



HTML5 FRAMEWORK AND USER-CENTRIC APPLICATIONS FOR CLIMATE RESILIENCE

ClimEmpower Work Package 3, D3.3, v1



Project ClimEmpower: User Driven Climate Applications Empowering
Regional Resilience

Work package 3, Deliverable D3.3

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List of Acronyms

Acronym	Definition
API	Application programming interface
CC	Climate Change
CI/CD	Continuous Integration / Continuous Deployment
CDS	(Copernicus) Climate Data Store
CLIMAAX	CLIMAAX - CLIMAtE risk and vulnerability Assessment framework and toolbox (Grant agreement ID: 101093864, 2023-2026; https://cordis.europa.eu/project/id/101093864)
CoP	Community of Practitioners
CSS	Cascading Style Sheets
DoA	Description of Action
DOI	Digital object identifier
DSS	Decision Support System
EC	European commission
ECMWF	European Centre for Medium-Range Weather Forecasts
FAIR	Findable, Accessible, Interoperable and Reusable
FIRMS	Fire Information for Resource Management System
GA	Grant Agreement
GUI	Graphical user interface
HANZE	Historical Analysis of Natural Hazards in Europe
HTML5	HyperText Markup Language version 5
ISF	Indicator Service Framework
ICARIA	ICARIA - Improving ClimAtE Resilience of crltical Assets (Grant agreement ID: 101093806, 2023-2025; https://cordis.europa.eu/project/id/101093806)
JSON	JavaScript Object Notation
JWT	JSON Web Token
KISS	Keep it simple, silly
LEAN	Project management approach that aims to minimise unproductive work through teamwork, empowerment, and continuous improvement of the workflows.
MU	Mission User
MongoDB	Document-oriented NoSQL database
netCDF	Network Common Data Form
RA	Regional Authority
REST	Representational State Transfer
SMART	Specific, Measurable, Achievable, Relevant, Time-bound
SPA	Single-Page Application
SSO	Single Sign-on
TRL	Technology Readiness Level
URI	Uniform Resource Identifier
WP	Work Package
WPL	Work Package Leader

Glossary

Term	Definition
Backend	In software development, the backend refers to the server-side infrastructure that handles data services, logic, and communication, enabling an application to function properly
Climate impacts	The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. Impacts generally refer to effects on lives; livelihoods; health and well-being; ecosystems and species; economic, social and cultural assets; services (including ecosystem services); and infrastructure (based on IPCC, 2018)
CoverageJSON	Standardized format for publishing spatiotemporal data to the Web. The primary design goals are simplicity, machine and human readability and efficiency. (https://www.ogc.org/standard/coveragejson)
C3S	The Copernicus Climate Change Service is an information service provided by the Copernicus Earth Observation Programme of the European Union. (https://www.copernicus.eu/en/about-copernicus)
Docker	Is an open-source platform allowing developers to build and run applications in an encapsulated (containerized) environment, which makes deploying these applications in various environments easier. (https://www.docker.com/)
Frontend	In software development, a frontend describes the (usually) graphical interface that a user sees when interacting with an application
GitLab	GitLab is an open-source code repository, allowing for collaborative software development. (https://about.gitlab.com/)
GitHub	Cloud based platform for collaborative code development. (https://github.com)
Jupyter Notebook	Jupyter Notebook is an open-source software, used for interactive, web-based, computational documents. (https://jupyter.org/)
netCDF	Set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. It is also a community standard for sharing scientific data. (https://www.unidata.ucar.edu/software/netcdf/)
xarray	Open source project and Python package that introduces labels in the form of dimensions, coordinates, and attributes on top of raw NumPy-like arrays (https://xarray.dev/)

Executive summary (publishable)

This document is a Deliverable D3.3 of the ClimEmpower project, reporting on the successful development and deployment of the HTML5 framework and user-centric applications for climate resilience (Task T3.4). The deliverable is of type DEM (Demonstrator, pilot, prototype) and is accompanied by this short report describing the outcomes.

Building on the application architecture established in **D3.1** and the reusable data and indicator services described in **D3.2**, T3.4 has produced an end-user application platform serving five pilot regions: **Andalusia (Spain), Croatia, Cyprus, Greece (Central Macedonia), and Sicily (Italy)**. The platform addresses **four climate hazards (heatwaves, droughts, pluvial floods, and wildfires)** and targets **local government authorities, urban planners, civil protection officers, and policymakers** as its primary user groups.

The platform consists of two main modules accessible from a unified web interface:

1. **Dashboard:** A configurable, widget-based workspace where users freely select, arrange, and resize data components. The widget library includes resilience indicator maps and charts, climate risk maps, vegetation index maps, Copernicus CDS datasets, FIRMS active fire maps, HANZE historical flood event tables, and social media monitoring components. Layouts are persisted per user.
2. **Resilience Recommendations:** A structured module presenting evidence-based adaptation interventions linked directly to the resilience indicators displayed in the dashboard. Recommendations are filterable by dimension and indicator and include strategic descriptions, policy roadmaps, co-benefits, and links to best practices.

All components are served from a containerised backend stack (FastAPI REST API, MongoDB, GeoServer) deployed on the project's production virtual machine. The system uses JWT-based authentication with HttpOnly refresh-token cookies.

A formal **user acceptance testing (UAT) round** was conducted with pilot region representatives during WP4 workshops. Nine feedback items were collected; **six have been resolved, one updated, and two closed as not technically feasible** with clear reasoning provided to the users.

In addition, the deliverable explores the idea of **transforming the Jupyter notebooks**, which are often used in co-creation and co-development, **into fully fledged web applications**. Three experiments demonstrate trade-offs between speed, customization, and reliability in operationalizing research code for end-users.

1. ClimEmpower summary

ClimEmpower is a Horizon Europe collaborative research project dedicated to addressing the ongoing Climate Crisis in Europe by empowering the regional stakeholders in some of the most vulnerable European regions ([Figure 1](#)).

