization.
5	<u>Geographic National Institute (IGN)</u>	The Spanish Geographic National Institute (IGN: http://www.ign.es/web/ign/portal), a Governmental Institute with more than 500 employees, that holds a long experience in designing and maintaining

		operative infrastructures and derived applications related to geodetic and geophysical purposes. It is officially responsible for the Seismic, Tsunami and Volcano Monitoring Early Warning System and associated risks assessment. It is also responsible for the installation, maintenance and data analysis from the Seismic, Geodetic, Gravimetric and Geomagnetic networks of Spain, as well as the drafting and updating of the Earthquake Resistant Building Design Code.
6	<u>Italian Civil Protection Department</u>	The ICPD (DPC; http://www.protezionecivile.gov.it/home), which coordinates the response to natural disasters, catastrophes or other events that must be faced with extraordinary powers and means. Moreover, also in agreement with the regional governments and local authorities, DPC works in the drafting of legislation on the prevention of risks and regulatory measures needed to cope with disasters and minimize damage to people and property. It promotes national and international training projects and activities that contribute to spreading the culture of civil protection.
7	<u>Mexican National Seismic Institute (SSN)</u>	The National Seismological Service (Spanish: Servicio Sismológico Nacional, SSN) is a seismological organization in Mexico that studies and records earthquake activity within the country. It is part of the Geophysics Institute at the National Autonomous University of Mexico (UNAM) and is based in Mexico City.
8	<u>National Computational Infrastructure Australia / Government organization</u>	The National Computational Infrastructure (NCI) Australia is the nation's most highly integrated high-performance research computing environment, providing world-class services to government, industry, and researchers. At NCI over the last 8 years we have been optimising several Solid Earth HPC and Magnetotelluric codes. We are doing this work in optimising codes in parallel with converting data into machine actionable High-Performance Data Formats. https://nci.org.au/
9	<u>PLINIVS Study Centre</u>	The PLINIVS Study Centre among the most representative research structures in the field of seismic, volcanic and hydrogeological risk modelling and assessment.
10	<u>The Buenos Aires Volcanic Ash Advisory Center (VAAC)</u>	The Buenos Aires Volcanic Ash Advisory Center (VAAC) is one of nine VAACs established by the International Civil Aviation Organization (ICAO) to monitor and provide information on volcanic ash clouds that may endanger aviation. The VAAC in Buenos Aires is tasked with monitoring ash movement in its assigned airspace and issuing ash advisories. It is part of the National Meteorological Service of Argentina.

Appendix B Pilot Service

PD3. Global probabilistic tsunami hazard and uncertainty quantification

Lead partner(s)	INGV, UMA, NGI, TUM, LMU
TRL initial	7
TRL target	8-9
Description	This Pilot provides a workflow for carrying out the Global Probabilistic Tsunami Hazard Assessment (PTHA). The model will enhance the current Global PTHA model built by Davies et al. (2017). The new PTHA workflow • can carry out PTHA capacity workloads that can exploit tier-0 and tier-1 machines. • provides enhanced capability of carrying out multiscale PTHA at any location worldwide. • Make PTHA: i) interoperable with seismic hazard tools (e.g., GEM OpenQuake), and ii) compatible and potentially coupled with analogous tools from other projects/frameworks (e.g., Geo-INQUIRE). The activity of this Pilot will provide a substantial advance in comparison with previous global models (e.g. Davies et al., 2017), including: i) better characterization of uncertainty from heterogeneous earthquake slip on global tsunami hazard, ii) greatly improved global coverage of hazard points, iii) more sophisticated uncertainty treatment through alternative model implementations, iv) the societal dimension, enabling better distribution of results and models to other users globally, and v) scalability and enabling of (HPC based) local models.
Objectives	The Pilot Demonstrator aims to provide a workflow for carrying out PTHA capacity workloads that can exploit tier-0 and tier-1 machines. The Pilot will also allow to carry out PTHA at different spatial scales (from global to local); in particular, it will be possible to compute the local PTHA at any location worldwide. Finally, the PTHA will be made interoperable with other seismic hazard tools (e.g., OpenQuake engine) thus facilitating a link between the Global Tsunami Model (GTM) and the Global Earthquake Model (GEM). Furthermore, probability and rates, fault data and earthquake source models can be customized by the users. The workflow will be applied: • by using 3D Meshes for 46 subduction zones (from Slab2.0 model) tessellated in triangular elements; • by generating stochastic slip distribution (by means of the pyANTI-FASc software)

