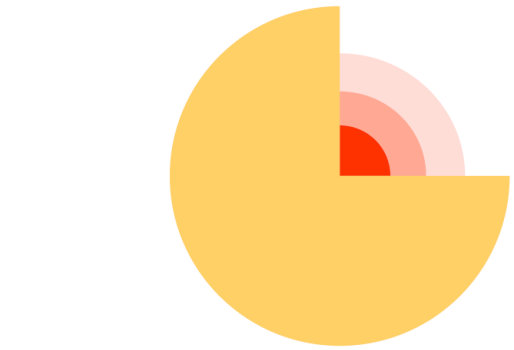

ChEESE

D6.8 Communication, Dissemination, Exploitation and Training Report

Version 2.0

Document Information

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Change Log

Version	Description of Change
V1.0	Initial draft for internal review
V1.1	Revised version after internal review comments
V1.2	Revised version after internal review comments
V2.0	Final version ready for submission

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List of Acronyms

CoE	Center of Excellence
KPI	Key Performance Indicator
GA	General Assembly
HPC	High Performance Computing
IPR	Intellectual Property Rights
IUB	Industry and Users Board
NDA	Non-disclosure agreement
PC	Project Coordinator
PD	Pilot Demonstrator
PEC	Project Executive Committee
PIM	Project Innovation Manager
PSB	Project Supervisory Board
TRL	Technology Readiness Level
WP	Work Package

1. Executive summary

This document reports on the communication, dissemination, exploitation and training activities carried out by ChEESE from November 2018 to March 2022.

This report includes a complete list of events, presentations, publications and promotional materials and training courses throughout its lifetime. It also includes detailed information on the website and social media performance, any coverage in the press, as well as activities about collaborations with other projects and initiatives.

During the 41 months of the project, the consortium participated in a total of 97 events, and organised and co-organised 15 training courses. Up to 34 press mentions were recorded and 62 open access scientific articles were published. With the aim to build a community around the project, the dissemination team posted regular updates on the project's dedicated Twitter and LinkedIn channels.

In terms of exploitation, this document reports up to M36+5, focusing on executed tasks related to exploitation and sustainability strategy for ChEESE as the European Centre of Excellence (CoE) for Solid Earth. Exploitation from a scientific, societal and industrial perspective it is a major commitment for ChEESE, as testified by the balanced consortium including a diversity of organizations. Another sign of the interest of the consortium for the utilization of project results has been the creation and involvement of an Industry and Users Board (IUB), which has followed the progress of the project not only during the face-to-face and remote meetings but also has provided continuous feedback, aiming to be part of the validation of the Pilot(s) Demonstrator(s) (PD) services in an operational environment. An extended description can be found in Deliverable 6.6.

The main **project joint outcomes**, from the ChEESE consortium as a whole, are:

- improving state of the art high performance simulation tools that help the modernization of the hazard related stakeholder's activities and are also of interest for European companies and scientific community.
- improving the cooperation between academia, R&D Centers, Public Entities and industries from EU and Pan-EU.
- Creation of an Industry and Users Board (initially composed by 12 stakeholders and, at the end of the project, composed by 28 institutions and initiatives).
- the definition of **urgent computing services** for natural disasters, with a particularization in seismic simulations of PD1, to be used in the context of the EuroHPC JU as a model for emergency access for HPC.
- A first demonstrator of PD2 has been implemented at the SPADA system of the Aristotle2-NHSP project to deliver advice to the EU Emergency Response Coordination Centre (ERCC).
- **La Palma eruption (Cumbre Vieja volcano): operational service of PD12.**
- 6 successful exercises carried out in collaboration with IUB and the extended network with 53 institutions + 99 individual and 26 countries represented.
- creation of the ChEESE Zenodo community (easy to trace OpenAIRE, metadata): https://zenodo.org/communities/cheese-coe/?page=1&size=20
- improving the cooperation between the leading solid Earth research groups in EU

- the shared use of computational resources: EU through PRACE[1] (EU) HPC calls.

The activities that have been implemented between M1 and M36+5 include:

1. Description of the main mission, vision and objectives, altogether with the used methodology.
2. Identification, collection and grouping of exploitable results generated.
3. Analysis of exploitable results towards their exploitation validation at CoE level and market uptake.
4. Selection of highly promising results and identification of Pilot exploitation strategies. (Definition of a Key Exploitable Result-KER)
5. Assessment of the external experts according to their technological and market potential. Inclusion and growth of the IUB members.
6. Initial discussion about the long-term sustainability strategy of ChEESE, becoming a legal status entity.

Finally, we already envision several success stories that will make sure of ChEESE's technologies being further developed, used and adopted on top of the project context.

The dissemination and exploitation team has successfully carried out several tasks indicated in D6.1 (Communication and Dissemination Plan), D6.5 (Training Plan), and D6.6 (Exploitation Plan).

2. Introduction

The objective of this report is to present a detailed list of the dissemination and exploitation activities which took place during the project's 41-month period, as planned in D6.1, D6.5 and D6.6. The activities were carried out in order to establish the ChEESE brand and build a community around the project. This deliverable covers the progress of tasks T6.1, T6.2 and T6.3 over this period.

3. General objectives and target audiences

The overall goal of ChEESE WP6 is to maximise the impact of the project, increase awareness, identify exploitable results and engage key stakeholders through training activities. The specific dissemination and exploitation objectives for the ChEESE project are the following:

1. To identify and perform communication and dissemination activities in order to maximize the impact of the project, in collaboration with other EU research activities, scientific audiences and industry forums.

[1] http://www.prace-ri.eu/

2. To identify the exploitable results of the project and to define the potential commercial strategies and services for the ChEESE results (market study, business models, distribution channel and promotional strategy) to reach the market.
3. To identify and perform training activities in order to engage interested parties in the usage of the ChEESE results.

In order to achieve the three objectives above, a number of target audiences and stakeholders were identified in D6.1 (Communication and Dissemination Plan) that are still in force:

1. Scientific community in geoscience and High Performance Computing (HPC)
2. Industrial stakeholders and policy makers
3. Young researchers
4. General public

4. Corporate image

In accordance with deliverable D6.1 Communication and Dissemination Plan, the first step was to define a common graphic identity. The branding of ChEESE (including logo and style, font, project templates, poster, etc.) was established and its guidelines have been shared with all partners via email and the project Wiki and correctly implemented by all partners throughout the duration of the project. The branding material of ChEESE can be found on the dedicated Branding page on the project website.

5. Communication and dissemination channels and tools

In order to efficiently reach the targets for promoting the results and maximising the visibility of the project, a broad spectrum of dissemination channels and tools have been used. The public website plays the central role in communication and dissemination as it is the most important channel for communicating the project's information. Social media, particularly Twitter, has been a very useful tool to reach out to the solid earth community. Press releases, participation as well as organization of events, as well as other outreach activities are described in detail in this section.

5.1 ChEESE Website (https://cheese-coe.eu/)

The ChEESE website is the main communication and dissemination channel of the project, where all project updates, news and technical information are published. During the first year of the project, the website consisted of overview pages (including about, partners, publications, media, and contact). In the second and third years of the project when more information about the ChEESE codes and pilot demonstrators (PD) were provided by the technical partners, the website was substantially updated and populated with more pages. Besides keeping the Collaborators page that lists ChEESE´s Industry and Users Board up-to-date, pages describing the project success stories and KPIs were also created.

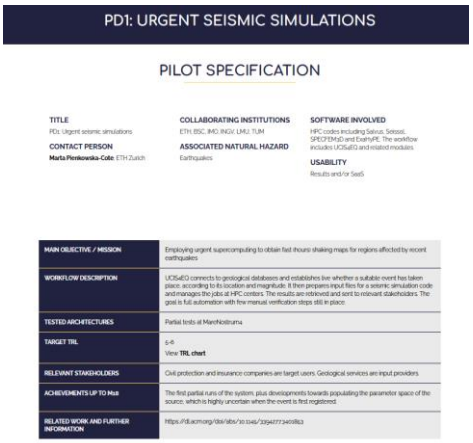

Figure 1 A Pilot Demonstrator page featuring Urgent Seismic Simulations page

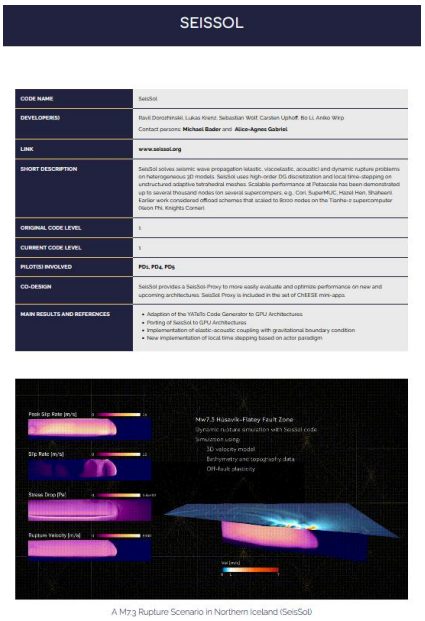

Figure 2 A Flagship Code page featuring SeisSol

A section called ShEESE was created in order to showcase the activities of the ChEESE Equality Committee. A detailed description about this page can be found here.

The ChEESE website was built using Drupal (open source CMS) and it complies with the technical requirements of performance and security. In addition, the website links to the project´s Wiki, which serves as the internal repository, allowing effective management by the dissemination team and seamless access by all consortium members.

The main indicators of the ChEESE website, shown in Google Analytics, show its successful performance in terms of the number of users, sessions, and page views. As shown in Figure 3, the total number of users and sessions during the project period was 20,764 and 27,894 respectively. The established KPI in the D6.1 Communication and Dissemination Plan for this metric is 1,000 website sessions per year, therefore these numbers have surpassed the initial predictions, demonstrating the strong interest in ChEESE and its activities.

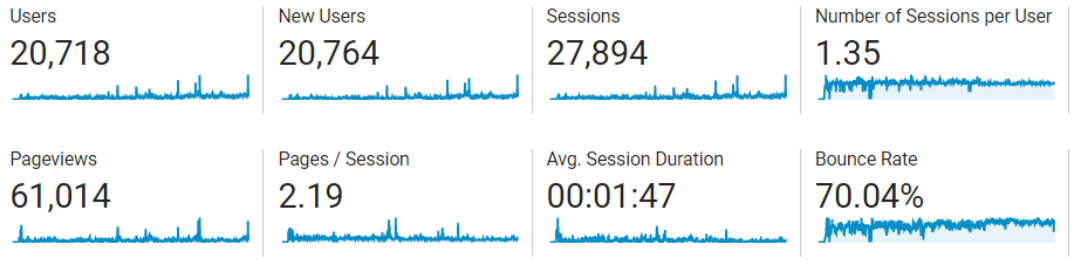

Figure 3 Website metrics from Google Analytics

The total number of page views was 61,014 while the average session duration of 2:19 min suggests that audiences have been suitably engaged with the ChEESE website. The bounce rate of 70.04% is considered average and indicates that a good number of people stay on the website once they visit it.

The flow of sessions during the 41-month period, shown in Figure 4 below, helps to better understand the performance of the page. In 2020 we have seen very high spikes in web visits which can be traced through Google Analytics. These were caused by ChEESE´s participation in EGU2020, the announcement of the ChEESE-organised PATC on Advanced Training on HPC for Computational Seismology, as well as a news item prepared by project partner INGV about their involvement in the project. In 2021 spikes in web visits were caused by ChEESE´s participation in EuroHPC Summit Week 21, the creation and promotion of the ShEESE page, as well as a news item of ChEESE´s table top exercises.

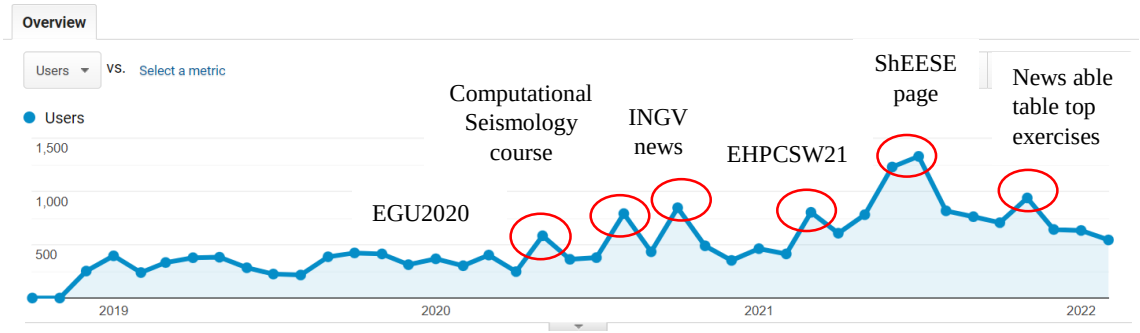

Figure 4 Peak visits to the ChEESE website as shown on Google Analytics

The most visited pages of the ChEESE website are shown in Figure 5. The landing page is the most viewed page with 15,975 views followed by the Events and News sections with 1,722 and 1,712 views, respectively. The CHEESE Advanced Training on HPC for Computational Seismology page, with 1,689 views, is the most viewed specific page.

	Page	Pageviews	% Pageviews
1.	/	15,975	27.81%
2.	/events	1,722	3.00%
3.	/media/news	1,712	2.98%
4.	/events/patc-cheese-advanced-training-hpc-computational-seismology	1,689	2.94%
5.	/results/pilots	1,589	2.77%
6.	/about/objectives	1,507	2.62%
7.	/publications	1,457	2.54%
8.	/about/partners-and-coordinator	1,357	2.36%
9.	/results/flagship-codes	1,091	1.90%
10.	/events/training	835	1.45%

Figure 5 Most viewed pages on the ChEESE website, as shown on Google Analytics

Social media has helped bring audiences to the ChEESE website, with Twitter, LinkedIn, Facebook and YouTube being the top four referrers (Figure 6). Twitter proved to be a highly engaging channel, bringing close to 2,453 sessions to the ChEESE website.

Social Network	Sessions
	3,200 % of Total: 12.20% (26,220)
1. Twitter	2,453
2. LinkedIn	501
3. Facebook	126
4. YouTube	74

Figure 6 Top social media referrers, as shown on Google Analytics

5.2 Social media

The two main purposes of ChEESE´s social media channels are to engage target audiences through interesting and informative posts and to lead them to the website in order to learn more about the project. ChEESE´s Twitter and LinkedIn channels are updated regularly. There has been a good level of engagement with ChEESE members and non-members, reflected in the growing number of followers and shares of ChEESE posts. The success of ChEESE´s social media channels can be attributed to the active engagement of individual partners and their institutions which have created a community around solid earth and HPC research.

5.2.1 Twitter

There are 1035 followers on the ChEESE Twitter channel as of M41 (Figure 7).

The ChEESE Twitter channel has been active in engaging with other European initiatives such as Focus CoE, ETP4HPC, PRACE, EPOS, the European Commission, as well as other CoEs in sharing each other´s content.

Figure 7 Twitter followers as of M41

The most popular tweet during the project lifetime is the announcement of ChEESE´s training course called "PATC: CHEESE Advanced Training on HPC for Computational Seismology" in August 2020 (Figure 8).

Figure 8 Most popular tweet on ChEESE Twitter channel

The success of ChEESE´s Twitter efforts could not have been achieved without the support of project partners. Many of ChEESE´s partners are active on social media and have consistently shared the project´s posts with their network. Several partners who have large followings on Twitter such as Steven Gibbons (21.1k followers) and Alice-Agnes Gabriel (2.4k followers) have helped further disseminate ChEESE news and results to a wider audience by either posting on their own or retweeting posts from the ChEESE account.

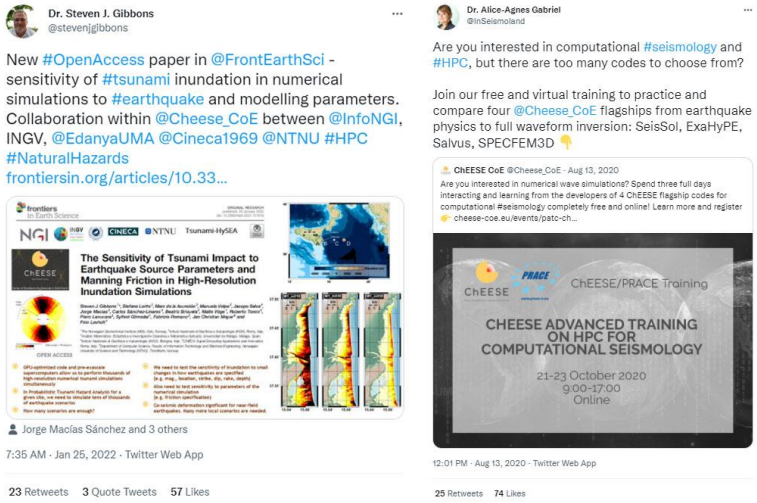

Figure 9 Tweets from ChEESE partners Steven Gibbons (L) and Alice-Agnes Gabriel (R)

Institutional partners have also helped push the message of ChEESE by either retweeting or posting from their own channel.

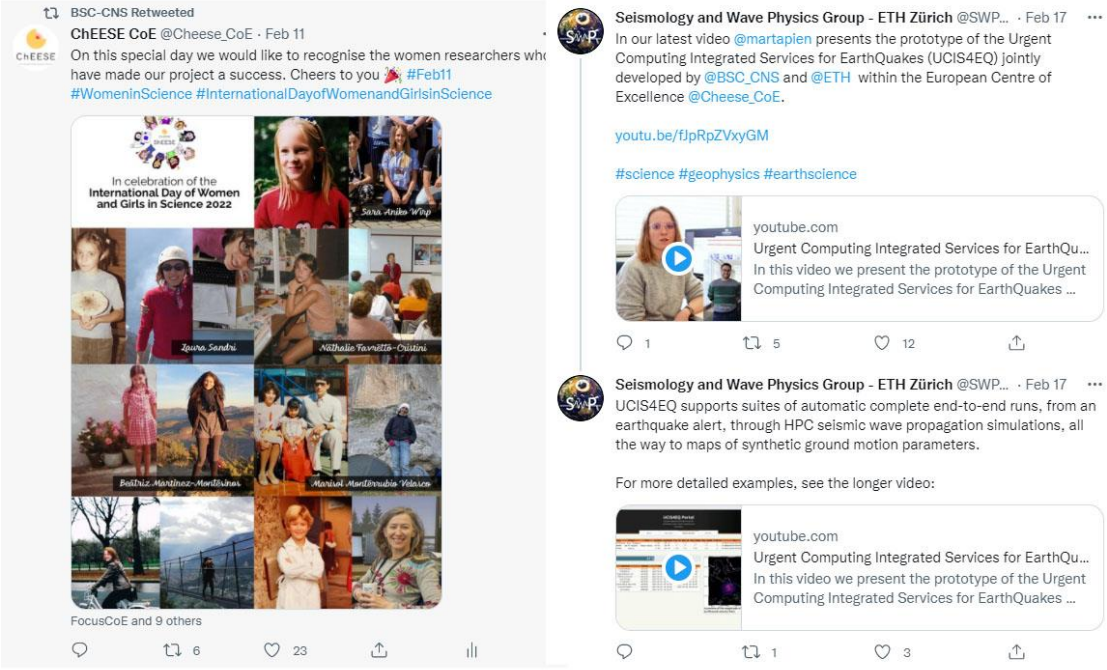

Figure 10 A retweet of a ChEESE post by BSC (L) and a post about ChEESE research by ETH (R)

5.2.2 LinkedIn

The ChEESE LinkedIn page has 378 followers as of M41 (Figure 11). ChEESE posts are disseminated by several partners who are active on LinkedIn as well as other European initiatives such as Focus CoE.

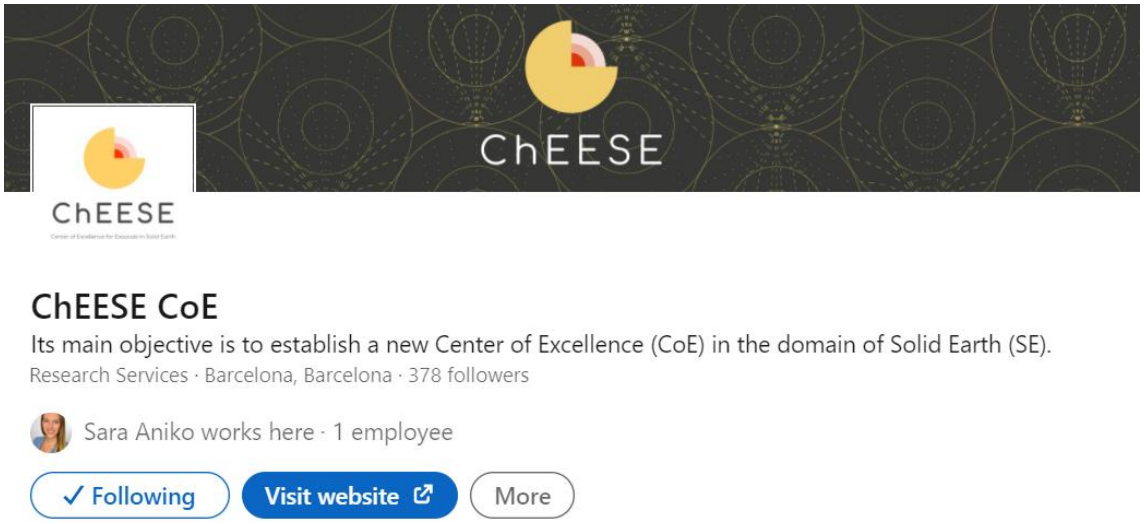

Figure 11 ChEESE LinkedIn followers

The most popular LinkedIn post as of M41 is [a video by ChEESE partner Marta Pienkowska-Cote describing the UCIS4EQ prototype that they tested in a live demo] (Figure 12).

Figure 12 Most popular LinkedIn post as of M41

According to LinkedIn analytics, this post has received 1,910 impressions, 107 clicks and 44 reactions.

Update title	Post type	Audience	Impressions	Views	Clicks	CTR	Reactions	Comments	Shares	Follows
Don´t miss the EuroHPC Summit Week happening on 22-24 March 2022! Posted by Rose Gregorio 2/22/2022 Boost	Reshare	All followers	31	-	0	0%	0	0	0	-
Urgent Computing Integrated Services for EarthQuakes (UCIS4EQ) - Overview Posted by Rose Gregorio 2/17/2022 Boost	Video	All followers	1,910	-	107	5.6%	44	4	3	-
Our partners Marta Pienkowska-Cote and Steven J. Gibbons will be presenting at th... Posted by Rose Gregorio 2/16/2022 Boost	Image	All followers	162	-	2	1.23%	8	0	1	-

Figure 13 LinkedIn analytics of most popular post as of M41

LinkedIn analytics provides demographic information about ChEESE followers. The information presented in Figure 14 shows the type of audiences that visit the ChEESE LinkedIn page. They are in line with the target audience mentioned in D6.1 Communication and Dissemination Plan.

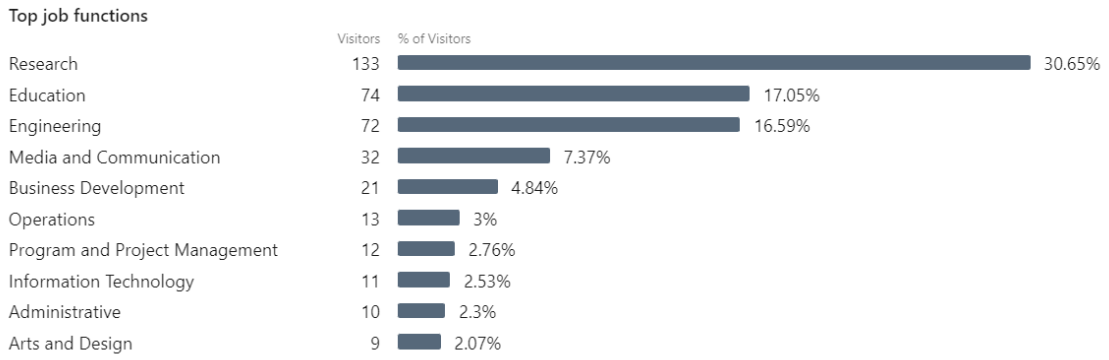

Figure 14 Top visitors on LinkedIn as of M41

5.2.3 Social media numbers

The overall performance of the social media accounts of ChEESE shows a high growth in the number of followers and engagement of users (Table 1). Both the Twitter and LinkedIn accounts performed very well, with Twitter being exceptionally successful. The continuous implementation of the editorial plan, the organisation and participation in numerous events, press mentions and creation of videos contributed to the great increase in the number of followers in both social media channels. It is worth mentioning that despite the COVID-19 pandemic, ChEESE partners did not slow down in their

communication and dissemination activities. As a result, there was a consistent growth in followers and engagement within the ChEESE community.

Social media followers	Followers in M12	Followers in M24	Followers in M41
ChEESE Twitter followers	261	702	1035
ChEESE LinkedIn followers	77	247	378

Table 1 A look at ChEESE´s social media followers in M12, M24 and M41

5.3 Videos

ChEESE has produced three official videos that present the research of the project. They have been uploaded to the Barcelona Supercomputing Center YouTube channel, published on the ChEESE website and shared on various social media channels.

The first video, titled "ChEESE: the HPC center of excellence in Solid Earth in three minutes", currently has 627 views. The video was a deliverable (D6.3) that was completed in M6 of the project.

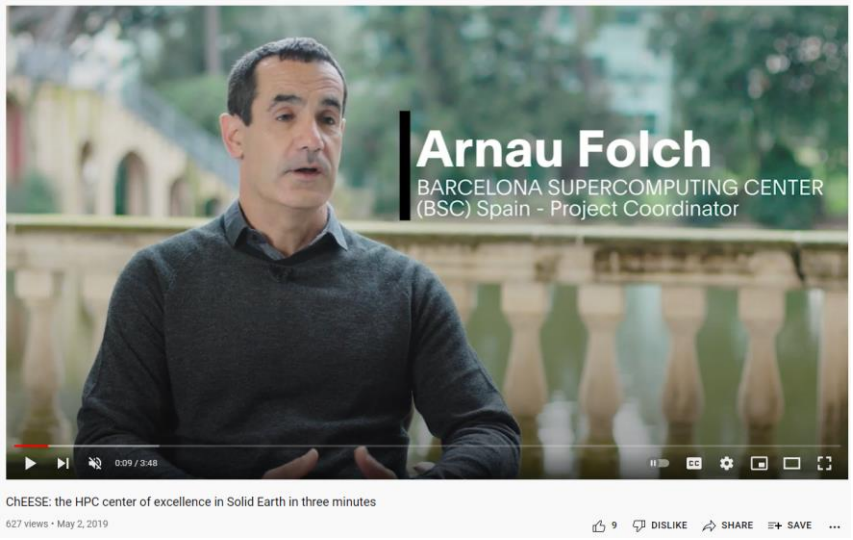

Figure 15 A screenshot of the first video entitled; ChEESE: the HPC center of excellence in Solid Earth in three minutes

The second video, titled "ChEESE: Saving lives and mitigating the effects of natural catastrophes" currently has 1,255 views. There was no commitment made in the grant agreement to create this video but the consortium felt it was appropriate to disseminate its work in urgent computing. It has been shared on various websites and social media channels, and at one point even placed on the main page of the Focus CoE website.

