



## Deliverable 1.3

# Report on the recommended methodologies and technologies to enhance the response capacity to geo and weather events to be integrated in the GOBEYOND platforms

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## Executive summary

The **GOBEYOND** project is committed to enhancing natural disaster risk management. One of its key objectives is to introduce operational platforms that enhance decision-making and situational awareness, thereby supporting more effective emergency response in the case of geo- and weather-related events. These platforms will incorporate advanced impact forecasting algorithms, technologies, and tools that provide state-of-the-art solutions, addressing specific needs at both local and international levels.

In recent years, the technological landscape has been constantly evolving. New digital tools are making the development of new applications feasible, while older, previously established tools are losing relevance. This dynamic is also true for natural disaster management. To assist in selecting the best tools for designing and developing **GOBEYOND** tool suites and platforms, this deliverable evaluates innovative methodologies and techniques that can enhance situational awareness, facilitate risk communication, and support more effective emergency response during geo- and weather-related emergencies. The evaluation leverages the experience and expertise of **GOBEYOND** partners.

All technologies and tools are described and analysed based on their current state, maturity, relevance to EU project solutions, benchmarking, and assessment, and their application to **GOBEYOND** solutions. An evaluation framework is defined for the comparative analysis of technological characteristics. Four broad dimensions are used: general, technological, business model and informational evaluation criteria.

The results highlight that criteria related to relevance and performance are most consistently met within the general category, while technological infrastructure and lead time score highest within the technological category. Budget and sustainability emerge as critical factors within the business model criteria. Related to the information criteria, data quality, reliability, and clarity of warning messages are deemed most significant. Based on these findings and the needs and requirements identified from the Living Labs, the most promising tools will be invited to participate for the Innovation Prize leading to them into the **GOBEYOND** platforms.

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## List of acronyms and abbreviations

AI	Artificial intelligence
API	Application programming interface
CEMS	Copernicus Emergency Management Service
EDO	Europe and Global Drought Observatory
EEWS	Earthquake Early Warning System
EFAS	European and Global Flood Awareness Systems
EFFIS	European Forest Fire Information System
EMSC	European Mediterranean Seismological Centre
EWS	Early Warning System
FF	Flash flood
FFC	National Hydrometeo Services
GDO	Global Drought Observatory
GIS	Geographic Information System
GloFAS	Global Flood Awareness System
GMPE	Ground motion prediction equation
GOBEYOND	GeO and weather multi-risk impact Based Early warning and response systems supporting rapid deploYment of first respONders in EU and beyonD
IoT	Internet of Things
LiDAR	Light Detection and Ranging
NFO	Near-Fault Observatory
NWP	Numerical Weather Prediction
PGV	Peak ground motion
QPE	Quantitative Precipitation Estimation
QPF	Quantitative Precipitation Forecasting
SPI	Standardized Precipitation Index
TRL	Technology Readiness Level
VONUT	VOlcano Notice for tsunami Threat
VRR	Volcanic Ash Rapid Response

## 1. Introduction

Natural hazards have a global impact, showing the importance of forecasting, early warning systems and rapid disaster risk information, in mitigating their effects on lives, property, and livelihoods. While traditional forecasts centred on the event's physical characteristics, like magnitude and duration, the focus has now shifted to potential impacts, like affected populations and infrastructure damage. Impact forecasting evaluates risk by assessing exposure and vulnerability. Situational awareness and communication tools are crucial for authorities and responders to manage risks effectively, coordinate response efforts, and communicate risks to the public, minimizing impact.

This deliverable builds upon the foundational work presented in deliverables, “D1.1 – Report on the most relevant methodologies and technologies for enhancing the response capacity to geo and weather events” and “D1.2 – Report on the most relevant methodologies and technologies for enhancing situational awareness and communication during geo and weather events”. The aim of this document is to present systematically knowledge on various digital technologies, methodologies, and tools relevant to the goals and needs of the **GOBEYOND** project. The state of the art of these digital technologies is highlighted using academic and industrial sources.

To evaluate the overall suitability of tools and technologies for a potential integration into **GOBEYOND** platforms, a benchmarking and evaluation framework is proposed. The results of this analysis serve as guidelines for partners developing the project's suites and tools. Input from numerous project beneficiaries was gathered, capitalizing on each partner's expertise expressed through their scientific background and involvement in previous related European Union funded research projects.

The benchmarking considers several aspects for each examined technology, including the level of infrastructural constraints, availability of source code for modifications, and level of adoption by the industry sector. Finally, this deliverable provides some initial recommendations by suggesting the use of tools that rank higher across the evaluation metrics for the development of the relevant **GOBEYOND** tools.

This document has been structured as follows. Section 2 introduces i) the benchmarking evaluation framework that consists of four dimensions and various criteria for assessing technologies relevant to the development objectives of **GOBEYOND** platforms solutions, and ii) presents a catalogue of tools and technologies proposed in earlier deliverables, characterizing the state-of-the-art. Section 3 presents benchmarking results collected from **GOBEYOND** partners, selecting 20 technologies for further evaluation. Section 3.22 focuses on benchmarking analysis and result interpretations of technology application in proposed solutions. Section 5 presents the deliverable's conclusions.

## 2. Benchmarking framework and State-of-the-art catalogue

### 2.1. Benchmarking evaluation framework

In this section, we introduce the benchmarking evaluation framework of **GOBEYOND**. First, we outline the motivation behind benchmarking and review related work. And then, we present our newly designed framework.

Benchmarking is a widely used approach to measure performance (Lankford, 2002). It has evolved from computer benchmarking to cover various types and applications (Stevenson, Hojati, Cao, & Mottaghi, 2007). A benchmarking evaluation framework is a structured approach designed to systematically compare and assess the performance, efficiency, and impact of various technologies, processes, or systems against established standards or best practices. This framework aims to provide an objective and reliable basis for evaluating the strengths and weaknesses of different solutions, facilitating informed decision-making and continuous improvement. By establishing a set of criteria and metrics, the framework enables stakeholders to identify areas of excellence, uncover opportunities for enhancement, and ensure alignment with organizational goals and industry benchmarks (Stapenhurst, 2009).

In the context of disaster risk management, there are some benchmarking frameworks proposed. However, none of them is relevant to our needs. The focus of Sengupta (2023) is more abstract and does not consider specific natural disasters. Bahmani and Zhang (2021) emphasize on socio-natural disasters and prioritize recovery projects. Zheng, et al. (2021) focus on building damage assessment and relevant metrics. Debnath, et al. (2014) propose an interesting methodological approach but their benchmarking is tailored to transport systems.

Moreover, **GOBEYOND** faces an additional challenge due to the diversity of underlying digital components, ranging from technologies and tools to algorithms, innovations, mathematical models, and methodologies. Therefore, we propose a novel benchmarking evaluation framework specifically tailored to the requirements of **GOBEYOND**.

#### 2.1.1. Methodology

The following steps outline the process to develop the **GOBEYOND** benchmarking evaluation framework are described below:

##### 1. Define Goals and Scope

- *Objective*: Evaluate and compare various natural disaster technologies and tools in enhancing disaster preparedness, response, and recovery with the goal of suggesting which ones should be integrated in the **GOBEYOND** platforms,
- *Scope*: Evaluation of early warning systems, emergency response platforms, and disaster management tools across different types of natural disasters. We consider both geo and weather hazards such as floods, flash floods, windstorms, storm surges, heatwaves, droughts, wildfires, earthquakes, hurricanes, tsunamis, and landslides.

##### 2. Identify Indicators and Evaluation Criteria

- Need to select the relevant indicators that will be used to measure performance, efficiency, and impact.

- Ensure that the indicators are aligned with the goals and industry standards.
- Consider both qualitative and quantitative indicators.
- Establish clear and measurable criteria for each indicator.
- Define the metrics and standards against which performance will be assessed.
- Ensure the criteria are broad and cover all relevant aspects of performance.

**Example:** An indicator like accuracy could be measured by the precision of predictions and warnings, with evaluation criteria including the percentage of correct predictions and false alarms.

### 3. Select Tools and Technologies for benchmarking

- Identify leading technologies and tools in the field of natural disaster management.
- Review earlier WP1 **GOBEYOND** deliverables and current state of the art.

### 4. Select Benchmarking Partners

- This report relies on the expertise and experience of **GOBEYOND** partners, who are leading experts in specific hazards and early warning systems (EWS) for forecasting and responding to these hazards.
- In particular, the partners involve University of Napoli (UNINA), European Centre for Medium-Range Weather Forecast (ECMWF), Federal Office of Meteorology and Climatology MeteoSwiss (MCH), Universitat Politècnica de Catalunya (UPC), Bureau de Recherches Géologiques et Minières, (BRGM), International Centre for Earth Simulation (ICES), National Observatory of Athens (NOA), PREDICT Services, Hydrometeorological Innovative Solutions (HYDS), and Vereinigung zur Förderung des Deutschen Brandschutzes (VFDB).

### 5. Data Collection

- Create a sample scorecard that contains 4 columns: criterion/indicator, weight, score, and explanation.
- Request partners to complete a scorecard for each technology and tool they have expertise in.

### 6. Data Analysis and Interpretation

- Calculate weighted scores for each technology and tool.
- Compare performance and summarize key findings.

#### 2.1.2. Benchmarking evaluation criteria

The list of indicators and accompanying evaluation criteria can be extensive. We have opted for a balanced approach, creating a set of criteria that is concise enough for the benchmarking partners to complete, but also comprehensive to ensure a thorough benchmarking process. We define four broad criteria categories/dimensions to classify and aggregate different criteria, as shown in Table 1.

Table 1 Benchmarking evaluation table for GOBEYOND technologies and tools

Dimension	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
<b>General</b>	Relevance			
	Multi-hazard Capability			
	Performance			
	Genericity			
	Coverage and Reach			
	Community Engagement and Training			
	Testing and Drills			
	Accessibility			
<b>Technological</b>	Technological Infrastructure			
	Maturity			
	Lead Time and Accuracy			
	Scalability and Adaptability			
	System Integration			
	Real-Time Monitoring			
	Interoperability			
	Security			
	Innovation and R&D			
	Support			
<b>Business</b>	Budget and Sustainability			
	Benefit-Cost Analysis			
	Policy and Governance			
	International Standards			
	Insurance and Liability			
<b>Informational</b>	Data Quality and Reliability			
	Warning Message Clarity			
	Disaster Risk Reduction Integration			
	Community Resilience			
	Feedback Mechanisms			

The dimensions are described below:

**1. General Dimension**

This dimension encompasses the broad aspects of a natural disaster technology that affect its overall applicability and usability. It includes the generic criteria related to the general characteristics of each technology and tool. Moreover, it involves:

- a. **Relevance:** Alignment with **GOBEYOND** solutions’ needs and requirements.
- b. **Multi-hazard Capability:** Assesses the technology's effectiveness in handling various types of natural disasters.
- c. **Performance:** Effectiveness and efficiency of the technology in achieving its intended goals and fulfilling development requirements.

- d. **Genericity:** Universality of the technology, allowing for personalized functionalities. The more general the technology is, the more specific elements will require design, but it also allows greater flexibility to customize various functionalities in the **GOBEYOND** solutions.
- e. **Coverage and Reach:** Assesses the extent to which the technology meets IT requirements and examines its geographic and demographic reach.
- f. **Community Engagement and Training:** Evaluates the involvement and education of communities in disaster preparedness efforts.
- g. **Testing and Drills:** Assesses the effectiveness of simulation exercises in preparing for disasters.
- h. **Accessibility:** Considers the inclusivity of the technology to diverse populations, including those with disabilities.

**2. Technological Dimension**

This dimension focuses on the technical aspects and performance metrics of the natural disaster technology. It includes:

- a. **Technological Infrastructure:** Evaluates the robustness and sophistication of the underlying technology.
- b. **Maturity:** Level of Technology Readiness Level (TRL), defined by NASA (Héder, 2017). It defines nine levels for classification as indicated in Table 2.

Table 2 Definition of Technology Readiness Levels

TRL	Definition
1	Basic principles observed
2	Technology concept formulated
2	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment <sup>1</sup>
6	Technology demonstrated in relevant environment
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment <sup>2</sup>

- c. **Lead Time and Accuracy:** Assesses the effectiveness of the technology in providing early warnings accurately and with sufficient lead time.
- d. **Scalability and Adaptability:** Assesses the technology's capacity to expand and adapt to changing conditions.
- e. **System Integration:** Ease of integration into existing or legacy systems.
- f. **Real-Time Monitoring:** Ability to provide live updates and monitoring.
- g. **Interoperability:** Ability to work seamlessly with different platforms and devices.
- h. **Security:** Safety and protection provided by the technology.

<sup>1</sup> Industrially relevant environment in the case of key enabling technologies.

<sup>2</sup> Competitive manufacturing in the case of key enabling technologies; or in space.

- i. **Innovation and R&D:** Level of ongoing research and development.
- j. **Support:** Availability of community-based support.

### 3. Business Dimension

This dimension examines the financial and organizational aspects of implementing and sustaining the natural disaster technology. It includes aspects such as **financials** (costs of implementing and/or deploying the technology); **regulatory** (legislative factors that must be considered as they can hinder the use of technology); and **risks** (factors that endanger the use or deployment of the technology). More precisely, it involves:

- a. **Budget and Sustainability:** Assesses the financial viability and long-term sustainability of the technology; typically, in favor of open-source solutions.
- b. **Benefit-Cost Analysis:** *Evaluates the economic justification for its use.*
- c. **Policy and Governance:** Examines the level of regulatory support and alignment with governance frameworks. The more complex and restrictive these regulatory aspects are, the more challenging the adoption and use of such technology for the development of **GOBEYOND** solutions.
- d. **International Standards:** Evaluates compliance with global benchmarks and protocols.
- e. **Insurance and Liability:** Coverage for risks and liabilities associated with the technology.

### 4. Informational/Communication Dimension

This dimension assesses the quality and effectiveness of the information or data provided by the natural disaster technology. It includes:

- a. **Data Quality and Reliability:** Examines the consistency and dependability of the data provided.
- b. **Warning Message Clarity:** Assesses the understandability and effectiveness of the warnings delivered.
- c. **Disaster Risk Reduction Integration:** Examines the integration of the technology into broader disaster risk management strategies.
- d. **Community Resilience:** Evaluates the contribution of the technology to the overall resilience of communities.
- e. **Feedback Mechanisms:** Assesses processes for receiving and incorporating user feedback for continuous improvement.

#### 2.1.3. Benchmarking evaluation table and guidelines

Now that the evaluation criteria have been defined and classified into different dimensions (Section 2.1.2), each technology and associated tools can be analysed based on this evaluation framework. Given the heterogeneous nature of the technologies the scoring system adheres to the following principles:

- **Weights (1 to 4):** Assign a weight to each criterion based on its importance relative to the other criteria within the same dimension.
  - 1: Low importance
  - 2: Moderate importance
  - 3: High importance

- 4: Critical importance
- If a criterion is not applicable or if there is insufficient information to make an assessment, the experts are advised to indicate this clearly in their evaluation by marking it as "NA" (Not Applicable) or "Unknown."
- **Scores (-3 to 3):** Assign a score based on how well the tool or technology meets this criterion.
  - -3: Strongly negative performance
  - -2: Moderately negative performance
  - -1: Slightly negative performance
  - 0: Neutral performance
  - 1: Slightly positive performance
  - 2: Moderately positive performance
  - 3: Strongly positive performance

Additionally, the weights and scores were coloured as **heatmaps (blue to red)** to visually illustrate data intensity and patterns across a range of values. These color-coded representations enable us to discern areas of high and low performance, enhancing the clarity of comparisons between multiple variables or entities. They effectively highlight trends, outliers, and areas requiring attention or further investigation.

## 2.2. Catalogue of state-of-the-art tools and technologies for GOBEYOND

This section presents a catalogue of the tools, methods, and technologies relevant to natural disaster management within the scope of **GOBEYOND**. This set of tools and technologies aims to strengthen emergency response capability by improving situational awareness, information flow, and decision-making, supporting emergency management professionals, authorities, and other stakeholders facing evolving geo- and weather-related hazards.

For clarity and usability, the catalogue is divided into two groups. Table 3 provides an overview of state-of-the-art datasets, models, and tools already available within the **GOBEYOND** consortium. These were taken from earlier WP1 deliverables, namely D1.1 and D1.2, and are directly accessible, making them particularly suitable for benchmarking, testing, and validation.

Table 3 Recommended tools inside the Consortium for integrating into the GOBEYOND platforms

No.	Category	Tool/Technology Name	Involved GOBEYOND partner
1	Flood EWS	European Flood Awareness System (EFAS)	ECMWF
2		Global Flood Awareness System (GloFAS)	ECMWF
3	Flash flood EWS	Local flash flood systems (FF-EWS)	UPC
4	Windstorms	Meteoswiss - Impact forecasting pipeline	MCH
5		CLIMADA platform	MCH
6	Heatwave	Local Forecasts (Swiss system) - SMHI	MCH
7		European-wide Systems - Heat Health Indices	ECMWF

No.	Category	Tool/Technology Name	Involved GOBEYOND partner
8	Droughts	Local and European Forecasting systems	ANYWHERE partners
9	Fire danger	Drought and fire observatory and early warning system (DISARM)	NOA
10	Earthquake Early Warning	PRESTo: Source-based impact estimates	UNINA
11		QuakeUp: P-wave based impact estimates	UNINA
12		SAVE: OnSite Alert Level	UNINA
13		P-alert: Onsite P-wave based warnings	UNINA
14	Earthquake Rapid Response and Loss Estimates	Bayesian updating of loss estimates	BRGM
15		SEISAid-Antilles tool: rapid response in French West Indies	BRGM
16		QLARM - Quake Loss Assessment for Response and Mitigation	ICES
17	Volcano Early Warning & Volcano Rapid Response	EASE system for volcanoes	PLINIVS, UNINA
18		Volcanic Ash Dispersion EWS	NOA
19		Volcanic Ash Rapid Response (VRR)	NOA
29	Tsunami Early Warning Systems	Tsunami DSS - Vigirisks platform	BRGM
21	Landslide EWS	The Catalan LEWS	UPC
22	Operational Platforms	ARGOS Services: Multi-Hazard Impact Based Early Warning System platform	HYDS
23		Wiki-Predict: Real-time risk management platform	PREDICT
24		beAWARE platform: Real-time natural disaster management with AI capabilities	DRAXIS
25	Social Media Monitoring Tool	Suricate-Nat: Continuous Monitoring and Analysis of tweets after natural disaster (flood & earthquakes)	BRGM
26		beAWARE modules: Social Media Analysis for gathering and verifying Twitter posts and Social Media Clustering	DRAXIS
27	Remote Sensing: IoT applications & Platforms Platform	PANGEA: PANhellenic GEophysical observatory of Antikythera	NOA
28	Crowdsourcing for data collection and rapid impact assessment	beAWARE crowdsourcing solutions for incident reporting	DRAXIS
29	Alert and communication systems	A4alerts mobile app: Dissemination platform for the warnings triggered by the location or site-specific impact-based flood early warning system	UPC
30		SeismUP: Mobile app that warns Android users in southern Italy of small to moderate earthquakes	UNINA

No.	Category	Tool/Technology Name	Involved GOBEYOND partner
31		GIN – Meteoswiss: displays measurements, forecasts and natural hazard warnings and collects crowdsourcing observations	MCH

In contrast, Table 4 provides an overview of state-of-the-art datasets, models, and tools that lie outside the **GOBEYOND** consortium but are widely used across Europe. Although most of these external systems were not included in the D1.3 benchmarking exercise, the project acknowledges them as solutions for maintaining situational awareness, identifying future interoperability opportunities, and ensuring alignment with best practices.

Table 4 Recommended tools outside the Consortium for integrating into the GOBEYOND platforms

No.	Category	Tool/Technology Name	Organisation
1	Flood EWS	National Hydrometeo Services - Flood Forecasting Centre (FFC)	UK
2		NWC-SAF Convective Rain Rate (CRR / CRR-Ph / PC)	EUMETSAT
3	Flash flood EWS	Global Flood Awareness System (GloFAS)	Copernicus
4	Windstorms	C3S Storm Indicators / Storm Severity Index	Copernicus
5	Storm surge	Storm Surge Warning Service (Sturmflutwarndienst)	Germany
6		ANYWHERE solutions	Anywhere Solutions ApS
7	Heatwave	ERA5-HEAT	Copernicus C3S
8	Droughts	European and Global Drought Observatory (EDO, GDO)	JRC/Copernicus
9	Wildfire	Fire Weather Index (FWI)	ECMWF/Copernicus
10		Global Wildfire Information System (GWIS)	Copernicus
11		European Forest Fire Information System (EFFIS)	Copernicus
12		National Warning Systems - SMHI	Sweden
13	Earthquakes	USGS services - ShakeMap, ShakeCast and PAGER	USGS
14		SIGE - Information System for Emergency Management in Italy	Italy
15		ELER system - Earthquake Loss Estimation Routine for Turkey	Turkey
16	Tsunami Early Warning Systems	ICG/NEAMTWS - North-eastern Atlantic, the Mediterranean	Intergovernmental
17		CAT - Tsunami warning in Italy	Italy
18		VOlcano Notice for tsunami Threat (VONUT)	Intergovernmental
19	Landslide EWS	The Norwegian LEWS	Norway
20		The Italian (Tuscany) LEWS	Italy
21	Social Media Monitoring Tool	AIDR: Twitter monitoring (natural disasters, landslides)	COEUS Institute

No.	Category	Tool/Technology Name	Organisation
22		A near-real-time global landslide incident reporting tool	QCRI
23	Remote Sensing: IoT applications & Platforms Platform	Copernicus Emergency Management Service (CEMS)	Copernicus
24		Maestro: Managing Forest Fires via IoT	AUTh
25	Crowdsourcing for data collection and rapid impact assessment	FloodTags: Chatbot for geolocated reports	FloodTags
26		RiskMap: Chatbot to be reached via direct messaging	RiskMap
27		LastQuake: Multi-channel to collect and share reports.	LastQuake
28	Alert and communication systems	Location-based SMS technologies: EU-Alert, FR-Alert, BE-Alert, ES-Alert, Sweden (VMA)	France, Belgium, Spain, Sweden
29		Public location-based alerts for emergencies, Satellite-based (NINA)	NINA

The benchmarking carried out in this deliverable focuses on the tools and datasets listed in Table 3 (sections 3.1 to 3.19), mainly because partners can provide access to them and meaningfully assess them. This approach ensures that the benchmarking exercise remains feasible, practical, and aligned with what can be meaningfully incorporated into the **GOBEYOND** platforms in the mid-term.