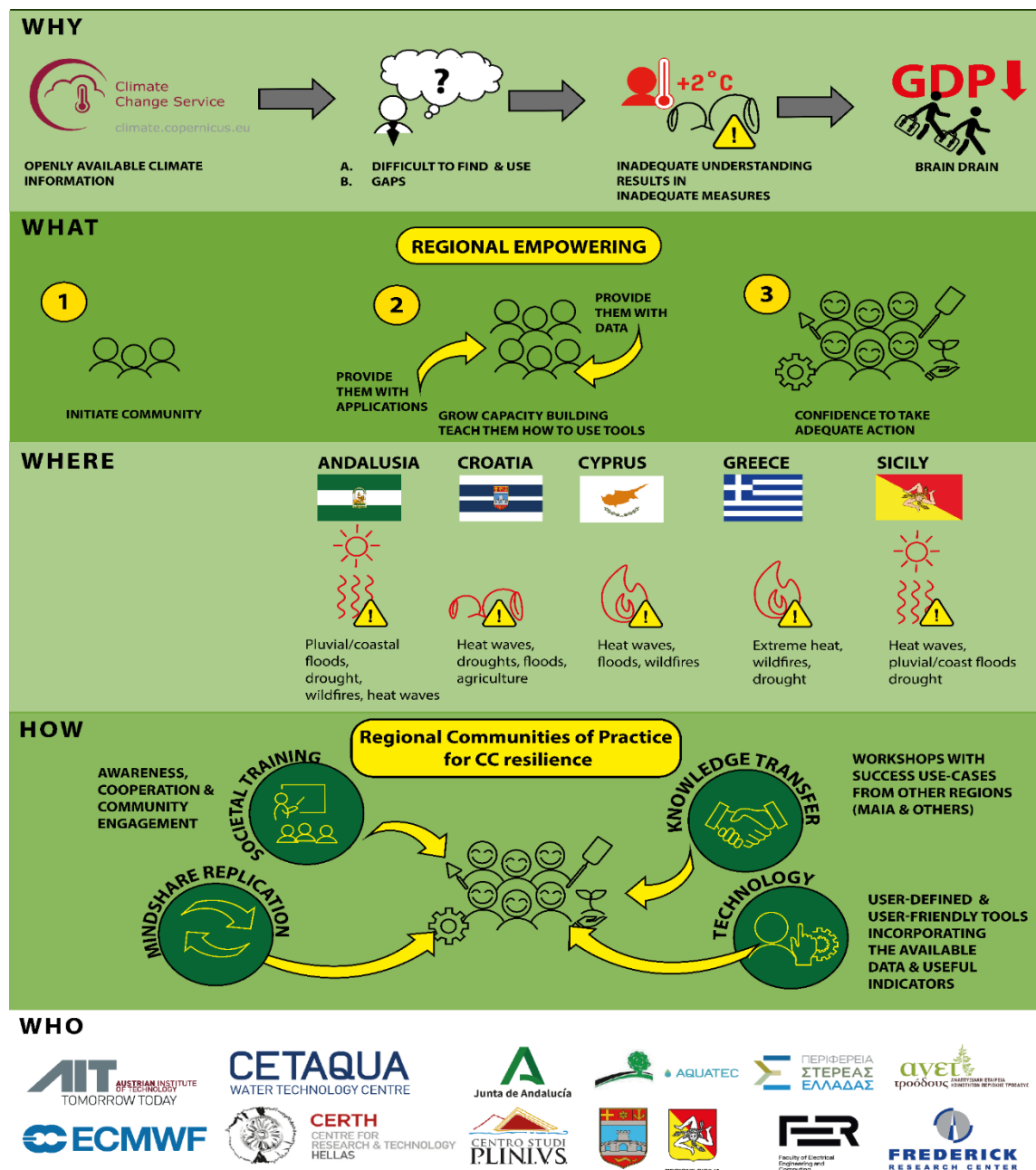
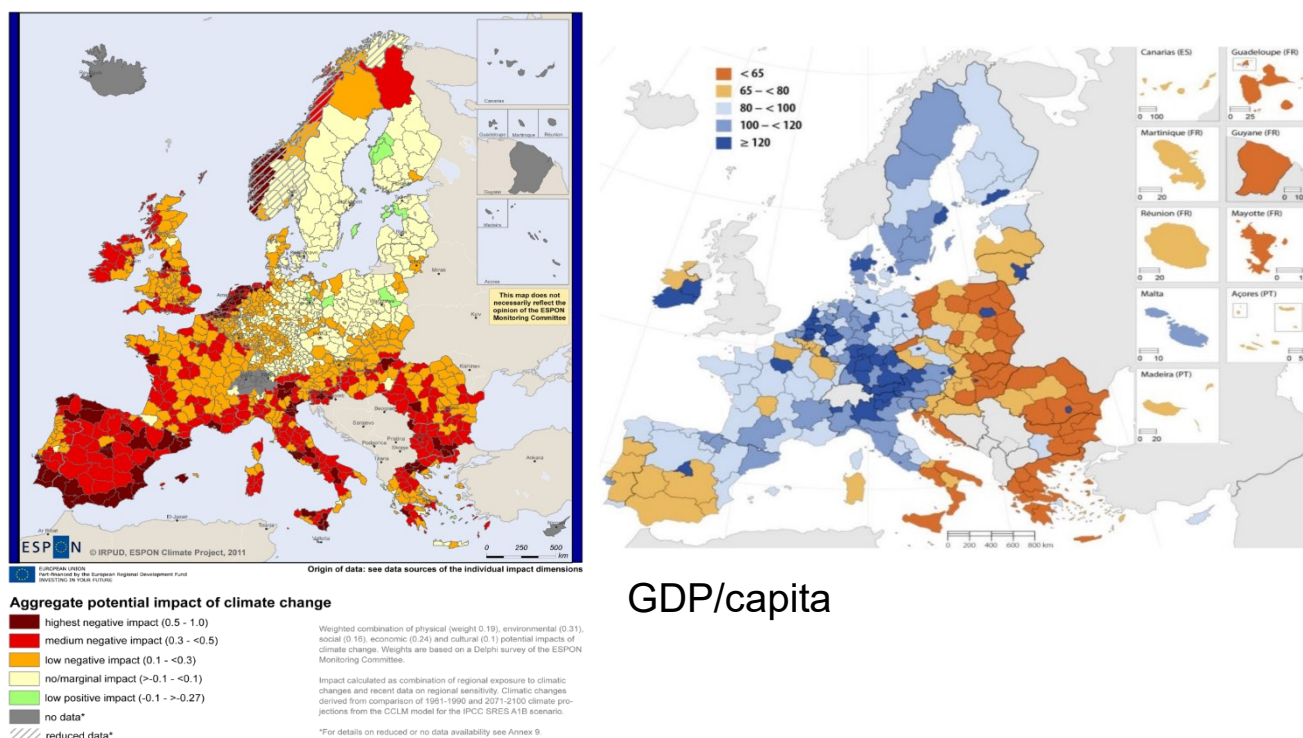


Figure 1: ClimEmpower at a glance: why, what, where, how and who.

1.1 Project Context

Climate risks results from a combination of a hazard, exposure, and vulnerability (REF). Addressing all three aspects is crucial for effective increase of regional resilience. However, exposure, vulnerability, and related aspects, such as adaptive capacity, strongly depend on available knowledge and climate literacy. Consequently, global climate crisis frequently has a higher impact on socioeconomically vulnerable regions, thanks to a higher human and economic potential for addressing the issue in more affluent regions. To maximize its impact, ClimEmpower has therefore chosen to address the EU regions featuring a combination of high potential CC impacts and low and/or stagnant regional GDP/capita. This is mainly the case for



regions in South and Southeast Europe ([Figure 2](#)).

Figure 2.- aggregated potential impact of climate change (<https://www.espon.eu/climate-2012/>); **GDP/capita** (based on <https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210303-1>)

The context the project addresses is thus one of an ongoing global warming, high regional vulnerability and low coping capacity of the participating regions, and the **overarching strategic objective of ClimEmpower** is to empower the Regional Authorities (RAs) and other Mission Users (MUs) in five EU-regions featuring a combination of exceptionally high climate hazards and exceptionally low coping capacity by improving their collective understanding of the Climate Change (CC) hazards, risks and resilient development pathways and supporting their knowledge-based regional planning and development through provision of relevant data, knowledge and user-defined and user-friendly decision support applications.

1.2 Project Objectives

To achieve this overarching goal, **ClimEmpower has identified six SMART² Strategic Objectives (SO)**, each one related to one or several work packages. The SOs have also been classified according to different categories: societal, contributing to improved dialogue, awareness, cooperation and community engagement as highlighted by the European Climate Pact (SO1, SO5); scientific, corresponding to research activities for advances beyond the state of the art (SO2, SO3); technological, suggesting and/or developing novel solutions, integrating state-of-the art and digital advances (SO4); and outreach, aimed at sharing ClimEmpower results to a broader scientific and non-scientific audience, including additional regions and communities, to maximize project impact (SO6).

- SO1 Understand regional background, challenges and expectation (WP1, societal)
- SO2 Addressing the gaps in availability and usability of CC data and services (WP2 and WP4, scientific)
- SO3 Identification, definition, estimating, and communication of climate impact/resilience indicators suitable for local end-users (WP2 and WP4, scientific)
- SO4 Simplify access to CC data and development of end user applications (WP3, technological)
- SO5 Empower the regions to activate and enhance their potential for addressing the climate change challenge. (WP4, societal)
- SO6 Ensure the use and impact of the ClimEmpower outputs (WP4 and WP5, scientific and societal)

ClimEmpower's key ambition is to **prove beyond doubt that CC-resilience should, and can, be an integral part of regional development** everywhere in EU and beyond it. That is, we anticipate that the regional stakeholders will recognise that CC-resilient development pathways offer multiple benefits to them, including but not limited to **higher quality of life and reviving economy**, and that these can be understood using available **data, tools, and services**. Second key ambition of the project is to **help the regions address the CC resilience** in key community systems addressed in five ClimEmpower trials.