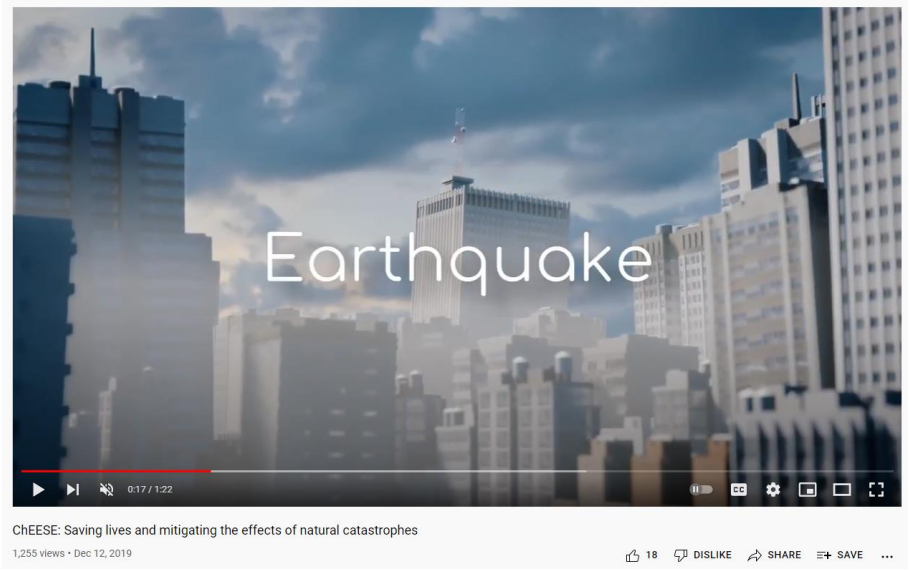

Figure 16 A screenshot of the second video entitled: ChEESE: Saving lives and mitigating the effects of natural catastrophes

The third video, titled "ChEESE: using the power of Exascale simulations to save lives", focuses on ChEESE results and data currently has 792 views. This video was a deliverable (D6.4) that was completed in M33 of the project.

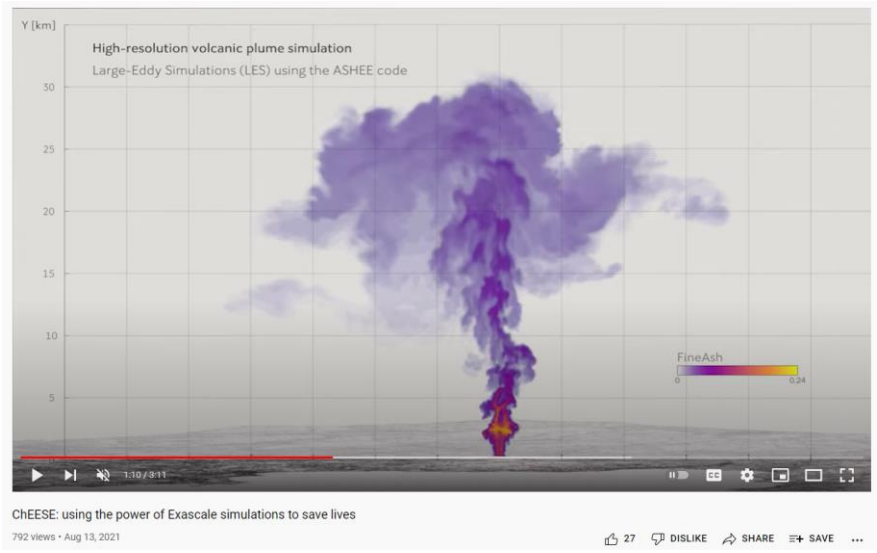

Figure 17 A screenshot of the third video entitled: ChEESE: using the power of Exascale simulations to save lives

ChEESE also produced and recorded other videos which have been uploaded on the BSC, ETH, INGVterremoti and Grupo Edanya (UMA) YouTube accounts. These include video recordings of ChEESE´s popular course on computational seismology and a video acknowledging the women researchers of the project in celebration of the International Day of Women and Girls in Science. They are presented below:

#	Video title	Views as of M41

1	ChEESE project meeting in Rome	96
2	CHEESE Advanced Training on HPC for Computational Seismology Day 2-SeisSol session	201
3	CHEESE Advanced Training on HPC for Computational Seismology Day 2-SPECFEM3D session	188
4	CHEESE Advanced Training on HPC for Computational Seismology Day 3-Salvus session & Wrap up	228
5	ChEESE presentation at the Women in HPC Workshop by Marisol Monterrubio-Velasco	38
6	ChEESE presentation at the Women in HPC Workshop by Beatriz Martinez Montesinos	77
7	ChEESE Advanced Training on HPC for Computational Seismology 2021	128
8	CHEESE Advanced Training on HPC for Computational Seismology Day 1-Introducing the codes	352
9	ChEESE Women in Science	497
10	SHAKEMOVIE: propagazione onde sismiche Mw 6.9 del 23 novembre 1980 in Irpinia e Basilicata	25,731
11	Urgent Computing Integrated Services for EarthQuakes (UCIS4EQ) - Overview	143
12	PD2 ChEESE Live Demo on FTRT Tsunami Simulations for Early Warning	110

Table 2 List of ChEESE produced or recorded videos uploaded to YouTube

All in all, there are 15 ChEESE videos and collectively, they have achieved 30,463 YouTube views. This shows that audiences are interested in ChEESE´s work and activities.

5.4 Dissemination pack

5.4.1 Brochure

The general ChEESE brochure provides an overview of ChEESE's project's objectives, main features, partners, and website and social media links. The design was approved by all partners. It has been printed to be distributed in events or local actions defined by each partner. It is available to download on the ChEESE branding page and the project Wiki.

Figure 18 ChEESE brochure front and back

5.4.2 ChEESE introduction poster

The ChEESE introduction poster, which contains general information about the project, is available on the Wiki (Figure 19). It has also been shared with all partners. It is editable so partners may modify it to suit their presentations.

Figure 19 ChEESE introduction poster

5.4.3 ChEESE introduction PowerPoint presentation

The ChEESE introduction PowerPoint presentation contains all the basic information about ChEESE such as funding information, coordinators and partners, as well as objectives and tasks included in the project (Figure 20). This presentation has been shared with all partners and is available on the project Wiki.

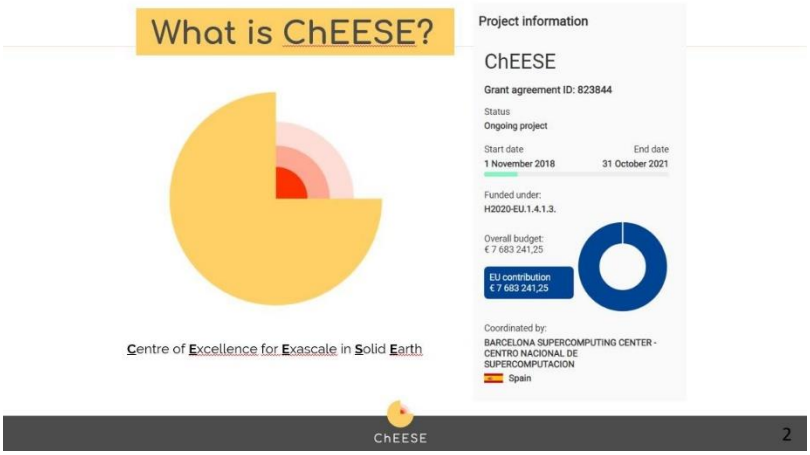

Figure 20 ChEESE introduction PowerPoint presentation

5.5 Press releases and mentions

ChEESE has launched one official press release at the beginning of the project. The project launched another one at the end of March 2022.

The first press release, titled "ChEESE: HPC Centre of Excellence in solid earth to mitigate impacts of geohazards", focused on introducing ChEESE´s objectives, including the preparation of flagship simulation codes in the solid earth domain to run efficiently on future European Exascale high-performance computing (HPC) systems.

The second press release, titled "Exascale-compatible geohazard mitigation services developed to help authorities in decision-making", focused on the achievements and results of ChEESE.

A strategy to contact individual media outlets was developed, resulting in many press mentions. Besides the dissemination team´s efforts, the activities of ChEESE partners have also resulted in a lot of press mentions.

As listed in Table 3, ChEESE has recorded a total of 53 mentions, with 34 in the press and 19 in institutional websites as of M1-M41. Press mentions include mainstream media such as BBC and National Geographic, as well as Spanish television channels CanalSur and RTV Marbella. The following list enumerates the media that have featured ChEESE research or activities:

#	Website	Date	Title
1	Eurolab4HPC	23 February 2019	The first Eurolab4HPC Business prototyping Projects kicking off: "USER"!
2	The EPOS Newsletter issue 03 July 2019	31 July 2019	Riding the wave of the future in supercomputing: Center of Excellence for Exascale in Solid Earth (ChEESE) will share Exascale-compatible codes on EPOS repository
3	Scientific Computing World HPC Yearbook 2019-2020	8 October 2019	Say ChEESE
4	Focus CoE	17 December 2019	How do EU citizens benefit?
5	PRACE	8 January 2020	Dr. Alice-Agnes Gabriel wins 2020 PRACE Ada Lovelace Award for HPC
6	HPCwire	8 January 2020	Dr. Alice-Agnes Gabriel Wins 2020 PRACE Ada Lovelace Award for HPC
7	InsideHPC	8 January 2020	Dr. Alice-Agnes Gabriel from LMU wins Ada Lovelace Award for HPC
8	Scientific Computing World	9 January 2020	Dr Alice-Agnes Gabriel wins the 2020 PRACE Ada Lovelace award
9	EPOS website	13 January 2020	ChEESE doubles speedup of seismic wave propagation code SPECFEM3D
10	CORDIS	6 February 2020	ChEESE doubles speedup of seismic wave propagation code SPECFEM3D
11	BSC website	27 February 2020	The paradox of Anak Krakatau, the Indonesian volcano that froze the atmosphere
12	Earth Networks	28 February 2020	How Volcanic Lightning Happened for Six Days
13	BBC	28 February 2020	Anak Krakatau: Lightning frenzy points to scale of volcanic plume
14	National Geographic	28 February 2020	Volcanic eruption sparked a weeklong thunderstorm, and scientists want to know why

15	The Nation	2 March 2020	Flash frenzy reveals scale of Anak Krakatau plume
16	CORDIS	6 March 2020	Boosting EU's research and innovation potential with a cutting-edge computing ecosystem
17	MeteoWeb	10 March 2020	L'eruzione del vulcano Anak Krakatau ha congelato l'atmosfera: ha generato dieci milioni di tonnellate di ghiaccio e 100.000 fulmini
18	Sicilia Report	10 March 2020	L'eruzione dell'Anak Krakatau ha creato ghiaccio e fulmini
19	Canal Ansa	11 March 2020	Il vulcano che nel 2018 ha congelato l'atmosfera
20	Villaggio Globale	10 March 2020	L'eruzione dell'Anak Krakatau ha creato ghiaccio e fulmini
21	Popular Science	11 March 2020	Anak Krakatau: il vulcano indonesiano che ha congelato l'atmosfera
22	Forbes	29 March 2020	Eruption Triggers 'Volcanic Freeze'
23	Mother Nature Network	1 April 2020	Fatal eruption triggered a 'volcanic freeze'
24	Canal Sur	2 April 2020	La Universidad de Málaga, a la cabeza en la prevención de tsunamis
25	Science Node	27 April 2020	Lava and lightning
26	NIUS	5 July 2020	El tiempo de reacción ante un tsunami sería de 45 minutos en las costas de Huelva y Cádiz
27	RTV Marbella	3 August 2020	Microplaya: El Cable y la Bajadilla
28	GEM Foundation	16 November 2020	GEM to contribute expertise to high performance computing in the field of seismology hazards
29	Cadena COPE	22 November 2020	Una simulación de tsunami en Andalucía: el primer paso para crear un plan de actuación
30	RTV	19 January 2021	¿Cómo pueden las Matemáticas responder ante un Tsunami?
31	EC Innovation Radar	27 February 2021	Faster Than Real Time (FTRT) environment for high-resolution simulations of earthquake generated tsunamis
32	INGV website	11 March 2021	ChEESE: The European Union prepares to enter the exascale era
33	Todo Noticias (RNE)	24 March 2021	Informativo Málaga
34	laSexta	3 June 2021	España ya cuenta con un plan de emergencia ante tsunamis para evitar catástrofes como la de 1755
35	Antena 3	4 June 2021	Jorge Macías, sobre los tsunamis en España: "Si el aviso lo damos en 15 minutos, se pueden salvar muchas vidas"
36	LaSexta	7 June 2021	¿Qué hacemos si hay un Tsunami?
37	HPCwire	6 July 2021	How HPC is Shaking Up Modeling of Mysterious Earthquakes
38	NGI website	28 September 2021	New method forecasting tsunami uncertainty
39	Rivista Natura	29 September 2021	Una nuova procedura di allarme tsunami dopo un terremoto
40	La Vanguardia	13 October 2021	El MareNostrum contra el volcán: cómo el superordenador limita los daños de la erupción
41	Newtral	4 October 2021	Del volcán a la emergencia climática: Los 'big data' que salvan vidas en catástrofes

42	Nius	10 October 2021	El superordenador de Barcelona que predice el volcán de La Palma: "Sería imposible sin él"
43	BSC website	20 October 2021	MareNostrum 4 makes forecasts on the ash clouds and aerosols of the La Palma volcano for the emergency services
44	HPCwire	20 October 2021	BSC's MareNostrum 4 Supercomputer Forecasts La Palma Volcano's Ash Clouds
45	Geopop	24 October 2021	Tsunami alert, the new forecasting model of INGV
46	Podium Podcast	29 October 2021	MI AÑO FAVORITO T04E03
47	NEAMTIC-UNESCO	29 October 2021	An international team coordinated by INGV presents a new model for tsunami early warning following an earthquake
48	CINECA	4 November 2021	World Tsunami Awareness Day, Urgent Computing Per Prevedere Gli Tsunami
49	PRACE Digest 2021 (p.16-17)	11 November 2021	Mapping the Earth's interior
50	European Commission website	15 November 2021	EU Centre of Excellence in High Performance Computing: ChEESE's urgent computing in the service of Cumbre Vieja volcanic eruption
51	Tierra y Mar & Espacio Protegido Canal Sur	15 November 2021	Conocemos el plan de contingencia ante el riesgo de maremotos en Andalucía
52	European Commission website	3 December 2021	Supercomputers help save lives during natural disasters
53	BSC website	14 December 2021	ChEESE´s volcanic ash forecasting service is validated in exercise conducted with the Buenos Aires Volcanic Ash Advisory Center

Table 3 List of media and institutional website mentions

5.6 Website news articles

The communication and dissemination team populates the ChEESE website with news items according to the editorial calendar and guidelines put together by the WP6 team and shared with the partners in the beginning of the project. These news items written by the dissemination team concern events that partners attend, general news and updates about the project. News items written by researchers concern the development of the technical work done in the project including progress in code development and the organisation of live demos and exercises.

The aim of keeping the news section updated regularly is to keep the ChEESE news page updated, drive traffic to the website and share content on the social media channels in order to increase engagement. By the end of the project, there were 60 project-related news items published on the ChEESE website and shared on ChEESE social media, as well as through the media channels of the partners. A detailed list can all be found on the ChEESE News page.

5.7 Events

ChEESE partners have overwhelmingly gone above and beyond in their participation in events. As of M41, ChEESE partners have participated in 97 conferences, workshops and other events and have given 202 presentations in total. The project has made a huge effort in participating in important conferences such as the American Geophysical Union (AGU) Fall Meetings and the European Geosciences Union (EGU) General Assemblies.

For example, ChEESE had a whopping 16 presentations coming from AGU Fall Meeting 2019 alone. ChEESE´s strong presence was also felt at the EGU General Assembly 2020 (12 presentations), AGU Fall Meeting 2020 (8 presentations), EGU General Assembly 2021 (11 presentations) and AGU Fall Meeting 2021 (10 presentations). It is worth noting that this report only includes presentations made by ChEESE partners, not presentations in which they collaborated but was presented by non-ChEESE members. Despite ChEESE ending at the end of March 2022, there are still plans to present ChEESE research at this year´s EGU General Assembly in May 2022.

ChEESE partners have also demonstrated their expertise in the field by not only presenting in events but also organising workshops, minitutorials and minisymposia within conferences. A great amount of collaboration and teamwork has been shown by the consortium which has resulted in the following: HPC Aspects of Tsunami Simulation (PP20), Towards Exascale Supercomputing in Solid Earth Geoscience and Geohazards Workshop (EGU 2021), European Urgent Computing Workshop (EHPCWS21), A Deep Dive into Shallow Water (CSE21), High-Performance Computing for Computational Seismology and Earthquake Physics (SIAM GS21) and Physics- Based Earthquake and Tsunami Simulation (SIAM GS21), Advances in Computational Geosciences, Part III (PASC21).

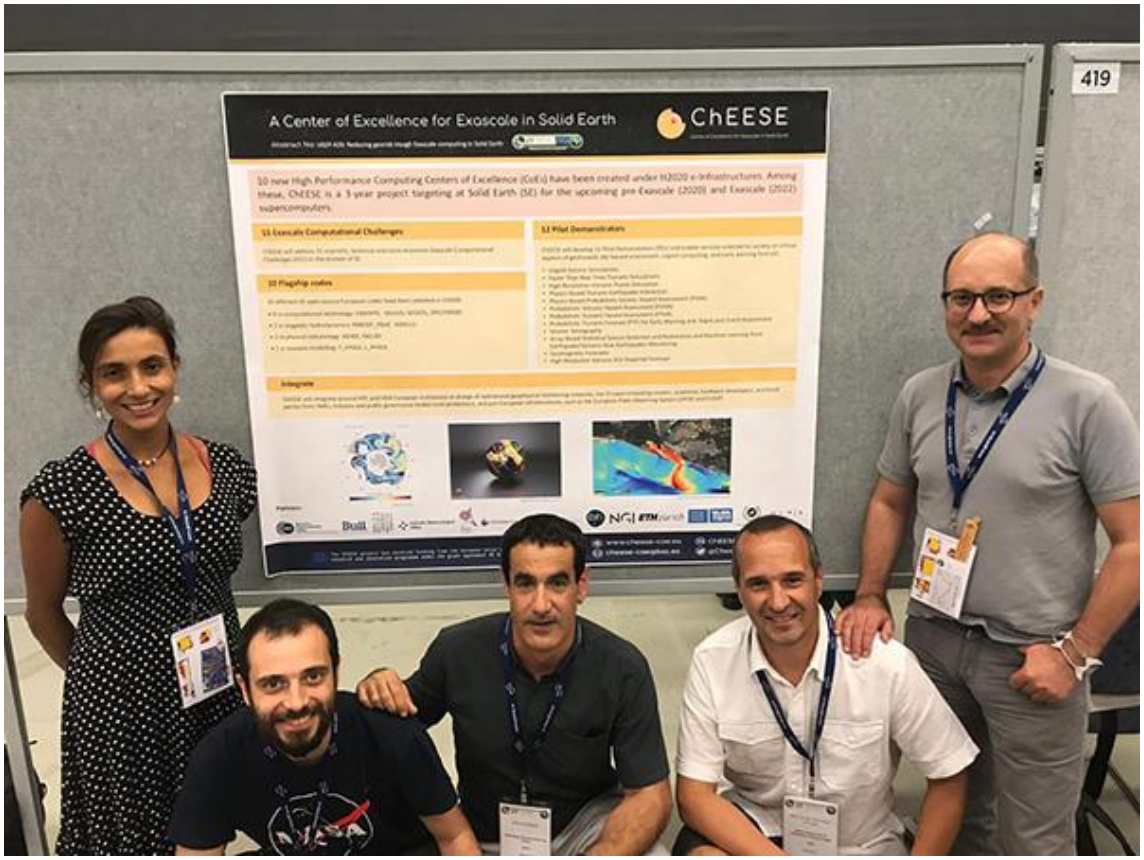

Figure 21 Photo from IUGG19, one of the events where ChEESE partners presented face-to-face

The table below (Table 2) lists all the events where ChEESE partners have disseminated their work. Every partner has been active in their dissemination efforts.

#	Type	Event	Date	Presentations
1	Workshop	PRACE, CoEs, FET-HPC, EXDCI workshop	30 October 2018	1
2	Workshop	FAULT2SHA Workshop	26 November 2018	1
3	Conference	AGU Fall Meeting 2018	10-14 December 2019	2
4	Workshop	Third Schatzalp Workshop on Induced Seismicity	5-8 March 2019	1
5	Conference	SIAM Conference on Mathematical & Computational Issues in Geosciences 2019	11 March 2019	1
6	Meeting	ESiWACE2 kickoff meeting	12-13 March 2019	1
7	Conference	EGU General Assembly 2019	7-12 April 2019	5
8	Conference	EuroHPC Summit Week 2019	13-17 May 2019	1
9	Seminar	Pint for Science	20 May 2019	1
10	Workshop	Northquake 2019 Workshop	21-24 May 2019	2
11	Workshop	Modelling of nonlinear dispersive waves: Mathematical theory and numerical approximation workshop	27-29 May 2019	1
12	Conference	deRSE19	4-6 June 2019	1
13	Conference	TERATEC 2019	11-12 June 2019	1
14	Conference	ISC19	16-20 June 2019	1
15	Workshop	NMEM 2019 workshop	30 June-4 July 2019	4
16	Conference	27th IUGG General Assembly	8-18 July 2019	4
17	Seminar	IMCE-UC seminar	22 July 2019	1
18	Workshop	Advanced Workshop on Earthquake Fault Mechanics: Theory, Simulation and Observations	2-14 September 2019	1
19	Conference	SCEC Annual Meeting	7-11 September 2019	1
20	Conference	PPAM 2019	8-11 September 2019	1
21	Seminar	Presentation of the Socio-economic Impact Report of Mathematics	19 September 2019	1
22	Seminar	European Researchers´ Night	27 September 2019	1
23	Workshop	MCS Megathrust Modeling Workshop	6-9 October 2019	1
24	Meeting	AGITHAR Kick-off meeting	7-9 October 2019	1
25	Hackathon	CINECA GPU Hackathon	7-10 October 2019	2
26	Workshop	Alboran Domain and Gibraltar Arc: Geological Research and Natural Hazards	16-18 October 2019	1
27	Workshop	Wind- Remobilisation Processes of Volcanic Ash Workshop	23-26 October 2019	2
28	Webinar	12th POP User Webinar - The Successful Interaction of ChEESE and POP	12 November 2019	1
29	Workshop	International Workshop on Tsunamis	14 November 2019	1
30	Workshop	2019 International Workshop on Software Engineering for HPC-Enabled Research (SC19)	17 November 2019	1
31	Workshop	UrgentHPC workshop	17 November 2019	1
32	Seminar	Insurance Compensation Consortium Annual Meeting 2019	28 November 2019	1
33	Workshop	ICG/NEAMTWS 2019	2-4 December 2019	1

34	Conference	Computing Insight UK 2019	5-6 December 2019	1
35	Conference	AGU Fall Meeting 2019	9-13 December	16
36	Workshop	SCEC Dynamic Rupture Group Ingredients Workshop on Fault Friction	8 January 2020	1
37	Conference	SIAM PP 2020	12-15 February 2020	4
38	Seminar	Bojos per la Supercomputacio	1 March 2020	1
39	Conference	Supercomputing Frontiers Europe 2020 (Virtual)	23 March 2020	1
40	Conference	High Performance Innovation Conference (Online)	30 March 2020	1
41	Seminar	The Deformation & Tectonics Talk Series (Online)	10 April 2020	1
42	Workshop	ExaHyPE user/dissemination workshop (Online)	22-26 April 2020	1
43	Conference	EGU General Assembly 20 (Online)	4-8 May 2020	12
44	Meeting	VECMA All-hands meeting	12 May 2020	1
45	Conference	ISC 2020	22-25 June 2020	1
46	Conference	LOD2020	19-23 July 2020	1
47	Conference	CMMSE 2020	30 July 2020	1
48	Workshop	SCEC CVM Workshop	1 September 2020	1
49	Conference	106 Congresso Nazionale	14-18 September	1
50	Conference	SCEC Annual Meeting 2020	14-17 September 2020	3
51	Conference	OpenPOWER Summit North America 2020	15 September 2020	1
52	Workshop	Virtual Seismic Tomography	6 October 2020	1
53	Workshop	Advancing Our Understanding of Earth Dynamics in CIG IV workshop	13-15 October 2020	1
54	Conference	Teratec 2020	13 October 2020	1
55		8th OpenFOAM Conference	14 October 2020	1
56	Workshop	Beyond the Horizon	15 October 2020	1
57	Workshop	Micromechanics, Statistics and Hazards of Mechanical Failure Workshop	19-22 October 2020	1
58	Seminar	Enzo Levi Seminar	30 October 2020	1
59	Workshop	Women in HPC Workshop @SC20	11 November 2020	2
60	Workshop	UrgentHPC@SC20	13 November 2020	1
61	Conference	GEOProcessing 2020	21 November 2020	2
62	Workshop	GenX workshop	24 November 2020	1
63	Seminar	Geociencias Barcelona (GEO3BCN - CSIC) seminar	1 December 2020	1
64	Conference	AGU Fall Meeting 2020	1-17 December 2020	8
65	Workshop	3rd Annual Workshop of HPC Training and Research for Earth Sciences (HPC-TRES)	11 December 2020	1
66	Conference	HPC Asia 2021	20 January 2021	1
67	Conference	HiPEAC 2021	20 January 2021	1
68	Workshop	First Joint CoEs Technical Workshop	27-29 January 2021	5
69	Conference	SIAM CSE 21	1-5 March 2021	3
70	Conference	SOS24 Virtual Conference	10 March 2021	1
71	Workshop	CoEs Co-Design Workshop	12 March 2021	1

72	Workshop	European Urgent Computing Workshop – EuroHPC Summit Week 2021	24 March 2021	4
73	Conference	Ada Lovelace Award Talk – EuroHPC Summit Week 2021	26 March 2021	1
74	Conference	GPU Technology Conference 2021	13 April 2021	2
75	Hackathon	EPCC GPU Hackathon	19-28 April 2021	1
76	Seminar	SMU Seminar Series	23 April 2021	1
77	Conference	EGU General Assembly 2021	19-30 April 2021	11
78	Workshop	Towards Exascale Supercomputing in Solid Earth Geoscience and Geohazards Workshop (EGU 2021)	29 April 2021	9
79	Hackathon	CINECA GPU Hackathon	14-21 June 2021	1
80	Conference	Congreso de Ecuaciones Diferenciales Y Aplicaciones (CEDYA)	14-18 June 2021	2
81	Seminar	Xv Jornadas Internacionales de Seguridad, Emergencia y Catástrofe. Retos Y Avances Tecnológicos	17 June 2021	1
82	Conference	International Conference on Computational Science (ICCS2021)	17 June 2021	1
83	Conference	SIAM Conference on Mathematical & Computational Issues in the Geosciences (GS21)	21-24 June 2021	5
84	Conference	ISC High Performance 2021 Digital Conference	24 June-2 July 2021	2
85	Conference	Platform for Advanced Scientific Computing Conference (PASC21)	6 July 2021	6
86	Conference	OpenACC Summit 2021	15 September 2021	1
87	Seminar	Aperitivo Scientifico: Tsunami, Terremoti, Vulcani. Cosa Può Fare Un Supercomputer	17 September 2021	1
88	Conference	37th General Assembly (GA) of the European Seismological Commission (ESC2021)	22 September 2021	1
89	Conference	82nd EAGE Annual Conference & Exhibition	21 October 2021	1
90	Hackathon	BSC-NVIDIA GPU Hackathon for HPC and AI	25 October 2021 and 2-4 November 2021	1
91	Workshop	2nd European VOs-VAACs Workshop	8-10 November 2021	1
92	Conference	SC21	14-19 November 2021	2
93	Workshop	Fault Tolerance for HPC at eXtreme Scales (FTXS) Workshop	14-19 November 2021	1
94	Seminar	Jornada Técnica sobre el Riesgo de Maremotos	2 December 2021	1
95	Conference	AGU Fall Meeting 2021	13-17 December 2021	10
96	Conference	SIAM PP22	23-26 February 2022	2
97	Workshop	VESTEC Final Workshop	23-24 February 2022	2

Table 4 List of events where ChEESE has disseminated its work

It is worth noting that in 2020, COVID-19 impacted several events that ChEESE was committed to. For example, DGG 2020 and PASC20 were cancelled and the project had spent a significant amount of effort organising the cancelled European Urgent Computing Workshop at EuroHPC Summit Week 2020. However, partners were committed to presenting at the same event if they were organised the following year. Furthermore,

ChEESE successfully organised its European Urgent Computing Workshop at the 2021 edition of EuroHPC Summit Week.