In addition, and as an indicative exercise two tools of Table 4 were also benchmarked (sections 3.20 to 3.21). The goal was to establish a reference methodology that may guide a more comprehensive benchmarking of additional external tools in later phases of the project, particularly when access to these systems becomes feasible.

Therefore, this staged approach allows **GOBEYOND** to:

1. Focus on tools that can be tested, validated, and potentially integrated now, using partner-accessible resources, while
2. Preparing for future operational readiness by clearly identifying and acknowledging external state-of-the-art solutions that should be considered in subsequent phases for enhanced performance, interoperability, and long-term adoption.

### 3. Benchmarking of promising technologies and tools

This section presents the benchmarking results based on the **GOBEYOND** partners expertise. Each tool and technology is first briefly presented and then benchmarked according to the evaluation framework described in Section 2. Note that a careful selection of the most appropriate tools and technologies was made. Benchmarking all 61 tools from Section 2 would not be feasible or realistic. Instead, we focused on the most suitable and promising tools that are currently operational.

Our aim was to choose at least one representative tool for each type of hazard (geological or weather-based). We prioritized tools that are actively maintained and in use, rather than those that are outdated or no longer supported. We aimed to strike a balance between:

- Tools designed or developed (partially or fully) by **GOBEYOND** partners to facilitate integration and familiarity.
- Tools from other sources that offer state-of-the-art solutions or additional complementary features.

This approach allows us to compile a set of tools that cover all possible hazards and can be readily integrated into **GOBEYOND** platforms for direct application and testing.

#### 3.1. Flood: European Flood Awareness System - EFAS

##### 3.1.1. Overview

The flood forecasting system [European Flood Awareness system](#) (EFAS) is a fully web-based flood forecasting system which became operational in 2012. EFAS provides flash flood and river flood forecasts with a lead time of hours up to 15 days.

##### 3.1.2. Capabilities

The main products are flood and flash flood notifications for upcoming events across Europe. These events are sent out to EFAS partners describing the severity of the event. The users can then follow the event as it unfolds on a web platform. There is also information on impact as well as a recently developed nowcasting forecasting system.

##### 3.1.3. Availability

The solution is available to the public and market, but not in real-time. The real-term information is shared only with the EFAS partners, this to preserve the “One voice principal” for forecasting agencies. The output is available to the public after a 30-day embargo, and it can be downloaded through the [Copernicus Climate data store](#). EFAS is fully open-source and is available free of charge.

##### 3.1.4. TRL

The TRL of EFAS is 9 since it has been fully operational since 2012. EFAS is provided with a high service level, which guarantees a 24/7 availability of the products.

##### 3.1.5. Solution in other EU projects

The LISFLOOD model is used in many EU projects, most recently the [EIFFEL](#) project and [SEED-FD](#).

### 3.1.6. Role in GOBEYOND

The LISFLOOD model is used in the EFAS system which provides operational flood forecasts across Europe. It also offers impact forecast products. The system is constantly revolving and adapting to the needs of its users. Within **GOBEYOND** new products will be developed that can go into the European-wide web interface, as well as serving the EFAS users. The experience of going from research to operations in EFAS will also contribute to successful implementation in **GOBEYOND**.

### 3.1.7. Benchmarking

Table 5 Benchmarking evaluation table for EFAS

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	2	Flood forecasts are very relevant for many users, and tools to predict the severity potentially saves lives. The score is lower since the system is on the European scale and misses some local information.
	Multi-hazard Capability	1	0	No multi-hazard as of now, but could be added.
	Performance	4	3	The system is carefully monitored and assessed, both from the developers and users.
	Genericity	1	-2	A hydrological model is trained on its data and spatial information; therefore, it is not easily transferred.
	Coverage and Reach	4	3	It covers all of continental Europe and beyond, which is one of the strengths of the product.
	Community Engagement and Training	3	2	EFADs has a strong user community which meets regularly and influences the development.
	Testing and Drills	3	1	Testing facilities exists, both technical and institutional. However, more can be done.
	Accessibility	4	3/-3	The system is available for EFAS partners (3) but not accessible for the public (-3).
Technological	Technological Infrastructure	4	3	The system is well tested and is running operationally with a high.
	Maturity	2	1	The system is mature, but it is not taking advantage of the latest technical developments.
	Lead Time and Accuracy	4	2	The lead time is up to 10 days, with some products going out to weeks and months. Accuracy can be improved.
	Scalability and Adaptability	2	-1	It is a robust, but not very scalable system. In principle you can apply it in other regions, but not without great effort.
	System Integration	3	2	
	Real-Time Monitoring	4	3	There are real-time products based on satellite and radar data that give updates in real time.
	Interoperability	3	2	The web services provided can be plugged in into other systems. Important data are archived in a standardized way.
	Security	2	2	Password protected, but sensitive to overload.
	Innovation and R&D	3	2	There are developments of the system and new things are added.
	Support	4	3	The system has operational support and a service desk for any queries and questions.
Budget and Sustainability	4	3	The system is part of Copernicus services.	

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Benefit-Cost Analysis	2	1	There have been scientific studies of the cost benefit.
	Policy and Governance	4	0	EFAS has to follow the policies of the European commission as well as individual countries. However, EFAS could be used more to shape policies.
	International Standards	3	3	EFAS follows protocols for warning exchange (CAP), ISO standards and comply with INSIPRE principles as well as OGC.
	Insurance and Liability	1	0	EFAS is not liable for any decision taken on the basis of the forecasts.
Informational	Data Quality and Reliability	4	1	The data quality control can be improved.
	Warning Message Clarity	4	2	The warning message has been done in collaboration with the users, but it could involve more interaction.
	Disaster Risk Reduction Integration	4	2	EFAS is used to guide the CEMS-mapping before severe event. It could be used more in the recovery phase.
	Community Resilience	3	-3	EFAS is not a community tool, it is an expert tool
	Feedback Mechanisms	2	2	There are feedback mechanisms on warnings, and each annual assembly this is discussed. There can be more follow-up on the issues.

### 3.2. Flash Flood: Local FF-EWS

#### 3.2.1. Overview

The flash flood (FF) EWS utilizes quantitative precipitation estimates and forecasts (Quantitative Precipitation Estimation - QPE and Quantitative Precipitation Forecasting - QPF, respectively) to derive flash flood warnings over the drainage network. For this, the system works under the assumption that the FF hazard at a point *D* (in terms of the exceeded return period) in the drainage network can be characterised by the rainfall accumulated upstream over its specific concentration time (i.e., basin-aggregated rainfall). This hypothesis specially holds for high return period events where the response of the catchment is mainly controlled by the rainfall amount, and thus, leading to similar slopes for the discharge and rainfall cumulative probability distribution functions (Guillot & Duband D., 1967).

Specifically, on hazard assessment, the basin-aggregated rainfall is computed at each cell of the drainage network and in a timeframe equally to its concentration time with the Kirpich (1940) formula. Operationally, the system works in real-time with pre-defined durations, and thus it selects the duration closest to the concentration time of the pixel. An additional assumption is made if a reservoir is located within the drainage network. At this location, the basin is split, and the upstream basin is not included in the calculations (assuming total discharge regulation).

As explained before, the computed basin-aggregated rainfall is compared to a set of thresholds to determine hazard level in terms of exceeded return period. These thresholds should be related to the climatology of the basin-aggregated rainfall, such as the available Intensity-Duration-Frequency curves. When QPEs (and QPFs) are available at each

computation step, the basin-aggregated rainfall is computed at the individual cells over the drainage network, considering their concentration time. Then, a comparison is made between the basin-aggregated rainfall and the thresholds to determine the value of the exceeded return period for the upcoming event.

The high performance ratings assigned to the UPC-CRAHI Flash Flood Early Warning System (FF-EWS) are based on extensive real-time testing and independent evaluations across diverse European regions. The rainfall-based ERICHA/FF-EWS indicator has been benchmarked against a distributed hydrological model for several severe flash-flood events in the Liguria region (north-west Italy), showing good agreement in identifying high-hazard sections of the drainage network during the autumn 2014 floods (Corral et al., 2019). Further work within EFAS and the ANYWHERE/ERICHA developments has implemented the pan-European FF-EWS using OPERA radar composites, with specific analyses over Alpine catchments and bias-correction for mountainous areas (Park et al., 2019; Alfieri et al., 2011). Operational evaluations and impact-based studies demonstrate that ERICHA/FF-EWS is currently running in real time in Switzerland, Liguria and Corsica, and provides flash-flood hazard nowcasts for the broader EFAS domain, including the Italian regions of Marche and other central-Apennine basins, Spanish coastal areas, and Alpine regions where flash floods are recurrent (Ritter et al., 2021; EFAS Bulletins 2019–2020). These applications consistently show that FF-EWS can anticipate the most damaging flash-flood events with lead times up to about 2 hours and with skill comparable to more complex flow-based systems, thereby justifying the high performance scores used in this benchmarking.

### 3.2.2. Capabilities

The FF-EWS can provide with enough time, the flash flood hazard, in terms of exceeded return period or hazard level, over the drainage network. The system has been proven in real time across Europe, providing successful results. Moreover, when compared to the traditional flow-based flood forecasts, the FF-EWS results indicate a good agreement in terms of the warnings triggered by both systems, the observed flow discharge and the reported inundations (Corral et al., 2019).

Although EUMETSAT provides the geostationary satellite observations essential for monitoring cloud development and precipitation, it does not produce 0–6-hour precipitation nowcasts. Instead, nowcasting products are generated by specialised processing chains such as the Nowcasting and Very Short Range Forecasting Satellite Application Facility (NWC-SAF), which applies advanced algorithms to EUMETSAT data from MSG/SEVIRI and MTG/FCI. Meteosat observations used by precipitation-nowcasting systems originate from MSG-SEVIRI imagery at approximately 3 km spatial resolution, and from the Meteosat Third Generation Flexible Combined Imager (MTG-FCI) at approximately 1–2 km spatial resolution, with Rapid-Scan Service capability at 2.5-minute temporal refresh over Europe. These include the Convective Initiation (CI), Rapidly Developing Thunderstorms (RDT), Precipitating Clouds (PC), Cloud Top Cooling Rate (CTC) and cloud-rainfall rate (CRRPh) products ([NWC-SAF, 2021](#)). Recent independent evaluations (Karagiannidis et al., 2023) have demonstrated that the latest NWC-SAF CRRPh precipitation product provides significantly improved quantitative precipitation estimates, especially in regions with complex topography, further confirming that the operational nowcasting capability resides in the SAF processing system rather than in EUMETSAT itself. Precipitation nowcasting in Europe also relies on blended radar–satellite systems such as OPERA and pan-European flash-flood forecasting chains such as ERICHA (Park et al., 2019; Park et al., 2024).

### 3.2.3. Availability

The UPC-CRAHI's FF-EWS is used at different spatial and lead time scales:

- Continental scale using European radar composites (OPERA) and nowcasts with six hours lead time. The spatial resolution scale is 1 km, and the nowcasts are refreshed every 15 min. The FF hazard level can be presented in terms of exceeded return period or in a three-level traffic-light scale (yellow: low, orange: medium, red: high) following the regional climatic characteristics as published by the [MeteoAlarm](#) consortium.
- Regional scale based upon regional radar observations and nowcasts with lead times of 2-6 hours. In the Autonomous community of Catalonia, Valencia and the Balearic Islands the FF-EWS runs at a spatial scale of 200 meters, and the nowcasts are refreshed every 5-10 min. Additionally, the FF-EWS is running in Ireland at a 500-meter resolution.
- Since 2017, the FF- EWS runs operationally as the radar-based flash floodforecasting module for the EFAS named [ERICHA](#), serving as a complement to the ERIC product.
- Satellite rainfall estimation data will be used in these cases to provide the required QPE and QPFs since they are well adapted to provide a global view of rainfall on a worldwide scale. The COSPARIN QPE data (spatial contribution for flood risk analysis) was developed as part of a European project with the ESA led by PREDICT Services. It has been developed using data from geostationary and polar satellites coupled with an artificial intelligence model to produce global data estimating rainfall every 30 minutes at a resolution of 5km. This new data will be fed into the FF-EWS models to identify FF warnings in the foreseen **GOBEYOND** EWS4Med platform for the Union for Mediterranean countries.

### 3.2.4. TRL

The FF-EWS performance has been widely tested across different regions, scales and climatology. Overall, the evaluations yielded encouraging results on the ability of the FF-EWS to identify the problematic sections in the drainage network during intense rainfall events with enough lead time. The outcomes demonstrated that the system can locate in real-time significant hazard levels in the main areas where the most damaging floods occurred up to almost 2 hours ahead (Alfieri et al., 2019). The FF-EWS has a TRL 9.

### 3.2.5. Solution in other EU projects

The concept of the rainfall-based FF-EWS was first developed within the EHIMI project (2001-2010), and operationally applied in 2008 at the Water Agency of Catalonia (ACA) in Spain (Corral et al., 2009). The concept of rainfall-based FF-EW was further developed in the framework of the FP7 EC project [IMPRINTS](#), setting the foundation for the European Precipitation Index based on Climatology (EPIC), integrated operationally in EFAS since 2012. EPIC index has since evolved to the indicator [ERIC](#) which considers the antecedent soil moisture.

The FF-EWS system was implemented at European scale in the context of the DG-ECHO project [ERICHA](#). The system uses the radar composites produced by the EUMETNET programme OPERA to generate FF forecasts with a resolution of 1x1 km<sup>2</sup> in real-time. In the ERICHA indicator, the FF hazard level is presented in a three-level traffic-light scale following the regional climatic characteristics as published by the MeteoAlarm consortium.

Since 2017, the FF- EWS runs operationally as the radar-based flash flood forecasting module for the EFAS, serving as a complement to the ERIC product.

During the H2020 [ANYWHERE](#) project (2016-2019), the FF-EWS was improved to run at a 200-meter resolution over the entire Catalonia region. This iteration is currently operational in real-time at the Catalonia Meteorological Service (SMC), ACA and within the ARGOS warning platform for municipalities, civil protection, private entities and regions across Spain and Europe (Corral et al., 2019).

Since 2018, a back-to-back of three EU Union Civil Protection Mechanism (UCPM) projects have provided the platform for innovative advancements to the FF-EWS. During the [UCPM SMUFF project](#) (2018-2019) a seamless and dynamic blending of probabilistic radar-based nowcast and numerical weather prediction model was developed to increase the precipitation forecasting window from 15 minutes to 5 days. As a result, the FF-EWS was ran and tested with the rainfall inputs from the above blend to provide FF hazard levels with extended lead times at Pan European scale.

In the second project [TAMIR](#) (2020-2022), the FF-EWS was improved by combining the FF hazard forecasts with enhanced vulnerability and exposure data, covering information about population, transportation infrastructure, energy infrastructure, education facilities and health facilities, and by developing methods to turn the combined information into improved flood rapid risk impact assessments. Finally, the latest project [EDERA](#) (2023-2024) inherits the results of the two above projects and focuses on the real-time application of the FF impact forecasts (through its incorporation in EFAS) to evaluate its performance at Pan-European and regional scale.

### 3.2.6. Role in GOBEYOND

Due to the explosive nature of FFs, disseminating impact-driven warnings with sufficient lead to trigger protection actions is a complex task. However, previous evaluations of the FF-EWS have demonstrated that the system can provide flash flood warnings to trigger actionable solutions through local self-protection protocols are available Thus, the FF-EWS will be used to empower the population and emergency responders to take appropriate actions to protect themselves and their communities. In this context, the planned demonstrations in **GOBEYOND** will provide an excellent platform to understand how to best improve and integrate the FF hazard levels as one of the activation warning signals for quickly deploying emergency responders and supporting the self-protection actions of citizens.

### 3.2.7. Benchmarking

Table 6 Benchmarking evaluation table for Flash Flood EWS

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	3	
	Multi-hazard Capability	4	3	Can be integrated for impact assessment and cascading effects.
	Performance	4	3	Widely tested across Europe.
	Genericity	3	3	
	Coverage and Reach	4	3	Widely tested across Europe.
	Community Engagement and Training	2	3	The FF-EWS has been evaluated and demonstrated in workshops with end-users.
	Testing and Drills	4	3	The system has been evaluated in real-time.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Accessibility	2	2	
Technological	Technological Infrastructure	3	3	Since 2017, the FF- EWS runs operationally as the radar-based flash flood forecasting module for the EFAS, serving as a complement to the ERIC product.
	Maturity	4	3	Proven system with a TRL 9.
	Lead Time and Accuracy	4	3	The FF-EWS evaluations yielded encouraging results on the ability of the FF-EWS to identify the problematic sections in the drainage network during intense rainfall events with enough lead time.
	Scalability and Adaptability	4	3	The UPC-CRAHI's FF-EWS is used at different spatial and lead time scales (Continental and regional).
	System Integration	4	3	
	Real-Time Monitoring	4	3	Since 2017, the FF- EWS runs operationally as the radar-based flash flood forecasting module for the EFAS, serving as a complement to the ERIC product.
	Interoperability	4	3	
	Security	3	NA	
	Innovation and R&D	4	3	
	Support	2	NA	
Business	Budget and Sustainability	2	2	
	Benefit-Cost Analysis	2	2	
	Policy and Governance	2	NA	
	International Standards	2	NA	
	Insurance and Liability	2	3	
Informational	Data Quality and Reliability	4	3	The outcomes demonstrated that the system is capable of locating in real-time significant hazard levels in the main areas where the most damaging floods occurred up to almost 2 hours ahead (Alfieri et al., 2019). The FF-EWS has a TRL 9.
	Warning Message Clarity	4	3	
	Disaster Risk Reduction Integration	4	3	Previous evaluations of the FF-EWS have demonstrated that the system is capable of providing flash flood warnings to trigger actionable solutions through local self-protection protocols for quickly deploying emergency responders and supporting the self-protection actions of citizens.
	Community Resilience	4	3	See above
	Feedback Mechanisms	2	2	

### 3.3. Remote Sensing: Satellite-Based Rainfall Estimation Tools (QPE/QPF)

#### 3.3.1. Overview

Satellite-based rainfall estimation (QPE/QPF) provides global, high-resolution precipitation information using blended infrared (IR), microwave (MW), and visible (VIS) satellite measurements. These systems are crucial for regions with sparse in-situ and radar coverage, such as parts of the Mediterranean basin and North Africa.

In D1.3, satellite rainfall estimation is already referenced as a core input to FF-EWS workflows.

Satellite rainfall products have been extensively validated (Huffman et al., 2020; Joyce et al., 2004; Mekonnen et al., 2021) and form the backbone of rainfall-based flash-flood hazard forecasting worldwide (Alfieri et al., 2011).

### 3.3.2. Capabilities

Satellite-based rainfall estimation provides near-global coverage across both land and ocean, delivering precipitation information at typical spatial resolutions of 5–10 km and refresh intervals of 15–30 minutes from geostationary satellites. Modern systems increasingly rely on AI-enhanced fusion of multiple satellite sensors, including infrared, microwave and visible channels, which significantly improves retrieval skill (Kidd et al., 2017; Ravuri et al., 2021). These characteristics make satellite rainfall products particularly suitable for quantitative precipitation estimation and forecasting (QPE/QPF) in regions with sparse or unreliable gauge and radar observations, offering an essential data source for hydrometeorological applications worldwide (Joyce et al., 2004).

### 3.3.3. Availability

- Freely available from NOAA (CMORPH), NASA (GPM/IMERG), EUMETSAT ([MSG/MTG](#)), and ESA.
- Data accessible via FTP, APIs, and Copernicus Climate Data Store.
- NWC-SAF provides operational nowcasting products using MSG/MTG satellite data ([NWC-SAF, 2021](#)).

### 3.3.4. TRL

Operational global products (IMERG, CMORPH, H-SAF) typically reach TRL 8–9.

AI-enhanced or demonstrational systems (e.g., COSPARIN) fall within TRL 6–7.

### 3.3.5. Solution in other EU projects

Satellite-based rainfall estimation plays a central role in several major European and international early warning and hydrometeorological initiatives. The [ANYWHERE project](#) pioneered the integration of satellite, radar, and NWP-driven rainfall inputs into pan-European multi-hazard forecasting chains, demonstrating the value of satellite QPE for extreme weather management. The [European Flood Awareness System \(EFAS\)](#) uses satellite rainfall estimation as a **fallback** and complementary input in regions with limited radar coverage, providing critical redundancy for continental-scale flood forecasting. The [EUMETSAT H-SAF](#) programme operationally generates satellite-derived precipitation, soil moisture, and snow products that are widely used for hydrological modelling and verification. In parallel, **ESA** and the **Copernicus Climate Change Service (C3S)** continue to develop advanced satellite precipitation datasets, including global high-resolution blended rainfall estimates suitable for flash-flood forecasting. Furthermore, satellite rainfall estimation is a foundational input to **ERICHA**, the pan-European flash-flood early warning system supporting civil protection operations (documented in Park et al., 2019 and Park et al., 2024), which combines satellite QPE, radar composites, and hydrological modelling for rapid emergency response.

### 3.3.6. Role in GOBEYOND

These mature European systems demonstrate the operational value, interoperability, and scalability of satellite-based rainfall estimation for flash-flood preparedness. Their experience directly informs GOBEYOND’s approach to rainfall-driven hazard detection: satellite-derived QPE is used to complement radar and model data, support hydrological triggering mechanisms, and ensure spatial coverage across regions where ground-based observations are sparse or unavailable.