Underlying philosophy of the project is to **"help the regions to help themselves"**. This will be achieved through various mechanisms, including co-creation and mediation of the regional "Communities of Practice", provision of the Climate Change -resilience training materials, as well as in provision and training in use of the user-centric data and services – including those that have already been made available through previous research projects and EU initiatives.

² Specific (related to WPs), Measurable (by relevant KPIs), Achievable (the WPs in which they will be achieved are listed), Realistic (since they are referred and explained in the methodology section), and Timebound (each KPI is related to a deliverable and a month of achievement).

2 Introduction

2.1 Deliverable summary

This Deliverable is part of **WP3 - User-centric CC-resilience enhancing services** and documents the outcome of the development of HTML5-based user-centric applications for climate resilience. It describes the architecture, functionality and deployment status of the ClimEmpower application platform, as well as user feedback collected during pilot testing and the corresponding improvement measures implemented.

2.2 End-Users

The ClimEmpower platform is designed to support different types of regional users involved in climate risk assessment and adaptation planning. While their technical backgrounds and information needs vary, three main user profiles can be distinguished.

Technical analysts and data-literate government staff use the platform for more detailed regional climate risk analysis. They work directly with climate and Copernicus datasets and can use computational notebooks and the available processing tools to explore data, calculate indicators, and assess regional risks.

Regional planners and coordinators mainly work with the resulting climate indicators and risk maps. For these users, the configurable dashboard provides access to relevant information without requiring programming skills and supports the preparation and updating of regional adaptation strategies.

Decision-makers and policymakers primarily use the consolidated results and the Resilience Recommendations module to identify adaptation priorities and support planning and policy decisions.

The platform therefore provides different levels of interaction, ranging from direct data analysis to the use of processed indicators and recommendations. Its modular structure and documentation also allow users to review and interpret the underlying indicators and results according to their role and technical expertise.

Access to the platform is currently limited to pre-registered users. Accounts are created by system administrators rather than through self-registration, and each account is assigned to a specific pilot region. The data, indicators and map layers available to a user are consequently restricted to the corresponding regional context.

Beyond the immediate pilot users, the underlying methods, reusable components and interfaces are intended to support future uptake in other regional contexts. This makes it possible to reuse individual elements of the ClimEmpower approach while adapting them to different technical capacities, data availability and adaptation needs.

2.3 Relation to other work

This deliverable is the culminating technical deliverable of WP3 and builds directly on the preceding work of D3.1 - ClimEmpower application architecture and D3.2 - Reusable libraries and services.

D3.1 (Application Architecture, submitted October 2024) established the overall ClimEmpower system architecture, defined the three-phase development strategy, and specified the design principles for the user-facing platform. D3.3 reports the successful realisation of that architecture: the Angular-based frontend, the FastAPI backend, and the GeoServer integration described here correspond directly to the components specified in D3.1, confirming that the implementation is consistent with the agreed architectural blueprint.

D3.2 (Reusable Libraries and Services, submitted January 2026) documented the T3.1 data access service stack — including Polytope, Earthkit, and Covjsonkit — and the T3.2 Indicator Service Framework, comprising climate risk map generation methodology and a structured set of resilience indicators across three complexity levels. The ClimEmpower Platform described in D3.3 is a direct consumer of all these services: risk maps produced by the D3.2 pipeline are published via GeoServer and visualised in the Risk Maps dashboard component; Copernicus Climate Data Store datasets are accessed through the Polytope API and displayed in the CDS Datasets widget; and the resilience indicator values computed by the D3.2 indicator framework are stored in MongoDB and presented in the Resilience Indicators Map and Chart components. D3.3 thus closes the loop between the data and service layer (D3.2) and the end-user interface.

D3.3 was developed in parallel with WP4 regional co-design and validation activities. Partners from the five pilot regions — Andalusia, Croatia, Cyprus, Central Macedonia, and Sicily — engaged with early versions of the platform and provided structured feedback through T4.3 and T4.4 activities. This feedback, collected and analysed by CERTH, directly informed the improvement cycle described in Section 5 of this document. The iterative co-design process ensured that the platform reflects authentic regional needs and use cases rather than purely technical requirements.

The outputs of D3.3 are intended for immediate use by the pilot region partners as a functional decision-support tool for climate resilience planning. Beyond the project, the open architecture and standards-based interfaces (REST, OGC WMS) facilitate reuse and integration in future European climate service platforms, consistent with the Copernicus and ECMWF ecosystem that underpins the broader ClimEmpower data infrastructure.

2.4 Data, security, and ethics

As in the other project deliverables, the work in D3.3 follows three main principles for handling data: KISS, FAIR and Societal Responsibility. The KISS principle is reflected in keeping processes as simple and transparent as possible, while FAIR aims to ensure that data are findable, accessible, interoperable and reusable. At the same time, data should be made openly available wherever possible. Restrictions may be necessary, for example for ethical or commercial reasons, and these need to be clearly justified. Ethical aspects related to the use of data, algorithms and resulting outputs are also considered explicitly. Together, these principles inform the development of the services and their documentation, as well as the publication of software and other information produced in D3.3.

2.4.1 Data interoperability

D3.3 describes the HTML5 frontend application and the backend API layer that constitute the user-facing component of the ClimEmpower Decision Support System. It operates exclusively at the presentation and integration layer: it consumes pre-processed data from D3.2 services and external providers via standardised interfaces and does not perform raw data ingestion or transformation.

The application integrates data from multiple sources. Pre-computed climate risk maps and geospatial layers are served by a GeoServer instance via OGC WMS and WFS standards and rendered in the frontend using Mapbox GL JS. Climate time-series data from the Copernicus Climate Data Store (CDS) is accessed through the Polytope API (developed in D3.2) and returned in CoverageJSON format. Historical flood event data (HANZE) and active fire observations (NASA FIRMS) are retrieved from external REST APIs. Resilience indicator values, user configurations, and structured recommendations are stored in and served from a MongoDB database via the ClimEmpower REST API.

Data exchanged between the backend and frontend follows standard formats: GeoJSON for vector and feature data, CoverageJSON for climate time-series, and OGC WMS tiles for raster visualisation. The backend API acts as an integration layer that abstracts heterogeneous upstream data sources behind a uniform REST interface, facilitating consumption by the Angular-based frontend without direct dependency on upstream data formats such as NetCDF or GRIB. This architecture ensures interoperability with D3.2 services and supports extensibility for future data sources. Non-geospatial and non-API-accessible datasets (e.g., most EUROSTAT tabular data) are not directly integrated in the current implementation.

2.4.2 Data accessibility and reuse:

D3.3 did not produce primary datasets. The deliverable outputs are the platform source code (Angular frontend, FastAPI backend) and associated configuration artefacts (GeoServer SLD styles, MongoDB schema, Docker Compose deployment configuration). Part of it that is considered open source will be made available under a permissive licence via the ClimEmpower project repository; a citable release will be deposited on Zenodo upon project completion.

The data consumed by the platform originate from external open sources: Copernicus Climate Data Store and ECMWF ERA5 (accessed via the Polytope API documented in D3.2, open under Copernicus licence), NASA FIRMS active fire observations (open, NASA public domain), and the HANZE historical flood event database (open research dataset). Pre-computed climate risk maps are produced by the D3.2 pipeline and served internally via GeoServer; these raster outputs may be made available on Zenodo as part of the D3.2 data deposit. Resilience recommendations and indicator metadata stored in MongoDB are project-generated content and will be released as structured open data (JSON/CSV) on Zenodo at project end.

The component most likely to have high reuse value is the platform source code itself, which provides a reusable template for climate resilience decision-support applications based on open standards (REST, OGC WMS, CoverageJSON). The GeoServer SLD styles for risk map visualisation may also be directly reused in similar geospatial applications.

All platform components are open source (Angular, FastAPI, MongoDB, GeoServer) and require no proprietary software.