	- by exploiting the Flagship code Tsunami-HySEA for the tsunami modelling, that includes - the possibility to compute the tsunami initial condition also for triangular elements - the possibility to include the contribution of the horizontal deformation to the tsunami initial condition - by considering for each element of the subduction meshes two different rake angle values (45° and 135°) that will be used to create a basis of Green's functions that can be recombined for any rake value in the range 0-360° - The results of the model will be made generally available as a database into the Geo-INQUIRE SDL (Simulation Data Lake)
Lead partner(s)	INGV, UMA, NGI, TUM, LMU
CHEESE results and components involved	The ChEESE-2P flagship code Tsunami-HySEA is central to this workflow.
Type(s) of asset	Demonstrator
Relevant stakeholders	Tsunami Service Providers; Civil Protection
Exploitation channel(s)	The Global PTHA model can be used by users that want to assess high resolution probabilistic tsunami hazard in specific areas. Examples of that will be presented through the SC3.1.
Possible competitors	No available or alternative commercial products/assets exist, apart from the Davies et al. 2017 model, but the current PTHA is an enhancement of that.
Replicability in other domains and ecosystems	The workflow can be applied to a different spatial scales, provided that topo/bathymetric models are available.
Action plan / status	The results of the global PTHA will be made available through the SDL, while the workflow, once finalised, will be made available through the Global Tsunami Model (GTM) initiative.
Other relevant information	N/A

PD4. Complex multi-source tsunami modeling

Lead partner(s)	NGI (partners INGV, UMA, LMU, TUM)
TRL initial	3
TRL target	5

Description	A workflow for modeling tsunamis with complex, multistage, or multiphysics sources, e.g. combinations that may involve one of more of the following sources: earthquake, landslide, volcanic explosion, atmospheric pressure wave, either taking place contemporaneously or in cascading fashion (e.g. earthquake triggered landslides, explosion triggered pressure pulses etc).
Objectives	Integrating multiphysics processes from earthquakes, landslides, volcanoes, and atmospheric forcing to tsunami generation, enabling coupling of flagship codes for comprehensive modeling.
CHEESE results and components involved	The ChEESE flagship codes HySEA (specifically Tsunami-HySEA, Multilayer-HySEA, and Meteo-HySEA), SeisSol, and ExaHyPE (specifically the landslide module), integrated through a simple workflow. Due to the relatively low TRL, the workflow is expected to necessitate some manual operations, but will inherit common input and output standards that enable interoperability and integration of different flagship codes to provide results merging information between them. This includes also modelling of some cascading processes.
Type(s) of asset	Demonstrator
Relevant stakeholders	The initial target users are researchers and model developers. However, the present development is just the first step, and possible exploitation on developments downstream might benefit for instance civil protection authorities and organizations, insurance and reinsurance, and coastal engineers.
Exploitation channel(s)	A flexible and dynamic tool for research and consulting projects on natural hazards.
Possible competitors	Very few. There are some similar developments in New Zealand and Japan, but they are predominantly research efforts.
Replicability in other domains and ecosystems	The present problem is quite domain specific, but on the other hand the multihazard representation may invite interest among domain specialists within e.g. earthquake, volcano, and tsunami science.
Action plan / status	At present, the main emphasis is on developing the code and testing it to sufficient degree to share a validated code for other researchers.
Other relevant information	-

PD5. Ensemble-based volcanic dispersal at multiple scales

Asset title	Ash dispersal forecast workflow
Lead partner(s)	CSIC
TRL initial	5
TRL target	8-9
Description	Workflow based on CWL and internal management of FALL3D
Objectives	In recent years, the recurrences of long-lasting volcanic events characterized by sustained low-intensity emissions of SO ₂ and ash affecting lower levels of the atmosphere have raised major concerns about public health, material damage, disruption of essential services and environmental impact. The WF intended to be used in future volcanic crises and has potential application in different areas including UC services for volcanic dispersal forecasts at local scale.
Lead partner(s)	Arnau Folch (afolch@geo3bcn.csic.es)
CHEESE results and components involved	FALL3D model, CLW workflow
Type(s) of asset	Demonstrator,
Relevant stakeholders	supporting forecasting systems running in operational environments such as local weather agencies or Volcanic Ash Advisory Centers (VAACs)
Exploitation channel(s)	Support, Training, Extension/Customization
Possible competitors	No similar product exists
Replicability in other domains and ecosystems	General applicability; no regional limitations
Action plan / status	Trial with the Buenos Aire VAAC
Other relevant information	Open source product; will be made available throughout the ChEESE centralised repository