### 3.3.7. Benchmarking

Table 7 Benchmarking evaluation table for Satellite-Based Rainfall Estimation Tools (QPE/QPF)

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	3	Essential input for flash-flood forecasting in regions with sparse radar/gauge coverage; widely used in EFAS, ANYWHERE, and ERICHA.
	Multi-hazard Capability	4	2	Primarily supports hydrometeorological hazards (flash floods, debris flows), with limited applicability to other hazards.
	Performance	4	1	Satellite QPE exhibits known biases and lower accuracy compared to radar; performance improves significantly when blended with ground data (Huffman et al., 2020; Park et al., 2019).
	Genericity	4	3	Global applicability and harmonised datasets (IMERG, CMORPH, H-SAF) enable broad geographic use.
	Coverage and Reach	4	3	Near-global coverage from geostationary and polar satellites, including areas without any in-situ observations.
	Community Engagement and Training	3	1	Limited end-user training; primarily technical datasets used by expert institutions (EFAS, NWC-SAF, H-SAF).
	Testing and Drills	4	2	Extensively evaluated in scientific studies; operationally tested in EFAS as fallback input.
	Accessibility	2	2	Freely accessible via NOAA, NASA, EUMETSAT H-SAF, and C3S, though some datasets require technical expertise.
Technological	Technological Infrastructure	3	3	Advanced multi-sensor fusion systems (IR/MW/VIS + AI) underpin IMERG, CMORPH, H-SAF, COSPARIN.
	Maturity	4	2	Operational products are TRL 8–9 (IMERG, CMORPH), while newer AI-enhanced systems vary (TRL 6–7).
	Lead Time and Accuracy	4	1	High temporal refresh (15–30 min), but accuracy affected by retrieval uncertainties; improved through blending (Joyce et al., 2004).
	Scalability and Adaptability	4	3	Easily scalable globally; adaptable across multiple hydrological models and EWS systems.
	System Integration	4	3	Widely integrated into EFAS, ANYWHERE, ERICHA, and hydrological chains.
	Real-Time Monitoring	4	2	Many datasets operational (IMERG-Early, H-SAF), but latency varies (5–60 minutes).
	Interoperability	4	3	Standard formats (NetCDF, HDF5); compatible with EFAS, ERICHA, NWP ingest.
	Security	3	NA	Not directly applicable; satellite data dissemination follows agency security standards.
	Innovation and R&D	4	3	Rapid advances with deep learning nowcasting and AI-based fusion (Ravuri et al., 2021).
	Support	2	NA	

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
<b>Business</b>	Budget and Sustainability	2	3	Long-term sustainability ensured by global satellite programmes; operational continuity guaranteed.
	Benefit-Cost Analysis	2	2	High benefit for regions lacking radar; low operational cost to users.
	Policy and Governance	2	2	Supported by EU programmes (C3S, H-SAF) and international frameworks.
	International Standards	2	2	Products follow WMO guidelines and harmonised QA/QC protocols.
	Insurance and Liability	2	2	Used as advisory information; ground truth still needed for liability-critical decisions.
<b>Informational</b>	Data Quality and Reliability	4	1	Uncertainty significant in convective environments; reliability increases when blended with radar/gauges (EFAS).
	Warning Message Clarity	4	NA	Not applicable; provides raw/processed data, not public warnings.
	Disaster Risk Reduction Integration	4	3	Strong integration in EFAS, ANYWHERE, ERICHA supporting flash-flood preparedness.
	Community Resilience	4	2	Indirect support through improved situational awareness.
	Feedback Mechanisms	2	1	Feedback loops mainly through expert hydrological modelling centres.

### 3.4. Remote sensing: COSPARIN

#### 3.4.1. Overview

COSPARIN is a satellite- and terrain-driven QPE/QPF system introduced through an R&D programme supported by the European Space Agency and approved by CNES ([PREDICT Services](#)). It uses geostationary and polar-orbiting satellite observations fused with artificial intelligence methods to produce rainfall estimates every 30 minutes at 5 km resolution.

It is particularly relevant for flash-flood hazard forecasting in areas without dense radar networks and is planned for integration into GOBEYOND’s FF-EWS chain.

COSPARIN has demonstrated a growing global evaluation track record, with QPE retrievals analysed and intercompared across more than 200 significant hydrometeorological events worldwide since 2020, supporting iterative algorithm improvement through institutional user feedback from industry, meteorological, and civil-protection actors.

The product incorporates advancements derived from successive retrieval versions, reflecting operational needs collected. COSPARIN rainfall accumulations have also been tested against available ground data, including national or OPERA radar composites and station rainfall records, confirming improved skill when multi-sensor observations are blended with surface verification data.

The system was presented at the European Geosciences Union (EGU) in 2021 (Guillaume et al., 2021) and is currently in operational deployment.

### 3.4.2. Capabilities

COSPARIN delivers global quantitative precipitation estimates (QPE) every 30 minutes at 5 km resolution (Guillaume et al., 2021) through an AI-enhanced fusion of infrared (IR), visible (VIS) and microwave (MW) satellite channels, following methodologies consistent with modern multi-sensor rainfall retrieval approaches (e.g., Joyce et al., 2004; Huffman et al., 2020).

The system was introduced and documented in the ESA-supported COSPARIN project (Guillaume et al., 2021), which demonstrated its ability to improve the detection of both convective and stratiform rainfall. Catchment flood-prone area mapping is generated using CEREMA's ExZEco/ExZEco 2011 flow-zone extraction method, a framework first applied in Flood Directive pilots and subsequently validated across Mediterranean-arc regions and large domains (Guillaume et al., 2024). Designed specifically for flood risk and flash-flood early warning applications, COSPARIN provides high-temporal-resolution precipitation fields essential for rapid-onset hydrometeorological hazards. It complements radar-based systems by filling observational gaps over the Mediterranean and other regions with limited radar coverage - a challenge well documented in European hydrometeorological studies (Park et al., 2019).

Its current pre-operational status makes it suitable for research, prototyping and integration testing within multi-hazard early warning environments. The terrain component relies on Airbus where elevation intervals of 5–25 m were successfully stress-tested for continent-to island-scale basins, including Madagascar (650,000 km<sup>2</sup>) and Indian Ocean islands (CEREMA proto tests IT and Indian Ocean demo 2018–2024 chain).

In low-radar-density regions such as North Africa and the Mediterranean, COSPARIN has shown valuable performance, as illustrated in its use to characterise intense rainfall accumulation and identify the relevant watersheds and corresponding hydrological basins, including successful basin localisation during a major event in northern Morocco.

COSPARIN is additionally innovative in its ability to integrate global Digital Terrain Models (DTMs) into its rainfall–runoff risk mapping workflow, converting data from Cartesian projections into the WGS-84 reference system, a standard required for globally interoperable geospatial applications. The methodology has been optimised so that it can utilise lower-quality DTMs with elevation intervals of 12–30 m, while also automatically scaling to larger catchments ([Cerema](#)).

### 3.4.3. Availability

COSPARIN is available for research use through ESA-backed and PREDICT Services' access portals, which support the evaluation of next-generation Earth Observation-based rainfall products. The dataset is formatted for compatibility with flash-flood forecasting chains, including FF-EWS ingestion workflows described in Sempere-Torres & Berenguer (2024), enabling its integration into hydrological and impact-based modelling environments. It also enables its integration into early action system provided by Predict Services. Ongoing evaluations across European flood-prone basins continue to assess its stability, suitability and performance under diverse meteorological conditions, building on the validation activities presented in Guillaume et al. (2021) and related ESA Earth Observation flood risk analysis pilots. Rainfall and runoff-zone outputs are provided in expert-ready formats compatible with FF-EWS hazard-to-impact ingestion chains (NetCDF/GeoJSON/HDF5), enabling integration, verification and drill testing by research and crisis-management partners.

### 3.4.4. TRL

The current TRL of COSPARIN is estimated at 9, consistent with an operational system internationally deployed for industrials and state services, and builds on high-resolution satellite observations, radar training and ground data calibration, ensuring a solid scientific basis.

### 3.4.5. Solution in other EU projects

COSPARIN aligns closely with ongoing ESA Earth Observation flood risk analysis initiatives and contributes to the broader evolution of satellite-based hydrometeorological services in Europe. Its design and data fusion approach mirror the blended rainfall methodologies used in the ANYWHERE project, which demonstrated the value of multi-sensor rainfall inputs for flash-flood prediction. COSPARIN also has potential for integration within ERICHA-like pan-European flash-flood chains, where satellite rainfall serves as a complementary or fallback data source to radar composites (Sempere-Torres & Berenguer, 2024). This positions COSPARIN as a promising contributor to next-generation early warning systems across Europe.

### 3.4.6. Role in GOBEYOND

Within GOBEYOND, COSPARIN provides strategic observational redundancy and spatial coverage for rainfall-induced flash-flood risk detection across the Mediterranean, informing the design of the GOBEYOND MR-Integrated Early Warning System (MR-IEWS) for the Mediterranean and EU-beyond first-responder domains. Its global, high-frequency rainfall estimates provide essential coverage in areas where radar observations are absent or unreliable - an important gap across several Mediterranean regions. COSPARIN strengthens the MR-IEWS rainfall data layer, ensuring that hydrological triggering mechanisms and flash-flood detection algorithms can operate under a wider range of observational conditions. By aligning with the methodologies proven in ANYWHERE, EFAS and ERICHA, COSPARIN enhances interoperability, supports redundancy in the rainfall data supply chain, and contributes to the overall robustness and scalability of GOBEYOND’s hazard monitoring and forecasting architecture.

### 3.4.7. Benchmarking

Table 8 Benchmarking evaluation table for COSPARIN

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	3	Critical for Mediterranean flash-flood monitoring where radar/gauges are sparse; used operationally by European systems for redundancy.
	Multi-hazard Capability	4	1	Focused primarily on hydrological hazards.
	Performance	4	2	Operational system; accuracy still under evaluation (Guillaume et al., 2021).
	Genericity	4	3	Near-global multi-sensor products (IMERG, CMORPH, H-SAF).
	Coverage and Reach	4	3	Global 5 km coverage every 30 min.
	Community Engagement and Training	3	0	Technical datasets; limited citizen-level engagement.
	Testing and Drills	4	2	Extensively evaluated in scientific and operational exercises as fallback or complementary input.
	Accessibility	2	2	Research access available; not yet public operational service.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
Technological	Technological Infrastructure	3	3	Advanced AI-based multi-sensor fusion system (ESA + PREDICT).
	Maturity	4	3	TRL 9; operational with starting market.
	Lead Time and Accuracy	4	1	Good temporal resolution but accuracy validation still in progress.
	Scalability and Adaptability	4	3	Fully global dataset; easily integrable into various hydrological models.
	System Integration	4	2	Compatible with FF-EWS; not widely integrated yet.
	Real-Time Monitoring	4	2	Operational and available every 30minute; latency and reliability still improving.
	Interoperability	4	2	Standard formats; integration workflows under development.
	Security	3	NA	
	Innovation and R&D	4	3	Highly innovative AI-based rainfall estimation method (deep learning fusion).
	Support	2	2	Backed by ESA and PREDICT Services.
Business	Budget and Sustainability	2	1	Sustainability depends on project-based funding cycles.
	Benefit-Cost Analysis	2	2	High potential value where radar/gauges are lacking.
	Policy and Governance	2	1	Not yet embedded in official EU operational frameworks.
	International Standards	2	1	Requires international benchmarking
	Insurance and Liability	2	1	Pre-operational; not suitable for liability-critical decisions.
Informational	Data Quality and Reliability	4	1	Reliability evaluation ongoing; requires more benchmarking.
	Warning Message Clarity	4	NA	Not a warning system.
	Disaster Risk Reduction Integration	4	2	Potential for strong integration in flash-flood DRR workflows.
	Community Resilience	4	1	Indirect support via improved hazard understanding.
	Feedback Mechanisms	2	1	Feedback via research validation campaigns.

### 3.5. Windstorms: CLIMADA platform

#### 3.5.1. Overview

Using state-of-the-art probabilistic risk modelling techniques (i.e. Monte Carlo simulations) (Aznar-Siguan et al., 2019; Bresch et al., 2021; Severino et al., 2024), [CLIMADA](#) allows to estimate impacts from weather and climate events on vulnerable exposures (such as population, critical infrastructure, monetary assets, ecosystems, etc.). CLIMADA is aligned with the IPCC definition of risk as the product of hazard, vulnerability, and exposure. CLIMADA supports the computation of today’s risk, the incremental increase from economic growth and the further incremental increase due to climate change. It provides decision makers with a fact base to understand the impact of weather and climate on their economies, including cost/benefit perspectives on specific risk reduction measures. The model is well suited to provide an open and independent view on physical risk, in line with e.g., the TCFD (Task Force for Climate- related Financial Disclosure) and underpins the [Economics of Climate Adaptation \(ECA\)](#) approach.

### 3.5.2. Capabilities

As of today, CLIMADA provides a global asset value and population layer, and global coverage of major climate- related extreme- weather hazards at high resolution via a [data API](#), namely (i) tropical cyclones, (ii) river flood, (iii) agricultural drought and (iv) European winter storms, all at 4km spatial resolution - wildfire to be added soon. For all hazards, historic and probabilistic event sets exist, for some also under select climate forcing scenarios (RCPs) at distinct time horizons (e.g., 2040).

As a fully user-definable platform, it further supports any user-ingested exposure, hazard (e.g., weather data from NWP) and vulnerability data in all common geo-spatial formats.

### 3.5.3. Availability

CLIMADA is developed, maintained and available open- source in Python 3.x Free use and access under GNU GPL3 on [GitHub](#). Data freely available under CC BY 4.0 via the CLIMADA data [API](#) (application programming interface, metadata provided).

### 3.5.4. TRL

TRL 7 - System prototype demonstration in operational environment. CLIMADA is under constant development as a research output product of the Weather & Climate Risks Group at ETH Zurich. Stable versions are released in a regular release cycle (approx. every 3 months). CLIMADA is being used operationally by many (I)NGOs, private companies and the public sector.

### 3.5.5. Solution in other EU projects

Among others, used within: CASCADES, PROVIDE, RECEIPT, UCLIMADAPT.

### 3.5.6. Role in GOBEYOND

CLIMADA can act as a **processing core** for computing any sort of weather and geo-hazard impacts, tailored to different needs and resolutions of diverse stakeholders. As a Python-based, open-source deployed software product, it can be easily integrated within cloud environments or similar.

### 3.5.7. Benchmarking

Table 9 Benchmarking evaluation table for CLIMADA platform

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	3	3	
	Multi-hazard Capability	4	3	Any hazard-data can be ingested.
	Performance	2	2	Fairly efficient source-cod, relying predominantly on C-based Python packages.
	Genericity	3	3	Has one standardized (“generic”) yet fully user-specific way of looking at risk/impacts (Hazard x Exposure x Vulnerability).
	Coverage and Reach	2	NA	Covers whatever the input data covers.
	Community Engagement and Training	2	1	Monthly technical community online gatherings; maintained issue page on GitHub; no specific trainings organized (usage is self-taught relying on ample documentation).
	Testing and Drills	2	Unknown	

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Accessibility	2	1	Open-source and open-access (technical accessibility). Platform itself requires coding knowledge (practical accessibility).
Technological	Technological Infrastructure	2		
	Maturity	2	1	Stable releases. Mature for physical risk computation. Constant development for further use-cases.
	Lead Time and Accuracy	3	NA	Depends on the accuracy and leadtime of the input data (hazard, calibrated vulnerability functions, ...).
	Scalability and Adaptability	2	2	Easily scalable and adaptable.
	System Integration	2	1	Quite a lot of code dependencies, but manageable with standard package managers.
	Real-Time Monitoring	2	-1	Not its main use-case.
	Interoperability	2	2	Very strong on IO flow.
	Security	2	0	The platform itself is an open-source project. Proprietary data must be protected accordingly.
	Innovation and R&D	2	3	Active development & research ongoing.
	Support	2	0	See community engagement & training.
Business	Budget and Sustainability	2	2	Comes “for free”; theoretically no guarantee for infinite future support.
	Benefit-Cost Analysis	2	3	CLIMADA features a cost-benefit module for measure appraisal.
	Policy and Governance	2	Unknown	
	International Standards	2	Unknown	Follows IPCC standard definition of risk.
	Insurance and Liability	2	Unknown	Comes with a no liability / no warranty licence.
Informational	Data Quality and Reliability	2		Depends on user-supplied data. Garbage in / garbage out.
	Warning Message Clarity	3	0	Computes impacts. These have to be translated into warnings by some post-processing / user interaction.
	Disaster Risk Reduction Integration	2		
	Community Resilience			
	Feedback Mechanisms	2	2	Can be constantly updated

### 3.6. Heatwave: European Heat Health Indices

#### 3.6.1. Overview

The European Heat Health Indices (HHIs) are designed to provide early warnings of thermal stress conditions affecting human health. Although the current HHI prototype developed by ECMWF and the TRIGGER project is still at an early operational stage, the underlying data, scientific methods and bioclimatic indicators on which it is built are well-established and extensively validated.

In particular, the [ERA5-HEAT](#) dataset provides a baseline bioclimatology record of thermal comfort indices ([MRT](#), [UTCI](#), EHF (Oliveira et al., 2022)) using globally consistent ERA5 reanalysis input (Di Napoli et al., 2020; Di Napoli et al., 2021; Pappenberger et al., 2015).

This enables the assessment of human heat-stress exposure and trend analysis across decades. These datasets are already widely used in climate services, heat–health research and operational risk assessments, offering pan-European coverage, multi-decadal consistency and suitability for both climatological analysis and near-real-time applications. The inclusion of ERA5-HEAT aligns with state-of-the-art heat-health modelling: hourly UTCI values at 0.25° resolution, global coverage from 1940 onwards, allowing comparison of hazard (heat stress) to exposure (population) for early-warning frameworks (Copernicus Climate Data Store, 2023).

Recent studies further strengthen the scientific basis for advancing this approach. Korhonen et al. (2025) demonstrate that ECMWF’s extended-range (subseasonal) forecasts provide meaningful probabilistic skill for heatwave events up to 2–3 weeks ahead, particularly during summer and over western and southern Europe. Their work demonstrates that heatwave predictability has improved significantly, strengthening the scientific basis for impact-based heat–health early warning systems.

### 3.6.2. Capabilities

The forecasts are calculated once daily and are currently disseminated to project partners via email. They will be made available through a web portal in development.

### 3.6.3. Availability

The solution is not yet operational, it is in development. It will be open source.

### 3.6.4. TRL

The solution is currently in TRL 3-4.

### 3.6.5. Solution in other EU projects

The solution is currently being developed within the EU-funded [TRIGGER](#) project, specifically described in *Deliverable D5.1 – “Co-development and selection of health-related hazard indicators”* and *Deliverable D2.2 – “Inventory of indicators, tools and models.”*, where also the web solution is being created.

### 3.6.6. Role in GOBEYOND

Although the prototype European Heat Health Index (HHI) receives relatively low scores in the current benchmarking—primarily due to its limited operational maturity (TRL 3–4), lack of real-time deployment, and absence of long-term validation with public-health authorities—it remains highly valuable for **GOBEYOND** for several reasons. First, scientific evidence indicates that heatwave predictability in Europe has improved substantially in recent years (Korhonen et al., 2025), and the underlying meteorological and bioclimatic indicators (UTCI, MRT, EHF) used in HHI are robust, well-established and supported by high-quality reanalysis products such as ERA5-HEAT (Di Napoli et al., 2020; 2021; Oliveira et al., 2022). This means the scientific foundation for an impact-based heat–health indicator is already strong, even if the operational chain is not yet mature

The solution is very suitable for **GOBEYOND** since it is still in its very early stage of development, and **GOBEYOND** can help shape the solution and make the transfer from prototype to operations.

### 3.6.7. Benchmarking

Table 10 Benchmarking evaluation table for Heat Health Indices

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
<b>General</b>	Relevance	4	3	Heat-health is a top public-health priority in Europe. ERA5-HEAT and EHF detect trends in heat-stress exposure across European cities. Highly relevant for early-warning and DRR.
	Multi-hazard Capability	3	0	EHHs are single-hazard but can be integrated into MR-IEWS as part of multi-risk decision support (temperature + air quality).
	Performance	3	2	Meteorological components show good skill, and extended-range forecasts have demonstrable predictability (Korhonen et al., 2025). Health-impact validation is still limited.
	Genericity	4	2	The scores are in principal generic, but the threshold for impacts need to be tailored to local conditions
	Coverage and Reach	4	3	Based on ERA5 and ECMWF modelling → global/pan-European availability; can be computed at any grid point.
	Community Engagement and Training	3	-1	Prototype under TRIGGER; no established user community yet, but end-user co-development is ongoing in D5.1.
	Testing and Drills	2	0	Not yet tested operationally; initial prototype evaluation ongoing in TRIGGER Deliverables.
	Accessibility	4	1	Currently only available as an automatic email
<b>Technological</b>	Technological Infrastructure	2	3	Built on robust ECMWF forecasting infrastructure and ERA5-HEAT datasets (Di Napoli et al., 2020; 2021).
	Maturity	4	-2	TRL 3–4: prototype validated using reanalysis and forecast data, but not operational and not validated with NMHS or health agencies (TRIGGER D2.2, D5.1).
	Lead Time and Accuracy	3	3	Extended-range forecasts provide meaningful probabilistic skill up to 2–3 weeks (Korhonen et al., 2025).
	Scalability and Adaptability	2	3	Can be generated for any location globally using ERA5/forecast inputs.
	System Integration	2	-2	No integration yet into operational chains, but technically feasible once APIs are available.
	Real-Time Monitoring	2	-3	No real-time production chain yet.
	Interoperability	2	-2	Not yet interoperable with health or civil-protection systems; potential exists through NetCDF/GRIB formats.
	Security			NA
	Innovation and R&D	3	2	Currently being developed within research projects
	Support	2	0	Not yet available
<b>Business</b>	Budget and Sustainability	2	-3	Currently research-funded; Not yet clear since the product is not operational
	Benefit-Cost Analysis	NA	NA	
	Policy and Governance	4	3	Strong alignment with WHO European Region heat-health recommendations; supports impact-based policies.
	International Standards	NA	NA	Nothing implemented yet
	Insurance and Liability	NA	NA	Nothing available

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
Informational	Data Quality and Reliability	3	2	High-quality reanalysis (ERA5-HEAT) and tested meteorological inputs; uncertainty remains for health impact modelling.
	Warning Message Clarity	4	1	The warning message produced is being co-developed with the users
	Disaster Risk Reduction Integration	4	-1	Not yet implemented, but ERA5-HEAT + EHF provides strong potential for risk-based planning.
	Community Resilience	3	1	Can support early preparedness and protect vulnerable populations, especially in urban areas (Oliveira et al., 2022).
	Feedback Mechanisms	2	0	Currently limited to project-based feedback; no automated operational mechanism.