In the grant agreement, ChEESE had committed to submitting a Galileo Conference proposal to the European Geosciences Union (EGU). This proposal was granted in 2021 and plans are underway to carry out the conference in May 2023.

ChEESE partners have adapted their dissemination activities very well despite the restrictions caused by COVID-19. From mid-March 2020 until the end of March 2022 (M41) partners have participated in most events virtually, sometimes pre-recording their talks to comply with conference presentation formats.

5.8 Training

ChEESE has organised or co-organised 15 training courses throughout the lifetime of the project.

ChEESE has collaborated with PRACE in order to use their PRACE Advanced Training Centre (PATC) platform for five of the project´s training courses. Specific training courses on codes Tsunami HySEA and ExaHyPe, as well as one on seismic risk analysis have also been organised. Project partners from UMA have been particularly prolific with their Tsunami HySEA training efforts, with six courses carried out during the project lifetime.

The PATC course called CHEESE Advanced Training on HPC for Computational Seismology (held in October 2020) was very popular with participants. We had received 160 registrations to this course and its announcement had resulted in over 1,600 visits to the website. Despite the huge number of registrations, the course only had space for 50 participants. Because of its success, the project decided to organise another edition of the course in 2021. For the 2021 edition more effort was made to include EU13[2] colleagues. The CASTIEL project was contacted in order to share the training course with their mailing list. Furthermore, ChEESE created a list of EU13 researchers working in seismology and computational seismology and emailed them directly. This has resulted in eight EU13 participants joining the course. Furthermore, efforts were made to regulate the genders in the registration list, resulting in an even split of men and women participants in the course.

It is worth noting that changing training courses to an online format has widened the reach of ChEESE, allowing for more people from all around the world to be able to participate.

#	Training course	Date
1	2nd ExaHyPE user workshop	22-26 July 2019
2	Tsunami-HySEA training course (UTFSM-Chile)	23-26 July 2019
3	Tsunami-HySEA training course (UNA-Costa Rica)	4-8 November 2019

[2] Bulgaria, Croatia, Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia

4	PATC: School on Numerical Methods for Parallel CFD	2-6 December 2019
5	PATC: HPC and natural hazards: modelling tsunamis and volcanic plumes using European flagship codes	2-5 December 2019
6	Curso sobre el Analisis del Riesgo Sísmico (Seismic Risk Analysis Course)	9 March 2020
7	PATC: CHEESE Advanced Training on HPC for Computational Seismology	21-23 October 2020
8	PATC: Tools and techniques to quickly improve performances of HPC applications in Solid Earth	26-27 October 2020
9	Tsunami-HySEA: An introduction course (Instituto de Hidráulica Ambiental de Cantabria)	16 April 2021
10	Tsunami-HySEA: An introduction course (Escuela Superior Politécnica-Ecuador)	24-25 May 2021
11	EU ASEAN High Performance Computing (HPC) Virtual School: System Design & HPC Applications	5-9 July 2021
12	Tsunami-HySEA: An introduction course (University of Malta)	8 July 2021
13	PATC: ChEESE Advanced Training on HPC for Computational Seismology	19-21 October 2021
14	Curso sobre el Analisis del Riesgo Sísmico (Seismic Risk Analysis Course)	7 March 2022
15	Tsunami-HySEA training course (University of Puerto Rico, Mayaguez)	28-30 March 2022

Table 5 List of ChEESE training courses

The chart and images in Figure 22 show the number and type of training course participants as well as the countries they are from.

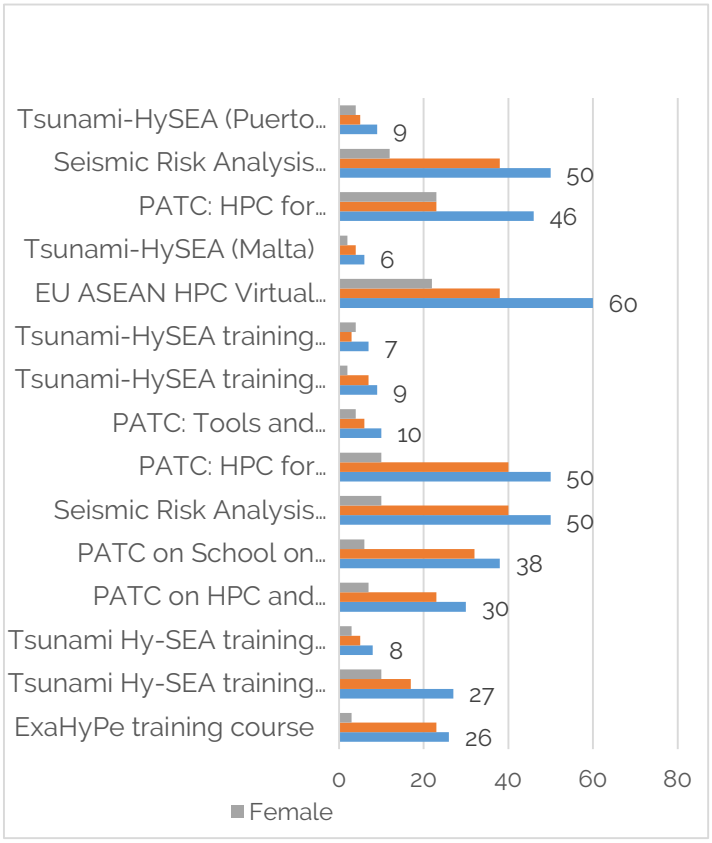

Figure 22 Training course participants M1-M41

5.9 Scientific publications

As of M41 there are now 62 peer-reviewed open access scientific publications, 51 in journals (91% in Q1 journals, 9% in Q2), 9 in conference/workshop proceedings and 2 in other types of publications such as white papers and book chapters.

The publications listed are open access and include the ChEESE acknowledgment sentence. It is worth mentioning that only articles that have been published have been included in this report. It does not include the many other papers that have been submitted or accepted (but not yet published). ChEESE partners have shown a high level of collaboration in terms of scientific output, with 20 publications involving at least 2 partner institutions.

#	Year	Publication	Journal/Conference	SJR	Quartile
1	2019	A Stochastic Rupture Earthquake Code Based On The Fiber Bundle Model (Tremol V0.1): Application To Mexican Subduction Earthquakes	Geoscientific Model Development	3.16	Q1
2	2019	Bayesian Dynamic Finite-Fault Inversion: 2. Application To The 2016 Mw6.2 Amatrice, Italy, Earthquake	JGR Solid Earth	1.96	Q1

3	2019	Bayesian Dynamic Finite-Fault Inversion: 1. Method And Synthetic Test	JGR Solid Earth	1.96	Q1
4	2019	Coupled, Physics-Based Modeling Reveals Earthquake Displacements Are Critical To The 2018 Palu, Sulawesi Tsunami	Pure and Applied Geophysics	0.6	Q2
5	2019	Delayed And Sustained Remote Triggering Of Small Earthquakes In The San Jacinto Fault Region By The 2014 Mw 7.2 Papanoa, Mexico Earthquake	Geophysical Research Letters	2.66	Q1
6	2019	Dynamic Viability Of The 2016 Mw 7.8 Kaikōura Earthquake Cascade On Weak Crustal Faults	Nature Communications	5.99	Q1
7	2019	Landers 1992 “Reloaded”: Integrative Dynamic Earthquake Rupture Modeling	JGR Solid Earth	1.96	Q1
8	2019	Modeling Active Fault Systems And Seismic Events By Using A Fiber Bundle Model – Example Case: The Northridge Aftershock Sequence	Solid Earth	0.8	Q1
9	2019	Modeling Megathrust Earthquakes Across Scales: One-Way Coupling From Geodynamics And Seismic Cycles To Dynamic Rupture	JGR Solid Earth	1.96	Q1
10	2019	Parallel 3-D Marine Controlled-Source Electromagnetic Modelling Using High-Order Tetrahedral Nédélec Elements	Geophysical Journal International	1.3	Q1
11	2019	On Energy Stable Discontinuous Galerkin Spectral Element Approximations Of The Perfectly Matched Layer For The Wave Equation	Computer Methods in Applied Mechanics and Engineering	3	Q1
12	2019	Volcanic Ash Forecast Using Ensemble-Based Data Assimilation: The Ensemble Transform Kalman Filter Coupled With Fall3d-7.2 Model (Etkf-Fall3d, Version 1.0)	Geoscientific Model Development	3.16	Q1
13	2020	Accelerating numerical wave propagation by wavefield adapted meshes. Part II: full-waveform inversion	Geophysical Journal International	1.3	Q1
14	2020	Alternating direction implicit time integrations for finite difference acoustic wave propagation: Parallelization and convergence	Computers and Fluids	0.999	Q1
15	2020	On the landslide tsunami uncertainty and hazard	Landslides	1.638	Q1
16	2020	Volcanic Ash Resuspension in Patagonia: Numerical Simulations and Observations	Atmosphere	0.7	Q2
17	2020	Space-time adaptive ADER discontinuous Galerkin schemes for nonlinear hyperelasticity with material failure	Journal of Computational Physics	1.94	Q1
18	2020	Anak Krakatau Triggers Volcanic Freezer in the Upper Troposphere	Scientific Reports	1.41	Q1
19	2020	Comparison Of Expansion-Based Explicit Time-Integration Schemes For Acoustic Wave Propagation	Geophysics	1.35	Q1

20	2020	Ensemble-Based Data Assimilation Of Volcanic Ash Clouds From Satellite Observations: Application To The 24 December 2018 Mt.Etna Explosive Eruption	Atmosphere	0.63	Q2
21	2020	Exahype: An Engine For Parallel Dynamically Adaptive Simulations Of Wave Problems	Computer Physics Communications	1.26	Q1
22	2020	FALL3D-8.0: A Computational Model For Atmospheric Transport And Deposition Of Particles, Aerosols And Radionuclides – Part 1: Model Physics And Numerics	Geoscientific Model Development	3.16	Q1
23	2020	Dynamic Fault Interaction during a Fluid-Injection-Induced Earthquake: The 2017 Mw 5.5 Pohang Event	Bulletin of the Seismological Society of America (2020)	1.35	Q1
24	2020	Evolutionary full-waveform inversion	Geophysical Journal International	1.34	Q1
25	2020	Evolution of the multifractal parameters along different steps of a seismic activity. The example of Canterbury 2000–2018 (New Zealand)	AIP Advances	0.45	Q2
26	2020	Probabilistic Tsunami Hazard Analysis: High Performance Computing for Massive Scale Inundation Simulations	Frontiers in Earth Science	1.16	Q1
27	2020	Synthetic seismicity distribution in Guerrero–Oaxaca subduction zone, Mexico, and its implications on the role of asperities in Gutenberg–Richter law	Geoscientific Model Development	3.16	Q1
28	2020	On the validity of the planar wave approximation to compute synthetic seismograms of teleseismic body waves in a 3-D regional model	Geophysical Journal International	1.34	Q1
29	2020	Linked 3-D modelling of megathrust earthquake-tsunami events: from subduction to tsunami run up	Geophysical Journal International	1.34	Q1
30	2020	A stable discontinuous Galerkin method for the perfectly matched layer for elastodynamics in first order form	Numerische Mathematik	1.93	Q1
31	2021	FALL3D-8.0: a computational model for atmospheric transport and deposition of particles, aerosols and radionuclides – Part 2: Model validation	Geoscientific Model Development	3.16	Q1
32	2021	A unified first-order hyperbolic model for nonlinear dynamic rupture processes in diffuse fracture zones	Philosophical Transactions of the Royal Society A	1.07	Q1
33	2021	Seismic Source Tracking With Six Degree-of-Freedom Ground Motion Observations	JGR Solid Earth	1.96	Q1
34	2021	Mean zonal flows induced by weak mechanical forcings in rotating spheroids	Journal of Fluid Mechanics	1.72	Q1
35	2021	Probabilistic Tsunami Hazard and Risk Analysis: A Review of Research Gaps	Frontiers in Earth Science	1.16	Q1

36	2021	Testing Tsunami Inundation Maps for Evacuation Planning in Italy	Frontiers in Earth Science	1.16	Q1
37	2021	A penalty-free approach to PDE constrained optimization: application to an inverse wave problem	Inverse Problems	1	Q1
38	2021	3D Linked Subduction, Dynamic Rupture, Tsunami, and Inundation Modeling: Dynamic Effects of Supershear and Tsunami Earthquakes, Hypocenter Location, and Shallow Fault Slip	Frontiers in Earth Science	1.16	Q1
39	2021	A New Discontinuous Galerkin Method for Elastic Waves with Physically Motivated Numerical Fluxes	Journal of Scientific Computing	1.53	Q1
40	2020	Deep Neural Networks for Earthquake Detection and Source Region Estimation in North-Central Venezuela	Bulletin of the Seismological Society of America	1.26	Q1
41	2021	Probabilistic tsunami forecasting for early warning	Nature Communications	5.56	Q1
42	2021	Physics-based secular variation candidate models for the IGRF	Earth, Planets and Space	0.84	Q1
43	2021	A Testable Worldwide Earthquake Faulting Mechanism Model	Seismological Research Letters	1.51	Q1
44	2021	Callback-based completion notification using MPI Continuations	Parallel Computing	0.3	Q3
45	2022	A stable discontinuous Galerkin method for linear elastodynamics in 3D geometrically complex elastic solids using physics based numerical fluxes	Computer Methods in Applied Mechanics and Engineering	2.53	Q1
46	2022	Ensemble-Based Forecast of Volcanic Clouds Using FALL3D-8.1	Frontiers in Earth Science	1.16	Q1
47	2022	Stress, rigidity and sediment strength control megathrust earthquake and tsunami dynamics	Nature Geoscience	5.44	Q1
48	2022	The Sensitivity of Tsunami Impact to Earthquake Source Parameters and Manning Friction in High-Resolution Inundation Simulations	Frontiers in Earth Science	1.16	Q1
49	2020	Data assimilation of volcanic aerosol observations using FALL3D+PDAF	Atmospheric Chemistry and Physics	2.62	Q1
50	2022	Long-term hazard assessment of explosive eruptions at Jan Mayen (Norway) and implications for air traffic in the North Atlantic	Natural Hazards and Earth System Sciences	1.12	Q1
51	2021	Offshore Geological Hazards: Charting the Course of Progress and Future Directions	Oceans	1.09	Q1
52	2019	A Microservices Approach for Parallel Applications Design: A Case Study for CDF Simulation in Geoscience Domain (Winner of Best Paper Award)	12th International Conference on Advanced Geographic Information Systems, Applications, and Services (GEOProcessing 2020)	-	-

53	2019	Towards Physics-Based Probabilistic Seismic Hazard Assessment in Complex Fault Networks - The Cheese Project	3rd International Workshop on Earthquakes in North Iceland (Northquake 2019)	-	-
54	2019	Urgent Tsunami Computing	UrgentHPC workshop (SC19)	-	-
55	2019	Towards Improved Seismic Monitoring, Earthquake Modeling and Ground Motion Simulation for Early Warning and Hazard Estimates in North Iceland	3rd International Workshop on Earthquakes in North Iceland (Northquake 2019)	-	-
56	2020	A High-Order Discontinuous Galerkin Solver with Dynamic Adaptive Mesh Refinement to Simulate Cloud Formation Processes	PPAM 2019 - 13th International Conference on Parallel Processing and Applied Mathematics	-	-
57	2020	Urgent Supercomputing of Earthquakes: Use Case for Civil Protection	Platform for Advanced Scientific Computing Conference	-	-
58	2021	SeisSol on Distributed Multi-GPU Systems: CUDA Code Generation for the Modal Discontinuous Galerkin Method	HPC Asia 2021	-	-
59	2021	3D Acoustic-Elastic Coupling with Gravity: The Dynamics of the 2018 Palu, Sulawesi Earthquake and Tsunami	SC21	-	-
60	2021	What is the humanitarian aid required after tsunami?	XXVI Congreso de Ecuaciones Diferenciales y AplicacionesXVI Congreso de Matem´atica Aplicada	-	-
61	2019	Modeling Earthquake Source Processes: From Tectonics to Dynamic Rupture	White paper	-	-
62	2021	Tsunami-HySEA: A Numerical Model Developed for Tsunami Early Warning Systems (TEWS)	Book chapter	-	-

Table 6 List of ChEESE scientific publications

ChEESE has published two papers that have gained significant attention and recognition in M1-M41. Anak Krakatau Triggers Volcanic Freezer in the Upper Troposphere covers interesting research that has been featured on various press including BBC, National Geographic, Forbes, etc. Another paper, A Microservices Approach for Parallel Applications Design: A Case Study for CFD Simulation in Geoscience Domain, has won the Best Paper Award at GEOProcessing 2020.

6. Synergies and collaborations with other projects and initiatives

ChEESE has synergised, collaborated or supported various European and international projects, initiatives and organisations throughout the lifetime of the project, as shown in the image below:

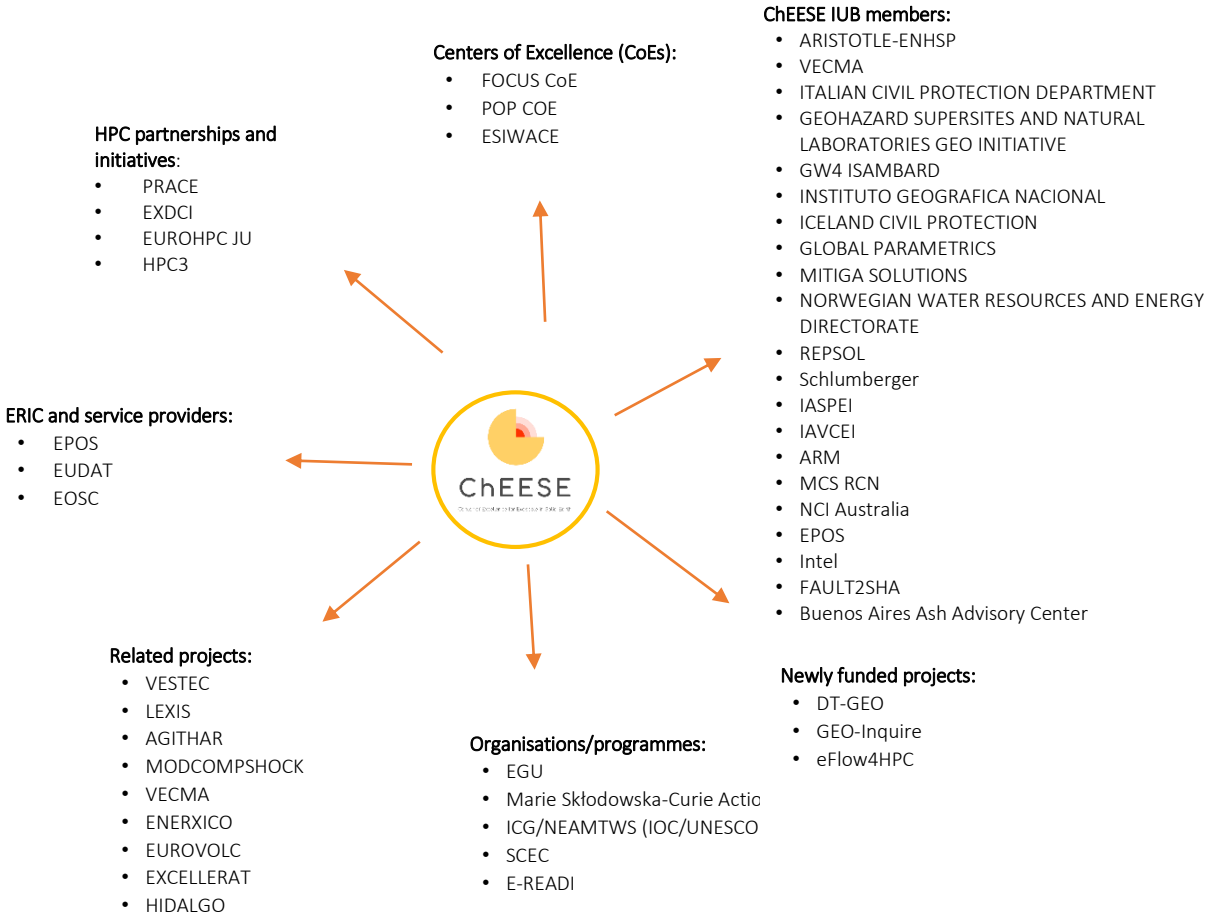

Figure 23 Synergies and collaborations with other projects and initiatives

6.1 HPC partnerships and initiatives

6.1.1 PRACE

ChEESE has used the existing training platform from PRACE to maximise the impact of its training activities. The following courses have been organized using PRACE Advanced Training Centre platform:

1. PATC: School on Numerical Methods for Parallel CFD
2. PATC: HPC and natural hazards: modelling tsunamis and volcanic plumes using European flagship codes
3. PATC: CHEESE Advanced Training on HPC for Computational Seismology (2020)

4. PATC: Tools and techniques to quickly improve performances of HPC applications in Solid Earth
5. PATC: CHEESE Advanced Training on HPC for Computational Seismology (2021)

6.1.2 EXDCI/EuroHPC Joint Undertaking

ChEESE had organised a EuroHPC Summit Week 2021 workshop titled "European Urgent Computing" that was held on 24 March 2021. Furthermore, ChEESE and EXDCI social media channels have also had regular interactions (sharing and liking) via Twitter.

6.1.3 HPC3

ChEESE is active in the HPC3 Sustainability Working Group and has supported them in their creation of communication materials about Centers of Excellence.

6.2 Centres of Excellence

6.2.1 POP

The collaboration between ChEESE and POP in code optimisation has been publicly communicated regularly through various channels. ChEESE presented a webinar hosted by POP called "12th POP User Webinar - The Successful Interaction of ChEESE and POP", POP has featured its work on ChEESE code PARODY_PDAF in its September 2019 newsletter, and POP has been mentioned in a news item on the ChEESE website. Besides that, both ChEESE and POP social media channels have shared each other´s posts.

6.2.2 Focus CoE

ChEESE and Focus CoE have collaborated or supported each other throughout the first 24 months of the project. Besides joining the Focus CoE booth at TERATEC 19 and various interactions on social media, ChEESE has also been featured on the Focus CoE website in relation to how EU citizens benefit from Centres of Excellence. ChEESE was supposed to take part in a Focus CoE podcast to be recorded at EuroHPC Summit Week 2020 but its cancellation led to the postponement of the podcast. ChEESE participated in a joint CoE workshop organised by Focus CoE, held at the HiPEAC conference in January 2021. Additionally, ChEESE has been in touch with Focus CoE regarding possible promotion of ChEESE activities and potential participation in Focus CoE booths at various events.

6.2.3 ESiWACE

ChEESE presented a talk at the ESiWACE kick-off meeting while a partner from ESiWACE had been a confirmed speaker at the cancelled European Urgent Computing at EuroHPC Summit Week 2020.

6. 3 Related projects

6.3.1 AGITHAR

ChEESE presented at the AGITHAR kick-off meeting.

6.3.2 ModCompShock

ModCompShock is using Tsunami-HySEA models and numerical schemes that are being improved by ChEESE.

6.3.3 VESTEC and LEXIS

ChEESE presented at 2 UrgentHPC workshops (collocated with the SC conference) in 2019 and 2020, which was co-organised by VESTEC and LEXIS. Furthermore, partners from VESTEC and LEXIS were panel speakers at the European Urgent Computing workshop organised by ChEESE. Lastly, ChEESE presented at VESTEC´s Final Workshop in February 2022.

6.3.4 VECMA

ChEESE presented at an Invited Talks session organised by the VECMA project.

6.3.5. ENERXICO

ENERXICO supported ChEESE in the ChEESE Advanced Training on HPC for Computational Seismology through its work with the ExaHyPE code.

6.3.6 EUROVOLC

ChEESE presented at the 2nd European VOs-VAACs Workshop, which was organised by EUROVOLC and EPOS.

6.3.7 EXCELLERAT AND HIDALGO

ChEESE co-organised a virtual workshop called the "First Joint CoEs Technical Workshop" together with EXCELLERAT and HIDALGO.

6.4 Projects, institutions and companies in ChEESE IUB

The IUB members of ChEESE are composed of organizations from all around the world. The IUB have used the project´s flagship codes and improved them by giving valuable feedback. Furthermore, many of them were involved in the live demos that ChEESE has organised. The current member list includes:

- ARISTOTLE-ENHSP
- VECMA
- ITALIAN CIVIL PROTECTION DEPARTMENT
- GEOHAZARD SUPERSITES AND NATURAL LABORATORIES GEO INITIATIVE
- GW4 ISAMBARD
- INSTITUTO GEOGRAFICA NACIONAL
- ICELAND CIVIL PROTECTION
- GLOBAL PARAMETRICS
- MITIGA SOLUTIONS
- NORWEGIAN WATER RESOURCES AND ENERGY DIRECTORATE
- REPSOL
- Schlumberger
- IASPEI
- IAVCEI

- ARM
- MCS RCN
- NCI Australia
- EPOS
- Intel
- FAULT2SHA
- Buenos Aires Ash Advisory Center

6.5 ERIC and service providers

6.5.1 EPOS, EOSC and EUDAT

ChEESE codes will be available in the EPOS, and EUDAT repositories. Additionally, an article about ChEESE´s intention to put codes in EPOS has been published on the EPOS website.

6.6 Organizations and Programmes

6.6.1 European Geosciences Union

Besides attending the annual EGU General Assembly, ChEESE´s proposal for a Galileo conference, entitled "Computational Geosciences in the Exascale Era", has been accepted. The conference will take place in Barcelona in May 2023.

6.6.2 Marie Skłodowska-Curie Actions

ChEESE participated in a European Researchers´ Night event, which was supported by the Marie Skłodowska-Curie Actions programme.

6.6.3 ICG/NEAMTWS (IOC/UNESCO)

ChEESE is part of the Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the North-eastern Atlantic, the Mediterranean and connected seas (ICG/NEAMTWS), a group coordinated by the Intergovernmental Oceanographic Commission of UNESCO (IOC/UNESCO). ChEESE partners have participated in steering committee meetings, plenary ICG Sessions, and other workshops, where ChEESE was always properly highlighted. NEAMTWS has been mentioned in the ChEESE website and on deliverables and reports.