PD5. Ensemble-based volcanic dispersal at multiple scales

Asset title	European Tephra Hazard Map
Lead partner(s)	CSIC, INGV, IMO
TRL initial	5

TRL target	8-9
Description	Catalogue of footprints and hazard mapping service in EPOS
Objectives	First homogeneous multi-volcano probabilistic hazard model for volcanic tephra in Europe. National tephra hazard model at high resolution, considering all the key and best-known explosive active volcanoes in the territory (e.g. Vesuvius, Campi Flegrei, Ischia and Etna). Such a model will show those areas in the country statistically more likely to receive tephra fallout. On the other hand, at European scale, a similar approach will be used to provide a European hazard model for airspace of areas prone to be contaminated by dangerous concentrations at cruise Flight Level
Lead partner(s)	Arnau Folch (afolch@geo3bcn.csic.es)
CHEESE results and components involved	FALL3D model
Type(s) of asset	Service, open dataset
Relevant stakeholders	National civil protections can implement evacuation routes when designing emergency plans; local administrations and policy makers can plan the construction of new buildings and critical infrastructures; Air Navigation Service Providers (ANSP) can assess whether the planned air routes will be safe on a longer time scale and consider if some routes are more exposed than others to volcanic ash contamination and related engine maintenance, and finally, airlines can use model-based information as input into their Safety Risk Assessment (SRA) which, in turn, controls their decision in terms of flyability in presence (or forecasted presence) of ash in the atmosphere.
Exploitation channel(s)	EPOS (TCS-VO); SDL@CINECA
Possible competitors	No similar product exists
Replicability in other domains and ecosystems	Limited to Europe
Action plan / status	
Other relevant information	Service will be implemented thanks to an EuroHPC regular access mode project

PD6. Multiphase 3D volcanic explosion modeling

Asset title	OpenPDAC workflow for Urgent Computing
Lead partner(s)	INGV
TRL initial	4
TRL target	7-8
Description	OpenPDAC is an open-source module of OpenFOAM®, developed by INGV to simulated explosive volcanic processes. The UC workflow is designed to automate most of the procedures and settings for simulating explosive eruptions (in particular, phreatic events) during volcanic crises, and for post-processing the simulation output to provide information directly usable by decision-makers.
Objectives	Demonstrator of an Urgent Computing workflow based on 3D, physics-based simulations of volcanic eruptions.
Lead partner(s)	INGV
CHEESE results and components involved	The UC workflow is linked to OpenPDAC, one of the ChEESE-2p flagship codes
Type(s) of asset	1. Open-source flagship code (software) 2. Open-source UC workflow (software) 3. Demonstrator
Relevant stakeholders	The Italian Department of Civil Protection (under discussion)
Exploitation channel(s)	The code and workflow will be exploited upon request of the stakeholders for consulting on specific applications to active Italian volcanoes (Vulcano island, Campi Flegrei, etc.)
Possible competitors	Presently, this is the first attempt to develop an Urgent Computing service with 3D physics-based models of explosive eruptions. No competitors are foreseen.
Replicability in other domains and ecosystems	The workflow is specific for volcanic eruptions. However, potential development and extension to other natural hazards (e.g., granular avalanches) is possible using the same numerical codes.
Action plan / status	Trial expected on one of the active Italian volcanoes under unrest (Vulcano or Campi Flegrei).
Other relevant information	Some confidentiality issues can be foreseen if the product will be used during volcanic crises. Discussion ongoing with the stakeholders.