2.4.3 Security and Ethics

The ClimEmpower Platform described in this deliverable requires user authentication via regional accounts (one per pilot region). No person-specific data is collected or stored; account credentials consist of a regional email address and password. Access to the platform is restricted to authenticated regional accounts. Authentication follows current web security best practices, including short-lived session tokens and secure cookie handling to prevent unauthorised access. All user-specific routes require prior authentication; no personal data is exposed through public API endpoints.

The work performed in this deliverable and the data used or produced are not considered sensitive in terms of ethics or security.

3 System Architecture and API

The ClimEmpower platform follows a clear separation between a web-based frontend and a set of containerised backend services. Figure 1 illustrates the overall architecture. The frontend communicates exclusively with the ClimEmpower REST API and directly with GeoServer for map tile retrieval. Backend services interact with MongoDB for data persistence and with the ECMWF Polytope DS2 service for on-demand Copernicus data access.

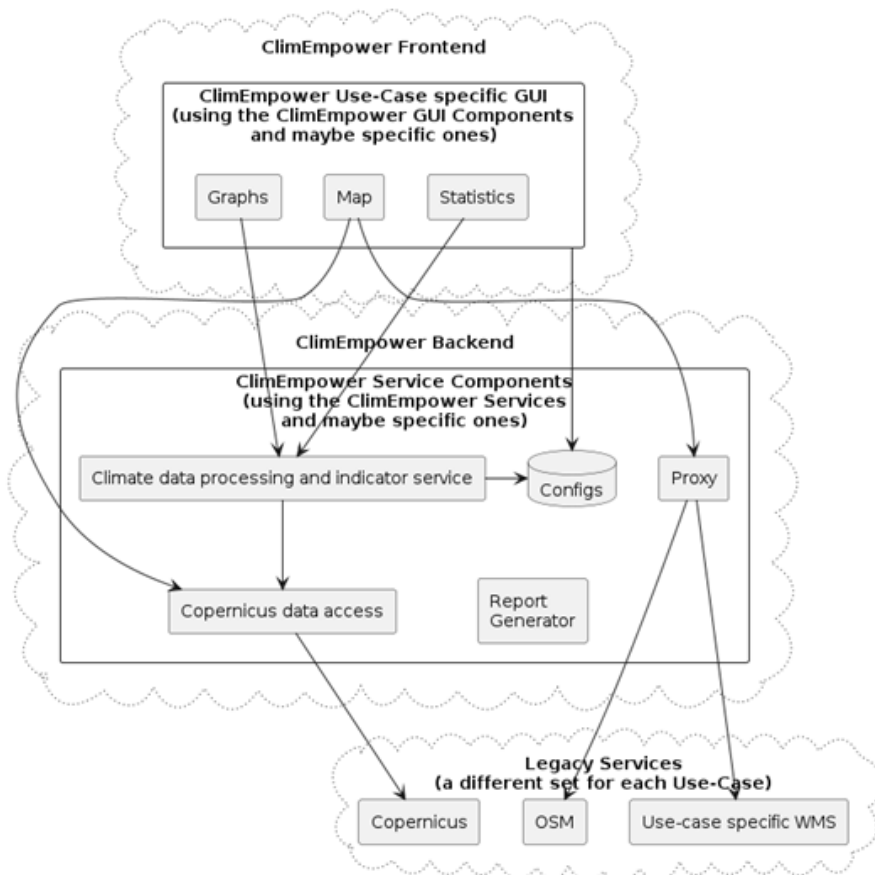


Figure 3: ClimEmpower architecture - component view

3.1 Technology Stack

The ClimEmpower platform is built on a modern, open-source technology stack chosen for its reliability, maintainability, and compatibility with European open data infrastructure. The frontend is a browser-based single-page application developed in Angular (TypeScript) with Tailwind CSS for styling and Mapbox GL JS for interactive map visualisation. The backend is implemented in Python using the FastAPI framework, with MongoDB as the database and GeoServer for serving pre-computed climate risk map layers. All services are containerised using Docker and deployed via Docker Compose, ensuring a reproducible and portable production environment.

Table 1: Technology stack overview

Layer	Technology	Purpose
Frontend framework	Angular (TypeScript)	Component-based SPA with lazy-loaded feature modules
Markup / Styling	HTML5, Tailwind CSS	Semantic markup, utility-first responsive styling
Interactive maps	Mapbox GL JS	Vector and raster tile rendering, polygon interaction
Charts	Plotly.js / Chart.js	Interactive time-series and statistical charts
HTTP client	Angular HttpClient	RxJS-based requests with JWT interceptor
Backend API	FastAPI (Python)	REST API with async support and OpenAPI docs
Database	MongoDB 6.0	Document store for regions, indicators, dashboards, risk maps
Geospatial server	GeoServer 2.25	OGC WMS/WFS serving for pre-computed risk map layers
Reverse proxy	Traefik	HTTPS routing, TLS termination
Containerisation	Docker Compose	Reproducible multi-service deployment

3.2 Frontend

The frontend presents two primary modules to the user: a configurable Dashboard and a Resilience Recommendations tab. Both are accessible via a persistent navigation bar after login. All data and map content is automatically scoped to the user's assigned region; no region selection is required after authentication.

User session state is managed transparently: on returning to the platform, the session is restored automatically without requiring re-login. The dashboard layout configured by each user is stored server-side and restored on every subsequent login, ensuring continuity between sessions.

3.3 Backend API

The backend exposes a REST API that serves as the single data interface for the frontend. It provides endpoints for user authentication, retrieval of regional metadata and resilience indicators, access to climate risk map layer configurations, dashboard layout persistence, and adaptation recommendations. All endpoints require authentication with the exception of a small set of publicly accessible indicator data. Table 1 provides an overview of the main API domains.

Table 2: Backend REST API

Layer	Technology	Purpose
Authentication	POST /token, POST /refresh, POST /logout	JWT login, token rotation, logout with cookie revocation
Regions	GET /regions	List of available pilot regions with metadata
Indicators	GET /indicators GET /region/{id}/available-indicators	Full indicator catalogue and region-specific availability
Public Indicators	GET /public-indicators	Publicly accessible indicator data (no auth required)
Hazard Risk	GET /hazard-risk/{region}/{hazard} GET /hazard-risk/{region}	Risk map layer metadata by hazard type and region
Dashboard	GET/POST/PUT/DELETE /dashboard-setup/{user_id}	CRUD for user dashboard layout persistence
Recommendations	GET /recommendations GET /recommendations/{id}	Adaptation recommendations linked to indicators

3.4 Deployment

The platform is deployed on a virtual machine provided by AIT. The three core backend services — the FastAPI application, MongoDB, and GeoServer — run as Docker containers on a shared internal network. This containerised setup ensures that the platform can be reproduced and migrated to other hosting environments with minimal effort, consistent with the ClimEmpower goal of regional reusability and transferability..

4 GUI

The following chapter provides a detailed description of the ClimEmpower platform Graphical User Interface (GUI). It covers every application screen, from the initial login through the full set of dashboard components and the Resilience Recommendations module. Each section follows a consistent structure: objective, methodology, a screenshot from the application, and step-by-step execution instructions.

The platform is designed for pre-registered regional end-users working with climate hazard data (floods, wildfires, drought, heatwaves) and resilience indicators. All data and map layers are strictly localised to each user's assigned region.

4.1 Login

4.1.1 Objective

Provide secure, friction-free access to the platform for pre-registered regional users. No self-registration is required; all accounts are provisioned in advance by the system administrator.

4.1.2 Methodology

The login screen presents a minimal credential form (username + password). On successful authentication, the user is redirected to an initially empty dashboard. Access is automatically scoped to that user's region, no further configuration is needed.

4.1.3 Screenshot



Figure 4: Login screen (left) and the empty dashboard state shown immediately after authentication (right)

4.1.4 Execution Instructions

Follow these steps to log in to the ClimEmpower platform:

- Open the ClimEmpower platform URL in your web browser.
- Enter your pre-assigned Username in the first field.
- Enter your Password in the second field.
- Click the Sign In button. The system will validate your credentials and redirect you to the Dashboard.