Despite its low benchmarking score, the Heat Health Index (HHI) remains essential for inclusion in **GOBEYOND** because it is currently the only harmonised, pan-European biometeorological heat-stress indicator produced by ECMWF and the Copernicus Climate Change Service (C3S). Its lower maturity reflects its prototype status rather than its scientific or operational relevance. The HHI is built on the ERA5-HEAT framework, which provides physiologically validated thermal stress metrics derived from reanalysis and forecasting data (Di Napoli et al., 2020; Di Napoli et al., 2021). As such, it represents a scientifically robust foundation for future pan-European heat-risk assessments. Evidence from the public health literature highlights that effective heat–health warning systems rely on clear, science-based thermal thresholds to initiate protective actions (Chandra & Lee, 2025). Moreover, a comprehensive review of European systems by Casanueva et al. (2019) shows that most Heat-Health Warning Systems (HHWS) across Europe depend on biometeorological indices - such as UTCI, apparent temperature, and similar thermal stress metrics - to activate preparedness and response measures. This underscores the strategic relevance of adopting the European HHI within **GOBEYOND**.

Importantly, HHIs serve as the core trigger mechanism for Heat-Health Action Plans (HHAPs), which translate meteorological and biometeorological information into actionable public-health interventions. HHAPs rely on threshold-based indices to determine when to activate heat warning systems, open cooling centres, issue public advisories, mobilise social and medical services, and protect vulnerable populations. The use of harmonised indices such as the European HHI ensures alignment with Martinez et al., 2022 and [WMO \(2023\)](#) guidance on heat–health warning systems, and it supports interoperable, cross-border heat-risk communication across the Mediterranean. By integrating the HHI now, **GOBEYOND** positions the MR-IEWS to remain compatible with emerging Copernicus and ECMWF services as the index evolves toward operational status.

### 3.7. Droughts: European EWS

#### 3.7.1. Overview

In the framework of the H2020 [ANYWHERE project](#), researchers at Wageningen University in the Netherlands developed algorithms for drought indicator forecasting based on EFAS and ECWMF long-term hydrometeorological forecasts (ANYWHERE, 2019). Such indicators at European level were integrated and automatically updated in real-time in a prototype platform oriented to civil protection authorities.

We propose here to re-implement the ANYWHERE algorithm for a drought indicator as the Standardized Precipitation Index (SPI) and extend the forecast to impact at local level at real time. Such forecasted impacts will be obtained crossing the most recent forecast of the drought indicator with known vulnerable elements (or areas) according to predefined thresholds.

### 3.7.2. Capabilities

The algorithm produces SPI forecasts at 5 km resolution for the next seven months at European scale.

### 3.7.3. Availability

It is being developed as an open-source algorithm.

### 3.7.4. TRL

This algorithm has been implemented in operational solutions in Spain along with in ANYWHERE prototypes, it may correspond to TRL 5.

### 3.7.5. Solution in other EU projects

The algorithm was implemented at European scale in an ANYWHERE prototype.

### 3.7.6. Role in GOBEYOND

The algorithm provides an answer for the hazard of Droughts in the Multi-Hazard context of **GOBEYOND**.

### 3.7.7. Benchmarking

Table 11 Benchmarking evaluation table for Drought Early Warning System

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	3		Aligned with multi-hazard requirement
	Multi-hazard Capability	1	0	Algorithm specific for droughts
	Performance	2	0	Few operational uses up to now
	Genericity	3	3	It applies to whole Europe
	Coverage and Reach	4	3	It applies to whole Europe
	Community Engagement and Training	NA		
	Testing and Drills	NA		
	Accessibility	NA		
Technological	Technological Infrastructure	2	0	It will be calculated at <b>GOBEYOND</b> processing core
	Maturity	2	1	Several academic publications support it but no technological standard implementation available.
	Lead Time and Accuracy	3	2	Up to seven months lead time, 3 months of reliable forecast
	Scalability and Adaptability	3	2	Beyond Europe, academic work is required
	System Integration	2	3	Easily integrable
	Real-Time Monitoring	2	3	Besides real-time is once a month in this case
	Interoperability	2	3	Outputs are in standard formats

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Security	NA		
	Innovation and R&D	3	3	Most recent research advancements
	Support	NA		
Business	Budget and Sustainability	NA		
	Benefit-Cost Analysis	NA		
	Policy and Governance	NA		
	International Standards	NA		
	Insurance and Liability	NA		
Informational	Data Quality and Reliability	NA		
	Warning Message Clarity	NA		
	Disaster Risk Reduction Integration	NA		
	Community Resilience	NA		
	Feedback Mechanisms	NA		

### 3.8. Fire Danger EWS: DISARM

#### 3.8.1. Overview

The [DISARM Early Warning System](#) (Drought and Fire Observatory and Early Warning System) is a tool developed under the DISARM project to address the escalating threat of wildfires in the Eastern Mediterranean region. The system is built on four key pillars: forecasting wildfire danger, detecting wildfires using remote sensing techniques, forecasting wildfire spread using a coupled weather-fire modeling system, and assessing wildfire risk in the context of climate change. By integrating these components, DISARM aims to enhance wildfire management and mitigation strategies in Greece, Bulgaria, and Cyprus. The system's innovative aspects, such as tailored fire danger classifications and improvements in satellite detection capabilities, highlight its potential for replication and adaptation in similar regions.

#### 3.8.2. Capabilities

DISARM EWS can predict fire weather conditions up to a month in advance, detect and monitor wildfires in real-time using satellite data, and simulate wildfire spread to support firefighting operations. Furthermore, it uses state-of-the-art regional climate model simulations to assess future fire danger and drought conditions, allowing for the development of long-term adaptation strategies to climate change. These capabilities enable DISARM EWS to provide accurate and timely predictions, enhance prevention and mitigation strategies, and support decision-making processes for wildfire management.

The DISARM EWS acknowledges the three fundamental drivers of wildfire risk in the Eastern Mediterranean - land management, human behaviour, and climate change. Land-use change and the expansion of unmanaged vegetation increase fuel availability, which is represented in DISARM through detailed land-cover and vegetation datasets. Human activity is identified as the dominant ignition source in the region, and thus anthropogenic

ignition likelihood is embedded in the fire danger modelling framework. Climate change is recognised as a major amplifier of fire-weather extremes, with rising temperatures, prolonged drought, and more frequent heatwaves increasing high-risk days (Kotroni et al., 2020).

Although DISARM is primarily a fire-weather early warning tool and not a real-time detection system, it is designed to operate in conjunction with satellite-based fire monitoring. Satellite observations provide near-real-time detection of active fires, thermal anomalies, and fire radiative power, which are essential for tracking wildfire ignition and spread.

Although DISARM engages with EUMETSAT satellite data, it is important to clarify that EUMETSAT itself does not produce operational 0–6 hour nowcasts for wildfire detection or fire-weather forecasting. Instead, EUMETSAT provides the core satellite observations - notably from the Meteosat Second Generation (MSG) SEVIRI instrument and the new [Meteosat Third Generation](#) (MTG) Flexible Combined Imager (FCI), which are used by specialised application facilities to generate value-added products. Near-real-time fire detection, Fire Radiative Power (FRP), and land-surface dryness indicators are produced by the Land Surface Analysis Satellite Application Facility (LSA-SAF) (Trigo et al., 2011; [EUMETSAT LSA-SAF](#), 2023; Roberts et al., 2015). LSA SAF recently released a demonstrational MTG-based FRP product ([October 2025](#)) derived from FCI/MTG observations, demonstrating the satellite-to-application chain but also confirming that the “nowcasted” fire products originate from SAF processing rather than from direct EUMETSAT output.

### **3.8.3. Availability**

The system is available at [DISARM webpage](#). It contains three dedicated dashboards tailored to each country Greece, Bulgaria, and Cyprus.

### **3.8.4. TRL**

The system has been operationally implemented and is currently maintained, so its TRL level should be at least 7.

### **3.8.5. Solution in other EU projects**

DISARM EWS was implemented at national level during the INTERREG Balkan-Mediterranean 2014–2020 cooperation programme (program DISARM).

### **3.8.6. Role in GOBEYOND**

DISARM EWS can play a significant role in European network of wildfire management and early warning systems. It provides functionalities like operational wildfire danger forecasting and wildfire spread modeling with IRIS. DISARM’s system is operational, contributes to the European Fire Information System and engages with EUMETSAT and LSA-SAF for enhanced fire danger index data.

### 3.8.7. Benchmarking

Table 12 Benchmarking evaluation table for DISARM EWS

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	3	The system is highly relevant for fire-prone regions in the Eastern Mediterranean.
	Multi-hazard Capability	3	2	Designed for wildfires, useful for droughts and contains various models.
	Performance	4	2	Positive results in detecting and predicting wildfires, although it does overestimate the burnt area due to not accounting for firefighting activities.
	Genericity	3	2	The system can be adapted for other regions, but requires specific calibration to local conditions.
	Coverage and Reach	3	2	The system covers three countries in the Eastern Mediterranean and could potentially be expanded.
	Community Engagement and Training	2	1	Aims to increase the awareness of both public authorities and the general public. Creation of DISARM Communication Plan
	Testing and Drills	4	3	The system has been evaluated in real-time.
	Accessibility	3	2	The system can be accessed via a web-based application developed within the DISARM project.
Technological	Technological Infrastructure	4	3	The system uses state-of-the-art observational and modeling techniques.
	Maturity	3	2	The system was developed and tested over several years and is now operationally implemented.
	Lead Time and Accuracy	4	2	The system provides near real-time detection and monitoring, but the accuracy of predictions can be affected by various factors.
	Scalability and Adaptability	4	3	The system is scalable and can be adapted to other regions after appropriate procedure
	System Integration	3	3	The system successfully integrates various components including weather forecasting, remote sensing, and fire spread modeling.
	Real-Time Monitoring	4	3	The system provides near real-time detection and monitoring of wildfires.
	Interoperability	2	1	The system can potentially be integrated with other systems, but the specifics depend on the compatibility of those systems.
	Security	NA	NA	
	Innovation and R&D	4	3	The system is innovative in its approach and is based on extensive research and developmen
	Support	2	1	The consortium has committed to continue support for the system for at least 5 years after the project completion.
Business	Budget and Sustainability	3	2	
	Benefit-Cost Analysis	2	0	
	Policy and Governance	3	1	
	International Standards	2	1	
	Insurance and Liability	1	-2	
Informational	Data Quality and Reliability	4	3	The system uses high-quality data from various sources, including satellite remote sensing and weather forecasts.
	Warning Message Clarity	3	2	

Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
Disaster Risk Reduction Integration	3	2	The system is integrated into disaster risk reduction strategies in the participating countries.
Community Resilience	2	1	
Feedback Mechanisms	2	-3	None existing

### 3.9. Earthquake EWS: PRESTo & QuakeUp

#### 3.9.1. Overview

[PRESTo](#) (Satriano et al., 2011) is a network-based Early Warning (EW) system that rapidly estimates the location and magnitude of an earthquake and predict the impact (PGV) (using ground motion prediction equations), while the earthquake is still occurring. It uses the early P-wave signal and (where available) the early S-wave signal recorded at the accelerometric and velocimetric stations of a dense seismic network deployed in the epicentral area.

QuakeUp is an impact-based earthquake early warning system that can identify an ongoing seismic event and estimate the impact of this event in the surrounding area in terms of peak ground velocity (PGV), acceleration (PGA) and instrumental intensity. This estimation is performed using both regional ground motion prediction equations (GMPE) and onsite P-wave amplitude measurements.

#### 3.9.2. Capabilities

PRESTo predicts the peak ground shaking produced at the regional level, using a point-source approximation and ground motion prediction equations. The estimation of the earthquake impact (peak ground acceleration or velocity) is time-evolutive and probabilistic. Alert messages are broadcasted to a dynamic set of users in the region through a central server, while the expected impact and lead-time is continually and directly sent to specific target sites.

As for QuakeUp, when a seismic station of a dense network deployed in the epicentral area is reached by the early P-wave radiated by the earthquake, the real-time measurements of P-wave acceleration, velocity and displacement are performed and used to predict (through previously calibrated empirical relations) the PGV at the site and in not-instrumented sites the Ground Motion Prediction Equation (GMPE) are used in combination with PGV predictions at seismic stations. Using a physics-based interpolation method, the onsite and GMPE predictions of PGV are combined to obtain a real-time evolutive shaking-forecast map of the earthquake potential damage area.

#### 3.9.3. Availability

PRESTo is a free and open-source software platform, available for Windows, Linux or Mac OS. Program and source code are distributed under the terms of the GNU General Public License, version 2 (GPLv2).

The QuakeUp software platform is under development and testing at the Seismological Laboratory (RISSC-Lab) of the Department of Physics at the University of Naples Federico II and it will be soon installed as a real-time early warning module of the Irpinia Seismic Network.

### 3.9.4. TRL

Both tools are running on the stations of the Irpinia Seismic Network, managed by the RISSC Seismological Laboratory within the University of Naples Federico II. On the one hand, the PRESTo EW system has reached TRL 5: Technology validated in a relevant environment. On the other hand, the QUakeUp EW system has reached TRL 4: Technology validated in the lab. QUakeUp has been tested offline through the playback of waveforms recorded during past events.

### 3.9.5. Solution in other EU projects

Part of the work for the development of PRESTo has been carried out within the SAFER project (Seismic Early Warning for Europe), founded by the European Community via the Sixth Framework Program for Research. Further development support has been provided by Early Warning related Work Packages of these projects: NERA (Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation, 2010-2014) and REAKT (Strategies and Tools for Real-Time Earthquake Risk Reduction, 2011-2014). PRESTo is currently running on the [CREW](#) - the EU Testing Center for Earthquake Early Warning and Source Characterization. CREW is a facility developed by the Near-Fault Observatory ([NFO](#)) community, to test real-time software and evaluate their performances.

Within the framework of the EPOS-ON action, QuakeUp is set to be included in the CREW - the EU Testing Center for Earthquake Early Warning and Source Characterization. CREW is a facility developed by the Near-Fault Observatory ([NFO](#)) community, to test real-time software and evaluate their performances.

### 3.9.6. Role in GOBEYOND

Both PRESTo and QuakeUp are network-based early warning systems that ground on the availability of real-time data streaming (deadline less than 1 sec). Their suitability is relevant to the conditions for data provided by the **GOBEYOND** test sites.

### 3.9.7. Benchmarking

Both PRESTo and QuakeUp are network-based early warning systems developed by the same laboratory and offer very similar functionalities. Consequently, their benchmarking is conducted together.

Table 13 Benchmarking evaluation table for PRESTo and QuakeUp

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	1	0	They provide earthquake Early warning alerts at local/regional scale. Difficult implementation in <b>GOBEYOND</b> due to the lack of real-time data streaming from current networks.
	Multi-hazard Capability	1	-3	It is only for earthquakes.
	Performance	3	2	correct alerts are normally between 85-90% over a total (100%) of successful, missed and false alert.
	Genericity	2	-2	It requires specific technological solutions, user-customized (hardware, sensors, algorithm parameters).
	Coverage and Reach	4	3	The technology meets very high requirements.
	Community Engagement and Training	3	-1	Education/training of the population is crucial for the effectiveness of EEWS. This action is demanding for its use.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Testing and Drills	3	-1	Education/training of the population is crucial for the effectiveness of EEWS.
	Accessibility	4	3	Full inclusive.
Technological	Technological Infrastructure	4	3	The technology meets very high-tech requirements.
	Maturity	4	1	High TRL are required.
	Lead Time and Accuracy	4	2	The methodology provides from a few-to about tens of seconds of Lead-time, depending on the user position with respect to the earthquake.
	Scalability and Adaptability	4	3	The EWS is scalable at different spatial scales and different work conditions. However, they require customization for the specific seismic network.
	System Integration	3	3	It is fully integrable with legacy systems provided that technology for data collection and transmission is updated to the RT operation mode.
	Real-Time Monitoring	4	3	The system processes data in real-time.
	Interoperability	3	2	The system works with different OS and requires a dedicated machine.
	Security	4	3	High-security level. The system is aimed at protecting people, building and machineries from the earthquake risk.
	Innovation and R&D	4	3	The system integrates advanced real-time algorithms and modern sensor networks.
	Support	2	2	Support is provided to a limited extent.
	Business	Budget and Sustainability	4	3
Benefit-Cost Analysis		4	3	In terms of saving human lifes the benefit-cost of the EEWS is among the highest withing Geo and Weather hazard systems.
Policy and Governance		4	-3	No regulation for real-time alert issuance is available in EU countries.
International Standards		4	3	It is fully compliant.
Insurance and Liability		4	-3	No insurance schemes are presently available in EU countries.
Informational	Data Quality and Reliability	4	3	Data Quality control is performed within the software at different levels.
	Warning Message Clarity	4	2	The current warning message is only sent to a technical audience and therefore it contains only a technical information.
	Disaster Risk Reduction Integration	4	-3	It is only used for research purposes and not currently integrated in any DRRRI actions in EU countries.
	Community Resilience	4	3	The system provides alerts for ongoing earthquakes, to start the activation of emergency procedures.
	Feedback Mechanisms	2	0	Only scientific exchanges and communication among users that implemented for research purposes the methodology.

## 3.10. Earthquake EWS: SAVE & P-wave alert

### 3.10.1. Overview

SAVE implements an on-site EEW systems based on a single sensor deployed directly at the target building, infrastructure, or industrial plant to protect. The alert is issued with the info about the expected ground shaking at the target, based on the actual signal recorded at the target itself.

P-alert is a P-wave-based, on-site earthquake early warning system, based on the real-time, continuous measurement of three peak amplitude parameters and their empirical combination to predict the ensuing peak ground velocity. The observed parameters are compared to threshold values and converted into a single, dimensionless variable. A local alert level is issued as soon as the empirical combination exceeds a given threshold.

### 3.10.2. Capabilities

The output of SAVE consists in an alert message about the expected intensity at the site of interest, the magnitude range, and the distance range of the source to the site of interest. The output is declared through a threshold-based method that considers the information coming from the P-wave onset within a maximum P-time window of 3 seconds starting from the first detected P-wave arrival.

As for P-wave alert, at each time along the seismogram, the tool measures Pd, Pv, and Pa on the vertical component of ground motion recordings and associate them with a fuzzy variable, which is finally used for warning declaration. In this way, the three ground motion quantities equally contribute to the final shaking prediction. The warning is issued as soon as the predicted shaking exceeds a prior established threshold. The methodology provides the expected intensity at each recording station.

### 3.10.3. Availability

The SAVE software is currently installed and running at a limited number of stations of the Irpinia Seismic Network and is under testing at the Seismological Laboratory (RISSC-Lab) of the Department of Physics at the University of Naples Federico II. The alert is visualized as a message on a computer screen showing real time streaming of data in the computer room of RISSC Lab at the University of Naples. Since SAVE is still under testing, no protocols for alert dissemination exist currently.

The P-alert software platform is under development and testing at the same laboratory. The methodology is under testing offline using data recorded at the Irpinia seismic network. There are no current protocols for alert dissemination.

### 3.10.4. TRL

The SAVE EW system has reached TRL 5: Technology validated in relevant environment. SAVE is running on the stations of the Irpinia Seismic Network, managed by the RISSC seismological Laboratory within the University of Naples Federico II.

The P-alert EW system has reached TRL 4: technology validated in the lab. P-alert has been tested offline through the playback of waveforms recorded during past events. Testing of the methodology on the stations of the Irpinia Seismic Network is planned.

### 3.10.5. Role in GOBEYOND

Implementation of SAVE & P-wave alert and their real-time demonstration is possible in **GOBEYOND** using real-time data streaming from available worldwide seismic stations, such as those of the IRIS network, but also EIDA for Europe.

### 3.10.6. Benchmarking

Both SAVE and & P-wave alert are on-site EWSs designed to predict earthquake impacts in terms of expected strong ground shaking. Developed by the same laboratory, these systems offer very similar functionalities. As a result, their benchmarking is conducted together.

Table 14 Benchmarking evaluation table for Earthquake EWS: SAVE & P-wave alert

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	3	3	They provide earthquake Early warning alerts at local scale. Implementation in <b>GOBEYOND</b> is possible to a limited extend, using real-time data streaming from available seismic stations, distributed worldwide.
	Multi-hazard Capability	1	-3	It is only for earthquakes.
	Performance	3	2	correct alerts are normally between 85-90% over a total (100%) of successful, missed and false alert.
	Genericity	2	-2	They require specific technological solutions, user-customized (hardware, sensors, algorithm parameters).
	Coverage and Reach	4	3	The technologies meets very high requirements.
	Community Engagement and Training	3	-1	Education/training of the population is crucial for the effectiveness of EEWS. This action is demanding for its use.
	Testing and Drills	3	-1	Education/training of the population is crucial for the effectiveness of EEWS.
	Accessibility	4	3	Full inclusive.
Technological	Technological Infrastructure	4	3	The technologies meet very high-tech requirements.
	Maturity	4	1	High TRL are required.
	Lead Time and Accuracy	4	2	The methodology provides a few of seconds of Lead-time, depending on the user position with respect to the earthquake.
	Scalability and Adaptability	4	3	The EWS can be easily exported and implemented in different places. However, it requires customization for the specific seismic station.
	System Integration	3	3	It is fully integrable with legacy systems provided that technology for data collection and transmission is updated to the RT operation mode.
	Real-Time Monitoring	4	3	The system processes data in real-time.
	Interoperability	3	2	The system works with different OS and requires a dedicated machine
	Security	4	3	High-security level. The system is aimed at protecting people, building and machineries from the earthquake risk.
	Innovation and R&D	4	3	The system integrates advanced real-time algorithms and modern sensor networks.
	Support	2	2	Support is provided to a limited extent.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
<b>Business</b>	Budget and Sustainability	4	3	The technology grounds on high-tech, robust, and reliable solutions, it is not cheap. But offer a service to a wide community.
	Benefit-Cost Analysis	4	3	In terms of saving human lives the benefit-cost of the EEWS is among the highest withing Geo and Weather hazard systems.
	Policy and Governance	4	-3	No regulation for real-time alert issuance is available in EU countries.
	International Standards	4	3	It is fully compliant.
	Insurance and Liability	4	-3	No insurance schemes are presently available in EU countries.
<b>Informational</b>	Data Quality and Reliability	4	3	Data Quality control is performed within the software at different levels.
	Warning Message Clarity	4	2	The current warning message is only sent to a technical audience and therefore it contains only a technical information.
	Disaster Risk Reduction Integration	4	-3	It is only used for research purposes and not currently integrated in any DRRI actions in EU countries.
	Community Resilience	4	3	The system provides alerts for ongoing earthquakes, to start the activation of emergency procedures.
	Feedback Mechanisms	2	0	Only scientific exchanges and communication among users that implemented for research purposes the methodology.