6.6. 4 Southern California Earthquake Center (SCEC)

ChEESE is using Cybershake, a PSHA map platform that SCEC has developed. ChEESE members have also given talks in SCEC workshops and annual meetings in 2019 and 2020.

6.6.5 Enhanced Regional EU-ASEAN Dialogue Instrument (E-READI)

ChEESE partners were lecturers at the 1st EU-ASEAN HPC School, which was carried out in the framework of the Enhanced Regional EU-ASEAN Dialogue Instrument (E-READI).

6.7 Newly funded projects

ChEESE´s work and creation of a rich ecosystem around the use of pre-exascale and upcoming exascale EuroHPC infrastructures have directly benefitted the creation of newly funded projects eFlows4HPC, Geo-Inquire and DT-GEO. ChEESE and eFlows4HPC have also worked together in promoting the UCIS4EQ prototype video since there are shared technologies between both projects.

7. ShEESE

ShEESE, which is a combination of the words “She” and “ChEESE”, is the Equality Committee of the project. ShEESE is composed of five women and four men from eight partner institutions. There are also four partners who participate as observers and help support the activities of the Committee. During the lifetime of the project, the Committee regularly held meetings in order to discuss gender and equality issues within the consortium. Actions as a result of these meetings include:

1. The introduction of associations which promote female scientists such as 500 Women Scientists, Valore D and AMIT, and the encouragement of ChEESE´s female scientists to join them. This has resulted in 2 women scientists of ChEESE to be interviewed for an article by Tembor.

2. The creation of an all-female editorial board to oversee a Frontiers in Earth Science special issue called "High-Performance Computing in Solid Earth Geohazards: Progresses, Achievements and Challenges for a Safer World". This special issue published 9 papers, 3 of which were submitted by ChEESE partners.

3. The encouragement of ChEESE´s women scientists to participate in the Women in HPC workshop in SC20. This resulted in 2 female partners giving presentations at the event.

4. The organisation of the Towards Exascale Supercomputing in Solid Earth Geoscience and Geohazards Workshop at EGU2021 with a focus on maintaining an equal number and men and women conveners from ChEESE.

5. The promotion of ChEESE women scientists on social media campaigns related to the International Day of Women and Girls in Science. In 2020, ChEESE prepared a simple picture collage showing all the women in ChEESE. In 2021, ChEESE prepared a video introducing the women, their work and their thoughts in general. In 2022, ChEESE prepared a “How it started/How it´s going” campaign wherein female partners were asked to prepare a before and after photo and a short description of how far they have come. An example is shown below (Figure 24).

Figure 24 How it started/How it´s going social media campaign featuring Nathalie Favretto-Cristini

These social media campaigns have been well received on social media. They received many likes and shares and have contributed to an increase of followers in ChEESE´s social media channels.

6. The creation of the ShEESE section on the ChEESE website, which lists all the activities that ShEESE has undertaken during the project lifetime.

8. Dissemination Key Performance Indicators

All dissemination activities and tasks are carefully monitored through the metrics defined in D6.1 Communication and dissemination plan. The WP6 KPIs' monitoring details (M1-M41) can be seen in Table 7 below:

KPI name	Description	Total target (by the end of the project)	Status as of M41
Press releases	At the beginning and towards the project end	2	2
Press impacts	ChEESE presence in mainly technical and scientific (and, if possible in generic) media	25	34
Website sessions	Number of sessions (Google analytics)	1000 sessions /year	27,894
Project flyer	General information flyer (to be updated regularly)	1	1
Trainings	PATC and other training courses	4	15

Scientific publications	Peer-reviewed journals and conference proceedings	40	60
Project videos	One teaser video to explain the project and its objectives and another video (5min) to show the project results and services.	2	3
Participation at events	Presentation of ChEESE results at conferences, workshops, etc.	12	202
Organization of conferences	Galileo conference	1	Proposal accepted

Table 7 ChEESE dissemination and communication KPIs

9. Conclusions about communication and dissemination

Over all, ChEESE has hit all its targets in dissemination and has overachieved in terms of web visits, events, press mentions, videos and scientific publications. Despite the challenges associated with COVID-19, ChEESE partners did not slow down partners´ dissemination activities at all and in fact intensified their activities since the virtual format made it possible for partners to attend even more events.

In terms of equality, ChEESE has not only promoted its principles and beliefs but created concrete actions that were achieved with the support of all project partners.

Finally, ChEESE has built a thriving community and ecosystem around its research which will be maximised with the Galileo Conference in 2023.

10. Overview of ChEESE exploitation strategy

This document reports up to M36+5, focusing on executed tasks related to exploitation and sustainability strategy for ChEESE as the European Centre of Excellence (CoE) for Solid Earth. Exploitation from a scientific, societal and industrial perspective is a major commitment for ChEESE, as testified by the balanced consortium including a diversity of organizations. Another sign of the interest of the consortium for the utilization of project results has been the creation, on-boarding and real engagement of an Industry and Users Board (IUB), which has not only followed the progress of the project during the face-to-face and remote meetings but also has provided continuous feedback, aiming to be part of the validation of the Pilot(s) Demonstrator(s) (PD) services in an operational environment through the exercises organized on behalf of WP5.

The main **project joint outcomes**, from the ChEESE consortium as a whole, are:

- improving state of the art high performance simulation tools that help the modernization of the hazard related stakeholder's activities and are also of interest for European companies and scientific community.
- improving the cooperation between academia, R&D Centers, Public Entities and industries from EU and Pan-EU.

- creation of an Industry and Users Board (initially composed by 12 stakeholders and, at the end of the project, composed by 28 institutions and initiatives).
- the definition of urgent computing services for natural disasters, with a particularization in seismic simulations of PD1, to be used in the context of the EuroHPC JU as a model for emergency access for HPC.
- A first demonstrator of PD2 has been implemented at the SPADA system of the Aristotle2-NHSP project to deliver advice to the EU Emergency Response Coordination Centre (ERCC).
- **La Palma eruption (Cumbre Vieja volcano): operational service of PD12.**
- 6 successful exercises carried out in collaboration with IUB and the extended network with 53 institutions + 99 individuals and 26 countries represented.
- creation of the ChEESE Zenodo community (easy to trace OpenAIRE, metadata): https://zenodo.org/communities/cheese-coe/?page=1&size=20
- improving the cooperation between the leading solid earth research groups in EU.
- the shared use of computational resources: EU through PRACE[3] (EU) HPC calls.

M1-M36+5 activities in a glance

This part of the deliverable overviews the **exploitation activities,** widely discussed up to M18 and M24 in the already submitted and accepted deliverables D6.6 and D6.7, and describes the tasks and methodologies conducted along the project execution:

i) **Identification, Collection and grouping of exploitable outcomes**, including interim and final results, with emphasis on the PDs and the services that have been validated in WP5, as to conclude on potential commercial services, business ideas and exploitation pathways.

ii) **Partners' individual exploitation plans**: Most partners are already involved in business and/or research activities in HPC-enabled activities. ChEESE enables them to strengthen and expand these activities, enhancing their existing products and service portfolios as well as enabling them to acquire greater market shares.

iii) **Intellectual Property Rights (IPR) protection** of the individual codes, workflows and toolkits developed by ChEESE.

iv) **Identification and analysis of the target users and stakeholders** that may benefit from the project findings and achievements. Initial identified target users are civil protection and other governmental organizations, (re)insurance companies, and companies providing services in natural hazard assessment and forecast or geophysical exploration for the Oil & Gas industry. It has also been of interest to briefly describe the **main targeted markets** (see D6.6 if more details are needed).

v) Engagement of complementary stakeholders, and **creation and evolution of an IUB.** According to the exploitation tasks, the initial composition of the IUB (12 members) has been largely increased, including **16 new engaged institutions** which have been committed to be part of the ChEESE eco-system, increasing the impact of the CoE. **More than 60 interviews have been conducted** by Pilot Demonstrator(s) and WP Leaders, the IUB members and the Project Innovation Manager (PIM). Additionally, personalized

[3] http://www.prace-ri.eu/

interviews with each PD Leader and IUB member have been done to fully understand the interest and the initial technical and partnership requirements. All actions regarding IUB interaction are carried out together with WP5 leader (Task 5.2), as the User Support Service needs IUB feedback for exploitation of Pilot Services. Hence, **the project results will be mainly exploited by the partners in collaboration with already existing institutions and initiatives (e.g. Spanish Civil Protection-IGN; ARISTOTLE; CAT-INGV, PLINIVS, IMO, etc.)**, as they are applying the innovative ideas and tools of the project to their internal procedures.

vi) **Analysis of the exploitation context and business opportunities** to find out what is the actual market situation for the different applications covered in the project (computational seismology, magneto-hydrodynamics, physical volcanology, tsunami modelling and early warning, and data analysis and predictive techniques). Besides the IUB interest, the major topics with regard to the potential **exploitation strategy of the ChEESE partners' owned foreground** has been also addressed. The ChEESE consortium has built an understanding of the project market and exploitation context, providing a solid base for further exploitation actions. All the already identified outcomes include a brief description of the knowledge and technology transfer initial discussion, including topics such as joint exploitation strategy, PD(s) interests, exploitable assets, and exploitation plans from each individual partner. More details can be found in D6.6 and in D6.7.

vii) 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. Either way and focusing on **business**, a real exercise to quantify and evaluate the interest of the foreground was done in the framework of a **Business Prototyping Project (BPP) of EuroLab4HPC**. The project (called USER) explores the exploitation possibilities of Urgent Seismic Simulations, in full synergy with PD1 developments. The report was shared with PD(s) leader(s) for its use within ChEESE.

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

ix) **Long-term sustainability strategy**. ChEESE would evolve into a **partnership** that drives a collaborative effort to develop scientific and high-quality resources for transparent assessment of Solid Earth hazards and to facilitate their application for risk management around the globe. **HPC tools** are of extreme importance to achieve this goal. An initial analysis is herein presented and has been already discussed at ChEESE corresponding governance bodies and described at D6.7.

Finally, according to the initial discussion about ChEESE long-term sustainability strategy, an initial document which explores different legal status beyond the end of the CoE funded stage, was prepared and discussed at **ChEESE governance bodies** (Project Executive Committee (PEC)-*Meeting September 30th 2020*, Project Supervisory Board (PSB) -*Meeting October 6th 2020*), including the close collaboration with FocusCoE and **HPC3**. This has been made possible by the participation at the HPC3 council by the ChEESE PC (Dr. Arnau Folch) and the PIM (Dr. Joan Farnós), which is an active member

in the Business Development and Sustainability Working Group from HPC3 and participates also in all the services and sustainability workshops organized by FocusCOE.

And, last but not least, the exploitation activities have also included the drafting and internal iteration process of the already submitted and accepted Deliverable D6.6-Exploitation Plan (M18), and the writing and submission of this Deliverable D6.7 Dissemination and Exploitation Report (M24).

Relations to other activities in the project

There is a strong interrelation of D6.6, D6.7. and D6.8 with the following WP(s):

WP4: The data received through the interviews with PD leaders is relevant to orient and support an initial exploitation strategy for the Pilots.

Either way, experts from the software development and also from optimization (**WP2-WP3**), have provided their feedback to validate the quality and market potential of the highly promising innovations and exploitable results and to provide publishable summaries that can be used to be provided to future end users or investors. Software, workflows, and final product data have been discussed as potential assets.

WP5: A strong interaction and exchange has taken place with the WP5 leader to identify synergies, especially with the information gathered oriented to service definition.

WP6: The interviews, workshops and trainings conducted in Task 6.1 were used to inform partners about dissemination activities, particularly the opportunity to attend a joint stall at a fair/conference and to make projects aware of the opportunity to present their exploitable technologies in information brochures (technology cluster brochures). From this strategy new IUB(s) members have been accepted to the board and included as new potential exploitation[4] partners. This acceptance has been always discussed at the PSB meetings.

11. Exploitable Results and Plans

This section collects the most relevant points from the **exploitation strategy,** widely described in the exploitation plan (D6.6). All this information is being developed, agreed and coordinated with WP5 leader Dr. Tomaso Esposti and is complementary to what is described in D5.1 (*Pilot analysis and service development strategy*). Overall, 8 of the targeted 12 PDs have been upgraded to reach a TRL of 5+.

High Performance Computing as an asset enabler associated with WP2, WP3 and WP4

This sub-section analyses the exploitation context for the different application fields of the ChEESE project to find out what the actual market situation is and the potential target users or clients by means of using **HPC as an asset enabler.**

[4] ChEESE exploitation: test in an operational environment the Pilot Demonstrator

HPC resources have undergone a dramatic transformation, with an explosion in the available parallelism and the use of special purpose processors. The next technological milestone will be exascale supercomputers (offering more than 10^{18} Floating Point Operations Per Second). These computers will have tens to hundreds of millions of cores. Therefore, it is mandatory to have software able to efficiently exploit this massive parallelism.

Either way, this project contributes both, to an increase of numerical assets and procedures (e.g. establishment of an emergency/urgent computing access) and to the optimization of software and workflow operation. Therefore, the most advanced numerical techniques are being used in WP2, WP3, and WP4 and deployed in the existing petascale computers. Moreover, scalability analysis for exascale computers have been addressed.

Knowledge and technology transfer to industry and scientific community

The Exploitation Strategy is outlined in line with the project progress at M36+5. This strategy, incorporates on the one hand, a market mapping directly linked to needs and assets offered by ChEESE and, on the other hand, defines a joint exploitation strategy which also incorporates elements of a future ChEESE business plan that is being discussed in this document. These three main pillars of the project's exploitation strategy will be:

- **Joint exploitation of the project results in the scope of the ChEESE ecosystem**: The ChEESE partners will engage in joint exploitation activities within the project's (business) ecosystem. Different alternatives are being discussed to assure the long-term sustainability of the CoE core goals: science (including grants and trainings) and asset delivery (product and services).
- **Exploitation of the ChEESE Pilots**: The Pilots associated with the IUBs act as key business channels to exploit CHEESE foreground, as they constitute a real proof of the added value that CHEESE can provide, becoming an essential part of the CHEESE business plan. Exascale PDs are proofs of concept aimed at testing codes and workflows on Exascale hardware prototypes. Up to 12 different PDs have been defined to address the 15 ECC. Pilots with a target TRL higher than 4 have evolved into a service during the project (from M12 onwards). Objectives:
  i. Increase TRL of all PDs by at least 2 points.
  ii. Increase TRL to ≥ 5 for 8 PDs (8 potential Services).
  iii. A minimum of 3 Services to be tested operationally (TRL ≥ 7) at the end of the project.

  The explanation of the TRL scale in the context of ChEESE technology is reported in D5.1. Finally, some success exploitation stories are also presented: a component of Pilot Demonstrator 2 has already been integrated in ARISTOTLE (IUB member), BSC software Fall3D has been used in different exercises (VOLCICE, VAAC) and in real operation (e.g. La Palma / Cumbre Vieja eruption), etc.

- **Partners' individual exploitation plans**: As explained in detail in D6.6, most partners are already involved in research activities in HPC-enabling activities. ChEESE is also helping all the Consortium partners by making these scientific

and technical activities more visible, and allowing them to acquire greater market impacts. Either way, the project results are mainly validated together with the IUB partners as they are applying the innovative ideas and tools of the project to their internal interests. Main tasks in collaboration with the IUB have been:

i. Provide feedback about potential interest in Pilot developments.
ii. Test the Services in an operational environment to foster its deployment and use by a broader community of users.
iii. Perform a market analysis for exploitation of services.
iv. Requiring strong involvement of the **IUB partners and Pilot Leader(s)** in the Service implementation and exploitation through the exercises.

Going into this relevant IUB Board role, the identification of potential members has established the basis to cover the whole service value chain. HPC providers, consultancy companies, insurance companies, Oil & Gas companies, Academia, EU Projects, Civil Protection Agencies, Solid Earth scientific communities, etc. have already been engaged, covering different needs at different TRL requirements. Based on this interest, many discussions have begun among PDs and IUB, allowing Pilot Leaders to understand and appreciate the existence of different needs and requirements.

The IUB has provided an efficient, independent, industry-based mechanism for quickly obtaining real-world feedback on project interim results. Moreover, it facilitates industry's direct participation in identifying and pursuing exploitation opportunities.

In the initial phase of the project (M1-M12), the IUB was focused on the feature requirements formulated by the project team, offering suggestions for prioritization based on current industry roadmap planning. During Phase 2 of the project (M12-M24), the IUB has helped to reassess and reprioritize based on the implementation status and preliminary results. In the final phase of the project (M24-M36+5), the IUB has helped to integrate in real operational conditions the higher TRL pilots (TRL>7), and has assisted the dissemination of these results once the exercises have been carried out.

Finally, and as part of the stakeholder engagement strategy, within M1-M36+5 new IUB members have been proposed, engaged, and accepted by the ChEESE PSB, enabling PDs to receive more feedback from different types of end-users. It has to be remarked that the IUB was initially composed of 12 members, and by the end of the project comprises 28 institutions and initiatives, with the interest of being increased even beyond ChEESE ends. IUB engagement has been crucial and its information, suggestion, and feedback has been continuous under the General Assemblies, bilateral meetings, etc. Other organizations related to ChEESE activities have been identified and will be invited to join the IUB: a) ChEESE is in contact with Asian agencies to discuss potential ways of collaboration. Representatives from Indonesia, Philippines, Brunei, and Thailand attended ChEESE PATC courses and, b) IUB members from Japan (Tsunamis/Earthquakes), from Norway, and from Mexico have joined the board in order to analyze the potential added value they can bring to the ChEESE community. India was also in the scope of joint collaboration via training activities, of paramount importance for ChEESE partners.

IUB members have been informed in detail, through specific talks and invited at the mid-

term and final GA, about the PDs foreseen in the project, have expressed which PDs were of their interest to follow up closely and have been an active stakeholder during the organized exercises, schedules to show how a Pilot Demonstrator can be used in a real operational environment. This task has been done together with the WP5 leader (Task 5.2).

Intellectual property management

For an effective exploitation of the project results and an accurate long-term sustainability strategy, it was considered necessary to establish the main aspects of the methodology that we have further developed on IPR. IPR Management for ChEESE is based on the following principles, **being monitored every 6 months**:

1. **Background knowledge and Access Rights**. Each partner owns the background that it brings to the project.

2. **Patents**. In case a partner wants to submit a patent application, the PC and the PIM have to determine if it is a joint foreground or not and initiate, if deemed, the appropriate study. All required measures are taken to guarantee that there is no disclosure that can ruin the patent possibility.

3. **Foreground knowledge and IP ownership**. Results are 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.

4. **IPR log.** An IP log has been established at the ChEESE intranet (Wiki: https://wiki.cheese-coe.eu), where the services developed by the partners are registered periodically and maintained. After this initial setup, new services are being monitored and added to the IPR-Log in order to protect the partners' efforts and provide a clear basis for any discussions about IP and its origin. This forms a stable basis for the partners to work on when they exchange ideas for the development of new offerings. The IP can be software (code, module, script), but also a workflow, a methodology, an invention, a dataset, or even a design. A detailed list will be presented at the ChEESE Final Review.

12. Market Segmentation according to WP actions

In this section a market assessment directly related to the expected assets, widely described in WP5 deliverables, emphasizing Early Warning Systems, Probabilistic Hazard Assessment products, Urgent Computing services, together with 3D imaging of the subsurface is presented. Thus, the selected market segments are positioned in terms of market context for civil protection agencies, insurance companies, consultancy services (mainly aviation), as well as Oil & Gas companies.

After this, and once the market target is clear, an explanation of what the Industry and Users Board is, what are the objectives of this board, the established methodology to interact, and the board composition is widely explained. Nonetheless an increase in the number of engaged stakeholders is shown, achieving a great milestone (28 current IUB members).

Finally, the communication channels that are used to understand the IUB needs are presented (initial survey, scheduled meetings, participation in the General Assembly, etc.) It must be put into consideration that a Pilot Demonstrator would have different end-users which work under different conditions and interests. Then, in order to have the whole picture it is important to establish an interaction mechanism among Pilots and IUB, whereas beginning to complement the initial exploitation objectives of each PD.

Service positioning and Stakeholder Engagement Strategy

Market context of ChEESE potential services

During the last decades, the level of impact of natural disasters worldwide has grown steadily. This is due to the increase in the frequency and intensity of some hazards, but also to the growing exposure of people and societies' assets to these hazards. In addition, natural disasters are often trans-boundary in nature. It is hence imperative that prevention, preparedness, monitoring and response activities take place in a coordinated way, cutting across national borders and based wherever possible on the best available scientific knowledge and evidence.

As an example, an estimate of 500 million people live near 1,500 active volcanoes and about 90% of the most in-demand flights travel over volcanic areas. As result, the global airline industry is losing more than US$500 million per year because of the disruption caused by volcanic ash clouds to airlines and, eventually, billions of dollars to related aviation stakeholders. Meanwhile, humanitarian organizations remain reactive to natural disasters - responding to them post-facto at higher costs and implications in human lives.

Preventative humanitarian efforts, however, would be more cost-efficient than current measures as they can help improve the recipient parties' ability to sustain themselves independently rather than relying on short-term immediate relief. At the core of the main targeted market segments - aviation, insurance, and humanitarian - rest archaic forecasting models, outdated datasets, and delayed information that prevent timely evidence-based decision-making processes against the impact of natural disasters. In this context, a stronger scientifically driven evidence and knowledge base in order to take sound emergency response decision and manage the response capacity is needed and, hence, developed within ChEESE exploitation goals.

Firstly, an efficient emergency decision-making process cannot exist without efficient **Early Warning Systems (EWS),** the systems of various actions linking the pre-disaster phase to the response phase and allowing mitigating or pre-empting in real-time the negative consequences of disasters. For example, there are several currently operational early-warning systems that are in use today relating to the mitigation of volcanic hazards. However, these systems only provide information on the thermal output of active volcanoes and do not provide information on volcanic ash/SO_2 or smoke dispersion. For tsunami, due to the extremely fast development of the phenomenon, state-of-the-art EWS

are based on the early recognition of potential tsunamigenic seismic events and on the picking of pre-computed (deterministic) tsunami inundation scenarios and impacts. Computing the generation, propagation and impact of tsunamis faster than the real time and in a probabilistic framework will require a step forward in our computational capability.

Secondly, **hazard assessment** is one of the main goals of modern geosciences, and it is done when a system (volcano, seismic zone, etc.) is quiescent or in a pre-disaster state. These two situations are referred to as the long and the short term hazard assessment respectively. For example, in volcanology, hazard evaluation is particularly relevant for large urban centers close to highly explosive volcanoes (e.g. the Neapolitan area in Southern Italy) but also for remote volcanoes located under air traffic routes (e.g., Jan Mayen in the Arctic Sea). Until a few decades ago, hazard assessment was largely based on the concept of "eruptive scenario", characterized by subjectively-defined eruption conditions. Hazard was then quantified under the strong assumption that the next eruption from a given volcano will be similar to the selected "representative eruptive scenario", neglecting the large uncertainties in the parameters that define the scenario. More recent approaches tried to circumvent this limitation by averaging hundreds of simulations in which eruption parameters (i.e. inputs to dispersal models like the eruption column height) are sampled within plausible ranges in the so-called "eruption range scenario". This succeeded in partially quantifying natural variability, but it was still limited to a specific range of eruption parameters. In the last years, the paramount importance of quantifying uncertainty has been recognized by all the Solid Earth Sciences, including volcanological, seismological and tsunami communities. It has been understood that, when assuming one or a few representative scenarios, the analysis is implicitly neglecting a large set of uncertainties.

Finally, in addition to these early warning systems and probabilistic hazard assessment, the European Parliament initiated the pilot project ARISTOTLE *(All Risk Integrated System TOwards The hoListic Early-warning)*, currently a ChEESE IUB member. This pilot project aimed at further reinforcing the linkages between emergency preparedness and scientific community at European level, including the ERCC and the European Commission's Joint Research Centre. It created a pilot multi-hazard scientific partnership for natural disasters which supports the ERCC with monitoring. Following the successful experience initiated by the pilot project ARISTOTLE, the Commission launched an open procedure to establish a European Natural Hazard Scientific Partnership, which started offering services to the ERCC on 1st October 2018. However, the evolving emergency management landscape together with new requirements and needs linked to the revised legislation approved in March 2019 renders the services provided by the current network limited, and hence an expansion is needed in order to fulfil the mandate of the ERCC as the EU's emergency response hub. This has been an opportunity that ChEESE Pilot Demonstrators have explored with regards to their own exploitation strategy. The need for such a 24/7 scientific service has also been recognized in the Annual Work Programme of the UCPM for 2020, bringing **urgent computing/emergency computing** to a realistic exploitation added value asset.

Market assessment

Specific market segments and the ChEESE extended network are presented in this section: **Civil Protection Agencies, Insurance and Consultancy services companies, Oil & Gas sector, EU projects, etc.**. These targeted market segments are fully aligned with the development and objectives of the Pilots and outcomes of the CoE.

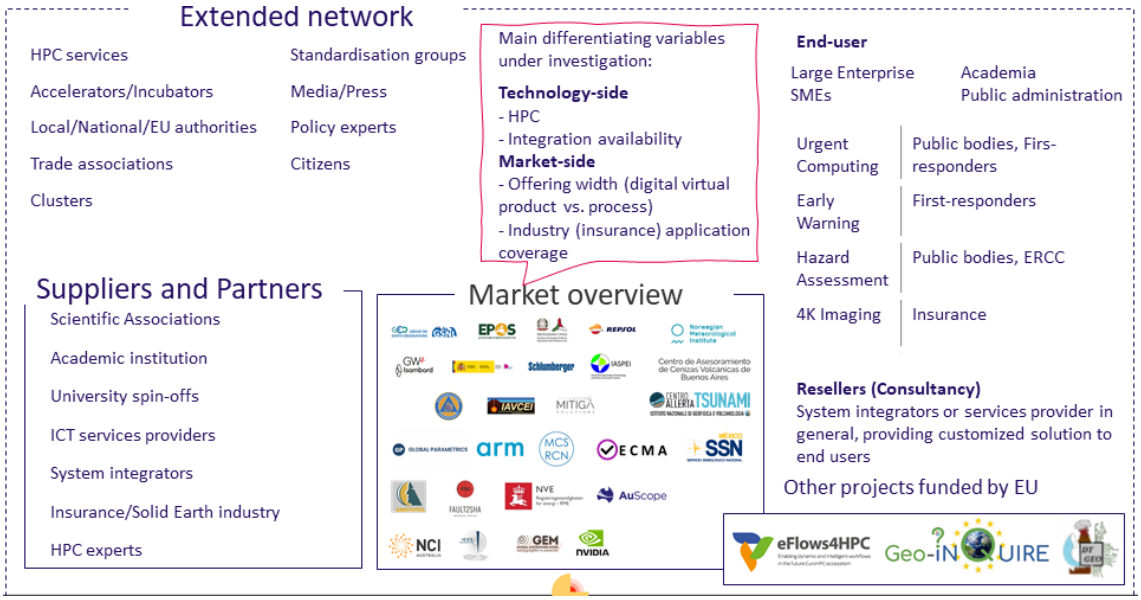

Figure 25 Overview of ChEESE extended network

Civil Protection Agencies

Any country in the world, but also the United Nations and its agencies or a relevant international organization, can call on the EU Civil Protection Mechanism for help. It is the Mechanism that has intervened in some of the most devastating disasters and complex emergencies. EU Member States and Participating States may commit national resources for emergency response to the European Civil Protection Pool (ECPP). This pool allows for better planning and coordination of response activities at European and national levels which means a faster and more reliable EU response to disasters. The ECPP constitutes the backbone of the Mechanism.