Note: If you do not have credentials, contact your regional administrator. Self-registration is not available.

4.2 Dashboard

4.2.1 Objective

Provide each user with a personalised, modular workspace where they can freely select, arrange, and resize data components relevant to their regional climate analysis needs.

4.2.2 Methodology

The Dashboard starts empty after login and must be configured by the user. Components are selected from a Library panel and individually configured via a Setup Pop-up. Once placed, every component can be repositioned and resized freely on the canvas. The top navigation bar gives persistent access to all application modules.

The top navigation bar contains three elements:

- **Dashboard:** Routes users to the customisable component workspace (current view).
- **Resilience Recommendations:** Accesses the module containing hazard mitigation strategies and planning information.
- **User Profile (avatar icon):** Handles account management and user preferences.

4.2.3 Screenshot - Empty State & Navigation

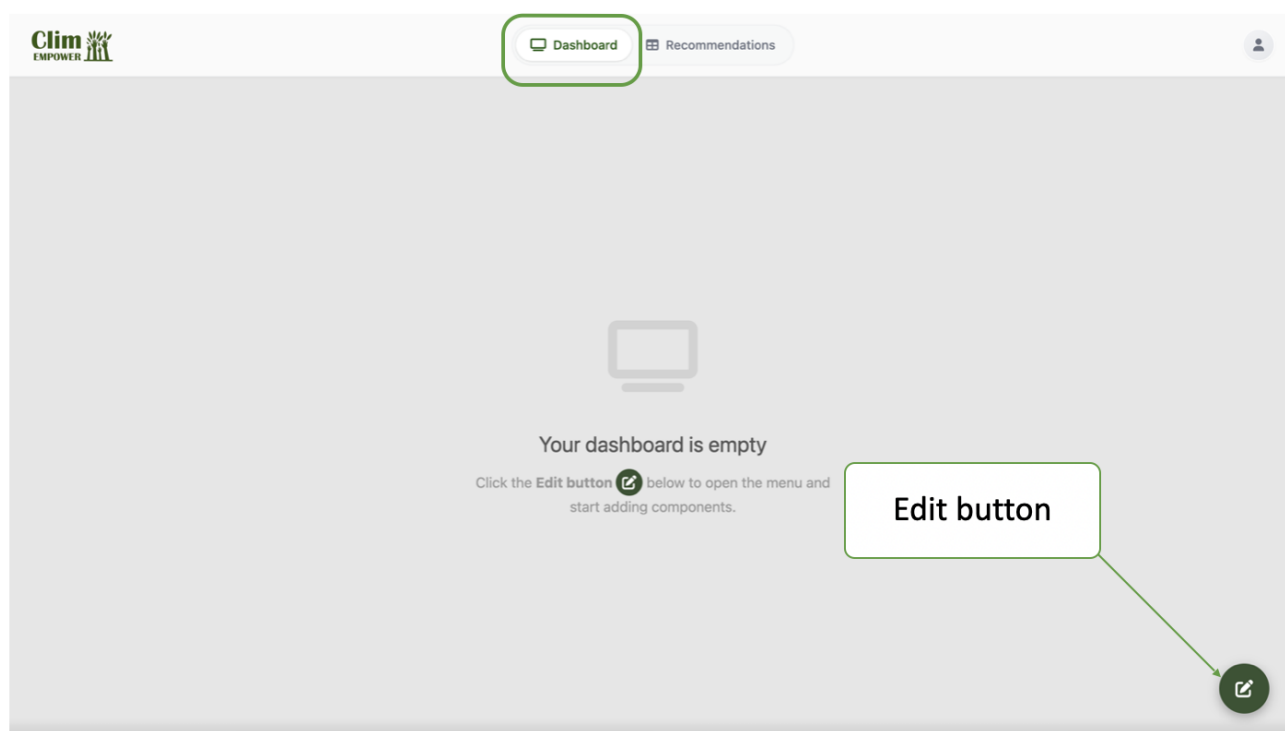


Figure 5: Empty dashboard state showing the top navigation bar and the Edit button (bottom-right)

4.2.4 Execution Instructions - Setting Up the Dashboard

To begin populating the dashboard:

- After login, the dashboard canvas is empty. An on-screen message prompts you to start.
- Click the Edit button (pencil icon, bottom-right corner) to open the Components Library panel on the left side of the screen.

- From the Library, click the component type you wish to add (e.g. Resilience Indicator Map, Risk Maps, Vegetation Map, FIRMS, HANZE, CDS Datasets, Social Map, SM Posts Chart, or FAQ).
- A Setup Window / Available Data pop-up appears. Configure the specific data for that component (see Section 2.5 below).
- After configuration, click Select. The component is placed on the canvas.
- Drag the component to reposition it. Use the resize handle at its edges to adjust size.
- Repeat steps 3–6 for each additional component.
- **When done, click the ✓ (check) button to save the current dashboard layout.**

4.2.5 Screenshot — Component Library & Configuration Pop-up

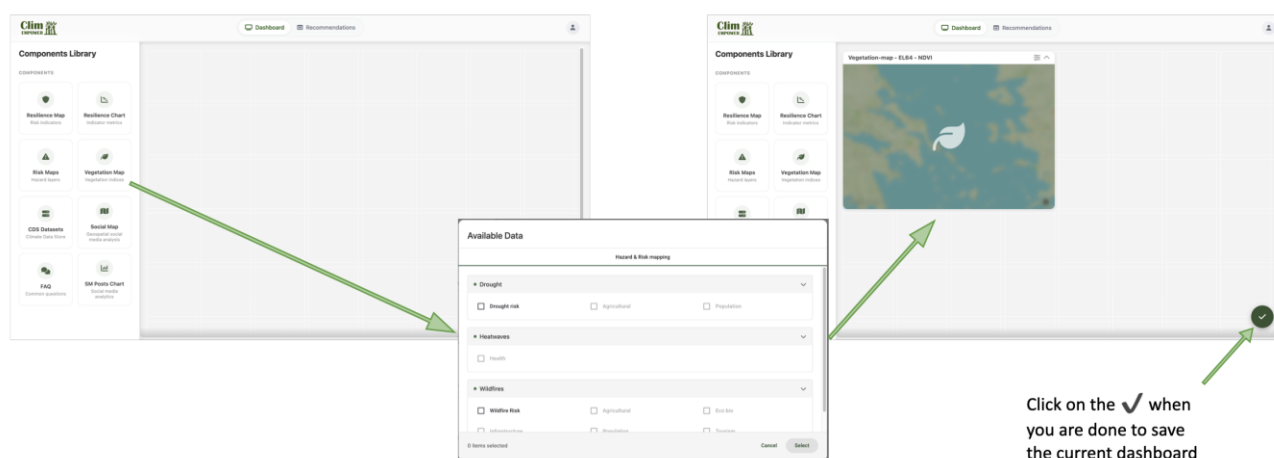


Figure 6: Three-step dashboard setup: (1) Component Library, (2) Available Data setup pop-up, (3) Component placed on canvas. Checkmark button saves the layout.