### 3.11. Earthquake Rapid Response: SEISAid

#### 3.11.1. Overview

In the context of Earthquake Rapid Response, BRGM has developed the SEISAid system, which, on receipt of an earthquake notification, produces rapid, automatic estimates of potential losses caused by earthquakes. The results of these estimates are automatically fed into a pdf report, the purpose of which is to provide very quickly the authorities with the relevant information they need to understand the scale of the earthquake and its likely consequences.

#### 3.11.2. Capabilities

SEISAid aims to estimate the extent of potential losses in less than half an hour, based on a rapid preliminary estimate of the intensity of ground-motions, in order to provide an anticipated view of both material and human tolls. It is based on a combination of an intensity map produced with the USGS "Shakemap 4.0" software (Worden et al., 2018), calibrated from field observations (PGA values), and a exposure inventory of buildings that statistically qualifies their vulnerability (i.e., use of semi-empirical damage functions based on a vulnerability index). This approach makes projections based on a realistic assessment of the seismic intensity and it estimates losses on the basis of an explicit consideration of the damage distribution of buildings.

### 3.11.3. Availability

The SEISAid is currently in a pilot phase, as the whole system is being tested on French West Indies area, as well as on the territory of the Metropole of Nice (southeast France). In the French West Indies, the system was successfully tested with users between July 2022 and May 2023, with the regular dispatch of dummy reports, including the replay of past real earthquakes. These tests confirmed the robustness of the tool and validated its operational relevance. In addition to the mock tests, several SEISAid-Antilles reports were sent out during 2023 following real earthquakes close to Guadeloupe.

SEISAid is an internal tool developed at BRGM: the commercial strategy (if any) is not clearly defined yet, and the dissemination or implementation of the tool is proposed on a case-by-case basis (depending on collaboration and funding opportunities).

### 3.11.4. TRL

The TRL of the SEISAid solution is estimated between 6 and 9: it is being demonstrated in an operational environment, while awaiting further proof that it performs adequately (i.e., pending the occurrence of a destructive earthquake in the deployment area).

### 3.11.5. Role in GOBEYOND

The SEISAid tool does not constitute an early warning system per se; however, it is useful to enhance situational awareness immediately after the occurrence of the earthquake, in a rapid response context. SEISAID is mostly focused on impact assessment (i.e., through the estimation of physical damages) and it is designed to operate at a local spatial resolution: these two features are among the goals that are pursued by the **GOBEYOND** project.

### 3.11.6. Benchmarking

Table 15 Benchmarking evaluation table for SEISAid

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	3	High relevant tool and outputs for the rapid response context.
	Multi-hazard Capability	3	1	Possibility to alter the algorithm (damage assessment part) in order to include other hazards; In particular, forecasts could be added concerning events triggered by shakings (landslides, liquefaction, tsunamis).
	Performance	3	2	The algorithm has been tested for 15+ years.
	Genericity	2	2	The algorithm is generic / Specific data (e.g., building exposure) is needed when applied to an area.
	Coverage and Reach	3	1	The tool is only tested in specific regions for now; Discussions underway with the French Ministry of the Interior to extend the tool's coverage to the whole of mainland France.
	Community Engagement and Training	2	2	Integration in earthquake drill exercises.
	Testing and Drills	2	3	The algorithm has been tested for 15+ years / Integration in earthquake drill exercises.
	Accessibility	2	-2	Internal tool at BRGM (access granted upon request).

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
				No special effort to make it accessible or inclusive, e.g. people with visual impairment.
Technological	Technological Infrastructure	3	2	Modular workflow running on the Vigirisks platform.
	Maturity	4	3	High TRL.
	Lead Time and Accuracy	4	2	Loss estimates within 30min of the earthquake's occurrence.
	Scalability and Adaptability	3	2	Has been tested with various spatial resolutions.
	System Integration	2	2	Modular workflow running on the Vigirisks platform.
	Real-Time Monitoring	3	2	Use of ShakeMaps (based on real-time monitoring).
	Interoperability	3	1	Uses data standards for seismology (FDSN Web Services) and earthquake engineering (USGS ShakeMaps).
	Security	2	2	Password protected; runs on dedicated servers at BRGM.
	Innovation and R&D	3	2	Possibility to propose improvements or updates.
	Support	3	3	Dedicated support team at BRGM.
Business	Budget and Sustainability	2	0	Dependent on BRGM's internal strategy for the development, but discussions underway with the French Ministry of the Interior to ensure the long-term viability of the tool.
	Benefit-Cost Analysis	3	-2	Not included.
	Policy and Governance	3	1	Collaboration with institutional end-users.
	International Standards	3	2	Use of the international EMS-98 damage scale.
	Insurance and Liability	2	-2	A liability waiver is included on the PDF report.
Informational	Data Quality and Reliability	3	1	Depends on the area of application.
	Warning Message Clarity	4	3	Structure of the PDF report decided with end-users.
	Disaster Risk Reduction Integration	3	2	Integration in crisis management operations.
	Community Resilience	NA	NA	
	Feedback Mechanisms	2	2	Collaboration with institutional end-users.

### 3.12. Earthquake Rapid Response: QLARM

#### 3.12.1. Overview

QLARM (Quake Loss Assessment for Response and Mitigation) has estimated numbers of fatalities and injured within 28 minutes, median, after potentially fatal earthquakes worldwide since October 2002. QLARM's data set of settlements is divided into three categories, cities, towns, and villages, with distributions of buildings into EMS98 classes of resistance to shaking appropriate for each country. The sum of settlement population equals the total number of people as listed by the CIA (Central Intelligence Agency, USA) for each country. The estimates of maximum intensity and the number of fatalities has been verified by QLARM in detail for 78 earthquakes in 17 countries, including the target countries of **GOBEYOND**. The construction of the code and data set QLARM was funded by DEZA, the Swiss Agency for Development and Cooperation. Its purpose is to allow first

responders to make an informed decision whether aid should be offered in response to potentially disastrous earthquakes.

### 3.12.2. Capabilities

For damage estimation, the expected percentage of buildings in each of five damage states (damage scale according to EMS98) is provided, as well as the mean damage. For estimates of fatalities and injured, a range of values is given for earthquake with  $M \geq 5$  along with an alert color (red, orange, yellow or green) describing the proposed severity of the impact. QLARM can estimate the level of an earthquake disaster, but information on fatalities in specific settlements is not reliable. It also calculates the population affected at each intensity level. The durations of QLARM loss calculations are about 10 sec for earthquakes in Europe of sizes  $6 \leq M \leq 7$  and 15 seconds for M7.5 beneath Crete. Larger magnitude earthquakes are unlikely in Europe and North Africa. QLARM can be run for point sources, the usual input, or for line sources, if the endpoints of the rupture are known. The depth selected is based on the assumed main source of energy release of the rupture.

### 3.12.3. Availability

QLARM earthquake alerts are distributed free of charge by email to anyone who subscribes and in abbreviated form to the public on the website X (Twitter). The code is currently being upgraded as part of the **GOBEYOND** project, with the aim to make it fully open source. At present, the code may be run by anyone who agrees to collaborate with QLARM staff.

### 3.12.4. TRL

QLARM has issued 1400 earthquake alerts in real time over the last 22 years (see the following map). Only earthquakes with  $M \geq 5$  and near populated areas are considered. Publications in scientific journals discussing QLARM results number 33 since 2017. They include not only fatality estimates of individual earthquakes, but also fundamental research concerning error sources and impacts on specific communities in connection with earthquake fatalities. QLARM has been proven reliable in estimating fatalities within minutes after worldwide earthquakes, and specifically for earthquakes in the target countries as demonstrated by Wyss and Rosset (2024 submitted). Except for the integration coding, it is fully ready to be integrated in any disaster alert system.

### 3.12.5. Role in GOBEYOND

The performance of QLARM was verified in some of the **GOBEYOND** target areas. For a verification to be acceptable, the maximum intensity of shaking,  $I_{max}$ , and the numbers of fatalities calculated must be equal, or at least approximately equal, to the values observed in past earthquakes.

Table 16 Evaluation of QLARM in GOBEYOND target countries

Country	Date	M	Fatalities		Delay (min)	Intensity (max)	Quality
			Estimated	Reported			
L'Aquila (I)	09.04.2009	6.3	50 - 500	309	22	ok	20
Irpinia (I)	23.11.1980	6.9	410 - 3120	2483	60	ok	20
Athens (GR)	07.09.1999	6.0	55-233	143	NA	ok	15
Thessaloniki (GR)	20.06.1978	6.2	27 - 337	45	NA	ok	15
Al Hoceima (MA)	24.02.2004	6.4	0 - 2700	631	104	ok	15
Al Haouz (MA)	08.09.2023	6.8	100 - 1000	2946	31	ok	15

Country	Date	M	Fatalities		Delay (min)	Intensity (max)	Quality
			Estimated	Reported			
Spain (ES)	25.12.1884	6.5	122 - 520	745	NA	ok	10
Spain (ES)	21.03.1829	6.4	257 - 1567	389	NA	ok	15

The delay time with which QLARM is expected to broadcast an estimate of fatalities in case of an earthquake in one of the target areas is expected to be 4 minutes. This is based on the delay time of 2 minutes for earthquake parameters being delivered to QLARM by a local/regional seismological institute, as it was the case in an M5.7 Greek earthquake plus a two-minute computing plus distribution time of loss estimates by QLARM. Therefore, QLARM contains data and algorithms that allow accurate fatality estimates for earthquakes in the target countries of **GOBEYOND**.

### 3.12.6. Benchmarking

Table 17 Benchmarking evaluation table for QLARM

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	3	QLARM is one of the few operational earthquake loss-estimation systems used in near-real-time. Its relevance is high for rapid impact assessment across Europe and globally.
	Multi-hazard Capability	1	0	QLARM is specifically designed for earthquake loss estimation and does not natively include other hazards.
	Performance	3	2	The modelling methodology is scientifically robust and performs well when EMS-98 vulnerability classes and exposure data are accurate. However, performance is sensitive to building-inventory quality and real-world code compliance (Del Mese et al., 2023; Saretta et al., 2021; Mavroulis et al., 2023).
	Genericity	2	1	QLARM is applicable in many regions, but EMS-98 classifications were developed for European building typologies. Regional differences in construction practices may reduce genericity.
	Coverage and Reach	3	3	QLARM can be run worldwide, and has been applied in multiple countries with different hazard contexts.
	Community Engagement and Training	NA	NA	
	Testing and Drills	4	3	Earthquake loss estimating tested for 78 earthquakes in 17 countries including GB target areas. Applied in many countries to calculate scenarios for likely earthquakes. No large-scale drills but extensive operational testing history.
	Accessibility	3	0	Currently available as a password-protected web application; full open access is not yet implemented.
Technological	Technological Infrastructure	3	3	Web application running in cloud environment (currently AWS).
	Maturity	3	3	22 years of experience in alert service.
	Lead Time and Accuracy	3	2	Worldwide 28 minutes, planned to be 4 minutes in target areas of GB.
	Scalability and Adaptability	3	3	Resolution of the grid could be variable depending on the needs.
	System Integration			Stand-alone application in the current version.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Real-Time Monitoring	3	0	Being programmed in GB.
	Interoperability			Stand-alone application in the current version, planned support for OGC/WMS output.
	Security	3	2	Password-protected web app (https).
	Innovation and R&D	2	2	Leader in the field of earthquake loss estimates.
	Support	2	-1	On voluntary basis and on demand.
<b>Business</b>	Budget and Sustainability	NA	NA	
	Benefit-Cost Analysis	NA	NA	
	Policy and Governance	NA	NA	
	International Standards	NA	NA	
	Insurance and Liability	NA	NA	
<b>Informational</b>	Data Quality and Reliability	3	1	QLARM relies on EMS-98 vulnerability classes and population/exposure datasets. Reliability is high when inventories reflect true building conditions, but recent events (Turkey–Syria 2023 earthquakes) show that nominal code classifications can diverge substantially from actual structural performance (Mavroulis et al., 2023; EEFIT, 2023), introducing uncertainty.
	Warning Message Clarity	4	3	Tested for 10 years over 1400 distributed earthquake alerts.
	Disaster Risk Reduction Integration	2	2	Used in alert and scenario modes since 2002 and 47 publications related to seismic hazard, risk and loss reduction in reviewed scientific journals.
	Community Resilience			NA
	Feedback Mechanisms	2	1	On individual bases, open to comments.

### 3.13. Volcanic EWS: EASE

#### 3.13.1. Overview

EASE tool is a tool, developed by UNINA-PLINIVS, in the framework of research activities funded by the Italian Civil Protection Department (DPC) to elaborate impact analyses caused by volcanic phenomena related to explosive eruptions of the volcanoes Vesuvius and Campi Flegrei (Campania Region, Italy).

The tool can provide the damage to ordinary buildings and their occupants due to seismic volcanic events and ash fall.

#### 3.13.2. Capabilities

EASE develops impact analyses combining hazard, exposure, and vulnerability, with reference a reference minimum unit constituted by a square cell 250x250m.

The hazard is assessed on the base of elaboration of the National Institute of Geophysics and Volcanology (INGV). In particular, the earthquakes analysed are those recorded in real time by the monitoring network of INGV, in terms of magnitude and depth. The loads due to ash fall are obtained through a real-time connection to the procedures developed by INGV, which estimate the distribution of ash thicknesses on the ground, as a function of the eruptive scale (small, medium, large) and the direction of the stratospheric winds.

The exposure models are developed by UNINA-PLINIVS on the base of statistical procedures (SAVE, BINC) able to assess the distribution of vulnerability classes of buildings, starting from data collected on the territory through quick survey activity, through an ad hoc form, called PLINIVS form.

The vulnerability models are developed by UNINA-PLINIVS on the base of empirical (for earthquake) and analytical (for ash fall) approaches, in terms of fragility curves.

For each reference minimum unit (250x250m), the output of the tool is:

- for earthquakes: unsafe buildings, collapsed buildings, dead, injured and homeless;
- for ash fall: collapsed buildings and homelessness.

### 3.13.3. Availability

EASE tool is available at the Plinivs Study Centre (University of Naples Federico II) and it is shared with the computer system of the DPC's Volcanic Service and Pozzuoli Municipality.

The elaborations produced are used to support DPC the emergency planning and management (rapid response) of the volcanic risk induced by the volcanoes of Campania.

### 3.13.4. TRL

EASE has passed the prototype stage. It is a tool normally adopted in risk analyses to support the planning and management of volcanic emergencies.

The models underlying the processing (hazard, exposure, and vulnerability) could be updated to improve the reliability of the output.

### 3.13.5. Role in GOBEYOND

Within the framework of **GOBEYOND**, UNINA-PLINIVS undertakes to integrate its impact model for explosive eruptions in the MH-IEW platform to improve response and preparedness in case of volcanic emergencies (WP1). The model will be implemented for precursor earthquakes, ash fall (automatic models) considering needs and gaps defined with end-users and local authorities (WP2).

The MH-IEW System for volcanic emergencies will be tested through the application to the pilot case of POZZUOLI in the context of an exercise that simulates a possible explosive eruption of the Campi Flegrei, which offers the possibility to train the city responders and to identify critical issues and improvement of emergency operating procedures. In collaboration with the Municipality of POZZUOLI, PLINIVS undertakes to design and coordinate this exercise and to develop the Recommendations for Explosive volcanic eruptions on the base of Lesson learnt (WP5).

### 3.13.6. Benchmarking

Table 18 Benchmarking evaluation table for Volcanic EWS: EASE

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	3	3	It provides RISK ASSESSMENT by earthquake and ash fall connected by explosive volcanic eruptions at Vesuvius and Campi Flegrei. The analyses are useful to support emergency planning and rapid response due to volcanic crisis. Implementation in

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
				<b>GOBEYOND</b> is possible to a limited to Campi Flegrei case.
	Multi-hazard Capability	3	3	EASE considers the impact of two different phenomena (earthquakes or ashfall), evaluated individually. A procedure for assessing the cumulative damage from multi-hazards (consisting of earthquakes + ash fall) is possible, although not foreseen in the project.
	Performance	3	2	The model concerning the damage induced by earthquake has been validated by comparing it with the damage recorded as a result of seismic events occurred in Italy. For ash fall, a similar validation was not possible, but empirical tests on the roofs of Neapolitan volcanic areas have made, with the aim to improve the fragility curves adopted the risk analyses.
	Genericity	2	-2	It requires specific models on hazard, exposure and vulnerability.
	Coverage and Reach	4	3	EASE is implemented for Campanian volcanoes. The methodology can be applied to other volcanic areas, but only after detailing the underlying models (Hazard, Exposure, Vulnerability).
	Community Engagement and Training	3	2	Education/training of the population is crucial for the effectiveness of planning and management of volcanic emergency.
	Testing and Drills	3	2	Education/training of the population is crucial for the effectiveness of planning and management of volcanic emergency.
	Accessibility	2	1	The accessibility of the model is limited to interested stakeholders (DPC + Pozzuoli Municipality).
<b>Technological</b>	Technological Infrastructure	4	4	The technology meets very high-tech requirements.
	Maturity	4	1	High TRL are required: TRL5.
	Lead Time and Accuracy	4	2	The methodology provides a few minutes of Lead-time, depending on the hazard data availability.
	Scalability and Adaptability	4	3	EASE can be exported and implemented in different places. However, it requires customization for the specific base-models.
	System Integration	3	3	It can be interfaced with other systems using standard protocols for data exchange.
	Real-Time Monitoring	3	3	The system processes data in near real-time (in the order of few minutes).
	Interoperability	3	2	The system works with the Linux OS and can be used in virtual dedicated machines.
	Security	3	2	Tool adopts normal security standard for web accessible application.
	Innovation and R&D	3	2	The system integrates advanced algorithms.
Support	2	2	Support is provided to a limited extent.	
<b>Business</b>	Budget and Sustainability	4	3	The functionality of the system requires limited economic resources.
	Benefit-Cost Analysis	4	3	The tool used in the planning and emergency management is able to increase the saving human lifes, so the contribution to the benefit-cost can be consistent.
	Policy and Governance	3	2	The outputs of the tool are useful in the emergency planning and management.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	International Standards	NA	NA	
	Insurance and Liability	4	-3	No insurance schemes are presently available.
Informational	Data Quality and Reliability	4	3	Data Quality control is performed within the software at different levels.
	Warning Message Clarity	4	2	The current warning message is only sent to a technical audience and therefore it contains only a technical information.
	Disaster Risk Reduction Integration	4	2	It is used for research purposes and it is integrated in DRR in Italy.
	Community Resilience	4	3	The system provides impact scenarios alerts for earthquakes and ash fall to support the planning and the activation of emergency procedures.
	Feedback Mechanisms	2	0	Scientific exchanges.

### 3.14. Volcanic Ash Dispersion: VONA

#### 3.14.1. Overview

The NOA early warning system for volcanic particles is an operational tool for monitoring and forecasting the volcanic plume pathway in near real time, identifying the volcanic ash and sulphate concentrations for the days following a volcanic eruption.

#### 3.14.2. Capabilities

The Early Warning Forecasting System for volcanic particles initiated when a red VONA message is issued either from INGV for Etna and Stromboli or IMO for volcanoes in Iceland. Then the FLEXPART-WRF model forecast runs are automatically started both for ash and SO2 species, in order to forecast the travelled path of the volcanic emissions the days following an eruption. The eruption data from the VONA alerts (1. duration of ash emissions and 2. Plume height) with meteorological data from NCEP Forecast System initialize the Lagrangian particle dispersion model FLEXPART. These data include winds, temperature, humidity, and eruption source parameters including the height of the plume. These VONA messages provide useful source information (e.g., the plume height and the duration of the ash emissions) to the PANhellenic GEophysical observatory of Antikythera (PANGEA) of the National Observatory of Athens (NOA) after Etna’s eruptions.

#### 3.14.3. Availability

The EWS for volcanic particles dispersion is currently available via a NOA local HPC server (the outputs are stored in a local S3-style repository).

#### 3.14.4. TRL

The EWS for volcanic particles dispersion system has reached TRL 5: This system is tested and validated in relevant environment. Some containerization solution for FLEXPART model is needed to be installed and run at another framework/environment

#### 3.14.5. Solution in other EU projects

The EWS for volcanic particles (EO4D\_ASH service) was developed in the frame of the EuroGEO flagship EU project e-shape.

### 3.14.6. Role in GOBEYOND

The EWS for volcanic particles dispersion, by utilizing higher resolution meteorological data from the European Centre for Medium Range Weather Forecasts (ECMWF) Integrated Forecast System (IFS), (preferably at 0.125° x 0.125° spatial resolution, with 137 vertical model levels), in order to initialize the FLEXPART model could enhance and facilitate modelling accuracy and in **GOBEYOND**. It will be efficient enough for real-time application and it could offer better volcanic ash forecasts. Improved forecasts would then allow more effective emergency response for aviation to ensure safe and optimized flight operations during volcanic eruptions.