Either way, prevention and preparedness activities mitigate the effects of disasters. The EU supports and complements prevention and preparedness efforts of its Member States and Participating States by focusing on areas where a joint European approach is more effective than separate national actions. These include risk assessments to identify the disaster risks across the EU, encouraging research to promote disaster resilience and reinforcing early warning tools. In fact, the upgraded EU Civil Protection Mechanism established a new European reserve of additional capacities (the *rescEU reserve*). Through the strengthened mechanism, the EU should be better prepared to respond to all types of emergencies, such as chemical, biological, radiological and nuclear emergencies, and through common stockpiling of medicine.

Additionally, aid for humanitarian purposes is neither *sufficient* nor *timely*. As crises increase in frequency and severity, so does the gap between what is needed to respond to an emergency and how much is actually received. Traditionally, the global humanitarian

system allocates over US$16 billion for emergency assistance each year. However, funds often arrive too late, limiting the ability of humanitarian actors to provide immediate assistance, and are very rarely released before disasters strike, despite the predictability of some of them. For 2020, the UN-coordinated humanitarian sector has already launched an appeal requiring more than US$29 billion to meet the humanitarian needs of 169 million people in >50 countries. Building on past experience, it is likely that these funds will not be fully covered, therefore humanitarian organizations are pressured to come up with creative ways of using limited resources. Part of the solution lies on preventative aid modalities and innovative financing.

Insurance companies

According to the consultancy firm KPMG, financial institutions have not been able to apply the same level of sophistication they use for financial risks for the management of non-financial risks, such as natural disasters. This is evident in the limitations of the classical catastrophe (cat) modelling approach adopted by insurance and reinsurance companies.

Either way, according to Deloitte, *"the global insurance industry is scrambling to grow and maintain profitability amid maturing markets and volatile economic conditions, all while reinventing their products, operations, and business models to cover evolving exposures, satisfy rising consumer expectations, and integrate new technologies"*. McKinsey reported that the highest growth was seen in Asia-Pacific (expansion of 8% 2016-2017), followed by the Americas, Europe, Middle East, and Africa.

The global insurance sector grew more than 4% in 2017, with premiums totaling US$4.7 trillion. The global Reinsurance market size is valued at USD 135.78 billion by the end of 2022, growing at a CAGR of 4.1% during 2020-2022. U.S. insurance industry net premiums written totaled US$1.22 trillion in 2018, with premiums recorded by property/casualty (P/C) insurers accounting for 51%. P/C insurers paid out US$49.5 billion in property losses related to catastrophes in 2018, according to the Property Claim Services (PCS) division of Verisk Analytics, down from US$105.7 billion in 2017, which was the highest loss since PCS began collecting insured loss data in 1949. There were 55 catastrophes in 2018, compared with 46 in 2017. Brokers have been consolidating and also attempting to increase their impact as an intermediary. The insurance brokerage market size has the potential to grow by US$19.56 billion during 2020-2024, and the market's growth momentum will accelerate during the forecast period. Of the market segment of re/insurance, P&C accounts for 51% of premiums. In Europe, P&C premiums grew 3.6% reaching a record high of €100bn. UK, Germany, France and Spain - the top four markets — accounted for 73% of all European property claims in 2017. This information has been provided by Mitiga Solutions, S.L.

Consultancy services

Airlines are the main agents within the aviation sector and the most vulnerable to volcanic ash events. A clear indicator that the aviation industry needs to manage atmospheric natural hazards was the impact effect on that sector of the 2010 Eyjafjallajökull eruption, where more than 100,000 flights were cancelled (source: IATA), causing a loss of more than US$3.8 billion airline revenues (source: Oxford economics) and more than 10

million stranded passengers. Forecasting what will occur in the next hours when a volcano is erupting or quantifying potential impacts from a future eruption are relevant issues to aviation stakeholders and to civil protection agencies and governmental bodies. HPC plays a major role in making forecasts compatible with the time-space constraints of aircraft operations (emergency management scenarios and related urgent computing) and to perform physics-based modelling approaches, thereby reducing uncertainties on impacts and related economic loss estimations.

According to IATA, the number of flights is expected to double every 5-10 years. In general, airlines report an average of US$ 500M a year in losses caused by volcanic eruptions. Airlines need a commercial Early Warning System to forecast and mitigate these impacts and would benefit from the implementation of an automated system for triggering and detecting volcanic ash clouds. To summarize, aeronautics is one of the EU's key high-tech sectors on the global market, generating around 220 Billion Euro and 4.5 Million direct and indirect jobs. The EU is a world leader in aerospace products and aeronautical technologies are catalysts for innovation contributing to the growth of the EU economy as a whole.
Finally, other public services such as meteorological data providers can be potential clients and/or future buyers of the technology.

Analogous services for companies operating along shorelines might be envisaged with respect to potential tsunami hazard and impact, and for the impact of large seismic events, for example on large energy production plants, including nuclear ones.

Energy- Oil & Gas (High resolution images market target)

Energy needs worldwide will continuously increase. The U.S. Energy Information Administration estimates that the world will require 56% more energy in 2040 than in 2010. Thus, energy scarcity (or inefficient usage) can lead to higher prices, which will have a critical impact on the economy, as emphasized by the Energy Challenge in the Horizon 2020[5] work program (the Energy Challenge is designed to support the transition to a reliable, sustainable and competitive energy system). In that sense, different governmental programs in EU and have been established to promote and improve the efficient use of energy, e.g. EERA[6], ESFRI Energy[7], InnoEnergy[8], Horizon 2020, the new EC Horizon EUROPE (2021-2027) programme, EuroHPC JU, etc. which have a predominant role fostering R&D at EU level.

[5] European Commission. Horizon 2020 Work Programme. 10. Secure, Clean and Efficient Energy. April 2017
[6] http://www.eera-set.eu/
[7] http://www.esfri.eu/working-groups/energy
[8] http://www.innoenergy.com/

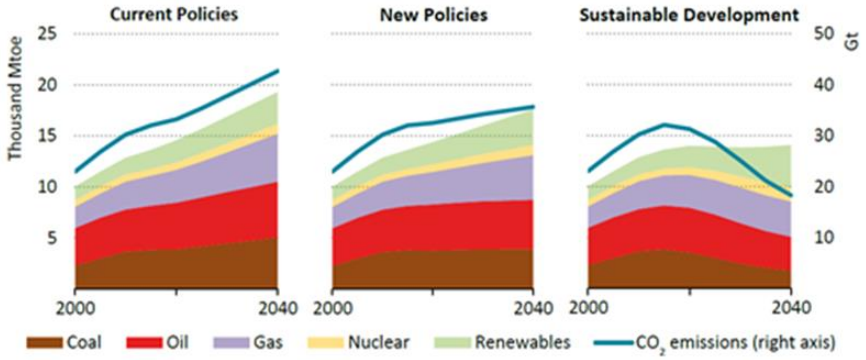

Figure 26 World primary energy demand by fuel and energy-related CO2 emissions by scenario[9]

On the other hand, Oil and gas (O&G) exploration is an industry in constant motion, from technological breakthroughs to shifting supply and demand. The high costs of finding and developing new oil and gas fields that can be commercially developed has created a challenging environment.

According to the U.S. Department of Energy, the world's crude oil proven reserves have been increasing annually since 1980, even despite the growing volume of oil extraction. There are two main drivers for this trend: technology improvement that allows increasing the level of extraction from the existing wells and discovery of new reservoirs mainly in offshore locations. While currently the largest volume of oil is obtained from onshore and shelf locations (in the Persian Gulf, Mexican Gulf and Russia), leading O&G companies focus their exploration efforts on the oceanic bed.

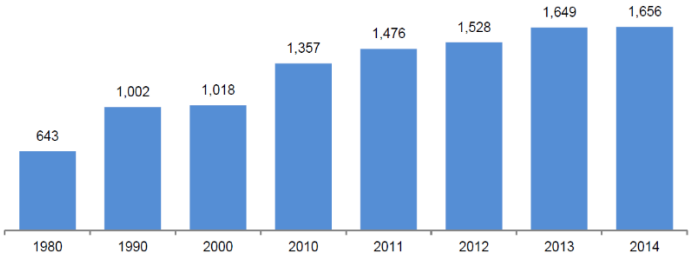

Figure 27 World crude oil proved reserves (billion barrels)[10]

On the other hand, the investments in seismic research are strongly correlated with the level of capital expenditures in oil exploration and production, which in turn is highly dependent on crude oil prices. Crude oil price is the key driver in this industry. Since the beginning of 2014, the oil prices have dropped drastically, also due to Sars-Cov-2 situation, which seriously harms the profitability of O&G companies and puts pressure on expensive exploration projects.

[9] IEA, International World Energy Outlook 2017
[10] U.S. Energy Information Administration. https://www.eia.gov/dnav/pet/hist/rbrteD.htm

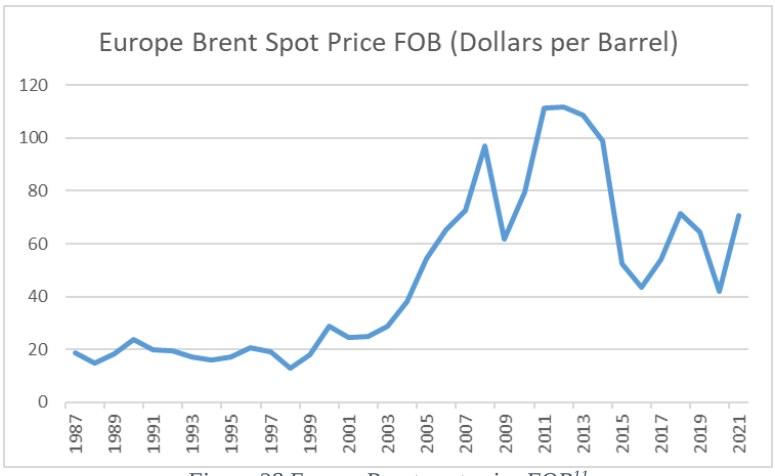

Figure 28 Europe Brent spot price FOB[11]

Additionally, after the "Black April" in 2020, the picture for the global oil market seems to be improving, in spite of the experienced decline in oil demand due to Sars-Cov-2 mobility restrictions in 2020 and 2021.
Many countries still have lockdown measures with increased mobility helping demand, and decline in oil production materialises quickly. While cuts agreed in OPEC plus countries enter into force, other major producers like the United States and Canada contribute strongly to the overall plunge of supply output. Dynamics in demand and supply points towards early signs of improvement, but major uncertainties remain. Chief among those include evolution of lockdown measures and pandemic diffusion, the level of compliance in cuts agreed among OPEC plus countries and the implications of the massive reduction of Investment announced by the oil and gas industry.

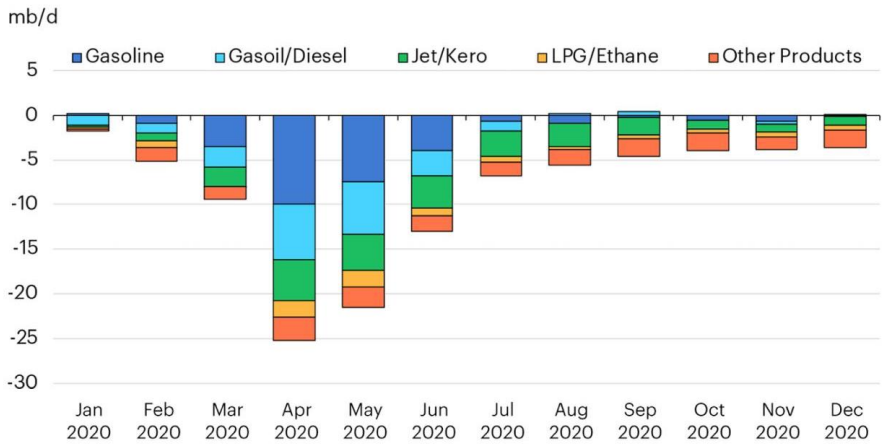

Figure 29 Annual oil demand change by product[12]

The Exploration & Production (E&P) lifecycle, has ups and downs depending on the oil production and demand. Over the last years, overproduction has led to oil price drop, decline of O&G companies' cash flow, need to cut spending, and low reinvestment in E&P.

[11] US Energy Information Administration: https://www.eia.gov/dnav/pet/hist/rbrteD.htm
[12] Oil Market Report: May 2020. International Energy Agency.

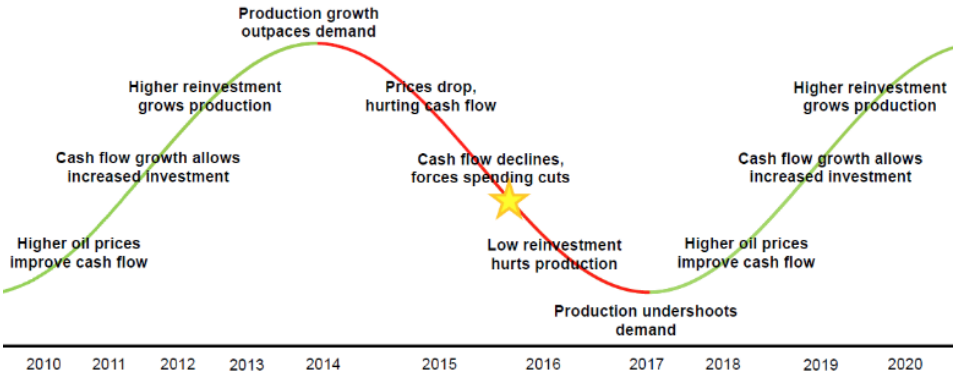

Figure 30 E&P lifecycle[13]

On the other hand, a research conducted by Barclays Capital[14] revealed that exploration accounts for around 20% of the total E&P capital expenditures and 4% are invested in geophysics. The investments in geophysics might be further divided into five categories: marine acquisition services, land acquisition services, marine and land equipment, data library sales and data processing. Data processing is the smallest segment with 8% of capital expenditures in geophysics exploration.

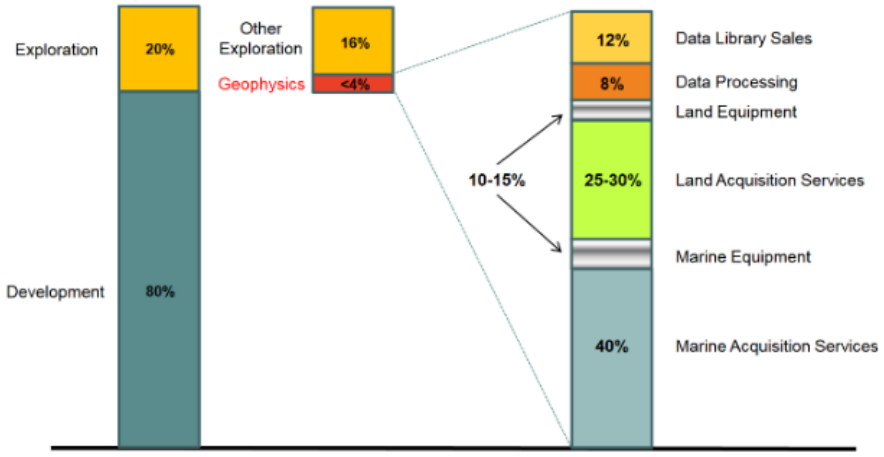

Figure 31 Seismic vs overall E&P expenditures

As said before, crude oil price is the key driver of all oil related business, **including seismic data processing**. In the case of E&P expenditures and, as a consequence, the investments in data processing, the interdependence is not so straightforward because oil prices fluctuate a lot in the short and mid-term, but exploration projects need several years to initiate and perform. Despite this fact, crude oil price is still the best variable for forecasting data processing in E&P market evolution. Increasing inventories have put downward pressure on oil prices since mid-2014. According to the U.S. Energy Information Administration, in the reference economic growth case the Brent crude oil price averages $37/barrel in 2016, decreasing to $20/barrel in 2020 as demand and supply come into a huge divergence due to Covid-19 impact.

[13] Friedmann, C. 2010, Seismic Sector Overview. ION Geophysical Investor Education Series
[14] Barclays Capital 2011 E&P Spending Forecast, previous Barclays research report.

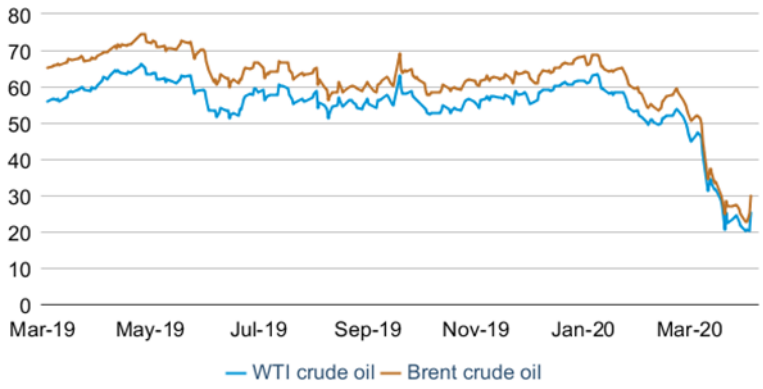

Figure 32 Projection of crude oil Brent spot prices (reference case).[15]

Although real-time data remain limited, EIA estimates global liquid fuels consumption declined by 11.4 million barrels per day (b/d) in March 2020 (due to Covid-19 situation) from the 2019 annual average and forecasts demand to decline by 17.1 million b/d in April from the 2019 average.

Finally, a study by Wood Mackenzie[16] warns the global oil market could face a supply shortfall of 4.5 million barrels/day by 2035, if exploration success does not improve. The oil price environment has caused exploration budgets to be largely reduced in the last years. Although significant discoveries made during the 2000s are key in securing medium term oil supply, **unless exploration results improve, continued supply growth in the longer term will become unsustainable**.

13. Relation of ChEESE to other EU Projects and Initiatives

The collaboration with current (and future) solid-earth EU related initiatives and projects is fundamental for the strengthening of the collaboration within the European Union, as solid earth is one of the current priorities for EU cooperation.

One of the goals of WP6 is to encourage synergies between projects and promote activities of common interest. Europe currently develops a strong energy effort with initiatives such as the EuroHPC JU eFlows4HPC project (H2020-JTI-EuroHPC-2019-1), Destination Earth through the DT-Geo Project (HORIZON-INFRA-2021-TECH-01-01), as well as to Horizon Europe through GeoInquire (HORIZON-INFRA-2021-SERV-01-07) Project, where the highest stakeholders define the future road-maps and advice on European solid-earth digitalization development and deployment. This, besides our previous collaboration with ENERXICO, and the on-going and well established strong collaboration with POP2 CoE, Focus COE and ChEESE Project.

European Projects	ChEESE advances and links
POP Centre of Excellence	Performance Optimization and Productivity of the project codes. https://pop-coe.eu/

[15] https://www.eia.gov/dnav/pet/hist/rbrteD.htm
[16] http://www.woodmac.com

PRACE	Scalability analysis of ChEESE applications over PRACE computer architectures. http://www.prace-ri.eu
ENERXICO	Collaboration in Solid Earth HPC based training.
eFlowsHPC	eFlows4HPC aims to deliver a workflow software stack and an additional set of services to enable the integration of HPC simulations and modelling with big data analytics and machine learning in scientific and industrial applications. The software stack will allow creating innovative adaptive workflows that efficiently use the computing resources considering novel storage solutions. ChEESE Urgent Computing approach is the basis of Pilar III of the project.
DT-GEO	The Destination Earth (DestinE) initiative is a decade-long and massive Community effort under the Digital Europe Programme towards the integration and coupling of Earth system components in a single digital twin. DT-GEO aims to assemble the building blocks of the geophysical extremes layer, initially intended as individual components but allowing for interaction and coupling during successive implementation phases.
GeoInquire	The services and new e-infrastructures provided by the ChEESE-CoE will provide access to comprehensive high-resolution physics-based numerical simulations, complex workflows integrating data, models and HPC resources. This will allow ensemble modelling for uncertainty quantification.
ETP4HPC	Define research priorities and action plans in the area of HPC technology provision. http://www.etp4hpc.eu/
EPI	European Processor Initiative: consortium to develop Europe's microprocessors for future supercomputers http://europa.eu/rapid/press-release_IP-18-64_en.htm
EuroHPC	Joint collaboration between European countries and the European Union about developing and supporting exascale supercomputing by 2022/2023. http://eurohpc.eu/

Table 8 EU Projects and Initiatives related to ChEESE

14. Project outcomes per Partner and Identification of Exploitable Foreground

This section focuses on the **outcome analysis** in Month 36+5 according to each WP and partner. The objective is to identify the exploitable results of the project and define the potential commercial products and commercial strategies for these results (target market, business model(s), distribution channels and promotional strategy) to reach the market. Further details can be found in Deliverable 6.6 (Exploitation Plan. Confidential report).

As has been widely explained, partners have complementary competences and knowledge, the experimental and computational resources are available and the relevant industries to transform this knowledge into real industrial solutions are present. R**elevant Academia / HPC R&D Centers/ Industry and public bodies are present. Some success stories towards a successful exploitation of ChEESE outcomes are summarized next:**

- The participation of Global Parametrics in PD1 with ETH for the Turkey case.
- The participation of Repsol in PD9 with CNRS.
- The participation of IMO and related partners in the VOLCEX exercises. VOLCEX are regular volcanic ash exercises in the EUR/NAT Regions promoted by the International Civil Aviation Organization (ICAO) and involving

EUROCONTROL, airlines, airports, Meteorological Offices, Aeronautic Service Providers (ANSPs) and others. VOLCEX-21 was held in Iceland and tested the development of PD12 in an operational setting.

- IMO participated also in the VOLCICE exercise, a country-scale reduced version of VOLCEX in conjunction with the U.K. Met. Office, the British Geological Survey (BGS) and the Icelandic Civil Protection (member of the ChEESE IUB).
- INGV Observatories following ChEESE developments (Tsunamis, Aviation, Seismic)
- First Urgent Seismic Simulation workflow executed on 2970 nodes of Mare Nostrum 4 (BSC, Spain) and 5320 nodes of Piz Daint (CSCS, Switzerland)
- First operational Tsunami Probabilistic Forecast workflow executed on 800 nodes (3200 NVIDIA V100 GPUs).
- First Tsunami Early Warning workflow with uncertainty estimation executed on 72 nodes (288 GPUs) on CINECA's Marconi100 (Italy).
- First Volcanic Short-Term Probabilistic Hazard Assessment and Probabilistic Forecast workflows run on 24 to 48 nodes on BSC's Mare Nostrum 4.
- Prototype probabilistic km-resolution forecast products have been delivered to Volcanic Ash Advisory Centres for Volcanic Ash dispersal, with uncertainty estimated on hundreds of ensemble members, in less than 1 hour.
- Operational volcanological services (PD6 and PD12) have been scaled by a factor > 103 (in terms of number of cells, time steps, and ensemble numerosity/sample size) with respect to current state-of-the-art.
- Operational Probabilistic Tsunami Forecast (PD8) as a game changer
- Operational faster-than-real-time tsunami warning (PD2) has increased its capability by hundreds of times, including an early assessment of tsunami coastal hazard and innovative uncertainty evaluation. A first demonstrator of PD2 has been implemented at the SPADA system of the Aristotle2-NHSP project to deliver advice to the EU Emergency Response Coordination Centre (ERCC).
- Two services (PD2 and PD12) based on ChEESE Flagship codes Tsunami HySEA and Fall3D have been deployed as fully Operational Services (TRL 9). Their codes, workflows and results are routinely used by the stakeholders to support decision-making processes.
- **ChEESE Zenodo community has been established (easy to trace OpenAIRE, metadata):** https://zenodo.org/communities/cheese-coe/?page=1&size=20
- **6 successful exercises carried out in collaboration with IUB** and the extended network with 53 institutions + 99 individual and 26 countries represented.
- **The definition of urgent computing services for natural disasters, with a particularization in seismic simulations of PD1, to be used in the context of the EuroHPC JU as a model for emergency access for HPC.**
- **Operational Service of PD12 during real eruptions in 2021:**
    - **Volcanic eruption in Iceland** (We run the modelling system to provide daily forecasts of volcanic ash and SO2 during March 2021)
    - **La Palma/Cumbre Vieja (Spain) operational service of PD12 (September to December 2021).**

Exploitation and main contributions at Partner and WP level

Barcelona Supercomputing Center (BSC): BSC will use the results of this project to improve its internal research lines in Exascale computing, volcanic ash modeling and seismic imaging. The benefits will be: four exascale pilot demonstrators on seismic urgent computing, volcanic plume modeling, hazard assessment, and volcanic ash dispersal forecast that could lead to commercial or governmental services; the improved scalability of the FALL3D code, which will be ported to Exascale prototype architectures. The main BSC's outcomes achieved are the following:

WP2 HPC Software Engineering	
Fall3D	Fully rewritten from scratch using Fortran 2008 Successfully implemented a parallel I/O using NetCFD OpenMP introduced at some regions of the code Developed mini-app fall3d both CPU&GPU GPU porting using Open ACC directives Ensemble forecast and data assimilation. Atmospheric transport and deposition of particles, aerosols and radionuclides Better communication /computation ratio: speedup 4.3x Vectorization: speed up to 1.2x Parallel I/O: performance increases 2x GPU porting using OpenACC directives (almost the full app is ported to accelerators) Fall3D Sotrong scaling: 7.5x (16 nodes)
WP4 Exascale Pilot Demonstrators: Participation in PD1, PD2, PD3, PD5, PD6, and PD12	

INGV: INGV will exploit the creation of the CoE to consolidate its cross-disciplinary expertise in HPC, bringing other key numerical models and codes at higher performances, towards Exascale; to strengthen its capability to envisage scientific grand-challenges in the field of SE research; to improve the quality, reliability and accuracy of services towards Italian Civil Protection, especially for what concerns Probabilistic Hazard Assessment, as well as towards TEWS end-users.

WP2 HPC Software Engineering	
ASHEE	Based on OpenFOAM library (C++,MPI) Mini-app development (test new OF versions) I/O issue resolved with new OF MPI communications cost: optimal domain decomposition Asyinchronous I/O (mini-app) Memory usage & intra-node scaling improved with mixed precision Porting to GPU library (gain2.4x, preliminary; offloading all equations on GPU). Link of OpenFoam to Solver library (linear algebra). Co-design: performance vs power consumption: tested efficient architectures (intel&AMD) and CPU clock frequency. Up to 20% energy reduction with 5% time increase.
WP4 Exascale Pilot Demonstrators: Participation in PD1, PD3, PD4, PD5, PD6, PD7, PD8, PD12	

IMO: IMO will take advantage of the CoE to improve its internal research on volcanic ash modeling, volcanic hazard, seismic simulations and seismic hazard. The IMO will use the results of the project to produce new physics based services for the scientific community and stakeholders.

WP4 Exascale Pilot Demonstrators: Participation in PD1, PD5, PD6, PD12

ETH: Improvements of the code Salvus will be used to improve a range of applications for which Salvus is currently and will soon be used. This includes the location and characterization of earthquakes (e.g., or early warning), monitoring and exploration for natural resources (e.g., geothermal), as well as technology transfer to non-destructive testing and medical imaging.