PD6. Multiphase 3D volcanic explosion modeling

Asset title	Probabilistic maps of phreatic explosion hazards
Lead partner(s)	INGV
TRL initial	4
TRL target	7-8
Description	OpenPDAC is an open-source module of OpenFOAM®, developed by INGV to simulated explosive volcanic processes. By running multiple instances of OpenPDAC, we will simulate ensembles of phreatic eruption scenarios, allowing a quantitative probabilistic volcanic hazard assessment (PVHA) and uncertainty quantification.
Objectives	Develop the first Probabilistic Hazard Maps of phreatic explosion impacts based on 3D, physics-based simulations.
Lead partner(s)	INGV
CHEESE results and components involved	The PVHA workflow is linked to OpenPDAC, one of the ChEESE-2p flagship codes
Type(s) of asset	1. Open-source flagship code (software) 2. PVHA workflow (software) 3. Hazard maps
Relevant stakeholders	The Italian Department of Civil Protection (under discussion)
Exploitation channel(s)	The code and workflow will be exploited upon request of the stakeholders for consulting on specific applications to active Italian volcanoes (Vulcano island or Campi Flegrei)
Possible competitors	Presently, this is the first attempt to develop PVHA maps with 3D physics-based models of explosive eruptions. No competitors are foreseen.
Replicability in other domains and ecosystems	The workflow is specific for volcanic eruptions. However, potential development and extension to other natural hazards (e.g., granular avalanches) is possible using the same numerical codes.
Action plan / status	Demonstrator expected on one of the active Italian volcanoes under unrest (Vulcano or Campi Flegrei).
Other relevant information	Some confidentiality issues can be foreseen if the product will be used during volcanic crises. Discussion ongoing with the stakeholders.

PD7. The Earth's dynamo model

Code	XSHELLS
Lead partner(s)	IPGP (L) ; CNRS

TRL initial	3
TRL target	5
Description	The Earth's magnetic field is generated and maintained by turbulent flow of liquid metal in the Earth's outer core. Its variability exhibits a wide range of time and length scales, from interannual pulses of secular acceleration to the occasional reversal of the geomagnetic field. This system is characterized by a high degree of scale separation: the magnetic field is large-scale while flow and buoyancy (which is of thermo-chemical origin) are small-scale, on the account of their lower diffusivity coefficients. The developments in ChEESE-1 were constrained to a limited time span and an arguably limited range of spatial scales, which may be detrimental to the quality of short-term geomagnetic forecasts. This PD will extend the previous developments by embracing the full spectrum of flow motion at stake and enabling a longer time integration by using a handful of very high-resolution simulations (over short time spans) to train dedicated neural networks for subgrid-scale modelling. The work plan consists of 3 successive steps: 1) use AI to infer the free parameters of standard subgrid-scale models using Neural Networks (NN); 2) use AI to infer the subgrid-scale contribution, in a fully data-driven way; 3) the final step will be to implement end-to-end training that requires a fully differentiable code.
Objectives	The main objectives of this PD are: (1) simulate the geodynamo process with an unprecedented level of realism, most notably by acknowledging that the fluid flow is highly turbulent and small-scale, while the magnetic field is large-scale; (2) assess the impact of turbulent flow on the short and long term working of the geodynamo, and propose an AI-based parameterization of subgrid-scale fluxes that is physics-informed.
CHEESE results and components involved	Better subgrid-scale models of (M)HD turbulence
Type(s) of asset	Demonstrator
Relevant stakeholders	Academia
Exploitation channel(s)	Academic
Possible competitors	N/A

Replicability in other domains and ecosystems	Of interest for the general field of astrophysical and geophysical fluid dynamics
Action plan / status	-
Other relevant information	

PD8. Geodynamics to geohazards

Codes	LaMEM
Lead partner(s)	UM
TRL initial	3
TRL target	5
Description	The slow deformation of the solid Earth takes place over long timescales, and involves large strains and non-linear viscoelastoplastic rheologies. This deformation governs processes on a wide range of scales, from fluid flowing through porous rocks on a micrometer scale to the motion of tectonic plates on thousands of kilometers, and controls the stress state of the lithosphere, affects where earthquakes occur, or how magma migrates through the crust. It also affects stresses within sedimentary basins and geothermal reservoirs and thus plays a key role for the long-term safety of nuclear waste deposits. Whereas existing geodynamic codes are typically applied to more basic scientific questions (such as how mountain belts form), they can equally well be used to simulate geohazards such as landslides or coupled geodynamic/seismic simulations. This PD focusses on these topics, which requires work to couple geodynamic with seismic codes.
Objectives	The main objectives of this PD are: (1) improve the workflow of geodynamic codes to such an extent that they can be rapidly deployed to simulate any part of the Earth and model output can be compared with observations, (2) export and project material properties and state of stress to other codes for multiphysics modeling purposes and, (3) prepare geodynamic codes for the next generation GPU machines, by improving multigrid strategies, implement matrix free solvers and as well as novel BFBt preconditioners.
CHEESE results and components involved	UM contributes to ChEESE through integration of LaMEM in multiple simulation cases within SC8, supporting high-resolution 3D modeling of tectonic and magmatic systems.