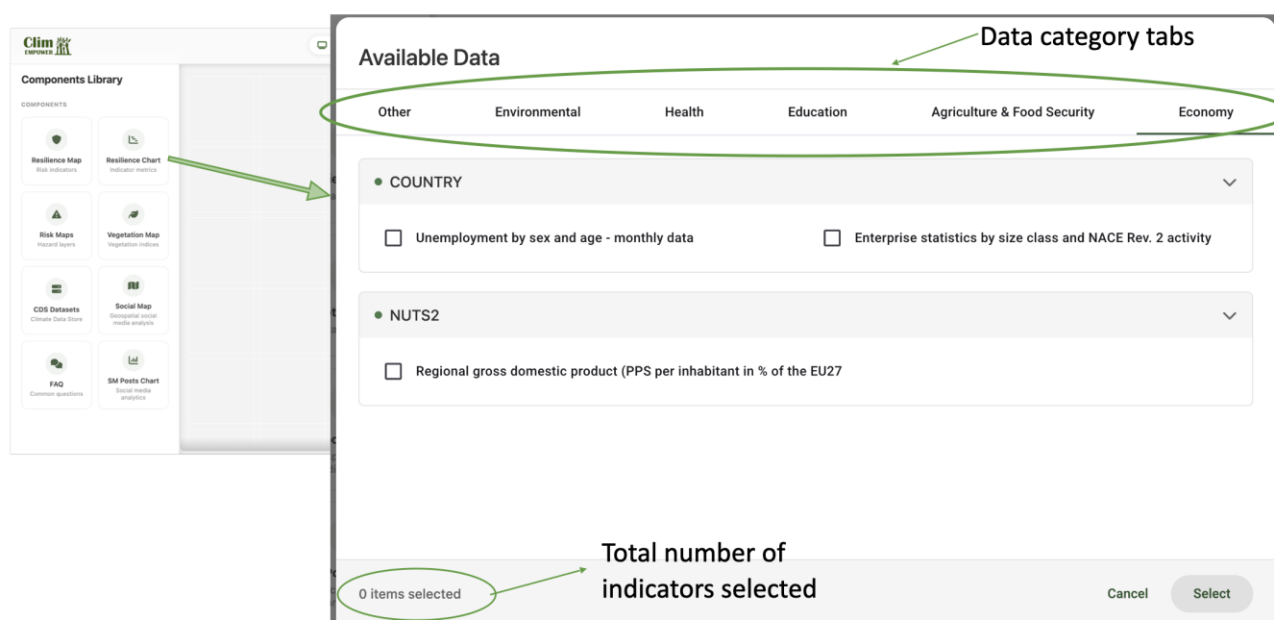


Figure 7: Detailed view of the Available Data configuration pop-up showing data category tabs, collapsible NUTS-level sections, indicator checkboxes, and the items-selected counter

4.2.6 Execution Instructions - Using the Data Configuration Pop-up

When the Available Data pop-up opens for a component:

- Use the category tabs (Other, Environmental, Health, Education, Agriculture & Food Security, Economy, etc.) at the top to filter the indicator list.
- Expand a NUTS-level section (e.g. NUTS2, Country) by clicking the chevron on the right.
- Tick the checkbox(es) next to the indicators you want to include in the component.
- Monitor the "N items selected" counter at the bottom-left to track how many indicators are chosen.
- Click Select to confirm or Cancel to discard changes.

4.2.7 Screenshot - Populated Dashboard Example

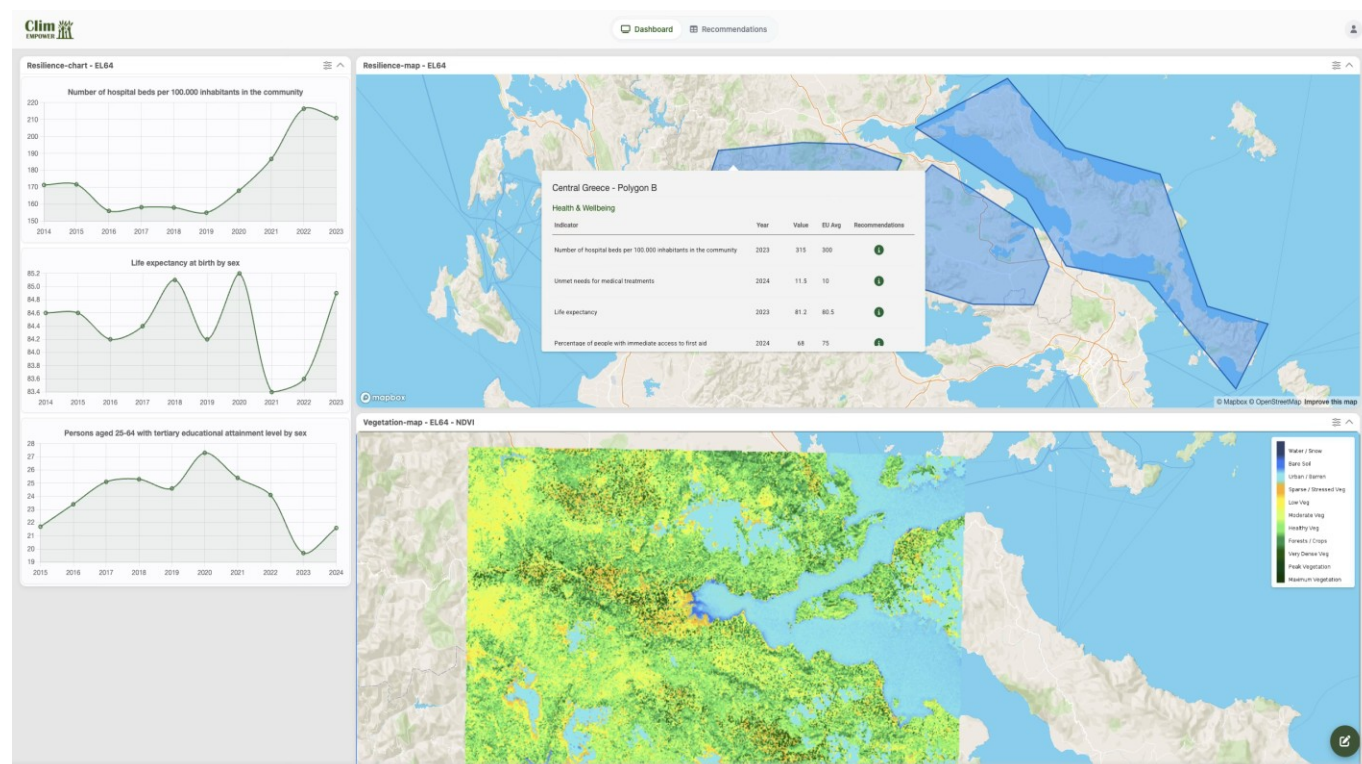


Figure 8: Fully populated dashboard showing a Resilience Chart (left), a Resilience Indicators Map with an interactive popup table (centre-right), and a Vegetation Index Map (bottom)

4.3 Resilience Indicators Map Component

4.3.1 Objective

Display selected resilience indicators as colored polygon layers on an interactive regional map, enabling users to visualize spatial patterns and benchmark their region against the EU average.

4.3.2 Methodology

The component queries NUTS-level resilience indicator data and renders colored polygons on a Mapbox base map. Clicking a polygon opens an interactive data table showing the indicator value, the year of measurement, and the EU average for direct benchmarking. A shortcut button inside the table links directly to the Resilience Recommendations tab.

4.3.3 Screenshot

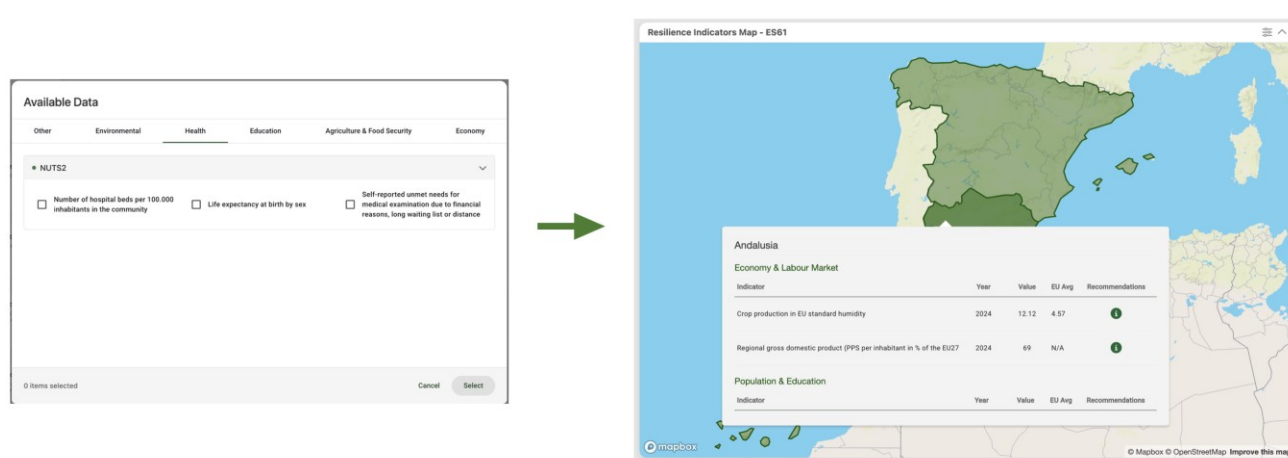


Figure 9: Resilience Indicators Map component (ES61 region) with polygon selection and the interactive NUTS/EU-average comparison popup, alongside the indicator selection panel