WP2 HPC Software Engineering	
Salvus	Parallelisation of: DMPlexRead: new HDF5 input, parallel read into partition. DMPlexInterpolate (generation of mesh faces & edges in parallel), Construction of local-to-global mapping Main result: Much larger meshes and Released to community in PETSc3.13 Urgent Computing through pilots.
WP4 Exascale Pilot Demonstrators: Participation in PD1	

HLRS: HLRS will use results obtained during the project to forward its research into user productivity enhancement in application development for extreme-scale systems. In particular, we have encapsulated results of Task 3.2 in a generic library to support the implementation of application-driven load-balancing techniques. Similarly, we have deployed the workflow manager of Task 3.4, and the visualisation tool (Vistle) of Task 3.3 on HLRS resources thus making it available to European and German national researchers. HLRS is going to publish all its software developments under an Open Source licence.

WP3 HPC Modelling and Tools:
6 Data Management Plans: Pilot entries with 16 data sets 2 software packages (workflow management system) Common data format for hazard data implemented in various codes and visualization tools. Mesh partitioning and load balance: Development of a topological partitioner based on Hilbert Post-processing and visualization: Enable post-processing and visualization extremely large 3D and 4D datasets; Extend visualization tools for use with ChEESE codes (e.g. Vistle). Distributed data-parallel scientific visualization in VR (Vistle; LPGL license, available in GitHub): modular, extensible, parallel. Rendering in virtual reality environments, hybrid remote rendering, in-situ visualization ChEESE extensions: 2 readers (ReadSeisSol, ReadTsunami); new geometry object height map. Workflow manager implemented in ChEESE: WMS light 1.0 released with D3.5. *These tasks have been done under WP3 in collaboration with the rest of the partners.*
WP4 Exascale Pilot Demonstrators: Transversal support on Pilot Demonstrator developments, specially in PD2 (Augmented Reality visualization tools: Vistle).

CINECA: CIN will foster the use of the hardware and software solutions developed within the project into national and international initiatives; in particular, those related to pre-exascale and exascale deployment plans and co-design (EuroHPC) and PRACE future calls. From the national point of view, the partnership with INGV will drive the development and use of turnkey software solutions for the research and operational activities in Italy related to Solid Earth phenomena and in strict cooperation with the national Civil Protection Department. CINECA has also participated in PD3 (High-resolution volcanic plume simulation).

TUM: TUM will integrate all software improvements developed within the CoE into the open-source software packages SeisSol and ExaHyPE. As part of the project SeisSol-CoCoReCS (2018-2020, with LMU and the Leibniz Supercomputing Centre) granted by the German Research Foundation, SeisSol will be improved towards a community code

for reproducible research. The CoE activities will both profit from and further strengthen the respective activities.

WP2 HPC Software Engineering	
ExaHyPE	Switch data layout: AoS, SoA, AoSoA (vecorisation improvement by 100%) Reactive load balancing and resilience with task sharing: Reactive task offloading; Replication-based resilience.
WP4 Exascale Pilot Demonstrators: Participation in PD1, PD2, PD4, PD5	

LMU: LMU will link all developed software, workflow and analysis tools into on-going international research activities in computational seismology and earthquake source physics. Specifically, the projects GAST and FRAGEN for physics-based seismic hazard assessment on earthquake and geo-reservoir scale funded by KAUST-CRG and the German Research foundation funded project BAIES utilizing Bayesian uncertainty quantification pose natural application areas. This CoE will enable LMU to go well beyond scenario-based multi-physics simulations and establish excellency for physics-based PSHA in Europe. All developed scenarios and software will be made publically available via the open-source repositories of SeisSol and ExaHyPE.

WP2 HPC Software Engineering	
SeisSol (in collaboration with TUM)	Main goal: add GPU support, improve performance portability in general. GPU port: YATeTo: extend code generator New code generators as backends to execute batches matrix operations: GemmForge, ChainForge Local time stepping as main challenge: CUDA graphs and improved partitioning for GPUs and New actor-based algorithmic scheme.
WP4 Exascale Pilot Demonstrators: Participation in PD1, PD4 and PD5	

UMA: The results of the present project will have a direct and straightforward application 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 a efficient tool for PTHA studies making easier and boosting tsunami research. A new version of Landslide-HySEA will allow its used in warning systems for landslide generated tsunamis.

WP2 HPC Software Engineering	
Tsunami-HySEA and Landslide-HySEA	Improved load balancing by recomputing the weights Asynchronous transfers between CPU and GPU memories Directo GPU-to-GPU memory transfers Reduction kernel T-HySEA Monte Carlo version, allowing multiple simulations in one job (per GPU). Compressed NetCFD files in single precision except lon-lat Improved memory footprint for one resolution level. New algorithm for nested meshed, sponge layer, etc. (new features) T-HySEA: 30% improvement with 32 GPUs.
WP4 Exascale Pilot Demonstrators: Participation in PD2, PD7, PD8	

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 is presently not feasible due to our limited computational capabilities.

WP4 Exascale Pilot Demonstrators: Participation in PD2, PD7, PD8

IPGP: IPGP will integrate software developments developed with the CoE into the open-source code XSHELLS and will be in a position to release the ensemble assimilation software PARODY_PDAF. Results of the geomagnetic forecasts pilot will be made available to the scientific community and used notably for research on the magnetic environment of Earth.

WP2 HPC Software Engineering	
PARODY_PDAF	Improve parallel efficiency (extension of OpenMP regions) Parallel I/O Preliminary port to GPU (open ACC + interfacing with cuda version of SHTns) Testing new timesteppers using 2D code (IMEX-RK, SDC)
XSHELLS	Use of MPI-3 shared memory with nodes to improve parallelism and reduce explicit communication overhead. Implementation of an experimental, alternative All-to-all solver (abandoned because of communication overhead) Improvements on SHTns library on GPU Partial porting to GPU using CUDA Implementation of new time schemes (25% efficiency gain) Porting to GPU of an experimental implicit solver using cuSParse New GPU mode (partial port)
WP4 Exascale Pilot Demonstrators: Participation in PD10 and PD11.	

CNRS: CNRS will use all software improvements developed within the CoE into the open-source software package SPECFEM. The CoE framework and results will be beneficial for the wide community that uses that code, and will significantly strengthen the associated research, development and dissemination aspects. In the context of an ongoing French National Research Agency (ANR) grant, the SPECFEM package is currently being improved for open-source geophysical research. The CoE will drastically improve and strengthen that.

WP2 HPC Software Engineering	
SPECFEM3D	Vectorization: vectorization over elements insted of vectorization inside elements (spedd up >2x) IOs: HDF5 and parallel HDF5 to reduce the number of files (h5+ioserver) Scalability through asynchronism AMD GPU cuda kernels were ported to HIP for AMD GPU support
WP4 Exascale Pilot Demonstrators: Participation in PD9	

BA: Bull SAS will exploit the results both ways. First, as an integrator it aims at designing and providing supercomputers that satisfy the application needs, this project will make it possible to have direct interaction with developers and get intimacy with them. This helps us in our design choices. Second, some applications in this project are regularly seen in call for tenders, having an in-depth understanding provides us with a competitive advantage against world-wide competition.

WP2 HPC Software Engineering
New generation processors optimization methodology: Level 1 and Level 2. Evaluation of energy efficiency.

WP4 Exascale pilot demonstrators

At WP4 the main achievements are summarized next:

- All 8 PD service candidates moved to WP5, being enables as a potential service
- All 12 PDs have produced outstanding scientific and technological achievements
- TRL increase >2 for all PDs plus clear benefits from WP2/3
- We have successfully pushed the need to consider "Capacity" or "Urgent" computing in the EU HPC ecosystem.
- Several cases of multi-code PDs.
- Obtained >200 Mcore-h in PRACE and national calls (Irene, SuperMUC, Marconi100) + exclusive run at MN4.

WP5 Service validation and enabling

At WP5 level, besides the transition of the PDs towards a potential validation in an operational environment, it has been very important the engagement of the IUBs through an exercise based strategy. The following tables summarize this success approach which has demonstrated the high impact of ChEESE outcomes through 6 different organized exercises, involving 53 institutions, 99 individuals and more than 26 different countries represented.

PD	run date	Service delivered	Stakeholders	Time-to-solution	HPC resources
PD1	18/01/2022	Ensemble of synthetic seismic shake maps (acceleration, velocity), up to 5 Hz frequency, provided in Urgent Computing mode.	Global Parametrics, ARISTOTLE	< 1 hour	on BSC's Mare Nostrum 4
PD2	22/11/2021	Tsunami impact map based on multi-scenario simulations (variable seismic sources) for the Spanish Tsunami Early Warning System	Instituto Géografico Nacional - Civil Protection (Spain)	1 minute	72 nodes (288 NVIDIA V100 GPUs) on CINECA's Marconi 100
PD5	05/11/2021 18/01/2022	3D fully coupled (physics-based) high-resolution (1.5-5 Hz) earthquake and tsunami dynamics	-	< 6 hours	16 nodes (4096 CPU cores) on SuperMuc2
PD6	04/11/2021	Short-term probabilistic assessment of volcanic tephra hazard/impact over a large-scale domain.	PLINIVS (Italian Civil Protection competence centre) ARISTOTLE (ERCC)	3 hours	24 nodes (1152 CPU cores) on BSC's Mare Nostrum 4
PD8	05/11/2021 (World Tsunami Awareness Day)	Rapid probabilistic Post-Event Tsunami Assessment following the 2020, October the 30th, Mw 7.0 Samos-Izmir earthquake.	NEAMTWS Tsunami Service Providers (CAT-INGV, IPMA, KOERI, CENALT, NOA), ARISTOTLE	45 minutes	800 nodes (3200 NVIDIA V100 GPUs) on CINECA's Marconi100
PD12	10/12/2021	Early probabilistic ash dispersal forecast ("Quantitative Volcanic Ash" service).	Buenos Aires VAAC	25 minutes	48 nodes (2304 CPU cores) on BSC's Mare Nostrum 4

Table 9 Summary of the exercises carried out towards an integrated operational system

Stakeholders' institution	Mission	Role played in exercises
ARISTOTLE	ARISTOTLE is a long-term operational, research, and cooperation project financed by the Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO). ARISTOTLE-eENHSP aims to continue strengthening the monitoring and analysis functions of the Emergency Response Coordination Centre	PD6. Simulates reporting to ERCC. PD1. Evaluates rapid post-EQ assessment by using numerical simulations

	(ERCC) by delivering a unique multi-hazard advice service at global level and on a 24/7 operational basis.	PD8. Potential end-user
PLINIVS	PLINIVS (Study Centre for Hydrogeological, Volcanic and Seismic Engineering) is a National Competence Centre on Volcanic Risk for the Italian Civil Protection.	PD6. Receives hazard information and elaborate risk/impact maps and information on its basis.
IGN	IGN (Spain) has the mandate to plan and manage systems for detecting seismic movements countrywide and their possible effects on the coasts, and to notify them to the institutions.	PD2. Provides trigger and source information for simulated EQ and associated fault characteristics. Elaborate results and issue Alert messages.
Global Parametrics	Global Parametrics' mission is to leverage advances in climate science, data modelling and financial engineering to build the tools needed to understand, manage and mitigate the risks of extreme weather and natural hazards anywhere in the world.	PD1. Interested in exploring numerical simulations for parametric risk assessment and index-based payouts.
Buenos Aires VAAC	The Buenos Aires VAAC is one of the 9 Volcanic Ash Advisory Centers established by the ICAO (International Civil Aviation Organization) with the mission of monitoring and forecasting the location and trajectories of volcanic clouds occurring under their respective areas of responsibility. In the event of an eruption, the international civil aviation arrangements state that the affected VAAC must issue periodic Volcanic Ash Advisories (VAA), consisting of text messages including the forecasted ash polygons delineating unsafe flight areas.	PD12 exercise owner. Triggers the simulated events, issues the VAA messages. Coordinates the exercise.
CAT Tsunami Warning Centre	Centro Allerta Tsunami (CAT) of INGV is a Tsunami Service Provider (TSP) of the ICG/NEAMTWS (Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the North-eastern Atlantic, the Mediterranean and connected seas), which is an integral part of the global warning and risk mitigation system tsunami, established and coordinated by UNESCO's Intergovernmental Oceanographic Commission (IOC).	PD8 exercise coordinator. Triggers the simulated events, gathers information from the NEAMTWS Tsunami Service Providers, elaborates data and issues Tsunami warnings

Table 10 Real engagement of IUB members

15. Identification of the Foreground: Software

Finally, ChEESE partners have been developing and using several in-house software, listed in the next table**Error! Reference source not found.**, which collect the innovations generated in this project. The initial market analysis showed potential for a commercial exploitation of the application software. In fact, some exercises have demonstrated the full commitment to integrate these tools into services. Thus, specific outcomes of the

project have been obtained and reported as success stories, being impossible to be obtained without this software:

Type of IP Rights	Confidential YES/NO	Subject or title of application	Applicant (s) (as on the application)
ExaHyPE	NO	Modified BSD3	TUM
Salvus	YES	Propietary core and BSC/MIT licensed open-source modules	ETH
SeiSol	NO	BSD3	LMU
SPECFEM3D	NO	GNU GPL v3	CNRS
PARODY_PDAF	NO	Available upon request	IPGP
XSHELLS	NO	CeCILL License (compatible with GNU GPL)	IPGP
ASHEE	NO	GNU GPL v3	INGV
FALL3D	NO	GNU GPL v3	BSC
T-HySEA	NO	Core under CCA Non-Commercial-ShareAlike 4.0 International Public License. Full version under copyright	UMA
L-HySEA	NO	Core under CCA Non-Commercial-ShareAlike 4.0 International Public License. Full version under copyright	UMA
UCIS4EQ	TBD	License pending (in process)	BSC/ETH

Table 11 In-house software developed and used by the European partners

Additionally, the components of the software stack listed below, which can be classified as: physical model simulation codes (M); workflow manager, framework, and containerization tools (W); AI and ML software stack (AI), and data-related stack, e.g. generation of metadata or ontologies (D) have been also included in DT-GEO (HORIZON-INFRA-2021-TECH-01-01). All software stack components except Salvus and UCIS4EQ are open source.

- FALL3D (type: M | HPC: yes, GPU-enabled). ChEESE CoE flagship code for atmospheric dispersal of particles, aerosols and radionuclides.
- T-HySEA (type: M | HPC: yes, GPU-enabled). ChEESE CoE flagship code for tsunami simulations based on the 2D shallow water equations as well as more sophisticated dispersive versions.
- L-HySEA (type: M | HPC: yes, GPU-enabled). ChEESE CoE flagship code for landslide-tsunami simulations, two-layer model combining 2D shallow water equations for tsunami propagation, and a Savage-Hutter model for the landslide dynamics
- SeisSol (type: M | HPC: yes, GPU-enabled). ChEESE CoE flagship code for seismic wave propagation (acoustic, elastic, viscoelastic/-plastic, poroelastic), dynamic rupture earthquake and tsunami simulations on heterogeneous 3D models.

- ExaHyPE (type: M | HPC: yes, GPU-enabled). ChEESE CoE flagship code to solve hyperbolic partial differential equations in seismology and engineering on dynamically adaptive spacetree grids.
- Salvus and SPECFEM3D (M | HPC: yes, GPU-enabled). ChEESE CoE flagship codes for waveform modelling and inversion with applications ranging from laboratory ultrasound studies to planetary-scale seismology
- UCIS4EQ (type: W | HPC: yes). ChEESE CoE modular workflow for urgent seismic computing that manages the generation of synthetic shake-maps.

16. Identification of foreground: Pilot Level

In ChEESE, leading European HPC centers, academia, hardware developers, as well as SMEs, industry and public governance bodies such as civil protection are working together to prepare European flagship codes for upcoming pre-Exascale and Exascale supercomputing systems to tackle global challenges in the domain of Solid Earth. Potential services include urgent computing, probabilistic hazard assessment and early warning, together with 3D imaging of the subsurface. Finally, ChEESE aims at acting as a hub to foster HPC across the Solid Earth Community and related stakeholders and to provide specialized training on services and capacity building measures.

Services related to Pilot Demonstrators are described in D5.1. In addition, other services that ChEESE CoE may offer to the community include:

i. Repository (Zenodo: https://zenodo.org/communities/cheese-coe/?page=1&size=20). Various tools provided, including user-friendly and efficient systems for workflow executions and data processing
ii. Workshops (cheese-coe.eu/events/workshops)
iii. Meetings (cheese-coe.eu/events/meetings)
iv. Training courses (cheese-coe.eu/events/training)
v. Webinars (cheese-coe.eu/events)
vi. New business models based on Urgent Computing

In particular, the initial expected knowledge and technology transfer to industry per Pilot Demonstrator is the following:

No	Pilot Demonstrator name	Related service	Outcomes /Highlights
1	Urgent seismic simulations	Urgent computing	UCIS4EQ, designed to become a hybrid in-production service that runs in the cloud and on HPC clusters. Suites of high-frequency simulations from UCIS4EQ with Salvus can reproduce the right order of magnitude for a range of observed proxies.
2	Faster than real-time tsunami simulations	Urgent computing	PD2 Faster Than Real Time (FTRT) workflow (high level of stakeholder engagement)- Urgent Computing (ARISTOTLE-ENHSP Project-IUB member); Rapid post event assessment, and Multi-scenario simulations for the Spanish TEWS (Early Warning). Engagement of IGN-IUB member.

3	High-resolution volcanic plume simulation	None	Hekla and Etna test cases: Shocks, proximal aviation hazard and ash dispersion.
4	Physics-based tsunami-earthquake interaction	None	3D dynamic rupture simulation to obtain ocean floor displacements; Pipe (time-dependent?) displaments into tsunami simulation; Many assumptions w.r.t. modelling (filtering, coupling conditions, etc.); **3D fully-coupled elastic-acoustic model that captures the whole process.**
5	Physics-based probabilistic seismic hazard assessment (PSHA)	Hazard assessment	Engagement of FAULT2SHA and GEM
6	Probabilistic volcanic hazard assessment (PVHA)	Hazard assessment	Demonstrate feasibility and usefulness of PVHA by means of HPC resources at Campi Flegrei (Use-cases 1 and 2; one advanced draft of a paper) and Jan Mayen (Use-case 3, published on NHESS). Technological achievements: ChEESE Performance and Productivity Optimization (POP) to optimize the parallelization in postprocessing Fall3D simulations and calculating the hazard (execution time decreased by orders of magnitude); ChEESE WMS-light to execute different workflow modules on different servers and manage the data flow; PRACE project in association with PD3 and PD12 on Joliot-Curie at TGCC-CEA (France); Three Use-Cases completed.
7	Probabilistic tsunami hazard assessment (PTHA)	Hazard assessment	Probabilistic Tsunami Hazard Analysis Pilot Demonstrator. Thanks to ChEESE many outcomes have been possible: i)High resolution inundation calculations -From regional to local hazard, ii) Local tsunami hazard based in the NEAM – future community service, iii) Increase from a handful of tsunami sources to 10^4-10^5 sources for inundation runs, iv) HPC can provide much more fine grain source uncertainty treatment than previous studies as the source number is highly increased, v) Benchmark PTHA and understand how elaborate source uncertainty treatment needs to be. Scientific highlights: Case study for Catania and Siracusa; Local PTHA based on regional PTHA; Hazard disaggregation key for accuracy and reproducibility; Offset between regional and local analysis for highest intensities due to epistemic uncertainties; PD7 resolves the hazard locally with far greater resolution and sophistication; Possible reduction in uncertainty through the PD7 service; Comparison with practical GIS approaches which use safety margins; GIS estimate within PTHA uncertainty range if epistemic uncertainty is taken into account; PD7-derived maps show more limited extent; Understanding source parameter sensitivity: Fault uncertainty (dip, strike...) and Near field vs far field; Tsunami uncertainty; Surface friction (Manning number): Basis for selecting parameters in the far more elaborate PRACE study TsuHazAP. Operational Applications: i) the new Italian National PTHA model within the INGV-National Civil Protection Agreement, ii) the site specific hazard assessment for two localities in Sicily and Malta for local Civil Protection, iii) the site specific hazard assessment for 3 Versalis ENI petro-chemical plants in

			compliance with the Seveso Directive to prevent Natech relevant accidents. Simulations performed on HPC5 @ ENI peaking at ~6000 V100 GPUs used altogether for these applications.
8	Probabilistic Tsunami Forecast (PTF) for early warning and rapid post event assessment	Early warning	Pre-calculated scenarios (early warning version): t works in near-real time at the CAT-INGV Tsunami Warning Centre (https://www.ingv.it/cat/en/), which is a NEAMTWS Tsunami Service Provider (http://www.ioc-tsunami.org/). There are millions of pre-calculated tsunami scenarios. It is embedded in the operational data/information flow of the CAT-INGV. On-the fly scenarios (Urgent Computing): Prototype for applications in ARISTOTLE, event analysis at CAT-INGV and potentially other Tsunami Service Providers worldwide; Global scope; Simulation ensembles to be run from scratch on large enough HPC clusters in urgent computing mode; Provides exceedance probabilities for tsunami heights just off the coastline as it doesn't require linearity; First large scale tests allowed to identify several bottlenecks. Optimised scripts are now being integrated into the prototype WMS-light-based workflow developed in collaboration with HLRS. Achieved high Technology Readiness Level (From TRL 3 to TRL 7-8). PD8 will be distributed as a service by TCS Tsunami in EPOS.
9	Seismic tomography	Other	Seismological Data Management: Subsurface imaging based on seismic waves: LASIF python module extended to teleseismic case and support for SPECFEM3D solver, New GUI for data selection and downloading from seismological data centres (IRIS, FDSN, ...). Complete efficient workflow: Data management, HPC computation, Post-process. Gradient computation for seismic tomography: New workflow for gradient computation in SPECFEM3D. Complete efficient workflow: data management, HPC computation and Post-process.
10	Array-based statistical source detection and restoration and Machine learning from monitoring	None	Data-streaming workflow for seismic source location with PyCOMPSs parallel computational framework: Framework for efficient and easily reproducible analysis (detection and location of seismic sources) using continuous data recorded by (large) seismic networks. Improving seismic catalogue through efficient and reproducible workflow.
11	Geomagnetic forecasts	None	End-users: scientific community. Ensemble assimilation approach of data (last millennium). Orchestrate a new workflow manager (WMS-light). Study the impact of assimilating directly pointwise measurements of the geomagnetic field into models of the geodynamo. Assess the reliability of the forecasting strategy using synthetic data whose properties mimic the real data sets. Parallel python library.
12	High-resolution volcanic ash dispersal forecast	Urgent computing	Two exercises carried out during 2021. We provided deterministic & probabilistic forecast products: VOLCICE-2021 exercise, Buenos Aires VAAC exercise.

			Operational services during real eruptions in 2021: Volcanic eruption in Iceland and La Palma eruption (September to December)

Table 12 Services related to Pilot Demonstrator(s)

Further details about the exploitation strategy for each Pilot Demonstrator can be found at Deliverable 6.6 Appendix B.

Key Exploitable Foreground (Example of a Key Exploitable Result-KER)

According to the engagement and willingness to use from the ChEESE industry partners, next is described the most direct outcome from this **successful collaboration between the ChEESE partners**. A Lean Canvas is presented next as a first step to be discussed with the European Commission designated experts (https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/horizon-results-platform). This will be possible by means of a potential acceptance to run the EC Horizon Results Booster process beyond the end of the project (https://www.horizonresultsbooster.eu/).

Type of Exploitable Foreground	Nature of Exploitable Foreground	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Volcanic ash dispersal analysis	Software	SaaS, Research contracts, Scientific partnerships	YES	TBD	Available under license, publication in peer-reviewed journals, R&D Collaboration	Academia, Solid Earth,	TBD	GNU GPL v3	BSC

Table 13 KER Summary Table

17. Business Modelling and Planning for KERs

Value proposition

ChEESE is a project directly related to obtaining and managing more efficiently HPC resources both software and hardware. In the short-mid run, this will result in cheaper, cleaner and safer hazard response, which has a direct impact on society. Also, the HPC specific advances will benefit other disciplines as supercomputing is being used in almost every scientific and industrial field. In ChEESE, European HPC centers, academia, hardware developers, as well as industry have been working together to prepare codes for upcoming pre-Exascale and Exascale supercomputing systems to tackle global challenges in the domain of solid earth.

The algorithms developed in the project enable the application codes to efficiently run larger problems with higher fidelity to a better exploitation of various sources of hazards (seismic, tsunamis, etc.). Hence, potential services include geophysical exploration, emergency computing, early warning systems and high resolution imaging. ChEESE has promoted and facilitated the integration of HPC services to widen the access to codes to the solid earth related user's community. Finally, services that ChEESE is addressing to be offered to the community are also here itemized: Repository: Various tools provided, including user-friendly and efficient systems for workflow executions and data processing, Workshops, Meetings, Training courses, Webinars, etc. This information has been centralized in Zenodo: https://zenodo.org/communities/cheese-coe/?page=1&size=20

Channels

Some exploitation channels are herein itemized, such as: assets directly exploited by ChEESE partners, Web presence, Zenodo, Social media, industry events, seminars and conferences, Clusters, Trainings, Seminars, Workshops, direct contract, direct stakeholders contacts, etc.

Revenue Streams

There are no "expected revenue streams" at present but there could be potential funders related to continuation of the project, mainly engaged private industry such as Repsol, but also linked to civil protection entities and ARISTOTLE.

Other revenues may come from the academia and scientific community, bringing in-kind contributions. ChEESE offers code developers a communication platform to attract new partners. The use of the software would be limited to assure the exploitation of the whole workflow value chain, which should be covered under the ChEESE umbrella partners. In that sense, Academia would benefit from using Software as a Service (SaaS) from Pilot Demonstrators. Scientists could use some services offered on the ChEESE umbrella against payment directly to the service providers depending of the type of services but could also offer their own expertise.

Business Canvas for ChEESE KERs

Business Model Canvas for KER1: Volcanic Ash Dispersal

Our idea of business model is based on a Software as a Service solution that relies on the ChEESE reference architecture. As reported in D6.6, our main value proposition focuses on offering a complete workflow of volcanic simulation numerical tools oriented to services for hazard response assessment.

The main activities identified for building this idea are:

- Identify all the resources (HPC, data structure, data flows)
- Include the Key Exploitable Result at the Horizon Results Booster beyond the end of the project.

We plan to reach further customers via business oriented departments and using our online channels. The idea is to build an effective relationship that starts with the adoption of the service by the stakeholder (e.g. IGN, VAAC, Icelandic Civil Protection) and continues

with our direct assistance in plant configuration and after sales support. The cost structure is composed by:

- Software development costs
- Hosting of the proprietary Software as a Service solution
- Computational resources costs (HPC, storage, tenants)
- Internal customer service and software updates and patches

The identified revenue streams are based on Software as a Service embedded in R&D Projects: each service offered will have a dedicated plan (license of the tool) that the customer can choose. The idea is to develop a pay per joint R&D project that lets the customer use what is needed when it is needed with minimum configuration overhead. Finally, both a Lean Canvas and a Business Canvas have been prepared for the KER.