	These activities align with broader efforts to understand geohazards by simulating long-term deformation processes and assessing associated risks. In SC8.1, LaMEM enables forward modeling of volcano flank instability to evaluate the conditions leading to landslides and potential tsunami generation. In SC8.2, UM supports the analysis of upper plate tectonic evolution and stress field development in subduction zones. These efforts leverage LaMEM's scalability and advanced rheology to contribute to multi-partner workflows focused on dynamic hazard assessment. Results will inform downstream applications and link to other components, such as rupture modeling and inversion frameworks.
Type(s) of asset	Public stakeholders: Supports improved geohazard assessment, including volcanic flank collapse and tectonic deformation, aiding civil protection and risk mitigation strategies. Academics and Scientists: Advanced open-source modeling tool for high-resolution 3D visco-elasto-plastic geodynamic simulations. Enables studies of lithospheric processes, fault mechanics, and deformation. Scalable on HPC systems for large-scale research applications.
Relevant stakeholders	Civil protection, insurance companies, Academia
Exploitation channel(s)	Open-source software distribution, scientific training through workshops and courses, user support via GitHub and community forums, collaborative consulting for geohazard modeling, and code extension/customization in partnership with academic and research institutions.
Possible competitors	Geodynamical/geophysical 3D modeling software
Replicability in other domains and ecosystems	Using modular, open-source Julia package GeophysicalModelGenerator to easily reformat, transfer and recreate available datasets and model setup in any format.
Action plan / status	Replication capabilities in different domains. They should be as much as possible concrete and based on the bottom-up capability of the partners.

PD9. Glacial outburst floods

Asset title	Elmer/Ice
Lead partner(s)	CSC, IMO
TRL initial	2

TRL target	4
Description	Simulations of the evolution of subglacial rapidly-rising glacial lake outburst floods (GLOFs) – jökulhlaups in Icelandic – will provide insight into the dynamics of these relatively slowly moving (~5 m/s) floods.
Objectives	The physics of computing the evolution of a jökulhlaup is newly introduced into Elmer/Ice. The main objective is to get a numerically stable and accurate method that at the same time efficiently computes the propagation of the front of a subglacial pressurized water film in a synthetic setup that resembles the situation in real-world applications.
CHEESE results and components involved	The computations are very intensive. First results show that we will need to accelerate by about a factor of 10 to come close to real-time computations. This cannot be done by pure algorithmic scaling. Hence, the contribution from ChEESE on porting main parts of the algorithm to GPU's is a necessary input.
Type(s) of asset	Academic and Scientists: This will be the first time the problem of rapidly-rising glacier floods is addressed in the scientific world by a quantitative model End-users (hazard mapping): When operational, the code can be utilized to compute scenarios for glacier floods that would feed directly into hazard assessments
Relevant stakeholders	With IMO as the partner in the PD, we have the main stakeholder already with direct access to the new model. IMO is responsible for assessing natural hazards in Iceland.
Exploitation channel(s)	IMO will utilize the new model in their hazard planning
Possible competitors	No competitors in the field of subglacial floods. There are groups investigating subglacial hydrology in general
Replicability in other domains and ecosystems	We have records of several jökulhlaups at the same place (Skaftá, Vatnajökull), each with a different timing. Hydro-jacking (the main aspect of the problem) also occurs in front of marine terminated glaciers (this aspect is part of SC9.2) – which enhances the applicability of the method to other fields
Action plan / status	Currently the method is still under development. WP5 will contain updated strategies on moving the preliminary computations to real-world problems
Other relevant information	We are not yet (but that is according to plan in ChEESE-2p) at a production setup that allows us to compute large scale problems. We are also highly dependent on AMD/Cray to fix issues with compilers and ROCm stack on LUMI