4.3.4 Execution Instructions

- Add the Resilience Indicators Map component to your dashboard (see Section 2.4).
- In the Available Data pop-up, select the dimension (e.g. Health, Environmental) and tick the indicators you want to visualize. Click Select.
- The map renders colored polygons for your region at the selected NUTS level.
- Click any polygon to open the data popup table showing: Indicator name, Year, Local value, EU Average, and a Recommendations shortcut button.
- Use the Recommendations (i) button in the table row to jump directly to the Resilience Recommendations tab for that indicator.
- Use the component menu (≡ icon, top-right of the component) to access additional component settings or collapse the component.

4.4 Resilience Indicators Chart Component

4.4.1 Objective

Track the temporal evolution of resilience indicators for the user's region, enabling trend analysis and historical benchmarking against the EU average.

4.4.2 Methodology

The chart uses the same indicator set available in the Resilience Map, ensuring data consistency across both components. It displays one line chart per selected indicator, spanning the full available time series. A EU-average trendline will be overlaid for continuous comparative benchmarking.

4.4.3 Screenshot

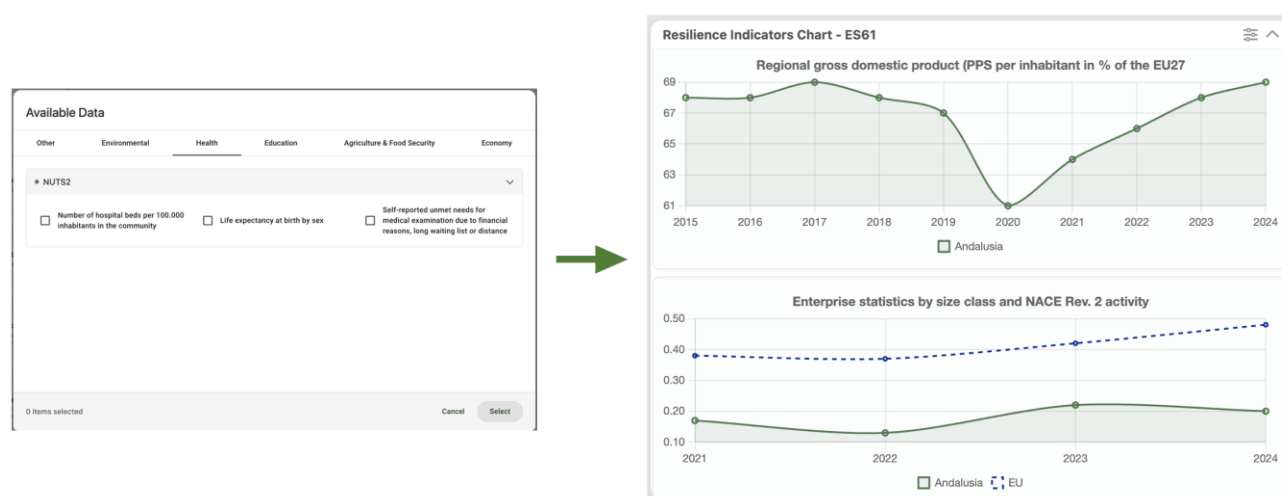


Figure 10: Resilience Indicators Chart component showing the indicator selection panel alongside the two time-series charts for the ES61 region.

4.4.4 Execution Instructions

- Add the Resilience Indicators Chart component to your dashboard.
- In the Available Data pop-up, select the indicators you wish to track over time. Click Select.
- The component renders one line chart per indicator, with the x-axis representing the time period and the y-axis the indicator value.
- Hover over any data point to read the exact value for that year.
- An EU-average trendline will appear alongside regional data for benchmarking (Not available for all indicators).

4.5 Risk Map Component

4.5.1 Objective

Visualise spatially the magnitude of climate hazard risks within the user's region, covering four primary hazard types: Floods, Wildfires, Drought, and Heatwaves.

4.5.2 Methodology

The Risk Map component renders hazard-specific risk layers on a Mapbox base map. Each hazard type is broken down into sub-indicators (e.g. Agricultural, Population, Infrastructure risk). The color scale runs from Very Low (light) to Very High (dark red), providing an visual signal of the most vulnerable areas.

4.5.3 Screenshot

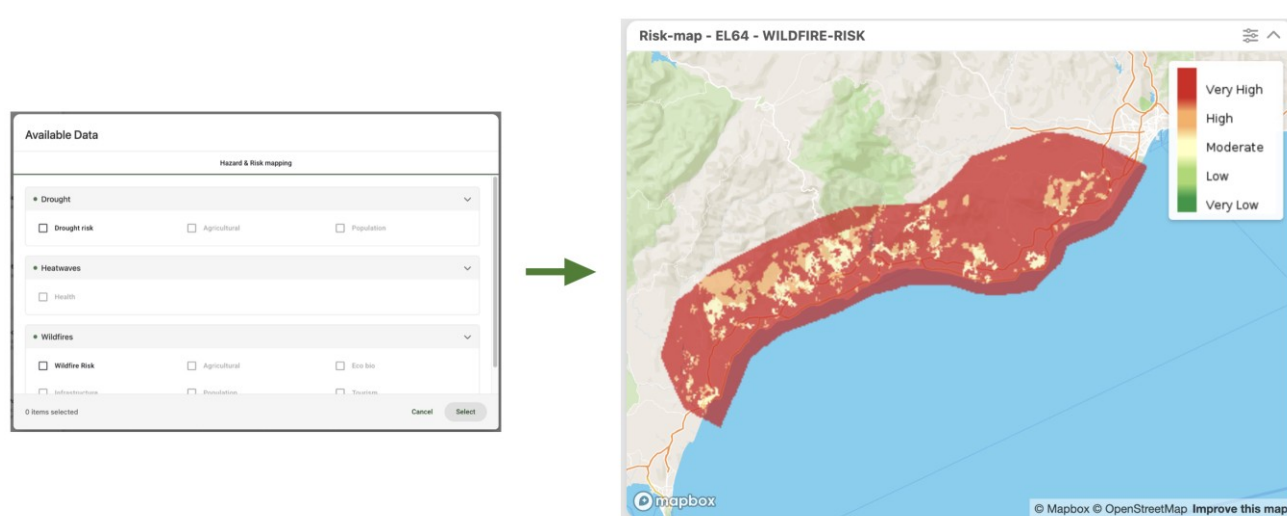


Figure 11: Risk Map component showing the Wildfire Risk layer for region ES61, with a five-class legend (Very Low to Very High), alongside the hazard & risk mapping configuration panel

4.5.4 Execution Instructions

- Add the Risk Maps component to your dashboard.
- In the Available Data pop-up, expand the hazard category you want (Drought, Heatwaves, Wildfires, or Flood).
- Tick one or more sub-indicators (e.g. Wildfire Risk, Agricultural, Population). Click Select.
- The map renders the selected risk layer(s) as coloured zones over the regional map.
- Read the legend (top-right of the component) to interpret the colour scale: Very High → Very Low.
- Switch between hazard types by re-opening the configuration from the component menu.