Problem: What are the top 3 problems or needs of your customers that you want to solve? -Analysis of ash dispersal to allow the development of evacuation plans and hazard countermeasures. Existing Alternatives: How this problems are solved today?	Solution: What are the 3 main solutions provided by your offer to meet the problems or needs of your customers? Obtain high-accuracy results by means of optimizing simulation tools. -Capability of running efficiently at largest worldwide Supercomputers. Key Metrics: What key indicators should you monitor as a priority to check the strength of your business? Number of PhD students Number of new R&D collaborations Number of research contracts	Unique Value Proposition Single Clear and compelling message that states why you are different and worth buying -Keep and Develop European Competitiveness -Provides Training High level concept: How does your product fit into the bigger picture; where does it fall in the grand scheme of things? The PD12 solution fits perfectly in the EC digitalization strategy, the EuroHPC Infrastructure strategy as well as the EC needs.	Unfair Advantage: Unique, clear and compelling message explaining why you are different and that you are worth the customer's attention. Added value of exascale HPC and software optimisation at software and hardware level including HPC experts Channels: Through which communication and distribution channels do you reach your customers? ChEESE Web portal Engineering events Scientifical collaborations Direct contacts Web presence Social media Industry events, seminars and conferences, Clusters Direct Marketing and sales Campaign Marketing activities of Stakeholders Trade groups	Customer Segment: Who are your target customers? Early Adopters: Who are your ideal customers / users? -First responders: civil-military planning agencies -HPC and simulation expertise consultants -Industrial End Users: Insurance, SMEs, mid caps companies, labs and research centres. -Academics and Scientifics
Cost Structure 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 Participation to scientific projects collaborations and HPC activities : services and improvements provided to our partners. Asset providing (services) Training revenues 3rd party funding	

Figure 33 KER 1 Lean Canvas

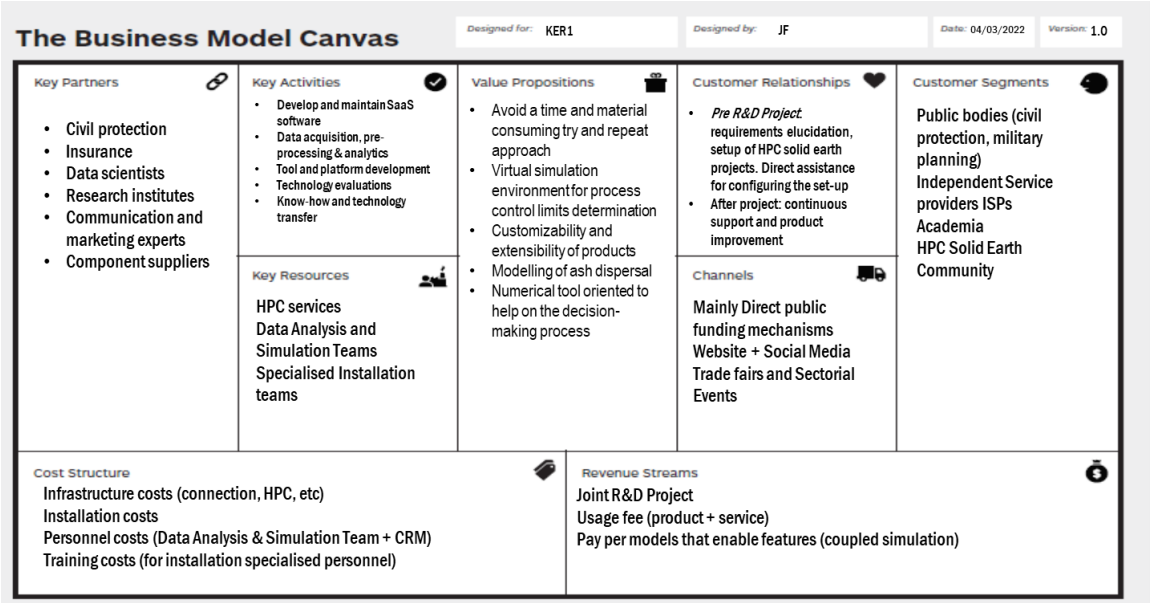

Figure 34 KER 1 Business Canvas

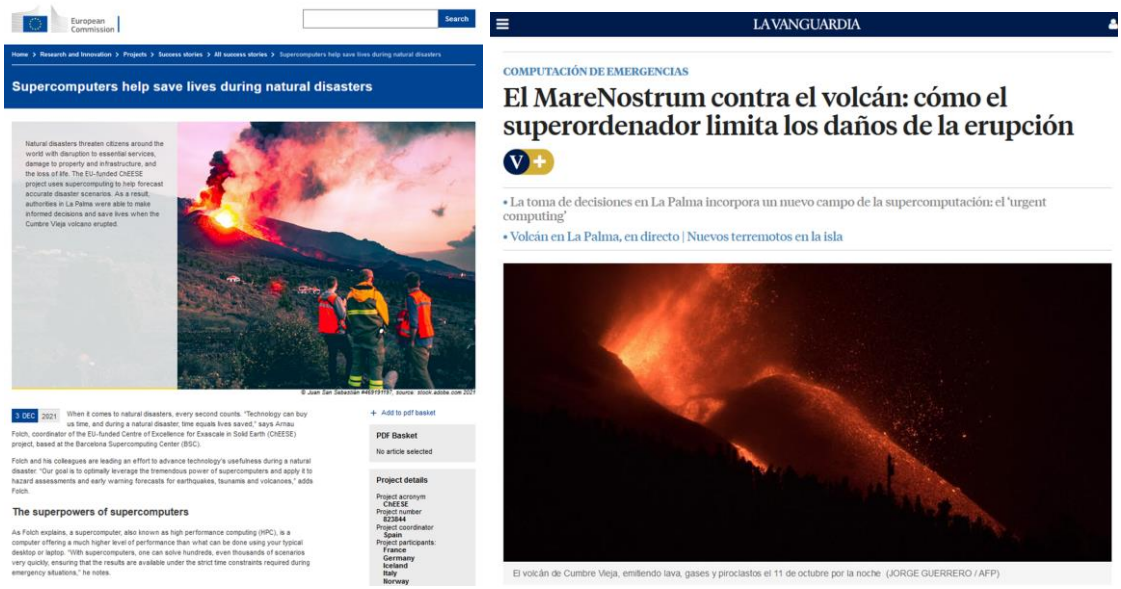

Figure 35 KER 1 High-impact news (EC portal, LaVanguardia)

Additionally, and following the Horizon Booster suggestions, a first identification of the risks associated with the KER has been done. Here in can be found the summary:

KER Risk Assessment Map

	Description of Risks	Degree of criticality of the risk related to the final achievement of this Key Exploitable Result. Please rate from 1 to 10 (1 low- 10 high)	Probability of risk happening Please rate from 1 to 10 (1 low - 10 high)	Risk Grade	Potential intervention	Estimated Feasibility/Success of Intervention Please rate from 1 to 10 (1 low- 10 high)	Conclusion
	Partnership Risk Factors						
1	Industry for demonstrator not available (i) Possible (ii) Low	*4*	*4*	**16**	Search of different partners	*8*	**Control.**
2	Communication between ICT and industrial sector (e.g. solid earth partners is not satisfactory	*10*	*2*	**20**	Internal reorganization to enhance the interaction	*8*	**Control.**
3	Links with other projects introduce dependencies.	*4*	*4*	**16**	Common meetings to improve the coordination and synergies will be organized.	*9*	**Control.**
	Technological Risk Factors						
4	Clients do not like the platform as it is not friendly	*5*	*2*	**10**	Focus less on the specific software but in the service	*9*	**Control.**
5	Computational resources too low (i) Possible (ii) Medium	*7*	*1*	**7**	BSC will send proposals to national networks such as RES or to PRACE	*9*	**Control.**
6	New HPC technologies appears during the development of the project (new architectures)	*4*	*3*	**12**	BSC will internally discuss the modification of the modules affected to include the new advances in this field.	*7*	**Control.**
7	Possible failure of algorithms	*6*	*1*	**6**	This is a useful outcome of the project and can drive research in this field towards other directions. In some of these areas, gains in performance will be higher than expected, in others lower.	*7*	**Control.**
	Market Risk Factors						
8	The market (Academia, R&D Centers and Industry) does not accept the KER	*6*	*9*	**54**	Offer R&D services that do not demand investment by the partners (scientific collaborations). Bad for business but good for social impact	*5*	**Between Action & Warning**
	IPR/Legal Risk Factors						
9	The test data are confidential	*2*	*5*	**10**	A non-disclosure agreement dealing with management of IPR will be signed by the partners.	*9*	**Control.**
10	Delay of a IPR definition of more than six months, variations in available budget devoted to foster the market implementation of more than 20%, Technology Transfer key personnel leaving BSC	*4*	*8*	**32**	Empowering of the responsible staff	*7*	**Control.**

	Financial/Management Risk Factors						
11	Marketing and distribution fails due to a weak strategy	*7*	*6*	**42**	Revise the strategy with the BSC dissemination and communication experts.	*6*	**Control.**
12	Marketing and distribution fails due to a lack of resources	*7*	*4*	**28**	Search for funding (private and competitive)	*2*	**No Action'**
	Environmental/Regulation/Safety risks:						
13	Project outcomes are not compatible with regulations of existing market procedures expressed through standards. (likelihood: low, severity: high)	*5*	*4*	**20**	Revise Alya strategy towards being an standard code, not only in Scientific environments.	*5*	**Between Control & No Action**

Figure 36 KER Risk Assessment Map

18. Sustainability of ChEESE as a whole

As it has been described in previous sections, ChEESE is facing its sustainability at 3 different levels: a) Pilot Demonstrators, b) Partner interests, and c) ChEESE as a whole. Thus, all foreground developed within the CoE must be covered by an exploitation strategy, aligning these three exploitation layers.

Regarding ChEESE as a whole, some of the PDs are being developed towards being validated in real operational environments. This step is strictly necessary to be prepared to face the last step, which is to prepare the asset to be launched to the market. All these assets, together with other relevant services which the CoE is willing to provide (trainings, workshops, data, etc.) must be organized inside an organization. Different options are analyzed taking into account the inputs received from FocusCOE, HPC3 and also by boosting and converging all ChEESE partners' interests.

Focus CoE and HPC3 collaboration framework

Once most of the PDs have been validated in an operational environment, assets are closer to an operational service stage. ChEESE does not currently have a current legal status as a brand. According to the advances in Pilots and to the HPC3 exploitation strategy Working Group, where the ChEESE PIM is involved, the Consortium has decided to strengthen the collaboration through new Solid Earth initiatives, (DT-GEO,

eFlows4HPC, GeoInquire), which will also determine to boost a feasible legal status aiming to exploit the ChEESE portfolio (period 2025-2030, in between the end of these initiatives and Destination Earth programm) as well as put science as core business of the institution, or to propose new exploitation procedures in accordance to the other Centers of Excellence, represented at FocusCoE and HPC3.

With regard to **business development and sustainability working group from HPC3 Council** an overview of some applicable business models, as considered by some CoEs, to include options for, e.g. public funding, private funding (investments), commercial revenue, challenges around setting up a commercial entity (distributed teams, different national laws, host institution rules etc.), challenges with operating both as a project and as a business has been discussed. Several points are expected to be addressed as a CoE: Level of scientific expertise that is not replicable, Global picture of HPC provision and use, i.e. public vs. private, Companies such as Amazon can also be regarded as competitors (cloud computing).

All these common topics are bringing the HPC3 members to consider which l**egal entity** forms would be the most suitable, analyzing the applicability of legal entity forms that have been considered by the CoE, the common challenges and opportunities, together with new **governance models** internally discussed by each CoEs, including what will be the legacy of the long-term investments and what is the impact on society and research communities.

Internal analysis of ChEESE long-term sustainability framework (Month 36+5)

A long-term sustainability discussion at ChEESE governance bodies (PEC and PSB) has been fostered from M18 up to M36+5 (including previous discussions at WP4, WP5, and WP6 levels), bringing different long-term sustainability options to the last PSB meeting, held in October 6th 2020, where all the partners which are part of the consortium were represented.

The main objective of ChEESE PSB meeting was to achieve an agreement to boost the fundamentals of the organization which may assure the continuity of the CoE, following the recommendations of the EC in terms of sustainability but also defining a structure which clearly faces Science (including research and trainings) and Assets, allowing the engagement of different kind of institutions and becoming the pool of reference in HPC for Solid Earth Sciences. A large presentation was carried out by the PIM, facing different pros and cons with regards to different exploitation strategies when ChEESE sustainability is considered as a whole. In the next table many different options are presented, as well as some of the advantages and disadvantages that ChEESE partners, representing Universities, R&D Centers, Non-profit Foundations, etc. consider appropriate to be continuously discussed in the period M24-M36+5.

Option	Advantages	Disadvantages
Profit organization	Easy implementation. Investment in R&D Projects.	Fix costs. Private entities may take profit of the organization, mainly in IP.

		Science investment would be compromised. Ownership sharing of the Company. Strategic control. Difficult entrance for public bodies (e.g. Universities, R&D Centers). Humanitarian projects may not be properly handled. Interaction with public bodies.
HPC3 branch	Sharing fixed costs (dissemination, communication, management, etc.) Supra-entity which directly interacts with RIAG.	Many CoES at different maturity status have to agree. Uncertain, HPC3 does not have legal status yet.
Non-profit Foundation	Direct reinvestment in R&D projects. Direct reinvestment in Grants Academia and R&D centers are used to be part of Foundations. Possibility to have Access to EU funds (Horizon Europe/DestinE). Clustering and Lobbying. Ownership of the institution. Easy engagement for Universities and R&D Centers.	Fix costs. Different boarding members from different kinds of institutions with different strategic interests.
NGO	R&D projects oriented to public interest. Ownership of the institution.	Fully independent of institutions, public bodies and political parties. ChEESE needs this interaction and commitment from public bodies. The legal status does not facilitate the entrance of Universities and R&D Centers. No possibility of access to grants for Partners.
Association	For the purpose of coordination of business activities, representation and protection of common property and other interests, profit-making legal entities can create an association by agreement between each other and jointly with non-profit organizations. Non-profit organizations may unite on a voluntary basis into associations (units) of such organizations. Members of such association will retain their autonomy and corporate privileges and rights.	Such association shall not be held liable for obligations of their members, while members of the association shall bear subsidiary liability for obligations of the above association. Even though unincorporated **associations** technically do not exist as a **legal entity** apart from its members, many state legislatures have recognized the separate existence of an **association** by statute. Thus, submission of proposals to the EC would not be allowed under the whole circumstances.
European Research Infrastructure Consortium (ERIC)	An ERIC is a legal entity with legal personality and full legal capacity recognized in all EU Member States. Its basic internal structure is very flexible, leaving the members to define in the statutes, case by	It should be noted that the ERIC is a legal tool which is appropriate only for high-profile research infrastructures with a European dimension. Therefore, only a limited number of ERICs are expected to be set up in the coming years.

	case, membership rights and obligations, the bodies of the ERIC and their competences.	

Table 14 Sustainability options for ChEESE as a whole

Based on the different legal status organizations, ChEESE would evolve into a **partnership** that drives a collaborative effort to develop scientific and high-quality resources for transparent assessment of Solid Earth hazards, and to facilitate their application for risk management around the globe. Thus, targeting real Exascale **HPC tools** are of extreme importance to achieve the goal.

As mentioned above, **Community building, real assets and Science** are in the core business of the ChEESE long-term sustainability strategy. Thus it will be mandatory to provide, at least, some of the benefits which are described here:

i. Access to a highly-skilled international **network** in Solid Earth: clustering and networking.
ii. Interaction with policy-makers, public institutions, entities in charge of critical infrastructures.
iii. Lobbying and definition of a scientific and humanitarian strategic agenda.
iv. Access to Project funding (R&D and Humanitarian).
v. Access to sabbatical options.
vi. Co-design with the relevant HPC players of the market.
vii. Easy recruitment of personnel (IT personnel) which collaborates with partners on specific topics/projects.
viii. Access to **scientific repositories**: papers, reports, codes, data, etc.
ix. Access to **trainings** and courses for member's staff: For young researchers (PhD students) and ad-hoc.
x. **Grants** (co-funding) to ChEESE members.
xi. **Lessons learnt** (e.g. from urgent computing services to be applied in epidemiology, climate/weather, synergies).
xii. **Entity able to receive IP and exploit it** through strategic projects.

Additionally, the ChEESE institution would produce and/or manage software, datasets, hazard models, scientific and informative articles, research reports, slides presentation, infographics, etc. These materials should be protected by IPR. The associated exploitation strategy will be discussed according to the Partner's interest. Either way, open and free distribution of data, models and tools are at the core of ChEESE work. All ChEESE products will address different target audiences: public, non and commercial use, but with different license restrictions. Thus, ChEESE may offer collaborative services, products and resources that can be used for public and commercial purposes by organizations or individuals worldwide.

Finally, and focusing on the monetary long-term sustainability of the ChEESE CoE, it requires a strategy to identify which incomes and outcomes are expected. Next are both initially detailed:

In terms of sustainability...		
Incomes	Marketplace	HPC services (subcontracted to 1 or more associated partners that pay an overhead to the institution) on urgent computing, early warning systems, hazard assessment, etc.
		Code and/or workflow licensing by partners (e.g. licensed). The institution would handle repositories, tech transfer assistance on IP agreements (e.g. LuLs), etc.
		Other products and services based on data and services produced by ChEESE, based on open-source codes and data.
		Consultancy through ChEESE is: a) Done by ChEESE if it owns IP (with the possibility of sub-contracting in codes, workflows, co-design) and b) Directly transferred to a Partner (including overhead).
	Trainings	Organized on-demand or regularly by Partners for Members
	Projects	EU (Horizon Europe), DestinE and other competitive calls
	Sponsorship	Governor (voting sponsors that pay a financial contribution) Advisor (non-voting sponsors that pay a financial contribution) Associates (non-voting sponsors that do not pay financial contribution; but may nominate a delegate to attend Governing Board meetings)
	EU funding	Discussion with different DG(s)
	Private	Emergency centers
	Overheads	Yearly remaining overheads are reinvested into internally-funded scientific projects, R&D (e.g. PhD grants) and humanitarian purposes participated by Partners (and eventually also by members)

Table 15 Incomes analysis for a potential legal status of ChEESE

Asset	**Marketplace**				**Trainings**	**R&D Projects**	**Sponsorship**	**EU funding (e.g. Horizon Europe)**	**Private**	**Overheads**
	HPC services	***Code and/or workflow IP licencing***	***Other products and services based on data and services produced by ChEESE***	***Direct services***						

Beneficiaries	HPC Centers	All codes, workflows and toolkits owners through direct and indirect IP exploitation.	IP owners of data and services.	All partners which provide services through ChEESE (e.g. Pilot associated services)	Partners, members	Partner, member, ChEESE	ChEESE	ChEESE	Partners ChEESE	ChEESE
Stakeholders (already engaged at IUB board)	HPC Providers	Scientific and Public bodies	SMEs and Data Management experts	Reinsurance and Oil&Gas companies	Universities, R&D Centers, Private companies.	Universities, R&D Centers, Private and Public Institutions	-	ERIC	First responders	-
Example	Co-design of a new processor which should handle application-related simulations	Scientific projects based on hazards analysis.	New business models First-responders necessities, etc.	Simulation of hazard phenomena for insurance industry.	HPC, Hazards	Solid Earth, HPC	Annual fee	New R&D projects	Agreement on basic services according to the annual fee	Directly reinvested in ChEESE

Table 16 ChEESE related services (incomes/assets)

On the other hand, in terms of outcomes, it is expected that different costs will need to be handled:

In terms of sustainability...	
Outcomes	Human resources (hired personnel)
	Computational Resources (on tier-0 and tier-1 machines access)
	Dissemination activities about: Success Stories, R&D Projects, Partners skills, Policy which affects Solid Earth Community, etc.

Table 17 ChEESE identified outcomes

19. Conclusions about Exploitation

The main purpose of exploitation activities has been to maximize the impact of the project, understanding impact as the transfer of knowledge and results from the project to the research community, industry, public institutions, policymakers and society. So, the main activities have been:

1. To identify the exploitable results of the project.
2. Perform an analysis of the exploitation context to find out the actual market situation, the potential target market (or target users) and the early adopters.
3. Promote synergies with major European and Mexican energy-related initiatives.
4. Bridge the gap between ChEESE and market players.

The exploitation of the results of the ChEESE project has been widely described at three levels:

i. **Industry/Public Bodies**: The industrial and public bodies related to solid earth (Repsol, Global Parametrics, IGN, ARISTOTLE) have direct access to the innovative ideas and tools of the project and apply them to their internal decision-making processes. Other companies will also have access to the generated knowledge through the dissemination at industrial associations.
ii. **Scientific community**: the outcomes of the research are published in peer-reviewed high impact journals, disseminated in congresses and conferences, transferred to other European projects related to solid earth (DT-Geo, GeoInquire, eFlowsHPC), and also available through a public repository under the Zenodo umbrella.
iii. **Society**: ChEESE is a project directly related to obtaining and managing more efficiently solid earth hazards by means of high performance computing. In the short-mid run, this will result in cheaper, cleaner and safer energy production, which has a direct impact on society.

The foreground is widely described in Deliverable 6.6. Besides these, all the technical foreground has been widely analyzed and three Key Exploitable Results have emerged as an innovative outcome from ChEESE, with plenty of business potential to be embedded in actual operation. These KERs are in the process to be discussed at the Horizon Results Platform with the European Commission experts (https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/horizon-results-platform), hence, maximizing the impact of the collaboration between EU partners and all the resulting foreground. A Lean and Business Canvas have been done for each KER as a first step to be part of these communities.

In this final release, a more in-depth analysis of the business opportunities and of their potential – supported by market – has been provided, to develop the business cases related to ChEESE results and start defining its business ecosystem. Finally, and in order to boost also the link with the scientific community, clear interactions with Centers of Excellence community, in particular with POP2, ChEESE, and EoCoE 2 has bave addressed.

In summary, the goal of the ChEESE exploitation strategy has been to outline the best possible path to capitalize on knowledge and results generated within the project, maximizing the impact for each of its actors – from academia, to developers to end-users – ultimately bridging the gap to enable the European industrial, service and business

domain, especially SMEs, to significantly improve profitability through digitalization, and opening up new opportunities for them for the creation of new services and business models based on HPC tools. It is clear that the project results provide a deeper understanding of new algorithms and procedures for the future exascale machines, allowing large scale simulations and the integration of workflows and visualization tools.

On the other hand, and as has been widely explained, partners have complementary competences and knowledge, the experimental and computational resources are available and the relevant stakeholders to transform this knowledge into real solutions. **Some exploitation related highlights are summarized next:**

- Creation of an Industry and Users Board (initially composed by 12 stakeholders and, at the end of the project, composed by 28 institutions and initiatives)
- The participation of ARISTOTLE and Global Parametrics in PD1 with ETH for the Turkey case.
- The participation of Repsol in PD9 with CNRS.
- The participation of IMO and related partners in the VOLCEX exercises. VOLCEX are regular volcanic ash exercises in the EUR/NAT Regions promoted by the International Civil Aviation Organization (ICAO) and involving EUROCONTROL, airlines, airports, Meteorological Offices, Aeronautic Service Providers (ANSPs) and others. VOLCEX-21 will be held in Iceland and test the development of PD12 in an operational setting.
- IMO participates also in the VOLCICE exercise, a country-scale reduced version of VOLCEX in conjunction with the U.K. Met. Office, the British Geological Survey (BGS) and the Icelandic Civil Protection (member of the ChEESE IUB).
- INGV Observatories following ChEESE developments (Tsunamis, Aviation, Seismic)
- First Urgent Seismic Simulation workflow executed on 2970 nodes of Mare Nostrum 4 (BSC, Spain) and 5320 nodes of Piz Daint (CSCS, Switzerland)
- First operational Tsunami Probabilistic Forecast workflow executed on 800 nodes (3200 NVIDIA V100 GPUs).
- First Tsunami Early Warning workflow with uncertainty estimation executed on 72 nodes (288 GPUs) on CINECA's Marconi100 (Italy).
- First Volcanic Short-Term Probabilistic Hazard Assessment and Probabilistic Forecast workflows run on 24 to 48 nodes on BSC's Mare Nostrum 4.
- Prototype probabilistic km-resolution forecast products have been delivered to Volcanic Ash Advisory Centres for Volcanic Ash dispersal, with uncertainty estimated on hundreds of ensemble members, in less than 1 hour.
- Operational faster-than-real-time tsunami warning (PD2) has increased its capability by hundreds of times, including an early assessment of tsunami coastal hazard and innovative uncertainty evaluation.
- Operational volcanological services (PD6 and PD12) have been scaled by a factor > 103 (in terms of number of cells, time steps, and ensemble numerosity/sample size) with respect to current state-of-the-art.
- Operational Probabilistic Tsunami Forecast (PD8) as a game changer

- A first demonstrator of PD2 has been implemented at the SPADA system of the Aristotle2-NHSP project to deliver advice to the EU Emergency Response Coordination Centre (ERCC).
- Two services (PD2 and PD12) based on ChEESE Flagship codes Tsunami HySEA and Fall3D have been deployed as fully Operational Services (TRL 9). Their codes, workflows and results are routinely used by the stakeholders to support decision-making processes.
- **The definition of urgent computing services for natural disasters, with a particularization in seismic simulations of PD1, to be used in the context of the EuroHPC JU as a model for emergency access for HPC.**
- **Cumbre Vieja operational service of PD12.**
- 6 successful exercises carried out in collaboration with IUB and the extended network with 53 institutions + 99 individual and 26 countries represented.
- ChEESE Zenodo community (easy to trace OpenAIRE, metadata): https://zenodo.org/communities/cheese-coe/?page=1&size=20

Annex 1: Dissemination Register

The ChEESE dissemination register, where all dissemination activities are recorded for M1-M41, can be found below:

Type of activity	Details	Starting date	Total audience size
Participation to a workshop	Alice-Agnes Gabriel presents at the FAULT2SHA workshop held in King Abdullah University of Science and Technology in Saudi Arabia	26-Nov-18	45
Participation to a conference	Marisol Monterrubio and Thomas Ulrich presented at AGU Fall Meeting 2018	12-Dec-18	24,250
Website	News article: ChEESE: HPC Centre of Excellence in solid earth to mitigate impacts of geohazards	18-Dec-18	247
Other	ChEESE mentioned on Eurolab4HPC website	23-Feb-19	300
Participation to a workshop	Alice-Agnes Gabriel presents at the Third Schatzalp Workshop on Induced Seismicity held in Davos, Switzerland.	5-Mar-19	53
Participation in activities organised jointly with other H2020	Arnau Folch presents at the ESiWACE 2 kick-off	12-Mar-19	60
Participation to a conference	Arnaul Folch (BSC), Marisol Monterubbio (BSC) and Alice-Agnes Gabriel (LMU) present at EGU 2019	8-Apr-19	16,263
Participation to a workshop	ExaHype workshop in Durham, UK	22-Apr-19	26
Website	News: ChEESE's strong presence at EGU 2019	25-Apr-19	67
Video / film	ChEESE: the HPC center of excellence in Solid Earth in three minutes	2-May-19	627
Participation to an event other than conference / workshop	Jorge Macias presents ChEESE at Pint for Science	20-May-19	50
Participation to a conference	ChEESE researchers present at EuroHPC Summit Week 2019	13-May-19	60
Participation to a workshop	ChEESE researchers present at Northquake2019	21-May-19	47
Participation to a conference	Manuel J. Castro Díaz presents at at CIEM Workshop at University of Cantabria	28-May-19	50
Participation to a conference	Alice-Agnes Gabriel and Duo Li present at deRSE19 - first Conference for Research Software Engineers	4-Jun-19	35
Participation to an event other than conference / workshop	Erwan Raffin exhibit at TERATEC 2019 Forum at the Focus CoE booth	11-Jun-19	1,700
Participation to a conference	Alexandre Fournier presents at SIAM 2019	11-Mar-19	100
Participation to a conference	Erwan Raffin (Bull Atos) presents at ISC19and Alice-Agnes Gabriel represents ChEESE at the INTEL plenary discussion on Exascale Computing Applications	16-Jun-19	3,573
Website	News article from WP2 - The ChEESE methodology: code audit towards exascale performance portability of ten European flagship applications in Solid Earth	26-Jun-19	93