### 3.14.7. Benchmarking

Table 19 Benchmarking evaluation table for VONA system

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	3	2	Weight is 3/4 as there are other hazards that will appear more in the pilots.
	Multi-hazard Capability	1	0	No multi-hazard as of now, but could be added
	Performance	4	2	More testing needed to evaluate its performance
	Genericity	3	1	
	Coverage and Reach	4	3	It provides coverage and IT requirements
	Community Engagement and Training	NA	NA	
	Testing and Drills	4	2	This solution has been tested in the framework of e-shape EuroGEO flagship EU project.
	Accessibility	1	-3	No special effort to make it accessible or inclusive, e.g., people with visual impairment
Technological	Technological Infrastructure	4	2	The technology is very sophisticated, its goal is to be low-cost, but with better data can be more robust.
	Maturity	4	3	This solution is tested and validated in relevant environment. This solution has a TRL of 5.
	Lead Time and Accuracy	4	3	This solution has been tested with real time data and provides early warnings with high accuracy.
	Scalability and Adaptability	4	3	The system is built with scalability in mind, allowing for easy expansion and adaptation.
	System Integration	3	2	Not 3/3 as it needs some containerization solution for the tool. Currently relies on having an existing installation somewhere, not very robust.
	Real-Time Monitoring	4	2	The solution is real time.
	Interoperability	4	2	It needs some containerization solution for the tool to work at different platforms
	Security	4	2	It contains a sensor that monitors a mail server (with IMAP) for new VONA alert messages.
	Innovation and R&D	3	3	Backed by ongoing research
	Support	2	1	
Business	Budget and Sustainability	4	3	Cost-effective solution, deemed sustainable
	Benefit-Cost Analysis	4	3	Low-cost (<150 euros per system), enabling larger coverage
	Policy and Governance	3	2	Aligns with most standards-need to follow a formal procedure
	International Standards	3	1	
	Insurance and Liability	2	1	

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
<b>Informational</b>	Data Quality and Reliability	4	2	High data quality but more validation efforts could help.
	Warning Message Clarity	2	1	
	Disaster Risk Reduction Integration	3	2	In principle
	Community Resilience	3	3	
	Feedback Mechanisms	2	1	Preliminary feedback mechanisms integrated so far

### 3.15. Volcanic Ash Dispersion: Innovative VONA

#### 3.15.1. Overview

An innovative Early warning forecasting system is assessed by using inverse modelling techniques for more accurate estimation of the aerosol mass rate from volcanic eruptions.

#### 3.15.2. Capabilities

An innovative inverse modelling framework that combines Lagrangian dispersion model outputs with remote sensing observations is proposed for EWS for volcanic particles dispersion, to estimate the vertical distribution of SO<sub>2</sub> and volcanic ash emission rates during volcanic eruptions. The ground-based Lidar measurements of volcanic aerosol concentration from the PANhellenic GEophysical observatory of Antikythera (PANGEA) of the National Observatory of Athens (NOA) (an ACTRIS Pan-European Research Infrastructure), downwind the source (Etna) and the output of the FLEXible PARTicle dispersion model (FLEXPART), will be utilised in the inversion algorithm. These observations serve as a-priori source information to estimate volcanic ash and SO<sub>2</sub> source strength, based on altitude and time, in conjunction with the FLEXPART model output, to inform aviation and ensure optimised and safe flights during volcanic eruptions.

#### 3.15.3. Availability

This solution is currently available at NOAs local SFTP. More information is available at Kampouri et al. (2023) and Amiridis, Kampouri, and Gkikas (2023).

#### 3.15.4. TRL

The innovative Early warning forecasting system has reached TRL 4: technology validated in the lab.

#### 3.15.5. Solution in other EU projects

The innovative Early warning forecasting system with the inverse modelling techniques was developed in the framework of the Aeolus-NEWTON ESA project and of the EuroGEO flagship EU project e-shape.

#### 3.15.6. Role in GOBEYOND

The innovative EWS for volcanic particles dispersion, by utilizing (1) higher resolution meteorological data from ECMWF, along with (2) the sophisticated inversion tools to estimate emissions at the source, could provide more accurate volcanic particles forecasts

in **GOBEYOND**. Improved forecasts would then allow more effective emergency response for aviation by the VAACs, to ensure safe and optimized flight operations during volcanic eruptions, minimizing the respective risk of accident and costs from flight cancelations.

### 3.15.7. Benchmarking

Table 20 Benchmarking evaluation table for innovative VONA system

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	3	3	Weight is 3/4 as there are other hazards that will appear more in the pilots.
	Multi-hazard Capability	1	0	No multi-hazard as of now, but could be added.
	Performance	3	2	More testing needed to evaluate its performance.
	Genericity	3	1	
	Coverage and Reach	4	3	It provides coverage in and IT requirements.
	Community Engagement and Training	NA	NA	
	Testing and Drills	3	2	This solution has been tested in the framework of e-shape EuroGEO flagship EU project and at the Aeolus-NEWTON ESA project.
	Accessibility	NA	NA	
Technological	Technological Infrastructure	4	2	The technology is very sophisticated, its goal is to be low-cost, but with better data can be more robust.
	Maturity	3	2	This solution is validated in the lab. This solution has a TRL of 4.
	Lead Time and Accuracy	4	3	This solution has been tested with real time data and provides early warnings with high accuracy.
	Scalability and Adaptability	4	3	The system is built with scalability in mind, allowing for easy expansion and adaptation.
	System Integration	3	2	Not 3/3 as it needs some containerization solution for the tool. Currently relies on having an existing installation somewhere, not very robust.
	Real-Time Monitoring	3	2	The solution with the emission inversion through observations is not real time (works offline, not operational).
	Interoperability	4	2	It needs some containerization solution for the tool to work at different platforms.
	Security	4	2	It contains a sensor that monitors a mail server (with IMAP) for new VONA alert messages.
	Innovation and R&D	3	3	Backed by ongoing research.
	Support	2	1	
Business	Budget and Sustainability	4	3	Cost-effective solution, deemed sustainable.
	Benefit-Cost Analysis	4	3	Low-cost (<150 euros per system), enabling larger coverage.
	Policy and Governance	3	2	Aligns with most standards-need to follow a formal procedure.
	International Standards	3	1	
	Insurance and Liability	2	1	
Informational	Data Quality and Reliability	4	2	High data quality but more validation efforts could help.
	Warning Message Clarity	2	1	
	Disaster Risk Reduction Integration	3	2	In principle.

Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
Community Resilience	3	3	
Feedback Mechanisms	2	1	Preliminary feedback mechanisms integrated so far

### 3.16. Tsunami DSS

#### 3.16.1. Overview

BRGM has been developing a tool for rapid access to potential tsunami impact, through analog research among precomputed tsunami modeling databases. Using previously modeled tsunami scenarios, the procedure may be used as a decision support tool in the case an alert from the official tsunami EWS when a potentially tsunamigenic earthquake occur (i.e., upon the release of a tsunami alert bulletin).

#### 3.16.2. Capabilities

The solution operates as follows:

- *Offline* phase:
  - Construction of a catalogue of seismic scenarios (e.g., fault rupture parameters of potentially tsunamigenic earthquakes).
  - From the seismic scenarios, construction of a database of simulated tsunamis (nested grids up to 30m, including flooding).
  - Post treatment of the results, homogenization, optimization of the formats and of the variables of interest (sea surface elevation, velocity, arrival time, polarity, wave number, number of waves, ...).
- *Online* phase:
  - Interpretation of the tsunami alert bulletin.
  - Application of an analogy research tool to the tsunami simulation campaign database.
  - Cartography of the results (statistical zoning of susceptible and exposed areas).

#### 3.16.3. Availability

The solution is in a pilot phase and it is being tested for the coast line of Martinique Island (French West Indies), in collaboration with the French Ministry of Interior. The procedure has been implemented as a workflow in BRGM’s Vigirisks platform.

#### 3.16.4. TRL

The TRL of this solution is estimated between 6 and 7 (implementation as an online procedure applied to an actual region, however not validated with real events yet).

#### 3.16.5. Role in GOBEYOND

This solution is in line with the **GOBEYOND** goals since it proposes a viable approach to address the issue of tsunami early warning systems. The outputs (e.g., flooding maps) may also be integrated in a damage assessment, if needed. The tool could be enriched with updated databases of simulated tsunamis.

3.16.6. Benchmarking

Table 21 Benchmarking evaluation table for Tsunami DSS

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
<b>General</b>	Relevance	4	3	High relevant tool and outputs for impact assessment in case of a tsunami early warning.
	Multi-hazard Capability	3	-1	Specific to tsunamis. The analog research tool could be extended to other physical phenomena.
	Performance	3	1	Still under test.
	Genericity	2	1	Need to generate offline scenarios each time a new area is considered.
	Coverage and Reach	3	1	The tool is only tested in specific regions for now.
	Community Engagement and Training	2		Unknown
	Testing and Drills	2	0	Still under test.
	Accessibility	2	0	Internal tool at BRGM, but access available on request.
<b>Technological</b>	Technological Infrastructure	3	2	Modular workflow running on the Vigirisks platform.
	Maturity	4	3	High TRL.
	Lead Time and Accuracy	4	3	Very accurate tsunami simulations (including flooding phenomenon); Very fast outputs thanks to the precomputed scenarios; Lead time dependent on the release of the tsunami alert bulletin (third-party organisations).
	Scalability and Adaptability	3	1	Requires new offline simulations in case of application to new regions.
	System Integration	2	2	Modular workflow running on the Vigirisks platform
	Real-Time Monitoring	3	2	Use of online tsunami alter bulletins.
	Interoperability	3	2	Database of tsunami simulations may be augmented with computations from other partners.
	Security	2	2	Password protected; runs on dedicated servers at BRGM.
	Innovation and R&D	3	2	Possibility to propose improvements or updates.
	Support	3	3	Dedicated support team at BRGM.
<b>Business</b>	Budget and Sustainability	2	0	Dependent on BRGM's internal strategy for the development.
	Benefit-Cost Analysis	3		Unknown
	Policy and Governance	3		Unknown
	International Standards	3	2	Use of international tsunami alert bulletins.
	Insurance and Liability	2		Unknown
<b>Informational</b>	Data Quality and Reliability	3	2	Depends on the area of application. Usually, offline simulations ensure high accuracy.
	Warning Message Clarity	4		Unknown
	Disaster Risk Reduction Integration	3	2	Results may be used for risk zonation of coast lines.
	Community Resilience	2		Unknown

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Feedback Mechanisms	2	2	Collaboration with institutional end-users (French Ministry of Interior).

### 3.17. Landslide: Local EWS

#### 3.17.1. Overview

The [Catalan Landslide Early Warning System \(LEWS\)](#) is designed to assess and quantify risks associated with landslides and debris flows. Originating from research by Berenguer et al. (2015) and further expanded by Palau et al. (2020, 2022), this system is currently operational in real-time across Catalonia. This system integrates two key components within a level warning matrix. The first component is a 30-meter-resolution susceptibility map, which remains static over time, providing a foundational understanding of the landscape's predisposition to landslides. The second component is high-resolution real-time rainfall estimates, constituting the dynamic aspect of the system. Together, these inputs generate a qualitative warning level map each time new rainfall information becomes available.

#### 3.17.2. Capabilities

The Catalan LEWS is designed to provide effective and timely warnings for landslides and debris flows, and it is currently operational and running in real-time since October 2022.

One of its key features is real-time rainfall monitoring, which incorporates high-resolution rainfall estimates from radar and rain gauges, ensuring continuous data updates. The system also includes automated data processing, guaranteeing uninterrupted real-time functionality. Additionally, the Catalan LEWS has efficient alert communication capabilities, disseminating warnings via a web-based platform administered by UPC and ICGC, along with automated email notifications to designated personnel from these institutions.

#### 3.17.3. Availability

The Catalan LEWS is primarily used by the Cartographic and Geological Institute of Catalonia (ICGC). The system is not open source but operates under a collaboration framework between UPC and ICGC.

The developed methodology is adaptable to other regions with some customization. This customization involves modifying the input files for the susceptibility map, such as loading regional maps or the European Landslide Susceptibility Map. Additionally, adjusting the Intensity-Duration-Frequency (IDF) curves and rainfall thresholds to suit the specific region would enable the system to function effectively in different areas.

#### 3.17.4. TRL

The Catalan LEWS's current Technology Readiness Level (TRL) is 9, indicating it is in the Actual system proven in an operational environment.

### 3.17.5. Solution in other EU projects

The Catalan LEWS is part of the available products within the *Floods, flash floods, debris flow, and landslides* catalogue of the EC H2020 project ANYWHERE (DRS-01–2015–700099).

### 3.17.6. Role in GOBEYOND

The Catalan Landslide Early Warning System (LEWS) aligns closely with the **GOBEYOND** goals, particularly in advancing impact-based early warning systems (EWS) and extending their application to geohazards. The system's real-time rainfall monitoring capabilities and automated data processing provide a solid foundation for developing an impact-based EWS tailored to geological and geophysical hazards.

In the context of multi-risk EWS, the Catalan LEWS can be integrated into a broader Multi-Risk Impact-based EWS (MR-IEWS) by incorporating additional hazard types and refining the system to trigger actionable decisions. The system's real-time monitoring and automated alert features support the delivery of site-specific warnings, enhancing the responsiveness of citizens and authorities to various hazards.

On an international scale, the Catalan LEWS's adaptability and scalability can contribute significantly to developing a European-scale MR-IEWS platform. Its high specificity in time and space and the capability to adapt to different regional requirements make it suitable for broader implementation.

The demonstration phase of **GOBEYOND** benefits from the Catalan LEWS by providing a tested and reliable platform for real-time operational environment evaluations. The system's performance during geo and weather events can be assessed and improved through these demonstrations, ensuring effective early warning capabilities.

### 3.17.7. Benchmarking

Table 22 Benchmarking evaluation table for Landslides EWS

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	3	The system directly addresses the need for advanced EWS in managing geohazards and extreme weather.
	Multi-hazard Capability	1	0	No multi-hazard capability.
	Performance	4	2	Proven effective in real-time monitoring and alerting.
	Genericity	3	2	The methodology can be adapted to other regions with some customization.
	Coverage and Reach	3	2	Currently regional, but has potential for broader application with scalability efforts.
	Community Engagement and Training	1	0	
	Testing and Drills	3	2	Regular testing conducted, but involving stakeholders could enhance readiness.
	Accessibility	2	0	
Technological	Technological Infrastructure	4	3	Utilizes high-resolution radar and rain gauge data.
	Maturity	4	3	System with real-time functionality currently operational.
	Lead Time and Accuracy	4	1	Effective in real-time but requires fine-tuning for predictive accuracy.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Scalability and Adaptability	4	2	Designed for scalability and can be adapted to other regions.
	System Integration	3	2	The system has been integrated into a platform.
	Real-Time Monitoring	4	3	Provides real-time data and updates continuously.
	Interoperability	1	0	
	Security	3	2	Accessible through a password-protected platform.
	Innovation and R&D	3	3	Ongoing research and development.
	Support	1	0	
Business	Budget and Sustainability	NA	NA	
	Benefit-Cost Analysis	NA	NA	
	Policy and Governance	NA	NA	
	International Standards	NA	NA	
	Insurance and Liability	NA	NA	
Informational	Data Quality and Reliability	4	3	High-quality data from monitoring systems.
	Warning Message Clarity	4	1	Clear and timely warnings; continuous improvement in communication strategies.
	Disaster Risk Reduction Integration	4	0	No integration with disaster risk reduction efforts so far.
	Community Resilience	3	0	
	Feedback Mechanisms	3	1	Validation of the system has been done, but more efforts are necessary.

### 3.18. Operational Platforms: ARGOS

#### 3.18.1. Overview

[Argos](#) is a Multi Hazard Impact Based Early Warning System for the monitoring and management of weather-induced emergencies. It is focused on generating hyperlocal early action in front of a variety of potential risks: floods, forest fires, snowfalls, storm surges, air pollution, droughts, etc.).

#### 3.18.2. Capabilities

Decision-making during the surveillance and management of meteorological emergencies carries great responsibility and requires all the information available at all times. Time is a key factor and therefore it is vitally important to optimize all the processes involved in information management. The system focuses on this by addressing the following points:

- **Single** access: integration and harmonization of data from different sources
- Dynamic **combination** of dynamic and static information: Impact-based oriented warnings
- Access to **source** data, not only maps
- Adaptation and incorporation of existing information
- Encapsulation of models and algorithms
- Architecture based on open standards

- Advanced display-web focused on warning information and optimized for the representation of spatiotemporal data
- Highly customizable

**3.18.3. Availability**

Argos is a commercial solution available to the market but only on weather hazards, geohazards are not available.

**3.18.4. TRL**

Argos is on TRL 9 on whether hazards because the solution is already on the market. Regarding geohazards some related products have been integrated in relevant environment in Spain, so it would make TRL 6.

**3.18.5. Solution in other EU projects**

Some outcomes of ANYWHERE H2020 project were several prototypes that served as a base for the ARGOS development during the following years after the end of the project.

**3.18.6. Role in GOBEYOND**

Argos aligns completely to the **GOBEYOND** goals as a Multi Hazard Impact Based Early Warning System. We expect to build part of the **GOBEYOND** system (implementation on some pilot sites) on top of Argos, taking benefit of the features already integrated and connecting to the **GOBEYOND** core system in real-time.

**3.18.7. Benchmarking**

Table 23 Benchmarking evaluation table for ARGOS platform

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	3	The interface of <b>GOBEYOND</b> system will be based on Argos on some pilots.
	Multi-hazard Capability	4	3	Multi-hazard capability is crucial in the project.
	Performance	3	2	
	Genericity	3	3	Can be easily adapted to different pilots.
	Coverage and Reach	3	3	Pilots are in different locations.
	Community Engagement and Training	1	1	Argos is oriented to authorities no general public.
	Testing and Drills	NA		No oriented to this aim.
	Accessibility	1	-2	Maps are difficult to make accessible to the visual impaired.
Technological	Technological Infrastructure	3	3	
	Maturity	3	3	
	Lead Time and Accuracy	3	3	
	Scalability and Adaptability	3	3	
	System Integration	3	3	
	Real-Time Monitoring	4	3	
	Interoperability	3	3	
	Security	3	2	There is room for improvement.
Innovation and R&D	3	3		

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Support	3	1	There is a still small community of users.
<b>Business</b>	Budget and Sustainability	4	2	Number of users growing.
	Benefit-Cost Analysis	4	2	
	Policy and Governance	3	3	Aligned with European flood directives and WMO recommendations.
	International Standards	3	3	
	Insurance and Liability	NA		
<b>Informational</b>	Data Quality and Reliability	3	3	Based on trusted sources.
	Warning Message Clarity	3	2	Room for improvement.
	Disaster Risk Reduction Integration	3	3	Fully integrable in a control centre room during emergencies.
	Community Resilience	1	1	Not directly involved in communities.
	Feedback Mechanisms	3	2	Feedback is taken personally, there is room for improvement.

### 3.19. Operational Platforms: Wiki-Predict Platform

#### 3.19.1. Overview

Wiki-Predict is a platform for managing risky hydrometeorological phenomena, enabling users to monitor the situation in real time and to be supported in implementing safeguard actions on the scale of their intervention territory.

#### 3.19.2. Capabilities

The Wiki-predict platform is a full-web platform, with a central mapping system giving users rapid access to information on risk awareness, crisis management procedures to be implemented, real-time hydrometeorological events and alert reception parameters for their area of jurisdiction. This platform adapts to the different working scales of users (continent / country / region / city), as well as to the specificities of each type of user (as the skills of each group of users may be different, the platform offers specific functionalities adapted to these skills).

It is also a multi-hazard management platform, enabling users to be supported in all aspects of crisis management (in line with the four pillars of the United Nations' EW4ALL initiative):

- Central cartography (Leaflet or Cesium engine) for real-time display of information relating to the expected/ongoing event (e.g., recommended safety levels, real-time rainfall, measurement stations/sensors, actions taken in the field, etc.);
- A function for preparing crisis management procedures, enabling in particular the creation of multi-hazard operational maps, booklets centralizing reflex cards for each phenomenon, and also awareness documents for the citizen.
- A cartographic and digital logbook function, enabling users to trace the actions implemented in their area of responsibility (in line with the actions previously entered on their operational maps) and the various information relating to the

hydrometeorological event in progress. Each logbook can be archived on the platform and exported as a PDF file.

- A function for sharing information on hydro-meteorological risks in real time via mapping, and for disseminating alerts (e-mails/SMS/notifications) to a list of pre-established recipients.

### 3.19.3. Availability

The Wiki-predict platform is a full-web platform solution which has been on the market for over 15 years now. It is constantly evolving, innovation being at the heart of Predict's activities. The solution is commercialized through a subscription model, including a 24/7 decision support service.

### 3.19.4. TRL

The Wiki-Predict solution can be classified as TRL level 9 (real system proven in the operational environment). Today, the platform is used on a daily basis by risk management departments in a wide range of organizations (cities, local authorities, fire departments, prefectures, departments, countries, insurers, companies) throughout the world.

### 3.19.5. Solution in other EU projects

The Wiki-Predict solution has already been proposed and used as part of the ANYWHERE project, between 2016 and 2019.

Furthermore, Predict's solutions have been enriched through elaboration of products developed as part of the [COSPARIN](#) project funded by European Space Agency (ESA). These 2 products are global rainfall estimation and flood prone area.

### 3.19.6. Role in GOBEYOND

The Wiki-Predict platform and its functionalities are directly aligned with the four pillars of the EW4ALL initiative, namely:

1. **Risk knowledge**: risk data concentrator mapping and COSPARIN hazard zone (hazards, issues, vulnerabilities);
2. **Preparedness**: operational mapping and crisis management procedures;
3. **Monitoring and detection**: capacity to integrate forecast data and real-time cross-referencing between vulnerability data and dynamic hazard data (e.g., rainfall);
4. **Dissemination**: inter-actor sharing of information on current risks and actions taken in the field.

The EW4MED platform, an integral part of the **GOBEYOND** project, is to be compatible with EW4ALL, and will be directly inspired by Wiki-Predict functionalities. In this sense, the Wiki-Predict solution is fully aligned with **GOBEYOND** objectives.