Participation to a workshop	ChEESE researchers present at NMEM Workshop (Numerical Modeling of Earthquake Motions)	30-Jun-19	76
Participation to a conference	ChEESE researchers present at IUGG 2019	8-Jul-19	4,000
Organisation of a Workshop	2nd ExaHyPE User Workshop	22-Jul-19	30
Participation to an event other than conference / workshop	Invited talk at the Seminar of the Mathematical and Computational Engineering group at UPSC, IIMC (Instituto de Ingeniería Matemática), Santiago de Chile, Chile	22-Jul-19	25
Organisation of a Workshop	Tsunami-HySEA training course at Universidad Técnica Federico de Santa María (UTFSM), Valparaiso, Chile	23-Jul-19	27
Website	News article: ChEESE in full force at IUGG2019	26-Jul-19	94
Press Release	On EPOS newsletter: https://www.epos-ip.org/riding-wave-future-supercomputing-center-excellence-exascale-solid-earth-cheese-will-share-exascale	31-Jul-19	1,230
Website	News article from WP3: ChEESE will explore parallel mesh partitioning strategies of simulation codes	15-Aug-19	56
Website	News article from WP4: about HPC for simulation local tsunami hazard	16-Aug-19	40
Participation in activities organised jointly with other H2020	Contribution to 12th POP COE newsletter of September 2019	1-Sep-19	847
Participation to a workshop	Alice-Agnes Gabriel and Luo Li present SeisSol Training at the ICTP Advanced Workshop on Earthquake Fault Mechanics: Theory, Simulation and Observations Trieste	2-Sep-19	82
Participation to a conference	Alice-Agnes Gabriel presents at 2019 SCEC Annual Meeting	8-Sep-19	541
Participation to a conference	Lukas Krenz, Leonhard Rannabauer and Michael Bader present at the 13th International Conference on parallel processing and applied mathematics (PPAM 2019)	10-Sep-19	15
Participation to a conference	Manuel Castro Diaz gives a talk at the Presentation of the Socio-economic Impact Report of Mathematics at the University of Sevilla	19-Sep-19	80
Website	News article from WP5: ChEESE HPC service prototypes	20-Sep-19	51
Participation to an event other than conference / workshop	Jorge Macias presents at European Researchers Night in Málaga, Spain	27-Sep-19	10
Website	News article: ChEESE partners reunite at PSB and face-to-face meetings in Rome	2-Oct-19	39
Video / film	Video about ChEESE technical meeting in Rome on BSC Youtube	3-Oct-19	69
Participation in activities organised jointly with other H2020	Jorge Macias presents ChEESE at the COST Action AGITHAR (Accelerating Global Science in Tsunami Hazard and Risk Analysis) kick-off meeting in Malta	7-Oct-19	70
Participation to a workshop	Alice-Agnes Gabriel presents at MCS Megathrust Modeling Workshop in Eugene, Oregon	7-Oct-19	75
Participation to an event other than conference / workshop	ChEESE researchers participate in CINECA GPU Hackathon	7-Oct-19	30
Press Release	Scientific Computing World HPC yearbook 2019-2020	8-Oct-19	50,000
Website	News article from WP2: SPECFEM3D speedup	11-Oct-19	134
Participation to a workshop	Jorge Macias presents at the Alboran Domain and Gibraltar Arc: Geological Research and Natural Hazards Workshop	16-Oct-19	50
Website	News article: ChEESE researchers join CINECA GPU hackathon	22-Oct-19	39
Participation to a workshop	Arnau Folch and Leonardo Mingari present at the 1st Wind-remobilization processes on volcanic ash Workshop, Bariloche, Argentina	24-Oct-19	30

Organisation of a Workshop	Jorge Macias Sanchez gives a training course about Tsunami-HySEA at the Universidad Nacional de Costa Rica (UNA) in San Jose, Costa Rica	4-Nov-19	8
Participation in activities organised jointly with other H2020	Claudia Rosas and Mauricio Hanzich present a webinar hosted by POP	12-Nov-19	34
Participation to a workshop	Jorge Macias presents at the International workshop on tsunamis - Malaga Museum	14-Nov-19	60
Website	News article about MITIGA solutions and ChEESE	14-Nov-19	38
Participation to a workshop / Participation in activities organised jointly with other H2020	Steven Gibbons presents at the Urgent Computing Workshop collocated with SC19 (Organised by VESTEC and LEXIS projects)	17-Nov-19	50
Participation to a workshop	J.-M. Gallard presents at the International Workshop on Software Engineering for HPC-Enabled Research (SE-HER 2019) at SC19	17-Nov-19	25
Website	News article about ChEESE and POP webinar	21-Nov-19	30
Participation to an event other than conference / workshop	Jorge Macias presents at the annual meeting of directors and assistant directors of the Consorcio de Compensación de Seguros (Insurance Compensation Consortium) in Granada, Spain	28-Nov-19	25
Organisation of a Workshop	ChEESE organizes a PATC course: HPC and natural hazards: modelling tsunamis and volcanic plumes using European flagship codes	2-Dec-19	30
Organisation of a workshop	Federico Brogi presents at a PATC course called School on Numerical Methods for Parallel CFD	2-Dec-19	38
Participation to a conference	Jorge Macias gives a talk at ICG/NEAMTWS 2019	4-Dec-19	20
Participation to a conference	Piero Lanucara presents at Computing Insight 2019	5-Dec-19	50
Participation to a conference	ChEESE researchers present at AGU Fall Meeting 2019	9-Dec-19	27,000
Video / film	ChEESE video about urgent computing on BSC YouTube	12-Dec-19	1,255
Other	Focus CoE mentioned ChEESE in an article on their website	17-Dec-19	3,890
Press Release	Alice Agnes Gabriel wins PRACE Ada Lovelace Award (PRACE website)	8-Jan-20	7,200
Press Release	Alice Agnes Gabriel wins PRACE Ada Lovelace Award (InsideHPC)	8-Jan-20	65,000
Press Release	Alice Agnes Gabriel wins PRACE Ada Lovelace Award (HPCwire)	8-Jan-20	160,000
Participation to a workshop	Alice-Agnes Gabriel presents at the SCEC Dynamic Rupture Group Ingredients Workshop on Fault Friction	8-Jan-20	38
Press Release	Alice Agnes Gabriel wins PRACE Ada Lovelace Award (Scientific Computing World)	9-Jan-20	10,000
Website	News article on ChEESE website about Alice winnings the Ada Lovelace Award	14-Jan-20	32
Press Release	ChEESE SPECFEM3D speedup on CORDIS	6-Feb-20	25
Website	News article about International Day of Women and Girls in Science	11-Feb-20	100
Participation to a conference	TUM and UMA researchers present at 2020 SIAM Conference on Parallel Processing for Scientific Computing	13-Feb-20	1,700
Other	TUM and UMA organised a minisymposium about HPC Aspects of Tsunami Simulation at 2020 SIAM Conference on Parallel Processing for Scientific Computing	13-Feb-20	1,700
Website	News article about ASEAN delegates joining ChEESE PATC course	14-Feb-20	40
Website	News article on BSC website about Anak Krakatau paper	27-Feb-20	71
Press release	Anak Krakatau paper on EarthNetworks	28-Feb-20	5,000

Press Release	Anak Krakatau paper on BBC	28-Feb-20	121,000,000
Press Release	Anak Krakatau paper on National Geographic	28-Feb-20	21,000,000
Participation to an event other than conference / workshop	Josep de la Puente presents ChEESE at Bojos per la Supercomputacio, an HPC training program for high school students	29-Feb-20	25
Press Release	Anak Krakatau paper on The Nation	2-Mar-20	1,000,000
Press Release	Cheese mentioned in CORDIS as part of Alice-Agnes Gabriel´s work	6-Mar-20	53
Participation to a workshop	Jorge Marcias presents at Curso sobre el Analisis del Riesgo Sísmico (Seismic Risk Analysis Course), organised by Direccion General de Proteccion Civil y Emergencias (General Directorate of Civil Protection and Emergencies) of Spain	9-Mar-20	50
Press Release	Anak Krakatau paper mentioned in Meteo Web	10-Mar-20	20,000
Press Release	Anak Krakatau paper mentioned in Sicilia Report	10-Mar-20	20,000
Press Release	Anak Krakatau paper mentioned in Canal Ansa	10-Mar-20	20,000
Press Release	Anak Krakatau paper mentioned in Vilaggio Globale	10-Mar-20	20,000
Press Release	Anak Krakatau paper mentioned in Popular Science	11-Mar-20	20,000
Website	News article from WP5 about ChEESE´s collaboration with ARISTOTLE-ENHSP	19-Mar-20	165
Participation to a conference	Michael Bader presents at Supercomputing Frontiers Europe	23-Mar-20	200
Participation in activities organised jointly with other H2020	ChEESE mentioned in booklet prepared by EOSC Secretariat	26-Mar-20	204
Press Release	Anak Krakatau paper mentioned in Forbes	29-Mar-20	7,000,000
Participation to a conference	Arnau Folch will speak at the High Performance Innovation Conference	30-Mar-20	120
Website	News article about success of Anak Krakatau paper in popular media	31-Mar-20	41
Press Release	Anak Krakatau paper mentioned in Mother Nature Network	1-Apr-20	10,000
Communication campaign (e.g. Radio / TV)	ChEESE´s work on tsunami warning systems mentioned in Canal Sur (Spanish TV channel)	2-Apr-20	300,000
Other	Alice-Agnes Gabriel presents the Deformation & Tectonics talk series	10-Apr-20	25
Website	News about ChEESE presenting at High Performance Innovation Conference	13-Apr-20	40
Organisation of a workshop	ChEESE researchers organized the ExaHyPE user/dissemination workshop	22-Apr-20	30
Video / film	Video of Michael Bader´s Supercomputing Frontiers in Europe conference presentation on YouTube	27-Apr-20	101
Website	News article about new workflow management system prototype for geoscience applications	27-Apr-20	43
Press Release	Anak Krakatau paper featured on Science Node	27-Apr-20	15,000
Participation to a conference	ChEESE researchers presented at EGU20 online	4-May-20	15,000
Website	News: ChEESE wins Best Paper Award at GEOProcessing 2020	11-May-20	44
Website	News: ChEESE awarded almost 110M core hours for earthquake, volcano and tsunami research	11-May-20	55
Participation in activities organised jointly with other H2020	Arnau Folch will present "Codes and Workflows in the Center of Excellence for Exascale in Solid Earth" at the VECMA all-hands meeting	12-May-20	30

Website	News: ChEESE flagship code XSHELLS simulates geomagnetic reversals with unprecedented realism	25-May-20	198
Participation in activities organised jointly with other H2020	ChEESE mentioned in Focus CoE newsletter #4	26-May-20	89
Website	News: ChEESE partner Alice-Agnes Gabriel wins SSA´s 2020 Charles F. Richter Early Career Award	10-Jun-20	38
Participation to a conference	Phillip Samfass presented at ISC20	23-Jun-20	3700
Press Release	ChEESE mentioned in NIUS	5-Jul-20	50,000
Website	News: ChEESE contributes to Spain´s unique insurance scheme against natural catastrophes	6-Jul-20	49
Website	News: First simulations with SeisSol on Marconi100 and Piz Daint	9-Jul-20	115
Participation to a conference	ChEESE results were presented at LOD 2020	19-Jul-20	50
Participation in activities organised jointly with other H2020	ChEESE appeared in the Focus CoE newsletter #5	22-Jul-20	89
Participation to a conference	Jorge Macias presented at CMMSE 2020	30-Jul-20	20
Press Release	ChEESE mentioned on RTV Marbella	3-Aug-20	60,000
Website	News: ChEESE infrastructures and datasets set to be integrated into EUDAT CDI	3-Aug-20	44
Website	News: Join the ChEESE Advanced Training on HPC for Computational Seismology	24-Aug-20	28
Participation in activities organised jointly with other H2020	ChEESE featured on Focus CoE newsletter #6 and Arnau Folch wrote the welcome message	1-Sep-20	89
Participation to a workshop	ETH Zurich participated in SCEC CVM Workshop	1-Sep-20	50
Participation to a conference	Arnau Folch presented "A computational model for atmospheric transport and deposition of tephra,dust, SO2and radionuclides" at the 106° Congresso Nazionale (106th National Congress)	14-Sep-20	100
Participation to a conference	ChEESE researchers presented at the SCEC Annual Meeting 2020	14-Sep-20	50
Participation to a conference	A presentation called "CINECA OpenPower-based HPC Infrastructure: Some porting results" at virtual OpenPOWER Summit North America 2020 mentioned ChEESE research and results	15-Sep-20	50
Website	News: ChEESE presents at the 106th Congresso Nazionale	22-Sep-20	25
Website	News: ChEESE awarded over 90M core hours for tsunami and earthquake research	29-Sep-20	82
Participation to a workshop	ETH Zurich participated in a Virtual Seismic Tomography webinar	6-Oct-20	200
Participation to a workshop	Alice-Agnes Gabriel presented at the virtual 2020 CIG Community Workshop	13-Oct-20	50
Participation to a conference	Bull Atos presented ChEESE at TERATEC Forum 2020 - Europa Village	13-Oct-20	900
Participation to a conference	INGV researchers presented at the OpenFOAM conference	14-Oct-20	40
Participation to an event other than conference / workshop	Antonio Costa participated in a Scientific Apereitifs session of a Beyond the Horizon public outreach event	15-Oct-20	50
Website	News: From research to societal relevance: How ChEESE and urgent computing may enhance INGV´s hazard forecasting	16-Oct-20	33
Participation to a workshop	Marisol Monterrubio-Velasco at the Micromechanics, Statistics and Hazards of Mechanical Failure Workshop	20-Oct-20	30

Organisation of a Workshop	ChEESE organizes a PATC course: CHEESE Advanced Training on HPC for Computational Seismology	21-Oct-20	50
Organisation of a Workshop	ChEESE organizes a PATC course: Tools and techniques to quickly improve performances of HPC applications in Solid Earth	26-Oct-20	10
Video / Film	CHEESE Advanced Training on HPC for Computational Seismology Day 2-SeisSol session	29-Oct-21	201
Video / Film	CHEESE Advanced Training on HPC for Computational Seismology Day 2-SPECFEM3D session	29-Oct-21	188
Video / Film	CHEESE Advanced Training on HPC for Computational Seismology Day 3-Salvus session & Wrap up	29-Oct-21	228
Participation to an event other than conference / workshop	Josep de la Puente presented at the Enzo Levi Seminar	30-Oct-20	50
Website	News: Participants from all over the world join ChEESE´s computational seismology course	30-Oct-20	71
Website	News: Women in HPC: Marisol Monterrubio-Velasco	2-Nov-20	21
Website	News: Women in HPC: Beatriz Martinez Montesinos	2-Nov-20	106
Website	News: POP and ChEESE work together to improve Probabilistic Volcanic Hazard Assessment pilot demonstrator	9-Nov-20	65
Participation to a workshop	Women in HPC Workshop @SC20	11-Nov-20	200
Participation in activities organised jointly with other H2020	UrgentHPC@SC20	13-Nov-20	50
Press release	GEM to contribute expertise to high performance computing in the field of seismology hazards (Global Quake Model)	16-Nov-20	500
Participation to a conference	GEOProcessing 2020	21-Nov-20	40
Press release	Una simulación de tsunami en Andalucía: el primer paso para crear un plan de actuación (COPE)	22-Nov-20	5,000
Video / Film	SHAKEMOVIE: propagazione onde sismiche Mw 6.9 del 23 novembre 1980 in Irpinia e Basilicata	23-Nov-20	25,731
Participation to a workshop	GenX workshop	24-Nov-20	40
Website	ChEESE presents tutorial at GEOProcessing 2020	30-Nov-20	21
Website	ChEESE training course helps participants solve HPC issues in Earth Science	1-Dec-20	17

Participation to an event other than conference / workshop	Geociencias Barcelona (GEO3BCN - CSIC) seminar	1-Dec-20	50
Participation to a conference	AGU Fall Meeting 2020	1-Dec-20	27,000
Video / Film	ChEESE presentation at the Women in HPC Workshop by Marisol Monterrubio-Velasco	2-Dec-20	38
Video / Film	ChEESE presentation at the Women in HPC Workshop by Beatriz Martinez Montesinos	2-Dec-20	77
Website	News: Editorial board composed of female ChEESE members oversees Frontiers in Earth Science special issue called "High-Performance Computing in Solid Earth Geohazards: Progresses, Achievements and Challenges for a Safer World"	2-Dec-20	196
Participation to a workshop	3rd Annual Workshop of HPC Training and Research for Earth Sciences (HPC-TRES)	11-Dec-20	100
Website	News: ChEESE 2020 highlights	12-Jan-21	73
Press release	¿Cómo pueden las Matemáticas responder ante un Tsunami? (RTVE)	19-Jan-21	10,000
Participation to a conference	HPC Asia 2021	20-Jan-21	575
Participation to a conference	HiPEAC 2021	20-Jan-21	200
Participation in activities organised jointly with other H2020	First Joint CoEs Technical Workshop	27-Jan-21	35
Website	News: Probing the earth subsurface	31-Jan-21	40
Website	News: ChEESE celebrates the International Day of Women and Girls in Science 2021	15-Feb-21	22
Press release	Faster Than Real Time (FTRT) environment for high-resolution simulations of earthquake generated tsunamis (Innoradar)	27-Feb-21	10,000
Participation to a conference	SIAM CSE 21	1-Mar-21	2000
Participation to a conference	SOS24 Virtual Conference	10-Mar-21	70
Press release	ChEESE: The European Union prepares to enter the exascale era (INGV website)	11-Mar-21	150
Participation in activities organised jointly with other H2020	CoEs Co-Design Workshop	12-Mar-21	30
Participation in activities organised jointly with other H2020	European Urgent Computing Workshop – EuroHPC Summit Week 2021	24-Mar-21	400
Press release	Informativo Málaga /RTVE)	24-Mar-21	10,000
Participation to a conference	Ada Lovelace Award Talk – EuroHPC Summit Week 2021	26-Mar-21	400
Website	News: ChEESE participates in EuroHPC Summit Week 2021	29-Mar-21	19
Participation to a conference	GPU Technology Conference 2021	13-Apr-21	200
Website	News: ChEESE partner Jorge Macias oversees GeoHazards special issue "Modelling and Numerical Simulation of Tsunami"	13 –Apr-21	29
Website	News: ChEESE talks about building a GPU ecosystem for earth science at GTC 2021	14-Apr-21	47
Organisation of a Workshop	Training: Tsunami-HySEA: An introduction course (Instituto de Hidráulica Ambiental de Cantabria)	16-Apr-21	9
Participation to an event other than conference / workshop	EPCC GPU Hackathon	19-Apr-21	50

Website	News: A successful simulation run of the 2020 Mw 7 Samos-Izmir earthquake	19-Apr-21	155
Participation to a conference	EGU General Assembly 2021	19-Apr-21	22,000
Participation to an event other than conference / workshop	SMU Seminar Series	23-Apr-21	50
Organisation of a Workshop	Towards Exascale Supercomputing in Solid Earth Geoscience and Geohazards Workshop (EGU 2021)	29-Apr-21	22,000
Website	News: ChEESE: The European Union prepares to enter the exascale era	3-May-21	60
Website	News: ChEESE in full force at vEGU21	4-May-21	52
Organisation of a Workshop	Training: sunami-HySEA: An introduction course (Escuela Superior Politécnica-Ecuador)	24-May-21	7
Press release	España ya cuenta con un plan de emergencia ante tsunamis para evitar catástrofes como la de 1755 (La Sexta)	3-Jun-21	10,000
Press release	Jorge Macías, sobre los tsunamis en España: "Si el aviso lo damos en 15 minutos, se pueden salvar muchas vidas" (Antenna 3)	4-Jun-21	10,000
Press release	¿Qué hacemos si hay un Tsunami? (La Sexta)	7-Jun-21	10,000
Participation to an event other than conference / workshop	CINECA GPU Hackathon	14-Jun-21	50
Participation to a conference	XV Jornadas Internacionales de Seguridad, Emergencia y Catástrofe. Retos Y Avances Tecnológicos	17-Jun-21	70
Participation to a conference	International Conference on Computational Science (ICCS2021)	17-Jun-21	20
Website	News: ChEESE Equality Committee actions presented to partners	18-Jun-21	
Participation to a conference	SIAM Conference on Mathematical & Computational Issues in the Geosciences (GS21)	21-Jun-21	50
Participation to a conference	ISC High Performance 2021 Digital Conference	24-Jun-21	3500
Website	News: ChEESE Pilot on Physics-Based Tsunami-Earthquake Interaction: Paper on 3D Acoustic-Elastic Coupling with Gravity Accepted for SC21 Conference	29-Jun-21	127
Participation to a conference	Congreso de Ecuaciones Diferenciales Y Aplicaciones (CEDYA)	14-Jun-21	100
Organisation of a workshop	Training: EU ASEAN High Performance Computing (HPC) Virtual School: System Design & HPC Applications	5-Jul-21	60
Press release	How HPC is Shaking Up Modeling of Mysterious Earthquakes (HPCwire)	6-Jul-21	160,000
Organisation of a workshop	Platform for Advanced Scientific Computing Conference (PASC21)	6-Jul-21	150
Organisation of a Workshop	Training: Tsunami-HySEA: An introduction course (University of Malta)	8-Juñ-21	6
Website	News: ChEESE teaches module on Urgent Computing for Natural Disasters to ASEAN participants	12-Jul-21	26
Website	News: ChEESE mentioned in 2021 ETP4HPC Handbook of European HPC Projects	13-Aug-21	15
Video / Film	Video titled "ChEESE: using the power of Exascale simulations to save lives"	13-Aug-21	792
Participation to a conference	OpenACC Summit 2021	15-Sep-21	80
Participation to an event other than conference / workshop	Aperitivo Scientifico: Tsunami, Terremoti, Vulcani. Cosa Può Fare Un Supercomputer	17-Sep-21	20
Participation to a conference	37th General Assembly (GA) of the European Seismological Commission (ESC2021)	22-Sep-21	15
Press release	New method forecasting tsunami uncertainty (NGI website)	28-Sep-21	150

Website	News: ChEESE paper about tsunami forecasting published on Nature Communications	28-Sep-21	57
Press release	Una nuova procedura di allarme tsunami dopo un terremoto (Rivista Natura)	29-Sep-21	10,000
Press release	Del volcán a la emergencia climática: Los 'big data' que salvan vidas en catástrofes (Newtral)	4-Oct-21	10,000
Press release	El superordenador de Barcelona que predice el volcán de La Palma: "Sería imposible sin él" (Nius Diario)	10-Oct-21	50,000
Press release	El MareNostrum contra el volcán: cómo el superordenador limita los daños de la erupción (La Vanguardia)	13-Oct-21	22,700,000
Organisation of a Workshop	Training: PATC: ChEESE Advanced Training on HPC for Computational Seismology	19-Oct-21	46
Press release	MareNostrum 4 makes forecasts on the ash clouds and aerosols of the La Palma volcano for the emergency services (BSC website)	20-Oct-21	74
Press release	BSC's MareNostrum 4 Supercomputer Forecasts La Palma Volcano's Ash Clouds (HPCwire)	20-Oct-21	160000
Website	News: MareNostrum 4 makes forecasts on the ash clouds and aerosols of the La Palma volcano for the emergency services	20-Oct-21	4
Participation to a conference	82nd EAGE Annual Conference & Exhibition	21-Oct-21	15
Press release	Tsunami alert, the new forecasting model of INGV	24-Oct-21	500
Participation in activities organised jointly with other H2020	BSC-NVIDIA GPU Hackathon for HPC and AI	25-Oct-21	56
Website	News: Presentations from the second ChEESE Advanced Training on HPC for Computational Seismology now available	29-Oct-21	121
Press release	MI AÑO FAVORITO T04E03 (Podium Podcast)	29-Oct-21	5,000
Press release	An international team coordinated by INGV presents a new model for tsunami early warning following an earthquake (NEAMTIC website)	29-Oct-21	200
Video / Film	ChEESE Advanced Training on HPC for Computational Seismology 2021	2-Nov-21	128
Video / Film	CHEESE Advanced Training on HPC for Computational Seismology Day 1-Introducing the codes	2-Nov-21	352
Website	News: ChEESE conducts two table-top exercises to test short-term volcanic hazard assessment and tsunami urgent computing	3-Nov-21	101
Press release	World Tsunami Awareness Day, Urgent Computing Per Prevedere Gli Tsunami (CINECA website)	4-Nov-21	200
Participation to a workshop	2nd European VOs-VAACs Workshop	8-Nov-21	50
Press release	Mapping the Earth's interior (PRACE website)	11-Nov-21	500
Participation to a conference	SC21	14-Nov-21	100
Participation to a workshop	Fault Tolerance for HPC at eXtreme Scales (FTXS) Workshop	14-Nov-21	30
Press release	EU Centre of Excellence in High Performance Computing: ChEESE's urgent computing in the service of Cumbre Vieja volcanic eruption (EC website)	15-Nov-21	5,000
Press release	Conocemos el plan de contingencia ante el riesgo de maremotos en Andalucía (Canal Sur)	15-Nov-21	300,000

Participation to an event other than conference / workshop	Jornada Técnica sobre el Riesgo de Maremotos	2-Dec-21	50
Press release	Supercomputers help save lives during natural disasters (EC website)	3-Dec-21	5,000
Video / Film	PD2 ChEESE Live Demo on FTRT Tsunami Simulations for Early Warning	3-Dec-21	110
Participation to a conference	AGU Fall Meeting 2021	13-Dec-21	27,000
Website	News: ChEESE conducts live demo of Faster Than Real-Time Tsunami Simulations	13-Dec-21	61
Press release	ChEESE´s volcanic ash forecasting service is validated in exercise conducted with the Buenos Aires Volcanic Ash Advisory Center (BSC website)	14-Dec-21	47
Website	News: ChEESE´s volcanic ash forecasting service is validated in exercise conducted with the Buenos Aires Volcanic Ash Advisory Center	14-Dec-21	4
Website	News: ChEESE 2021 Highlights	5-Jan-22	26
Website	News: ChEESE conducts live demo of Urgent Seismic Simulations	24-Jan-22	66
Video / Film	ChEESE Women in Science	8-Feb-22	497
Website	News: Social media campaign celebrates the ChEESE women in science	11-Feb-22	35
Video / Film	Urgent Computing Integrated Services for EarthQuakes (UCIS4EQ) - Overview	16-Feb-22	143
Participation to a conference	SIAM PP22	23-Feb-22	1,700
Participation in activities organised jointly with other H2020	VESTEC Final Workshop	23-Feb-22	40
Organisation of a Workshop	Training: Curso sobre el Analisis del Riesgo Sísmico (Seismic Risk Analysis Course)	7-Mar-22	50
Organisation of a Workshop	Training: Tsunami-HySEA training course (University of Puerto Rico, Mayaguez)	28-30 Mar-22	9
Press release	Press release: Exascale-compatible geohazard mitigation services developed to help authorities in decision-making	29 Mar-22	-