### 3.19.7. Benchmarking

Table 24 Benchmarking evaluation table for Wiki-Predict platform

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	3	The Wiki-Predict platform is a management platform whose objectives are truly aligned with the EW4ALL initiative.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Multi-hazard Capability	4	3	Wiki-Predict is a multi-risk management platform. In fact, each function is designed to be used and adapted to all existing major risks.
	Performance	4	3	The Wiki-Predict system has a high-performance obligation. The warnings function, for example, has to be very efficient, as the time taken to send SMS messages has to be as short as possible. Similarly, the information must be displayed on the map as quickly as possible (real-time display) so that users have the information instantly, particularly in the event of an event that can be very fast-moving.
	Genericity	2	1	The Wiki-Predict platform can be adapted to the different needs of its users, which can vary widely. The solution has a common base for all users even though it can require to fit specific needs.
	Coverage and Reach	4	3	The Wiki-Predict solution is available for a large number of different users around the world from local to global scale.
	Community Engagement and Training	4	3	The Wiki-Predict platform is user friendly and delivered with trainings/ presentation sessions to users.
	Testing and Drills	4	3	Simulation exercises involving the use of the Wiki-Predict platform are organized on a regular basis, as these are usefull to ensure the correct use of the tool during high-risk events.
	Accessibility	4	3	The platform is accessible 24/7 via the web and secure servers. Connection is via login and password.
Technological	Technological Infrastructure	4	3	The Wiki-Predict solution is based on a state-of-the-art technological infrastructure, with the latest software versions updated on a regular basis.
	Maturity	4	3	The solution has been developed and enriched and used by more than 25000 communities in France, more than 15 states services around the world for 15 years. It is daily used by Predict on call engineers since 2006.
	Lead Time and Accuracy	4	3	The solution integrates forecast and real time data (rainfall intensity at the scale of 1km <sup>2</sup> and each 5 min, gauging stations in real time).
	Scalability and Adaptability	4	3	The Wiki-Predict platform is constantly evolving, in the interests of its users and their needs. Its content and functionalities are adapted to the type of user/ It can integrate data in many format (shape, WMS, GEOTIFF, NetCDF, geoJson, ...).
	System Integration	4	3	The Wiki-Predict platform can be used to visualize different types of data. It is a full web platform that can be integrated in other tools. Links can be made with other specific tools as practiced in many other projects.
	Real-Time Monitoring	4	3	The platform allows to view various data (radar, gauging stations, etc.) in real time, supplied in different formats (WMS, API, etc.) and to publish different analyses in a pictogram format.
	Interoperability	4	3	Data or functionalities can be implemented in the platform and vice versa.
	Security	4	3	The web platform is hosted on secure European servers with user IDs and passwords.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Innovation and R&D	4	3	The platform evolves regularly in line with the needs of different users and through R&D projects to ensure that it is always at the cutting edge of technology.
	Support	4	3	Technical and expertise support (technical assistance).
<b>Business</b>	Budget and Sustainability	4	3	The platform has been shared with local authorities, insurers and businesses for over 15 years. This business model is sustainable, enabling tens of thousands of French local authorities to access the platform either directly or through insurers.
	Benefit-Cost Analysis	4	3	These preventive and early warning systems have proven their capacity to reduce losses, balancing their costs and enhancing prevention.
	Policy and Governance	4	3	These solutions have been chosen, funded and employed by thousands of communities to manage hazards for more than 15 years.
	International Standards	4	3	User friendly - format (shape, WMS, GEOTIFF, NetCDF, geoJson...).
	Insurance and Liability	NA	NA	The solution is delivered through an SAS licence. It integrates a continuous technical support. The help in decision information is delivered complementary to local's institutional hazards analyse.
<b>Informational</b>	Data Quality and Reliability	4	3	The data integrated into the platform is filtered so that users have access to reliable and, above all, operational data to meet their needs.
	Warning Message Clarity	4	3	Predict uses a concept that was developed over 15 years ago and regularly takes account of international standard and users' needs. The help in decision information integrates extensive experience of semantics adapted to climate risks prevention and anticipation.
	Disaster Risk Reduction Integration	4	3	Reflex action files on the behaviour to adopt in case of natural event, by level and by hazard, are included. Prevention documents for local authorities/companies and citizens are also integrated. Surveys led by users such as communities and insurance companies, industrials have proven the efficiency of the solution to reduce losses and impacts.
	Community Resilience	4	3	Surveys and feedbacks led consequently after each crisis continuously, confirm the efficiency for community resilience. These continuous feedbacks and return on experience are used to adapt the solution constantly to enhance its efficiency integrating users' needs and new technologies.
	Feedback Mechanisms	4	3	Users can use the platform to provide feedback on the various hazards by posting a photo and an associated comment. This feedback is then validated and shared with other users.

### 3.20. Social Media Monitoring Tool: SURICATE-Nat

#### 3.20.1. Overview

The [SURICATE-Nat platform](#) has been developed by BRGM for the continuous monitoring and analysis of original tweets (i.e., excluding retweets) written in French after the occurrence of natural disasters (earthquakes and floods).

#### 3.20.2. Capabilities

Thanks to the Twitter streaming API, each tweet captured is processed to extract thematic information, as well as a preferred geolocation.

In addition to feeding a dashboard contributing directly to situational awareness, this enriched Twitter data can also be merged with instrumental data (i.e., measurements from seismometers) to refine the rapid estimation of seismic intensity.

#### 3.20.3. Availability

The [SURICATE-Nat platform](#) has been in a pilot phase until early 2023. Then, the transformation of the Twitter social network into “X” has resulted in the loss of many platforms such as SURICATE-Nat with free access to the dynamic data collection function, making dynamic data collection impossible. In doing so, “X” has aligned itself with all the other major platforms that only distribute their data on a pay-per-use basis, with access costs prohibitive for civil security applications.

The SURICATE-Nat platform is currently not maintained, and it is not collecting any up-to-date data.

#### 3.20.4. TRL

The TRL of the SURICATE-Nat solution is estimated around 7 (demonstration for several years on a public website, with actual real-time events).

#### 3.20.5. Solution in other EU projects

The solution has also been presented and exploited during the [H2020 EU project TURNkey](#) (2019-2022).

#### 3.20.6. Role in GOBEYOND

Monitoring social media is clearly a way of enriching crisis managers' situational awareness of the effects of ongoing events, by capturing first-hand information from citizen-sensors. Such a solution is complementary to other solutions that are more heavily based on technical algorithms and sensors. A solution like SURICATE-Nat is also an efficient approach to engage citizens on social media platforms.

#### 3.20.7. Benchmarking

Table 25 Benchmarking evaluation table for SURICATE-Nat

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
Ge nat	Relevance	4	3	Complementary to technical tools (e.g., SEISAid)
	Multi-hazard Capability	3	1	Tested on earthquakes and floods.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Performance	3	0	Depends on Twitter/X coverage, as well as on the reliability of the information extraction codes, which depend in particular on the phenomena considered.
	Genericity	2	-2	Works only for Tweets in French (adding another langue requires a new thematic analysis)
	Coverage and Reach	3	0	Depends on Twitter/X coverage
	Community Engagement and Training	2	1	Facilitates the engagement of citizens via social media
	Testing and Drills	2	2	Tested for several years on real events
	Accessibility	2	-3	Issues with the new Twitter/X API
<b>Technological</b>	Technological Infrastructure	3	-3	Issues with the new Twitter/X API
	Maturity	4	2	High TRL
	Lead Time and Accuracy	4	2	Very quick estimates; accuracy depends on Twitter coverage
	Scalability and Adaptability	3	0	Works only for Tweets in French (adding another langue requires a new thematic analysis)
	System Integration	2	2	Integration of the Twitter/X API with BRGM's algorithms
	Real-Time Monitoring	3	-2	Issues with the new Twitter/X API
	Interoperability	2	-1	Designed for Twitter/X only
	Security	3	1	Secure IT infrastructure on BRGM servers
	Innovation and R&D	2	1	Platform enriched by work carried out through several research projects
	Support	3	-3	Issues with the new Twitter/X API
<b>Business</b>	Budget and Sustainability	3	-3	Not sustainable with the new conditions to access the Twitter/X API
	Benefit-Cost Analysis	2	-2	Not available
	Policy and Governance	2		
	International Standards	2		
	Insurance and Liability	3	2	Compliance with EU GDPR rules and with the Twitter/X platform usage rules
<b>Informational</b>	Data Quality and Reliability	3	0	Depends on Twitter/X coverage (number of users and messages)
	Warning Message Clarity	3	1	Only qualitative information
	Disaster Risk Reduction Integration			
	Community Resilience			
	Feedback Mechanisms	2	-3	No mechanism

### 3.21. Smartphone applications: GIN

#### 3.21.1. Overview

The Joint Information Platform for Natural Hazards (GIN) combines all available data on natural hazards in Switzerland in a user-friendly map application. It provides a solid foundation for identifying natural hazards early and mastering them successfully.

### 3.21.2. Capabilities

Extreme weather events such as storms, flooding and avalanches can never be accurately predicted. Federal, cantonal and local safety experts often find need to decide on protective measures under great time pressure, relying on a wide range of information such as water level and flow measurements, weather and hazard forecasts and much more. This information is available centrally to experts via GIN.

It includes measurements and observation data, predictions, warnings, models and bulletins: Real-time measurement data from 1,200 weather stations, 300 water-monitoring stations and 150 snow-monitoring stations, weather forecasts and predicted water levels and flows, earthquakes with expert assessments, imaging data such as satellite images or precipitation radar, natural hazard warnings, situation assessments by experts provided in bulletins.

### 3.21.3. Availability

Federal, cantonal and local natural hazard experts have access to the platform free of charge once they have registered. GIN currently has around 3,000 users, including emergency services, civil defense personnel, armed forces, cantonal specialist staff, natural hazard advisors to municipalities, regional management staff, mountain railway operators and private engineering firms. The platform is available solely to protect the public from the impact of severe weather or other natural hazards. Commercial use is prohibited.

### 3.21.4. TRL

The GIN platform can be classified as TRL 9 (real system proven in the operational environment).

### 3.21.5. Role in GOBEYOND

As a multi-hazard platform designed for first responders and other specialists in Switzerland, impact-related outputs produced within **GOBEYOND** will be integrated into it – likely by creating a closed user-group - and hence made available to our stakeholders.

### 3.21.6. Benchmarking

Table 26 Benchmarking evaluation table for GIN

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance			
	Multi-hazard Capability	2	3	Unites information of all relevant natural hazard phenomena in Switzerland.
	Performance	NA	NA	It is an information display platform, not a model.
	Genericity	2	2	
	Coverage and Reach	2	0	
	Community Engagement and Training	2	1	Regular user trainings are offered in all official Swiss languages; however, the tool may be somewhat overwhelming for non-technical practitioners due to its comprehensiveness.
	Testing and Drills	2	2	
	Accessibility	2	0	

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
<b>Technological</b>	Technological Infrastructure			
	Maturity	2	3	Operational platform.
	Lead Time and Accuracy	3	NA	It “just” displays the individual Numerical Weather Prediction products & other natural hazard products, which have their specific lead-times and accuracies; therefore, this cannot be generalized.
	Scalability and Adaptability			
	System Integration	3	1	See comment “interoperability”; however, use of the GIN platform is already part of many first responders “work flows”.
	Real-Time Monitoring			
	Interoperability	3	0	It brings together many modelling and information outputs, however, as a platform it is a standalone tool; ingesting new data pipelines into it challenging; retrieving data for further processing is not possible as it is not designed for this.
	Security			
	Innovation and R&D			
	Support	2	2	There is technical support available for the platform.
<b>Business</b>	Budget and Sustainability	NA		
	Benefit-Cost Analysis	NA		
	Policy and Governance	NA		
	International Standards	NA		
	Insurance and Liability	NA		
<b>Informational</b>	Data Quality and Reliability	3	3	
	Warning Message Clarity	3	2	
	Disaster Risk Reduction Integration			
	Community Resilience			
	Feedback Mechanisms	1	0	

### 3.22. IoT applications: Maestro Telemetry System

#### 3.22.1. Overview

The Maestro telemetry system is a recent research development that utilizes IoT technologies to enhance the forecasting and risk management of forest fires. More information is available at [Maestro website](#). The system is currently available as a prototype.

#### 3.22.2. Capabilities

The Maestro telemetry system predicts forest fire risks using geolocated weather data from low-cost sensor nodes. These nodes monitor forest microclimates and detect drought

conditions. In a fire, they switch to emergency mode, sending frequent updates to aid real-time fire spread prediction, firefighting management, and evacuation planning.

### 3.22.3. Availability

The system is currently available as a prototype. More information is available at: [https://maestro.csd.auth.gr/?page\\_id=292](https://maestro.csd.auth.gr/?page_id=292)

### 3.22.4. TRL

The Maestro telemetry system has reached TRL 4: technology validated in the lab. Field tests are currently being scheduled pending permissions from the Greek forestry department.

### 3.22.5. Solution in other EU projects

The Maestro telemetry system was designed as part of a national project, specifically as a component of Greece's recent disaster management initiative, *Maestro: Managing Forest Fires via IoT*. As of now, it has not been tested or integrated into EU projects.

### 3.22.6. Role in GOBEYOND

The Maestro telemetry system, utilizing IoT, could enhance and facilitate wildfire management solutions in **GOBEYOND**. It could complement existing solutions based on hazard maps, surveillance UAVs and drones, and video and radar surveillance systems. Its advantage over the systems currently used by the Greek civil protection for issuing fire risk prediction maps lies in its ability to provide real-time, geographically localized information throughout the forest. In the event of a fire, the sensor nodes switch to an emergency state, providing more frequent measurements to predict fire spread and effectively manage firefighting forces and population evacuation.

### 3.22.7. Benchmarking

Table 27 Benchmarking evaluation table for Maestro Telemetry System

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	3	3	Weight is 3/4 as there are other hazards that will appear more in the pilots. Score 3/3 as due to its relevance for wildfire management.
	Multi-hazard Capability	1	0	No multi-hazard as of now, but could be added.
	Performance	4	2	More testing needed to evaluate its performance.
	Genericity	3	1	
	Coverage and Reach	4	3	It provides coverage in comparison with other wildfire solutions and it.
	Community Engagement and Training	NA	NA	
	Testing and Drills	2	Unknown	
	Accessibility	1	-3	No special effort to make it accessible or inclusive, e.g., people with visual impairment.
Technologic	Technological Infrastructure	2	2	The technology is not the most sophisticated one but its goal is to be low-cost and it will be commonly destroyed/burned.
	Maturity	2	1	It is a very recent solution with a TRL of 4.
	Lead Time and Accuracy	4	2	Providing accurate and timely data is crucial, but the times are not rigorously tested yet.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Scalability and Adaptability	3	2	The system is built with scalability in mind, allowing for easy expansion and adaptation.
	System Integration	3	2	Not 3/3 as it contains many components/building blocks and their interconnection must be seamless.
	Real-Time Monitoring	4	3	
	Interoperability	3	1	Custom configurations are needed.
	Security	4	2	It contains temperature, fire, smoke detectors.
	Innovation and R&D	2	3	Backed by ongoing research.
	Support	2	1	
<b>Business</b>	Budget and Sustainability	3	2	Cost-effective solution, deemed sustainable.
	Benefit-Cost Analysis	4	3	Low-cost (<150 euros per system), enabling larger coverage.
	Policy and Governance	3	2	Aligns with most standards-need to follow a formal procedure.
	International Standards	3	1	
	Insurance and Liability	2	1	
<b>Informational</b>	Data Quality and Reliability	4	2	High data quality but more validation efforts could help.
	Warning Message Clarity	2	1	
	Disaster Risk Reduction Integration	3	2	In principle
	Community Resilience	3	3	
	Feedback Mechanisms	2	1	Preliminary feedback mechanisms integrated so far.

### 3.23. Storm Surge: German Warning System

#### 3.23.1. Overview

The Storm Surge Warning Service (Sturmflutwarndienst) in Germany is a key component of the country's disaster risk reduction measures. Operated by the Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie - BSH), this system specifically focuses on the North Sea and Baltic Sea coasts. It aims to provide early warnings about potential storm surge events, allowing local authorities to take necessary precautions and evacuate citizens if needed.

#### 3.23.2. Capabilities

The Storm Surge Warning Service uses a complex set of hydro-meteorological data, including wind speed, atmospheric pressure, sea surface temperature, and tide levels, to predict storm surges. The system utilizes advanced hydrodynamic models to simulate potential storm surge scenarios, providing accurate and timely forecasts. These forecasts are then disseminated to local authorities, emergency services, and the public. The service operates 24/7, ensuring continuous monitoring and forecasting of storm surge events.

### 3.23.3. Availability

Information can be found on the [official website](#) of the Federal Maritime and Hydrographic Agency of Germany (Bundesamt für Seeschifffahrt und Hydrographie). Nevertheless, specific details on the Storm Surge Warning Service is not readily available in English.

### 3.23.4. TRL

The Storm Surge Warning Service should have a TRL 9 since it is a well-developed and validated system. It has been operational for many years and has successfully provided early warning for numerous storm surge events, enabling effective responses and minimization of potential damages. The system is continually updated and improved based on the latest scientific research and technological advancements, ensuring its ongoing effectiveness and reliability.

### 3.23.5. Role in GOBEYOND

This national storm surge warning service offers early warnings and forecasts for storm surges, ranging from normal to very severe, accessible on the [BSH website](#), fax to authorities, FTP download, radio broadcasts, the WarnWetterApp of the German Weather Service, and fee-based automated telephone alerts (FACT 24). Model results support BSH services such as water-level forecasting and storm-surge warnings, and are also used by national institutions such as the Navy and the Maritime Search and Rescue Association. These results are stored in a data archive, available for internal and external use.

### 3.23.6. Benchmarking

Table 28 Benchmarking evaluation table for Storm Surge Warning System

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
General	Relevance	4	3	Crucial for storm surge events
	Multi-hazard Capability	3	2	While primarily focused on storm surges, the service also provides data useful for other coastal hazards, including flooding and ice conditions.
	Performance	4	3	Strong track of good results
	Genericity	2	2	While specialized for storm surges, the model results can be adapted for other maritime and environmental applications.
	Coverage and Reach	3	-2	Extensive coverage of the North Sea and Baltic Sea. Not covering well GOBEYOND pilots.
	Community Engagement and Training	2	1	Some community engagement and training programs exist.
	Testing and Drills	3	3	Regular testing and drills are conducted, involving various national institutions, ensuring preparedness.
	Accessibility	3	2	Information in German, warnings to everyone, many open data, e.g. <a href="https://www.geoseaportal.de/">https://www.geoseaportal.de/</a> but access to models can be limited to partners/ products.
Technological	Technological Infrastructure	4	3	robust and comprehensive numerical model system for accurate forecasts and data dissemination.
	Maturity	3	3	Many years of with years of operational experience and continuous improvements.

	Criterion	Weight (1 to 4)	Score (-3 to 3)	Justification
	Lead Time and Accuracy	4	3	Generally provides accurate and timely warnings
	Scalability and Adaptability	3	2	Need for adaptation
	System Integration	3	2	Integrates well with other national and regional systems.
	Real-Time Monitoring	4	3	
	Interoperability	3	3	Good interoperability with other systems and national institutions,
	Security			
	Innovation and R&D	3	2	
	Support	3	-1	Limited in German.
<b>Business</b>	Budget and Sustainability	NA	NA	
	Benefit-Cost Analysis	NA	NA	
	Policy and Governance	3	3	Strong governance framework supports the service
	International Standards	2	2	Complies with standards
	Insurance and Liability	2	0	Limited
<b>Informational</b>	Data Quality and Reliability	4	3	
	Warning Message Clarity	4	2	
	Disaster Risk Reduction Integration	3	2	
	Community Resilience	NA	NA	
	Feedback Mechanisms	2	1	

## 4. Benchmarking Analysis & Findings

In the previous section, 23 tools were evaluated and benchmarked by experts. The experts filled out a scorecard with four dimensions: general, technological, business, and informational. Each dimension had weights ranging from 1 to 4 and scores from -3 to 3.

- **General Dimension (8 criteria):** Relevance, Multi-hazard Capability, Performance, Genericity, Coverage and Reach, Community Engagement and Training, Testing and Drills, Accessibility.
- **Technological Dimension (10 criteria):** Technological Infrastructure, Maturity, Lead Time and Accuracy, Scalability and Adaptability, System Integration, Real-Time Monitoring, Interoperability, Security, Innovation and R&D, Support.
- **Business Dimension (5 criteria):** Budget and Sustainability, Benefit-Cost Analysis, Policy and Governance, International Standards, Insurance and Liability.
- **Informational Dimension (5 criteria):** Informational Data Quality and Reliability, Warning Message Clarity, Disaster Risk Reduction Integration, Community Resilience, Feedback Mechanisms.

The scores of the evaluations were presented in colour, as heat maps, visually illustrating data intensity and patterns across a range of values. They effectively highlight trends, outliers, and areas requiring attention or further investigation. In Table 29 , we present a brief summary of the trends found:

Table 29 Summary of findings in the GOBEYOND benchmark evaluation

No	Tool/Technology Name	Main finding
1	European Flood Awareness System (EFAS)	Has several strengths that make it an effective and rigorous tool for flood forecasts, there are also areas for improvement, particularly in terms of its accessibility, scalability, and data quality control.
2	Flash flood systems (FF-EWS)	Shows high relevance and performance for managing flash floods. It has been widely tested across Europe and offers good coverage and reach. The system also offers strong technological infrastructure and maturity and has shown encouraging results for lead time and accuracy.
3	CLIMADA platform	Is an open-source platform scored well in relevance, multi-hazard capability, and innovation and R&D but could improve in support and accessibility.
4	Storm Surge Warning System	It is a mature, accurate, and technologically robust tool that provides timely warnings and reliable data. However, it would benefit from broader coverage beyond the North Sea and Baltic Sea and improved accessibility in languages other than German.
5	European-wide Systems - Heat Health Indices	It is a promising prototype for forecasting heat-related health risks across Europe. It is currently in development and not yet operational. Its main strengths lie in its technological infrastructure and global coverage, while its main areas for improvement are community engagement, real-time monitoring, and system integration.
6	Drought warning system	It is specific for droughts and applies to the whole of Europe. It offers up to seven months lead time and 3 months of reliable forecast. However, it has few operational uses up to now and beyond Europe, academic work is required.
7	Fire danger EWS: DISARM	It is a mature, scalable, and technologically robust system that provides real-time wildfire monitoring with high-quality data. However, it could benefit from broader coverage beyond the Eastern

No	Tool/Technology Name	Main finding
		Mediterranean, improved interoperability, better community engagement, and clearer feedback mechanisms.
8	PRESTo: Source-based impact estimates	Provides strong technological infrastructure and scalability but lacks in multi-hazard capability and policy and governance.
9	QUAKEUp: P-wave based impact estimates	Scored well in relevance, coverage, and technological infrastructure but was marked down for its lack of multi-hazard capability and policy and governance issues.
10	SAVE: OnSite Alert Level	Demonstrated high relevance and coverage but lacks multi-hazard capabilities and has policy and governance issues
11	P-alert: Onsite P-wave based warnings	Is a relevant on-site earthquake early warning system, it requires further development and testing to become fully operational and integrated into broader systems. Its main strengths lie in its high-tech infrastructure and broad coverage, while its main areas for improvement are user education/training, customization for specific seismic stations, and integration into disaster risk reduction actions.
12	SEISAid-Antilles tool: rapid response in French West Indies	Has high relevance for the rapid response context, but its multi-hazard capability is limited. It has been tested extensively and has a high level of technological maturity. However, its coverage and reach are currently limited to specific regions.
13	QLARM - Quake Loss Assessment for Response and Mitigation	It is the only earthquake real-time loss estimating tool in Europe that operates in all countries. It has been the most accurate worldwide for the last 10 years and provides good coverage and reach. There are some opportunities for improvement, i.e. it currently lacks accessibility and is supported on a voluntary basis and on demand.
14	EASE system for volcanoes	Provides a strong multi-hazard capability, good performance and good scalability and adaptability. It, however, lacks in accessibility and has limited community engagement and training.
15	Volcanic Ash Dispersion	It is an operational tool for monitoring and forecasting the volcanic plume pathway in near real-time. It has been tested in relevant environment and has a high level of technological infrastructure. However, it lacks multi-hazard capability and its real-time monitoring is currently being programmed.
16	Volcanic Ash Dispersion - Inverse modelling	Affordable early warning solution, tested to TRL 4. It is scalable and adaptable but needs better robustness and real-time monitoring. While it aligns with some international standards and is supported by research, it requires more data validation and improved warning clarity and feedback mechanisms.
17	Tsunami DSS - Vigirisks platform	Is highly relevant for tsunami early warning and impact assessment. It provides very accurate tsunami simulations and fast outputs. However, it is currently tested only in specific regions and requires new offline simulations for application to new regions.
18	The Catalan LEWS	Is relevant and effective in real-time monitoring and alerting but lacks multi-hazard capabilities and has limited accessibility and support.
19	ARGOS Services: Multi-Hazard Impact Based Early Warning System platform	It is a multi-hazard management platform, that can be easily adapted to different pilots. It has a state-of-the-art technological infrastructure and is aligned with European flood directives and WMO recommendations. However, its maps are difficult to make accessible to the visually impaired.
20	Wiki-Predict: Real-time risk management platform	Is a management platform with multi-hazard capability. It has been shared with local authorities, insurers, and businesses for over 15 years and has proven its capacity to reduce losses.
21	Suricate-Nat: Continuous Monitoring and Analysis of tweets after natural disaster (flood & earthquakes)	Is relevant and adaptable for managing earthquakes and floods. However, its performance and coverage depend on Twitter coverage. Its technological infrastructure has some issues with the new Twitter API, which affects its real-time monitoring and support.

No	Tool/Technology Name	Main finding
22	Maestro: Managing Forest Fires via IoT	Shows high relevance for wildfire management and has been rated well for its coverage, real-time monitoring, and cost-effectiveness. However, it lacks in accessibility and needs further testing for performance evaluation.
23	GIN – Meteoswiss: displays measurements, forecasts and natural hazard warnings and collects crowdsourcing observations	Provides a comprehensive overview of various natural hazard phenomena but could improve on its system integration and interoperability. The criteria related to business were not evaluated given that GIN is the national Swiss platform which is actively maintained and is operational.

### 4.1. EU Project Coverage

Most of the solutions presented and benchmarked in this deliverable have already appeared, been discussed, developed or evaluated within other EU Projects.

Table 30 Benchmarked tools and relevance with other EU Projects

Tool	Relevant EU project
PRESTo	SAFER, NERA, Reakt
QuakeUp	EPOS-ON action
EFAS: LISFLOOD model	Numerous, e.g., EIFFEL, SEED-FD
Heat health indices	TRIGGER
CLIMADA	Numerous, e.g., CASCADES, PROVIDE, RECEIPT, UCLIMADAPT
Fire danger EWS	DISARM
Landslide EWS, ARGOS, Drought Warning System	ANYWHERE
Flash flood EWS	EMIHI, IMPRINTS, ERICHA, ANYWHERE, UCPM SMUFF, TAMIR, EDERA
SURICATE-Nat	TURNkey
VONA	E-shape
VONA with inversion	Aeolus-NEWTON ESA, E-shape
Wiki-Predict	ANYWHERE, COSPARIN

### 4.2. GOBEYOND Integration Index

To compute the **GOBEYOND** integration index, we use a weighted scoring system based on the provided weights and scores. The formula for the index is:

$$Integration\ Index\ (\%) = \frac{\sum_{i=1}^n (W_i \times \hat{S}_i)}{\sum_{i=1}^n (W_i)} \times 100 \tag{1}$$

Where:

$W_i$ : is the weight assigned to criterion  $i$ ,

$S_i$ : is the score assigned to criterion  $i$ ,

$\hat{S}_i$ : is the normalized score assigned to criterion  $i$  computed with the formula ( $\hat{S}_i = \frac{S_i+3}{6}$ )

$n$ : is the total number of criteria (28 in our case)

This formula ensures that each criterion's score is appropriately normalized to reflect its relative contribution based on its weight, while handling cases where criteria might not have been evaluated or are not applicable. It provides a simple but balanced approach to deriving an overall assessment index from diverse sets of criteria with different weights and score ranges.

Table 31 Computation of GOBEYOND integration indexes

Tool	General (%)	Technological (%)	Business (%)	Informational (%)	Overall Index
Wiki-Predict	97.8	100	100	100	<b>99.4</b>
Flash flood	98.8	100	88.9	98.1	<b>98.4</b>
ARGOS	91.2	95.2	90.5	89.7	<b>92.4</b>
In-VONA	85.3	87.7	86.5	82.1	<b>86</b>
Droughts	85	86	-	-	<b>85.6</b>
QLARM	88.3	78.1	--	91.7	<b>85.3</b>
VONA	78.3	89.3	86.5	82.1	<b>85.1</b>
Storm Surge EWS	81.3	88.3	81	85.9	<b>84.9</b>
EASE	83.3	90.4	70	87	<b>84.5</b>
DISARM EWS	87.2	91.7	63.6	73.8	<b>83.3</b>
MAESTRO	80.2	82.7	82.2	82.1	<b>81.9</b>
Landslide	80.1	89.4	--	61.1	<b>79.2</b>
Tsunami DSS	64.9	87.8	70	83.3	<b>78.8</b>
EFAS	77.1	85.5	77.4	64.7	<b>77.7</b>
CLIMADA	89.6	66.7	91.7	63.3	<b>77.6</b>
SEISAid	77	85.6	48.7	84.7	<b>76.8</b>
SAVE & P-wave alert	68.8	92.1	60	68.5	<b>75.6</b>
PRESTo & QuakeUp	63.5	92.1	60	68.5	<b>74.5</b>
GIN	72.2	71.7	--	85.7	<b>75.3</b>
Heat health	65.4	45.5	55.6	44.8	<b>53.7</b>
SURICATE-Nat	58.7	49.4	23.6	43.8	<b>47.1</b>

Based on the computed percentages and standard categorization ranges used in similar integration decisions, the tools can be classified as follows:

- Excellent Integration Candidates (85% and above):** Wiki-Predict (99.4%), Flash flood (98.4%), ARGOS (92.4%), In-VONA (86.0%), Droughts Warning (85.6%), QLARM (85.3%), and VONA (85.1%)
- Strong Integration Candidates (76% - 84.9%):** Storm Surge EWS (84.9%), EASE (84.5%), DISARM (83.3%), MAESTRO (81.9%), Landslide EWS (79.2%), Tsunami DSS (78.8%), EFAS (77.7%), CLIMADA (77.6%), SEISAid (76.8%), SAVE (76.3%), and P-Wave (76.3%)
- Good Integration Candidates (70% - 75.9%):** QuakeUp (75.4%), GIN (75.3%), and PRESTo (75.3%)
- Fair Integration Candidates (Below 70%):** Heat health (53.7%) and SURICATE-Nat (47.1%)

Note that the final evaluations were conducted by experts, but it is important to acknowledge the possibility of bias, so these findings should be interpreted with consideration for that context.

### 4.3. Benchmarking Findings

Figure 1 and Figure 2 present a comprehensive overview of the evaluated criteria and their corresponding tools.

While they highlight a broad coverage of strengths, it also reveals certain areas where improvement is needed. For instance, while several effective individual solutions have been identified, only a handful of them address multiple hazards.

Figure 3 and Figure 4 correlate each solution with the specific hazard it seeks to mitigate. A broad spectrum of solutions is evident, tackling a variety of hazards, both weather-related and geological. However, there is room for enhancing the range and diversity of hazards addressed by these solutions.

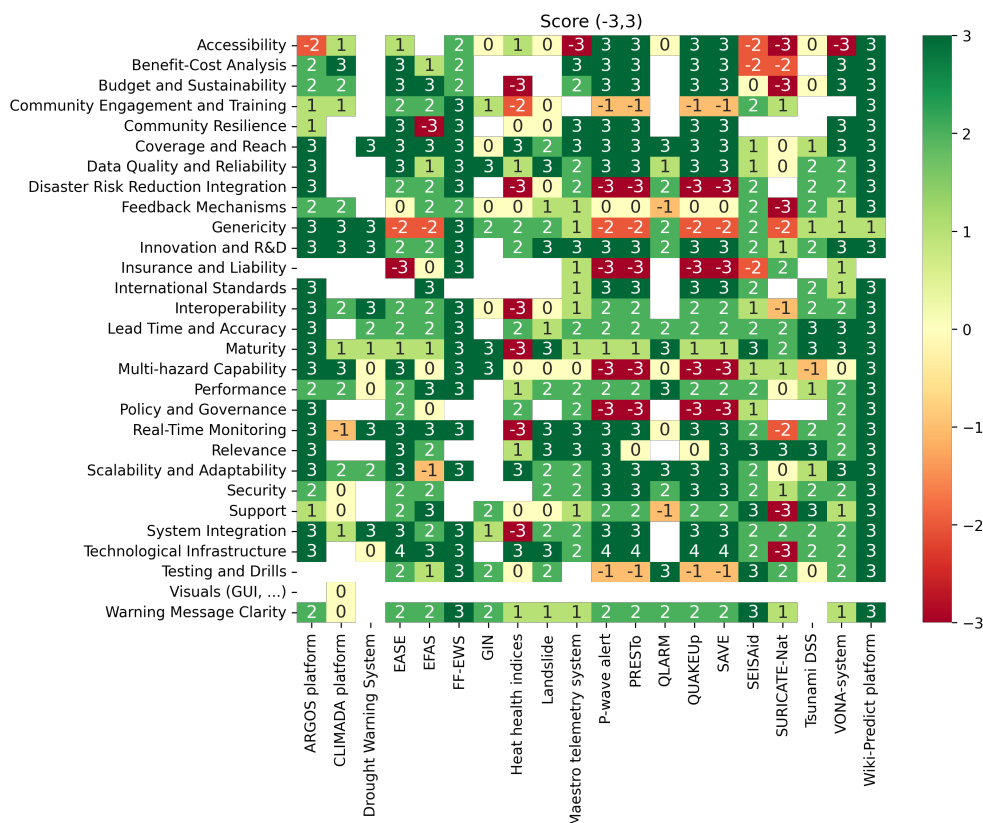


Figure 1 Heatmap for each criterion scores and benchmarked tools. Empty data corresponds to unknown or non-applicable answers in the benchmarking tables.

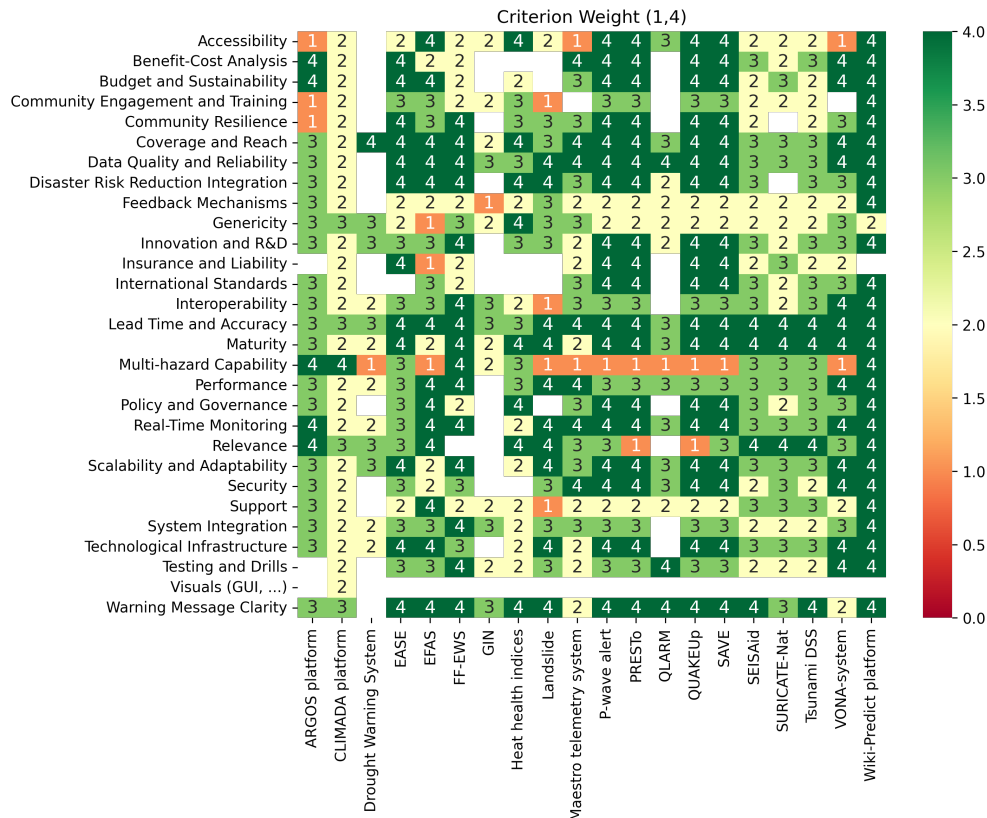


Figure 2 Heatmap for each criterion weight and benchmarked tools.

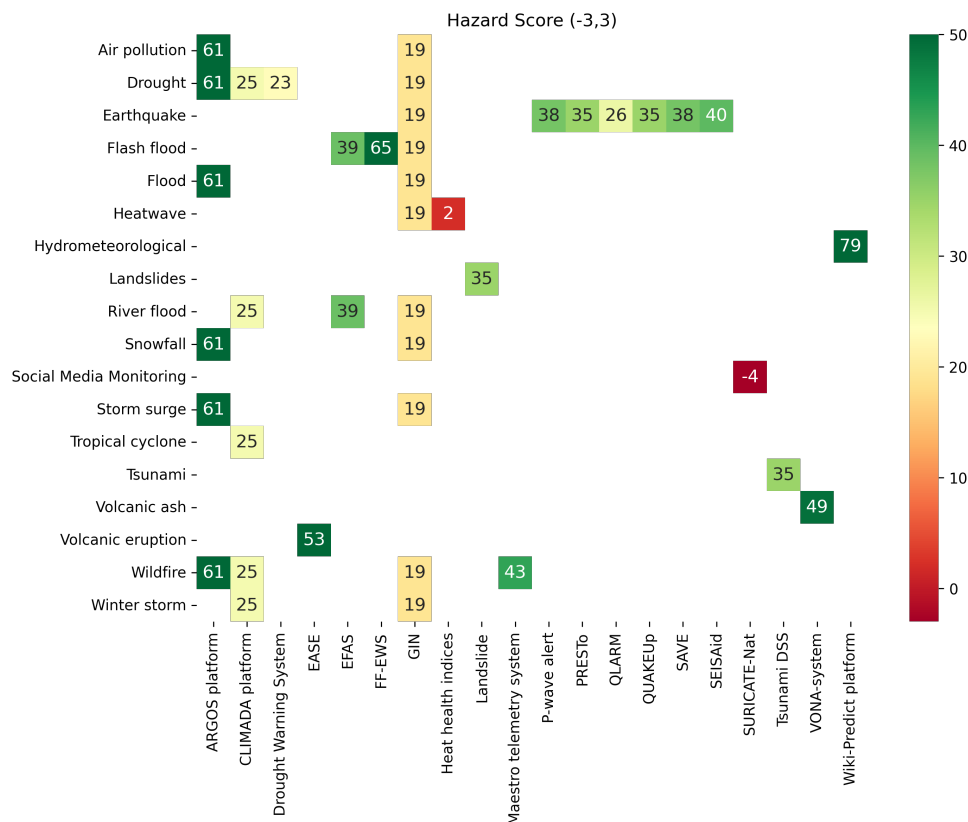


Figure 3 Heatmap for hazard types score and benchmarked tools. The scores are computed via addition of individual values.

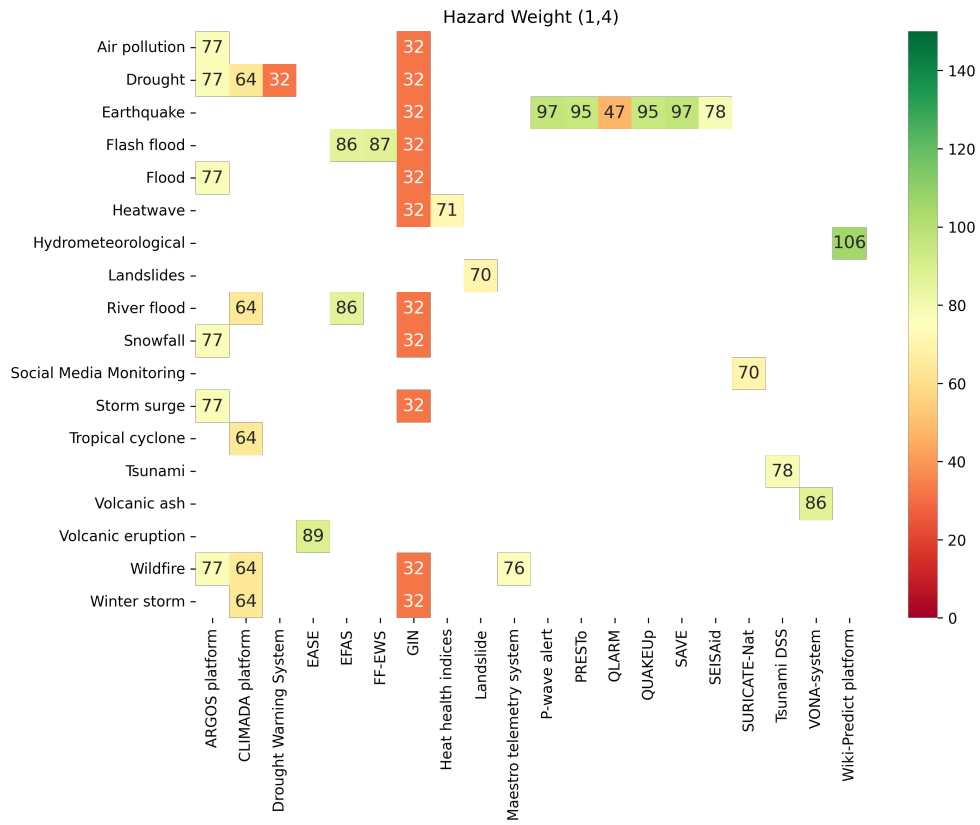


Figure 4 Heatmap for hazard types weight and benchmarked tools.

## 5. Conclusions

This deliverable has identified and assessed tools and technologies relevant to **GOBEYOND**, drawing on input from expert consortium partners and an academic literature review. It offers an overview of the current state-of-the-art in tools and techniques for natural disaster management, and highlights related EU projects to emphasise their strategic relevance.

A catalogue of tools was compiled, and a qualitative benchmarking framework was proposed to assess their relevance, usability, and applicability, guiding their selection for the project objectives. The framework also proposes evaluation metrics for each technology and presents indicative tools that would add value if integrated into the **GOBEYOND** platforms.

From the evaluation, the following insights are highlighted:

- Most tools show **high relevance** scores (close to 3) in terms of their alignment with the intended use cases or hazard mitigation objectives.
- Several tools **lack multi-hazard** capabilities indicating they are specialized for specific hazards rather than being adaptable to multiple types.
- Tools generally score **well in performance**, with some showing higher reliability and accuracy in their outputs and operational uses.
- Many tools score very well in **coverage and reach**, indicating they are accessible and applicable across various geographical scales or user needs.
- Scores for the **technological infrastructure are generally high** (around 3), suggesting most tools leverage advanced technologies and are adaptable to different platforms.
- **Scalability and availability** are weighted highly by partners along with real-time monitoring capabilities, testing, and drills.
- Scores for **interoperability** vary considerably, suggesting tools generally support integration with other systems but may require additional efforts for seamless interoperability.
- The criteria for the informational and business dimensions are ranked lower than the general and technological dimensions.
- Community resilience, support, and insurance & liability were among the criteria with the lowest weight.
- Most tools score moderately (close to 2) in security, indicating they implement basic security measures but may have room for improvement in terms of robustness.
- Insights into cost-effectiveness and benefits are mixed, with some tools scoring high (around 3) in delivering value relative to costs, while others have insufficient data.

Overall, this deliverable provides a structured foundation for selecting, integrating, and further evaluating technologies within the **GOBEYOND** ecosystem. The staged benchmarking approach supports immediate integration opportunities while preparing the project for future interoperability, scalability, and operational readiness.

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