4.6 Vegetation Indices Map Component

4.6.1 Objective

Provide a satellite-derived spatial overview of vegetation and ecological conditions across the region, supporting the identification of drought stress, burn scars, and water content anomalies.

4.6.2 Methodology

The component renders satellite-derived vegetation index rasters on the map. Four indices are available:

- **NDVI (Normalised Difference Vegetation Index):** measures healthy green vegetation.
- **NDMI (Normalised Difference Moisture Index):** determines vegetation water content.
- **NBR (Normalised Burn Ratio):** identifies burned areas and measures burn severity.
- **NDWI (Normalised Difference Water Index):** monitors changes in water content of leaves.

A classified color legend maps pixel values to vegetation condition categories, from Water/Snow through Bare Soil, Urban/Barren, Sparse/Stressed Veg, up to Maximum Vegetation.

4.6.3 Screenshot

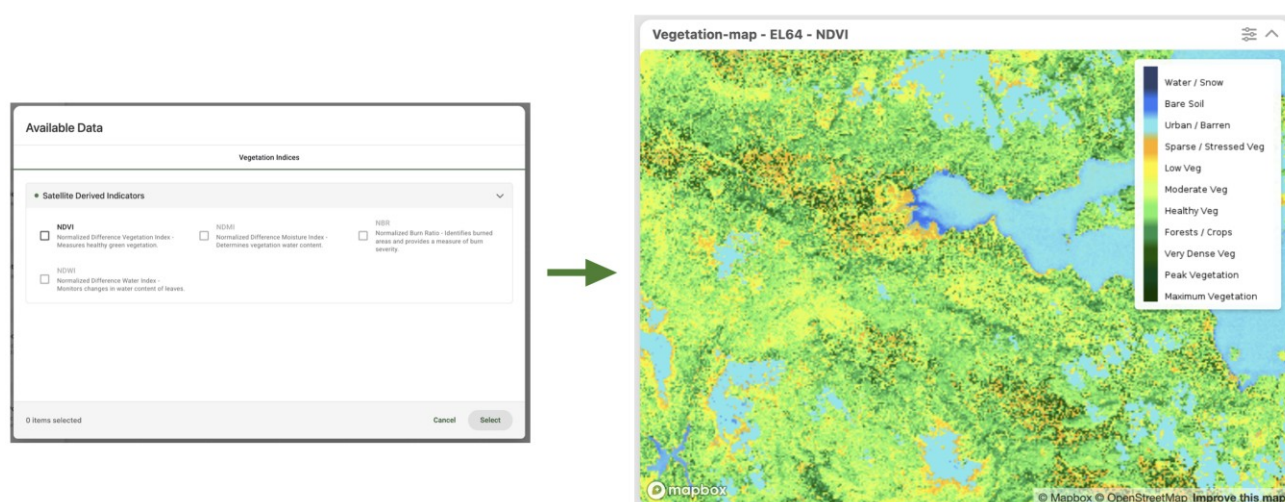


Figure 12: Vegetation Indices Map component (EL64 – NDVI) with classified colour legend, alongside the Satellite Derived Indicators selection panel

4.6.4 Execution Instructions

- Add the Vegetation Map component to your dashboard.
- In the Available Data pop-up, expand "Satellite Derived Indicators" and tick the desired index (NDVI, NDMI, NBR, or NDWI). Click Select.
- The map renders the selected index as a classified raster over your region.
- Read the legend (top-right) to interpret pixel colours: Water/Snow → Maximum Vegetation.
- To change index, re-open the component configuration and select a different indicator.

4.7 CDS Datasets Component

4.7.1 Objective

Allow users to query and visualise climate datasets directly from the Copernicus Climate Data Store (CDS), bound to their specific regional polygon.

4.7.2 Methodology

The component exposes climate datasets from CDS. Users select mandatory query parameters (variable, time period, and time aggregation) and the system retrieves data clipped to the regional polygon boundary. Results are displayed as a time-series chart on an interactive map. Note: the frontend visualisation is currently in early development stage and may be subject to change.

4.7.3 Screenshot



Figure 13: CDS Datasets component showing a Growing Season Length time-series chart at a selected coordinate (38.75, 21.25) over the regional map of Central Greece

4.7.4 Execution Instructions

- Add the CDS Datasets component to your dashboard.
- In the configuration panel, select the climate dataset/variable of interest
- Set the time period and aggregation level.
- Click Select. The system queries the Polytope API and returns data clipped to your regional polygon (**This process may take some time, as the data must first be retrieved from CDS and then cropped to your region**).
- Click on any data point on the map to display its time-series chart.

Note: This component is currently in early development. Some parameters and visualisation options may not yet be fully available.

4.8 FIRMS Active Fires Map Component

4.8.1 Objective

Provide near real-time situational awareness of active fire detections within the user's region, sourced from satellite-based fire monitoring, to support rapid identification of ongoing wildfire activity.

4.8.2 Methodology

The component renders satellite fire detections from the **FIRMS** (Fire Information for Resource Management System) dataset as flame-shaped pins on a Mapbox satellite base map. Each pin represents a thermal anomaly detected by NASA MODIS or VIIRS satellites and is geolocated by latitude/longitude. The component is **time-aware**: users can browse fire activity day by day using prev/next arrows or jump to any specific date through an embedded calendar picker. Clicking a pin opens a popup displaying the full detection metadata, including brightness, fire radiative power, satellite source, and detection confidence. Fire data is continuously ingested and persisted in a dedicated MongoDB store, with one record per detection.

4.8.3 Screenshot

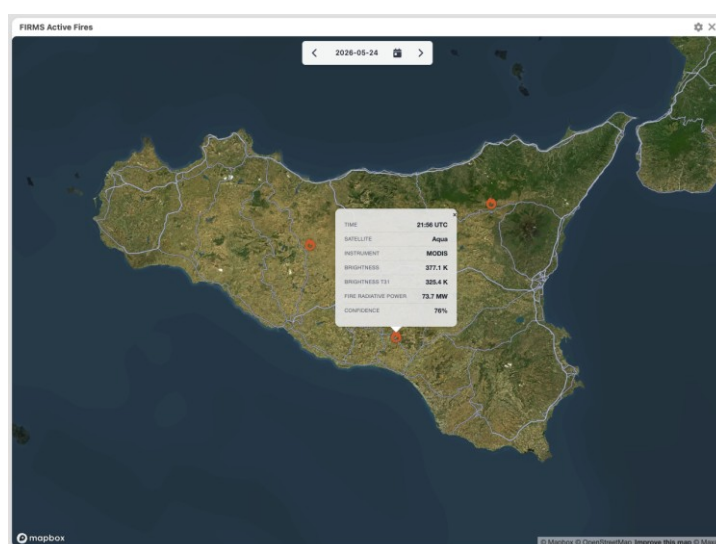


Figure 14: FIRMS Active Fires Map component (ITG1 region) showing flame pins distributed across the Sicilian landmass for the selected date, with the date navigation control at the top centre and a pin popup showing detailed metadata.

4.8.4 Execution Instructions

- Add the **FIRMS** component to your dashboard from the Components Library (no configuration pop-up is required — the component automatically uses your region).
- The map opens centred on your region, with the most recent available date selected by default.
- Use the navigation control at the top centre of the map to change date:
 - Click the **◀ / ▶ arrows** to step day-by-day backward or forward.
 - Click the **calendar icon** to open a date picker and jump directly to any date within the available range.
- Each detected fire is rendered as a flame-shaped pin at its geographic coordinates.
- Click any pin to open a popup showing:
 - **Time** - acquisition time (UTC) of the detection.

- **Satellite** - source satellite (e.g. Aqua, Terra).
- **Instrument** - sensor used (e.g. MODIS, VIIRS).
- **Brightness** - thermal brightness in Kelvin.
- **Brightness T31** - brightness in band 31 (K).
- **Fire Radiative Power** - measured energy output in MW.
- **Confidence** - detection confidence as a percentage.
- The pin set updates automatically when the selected date changes; no page refresh is required.

4.9 HANZE Historical Flood Events Table

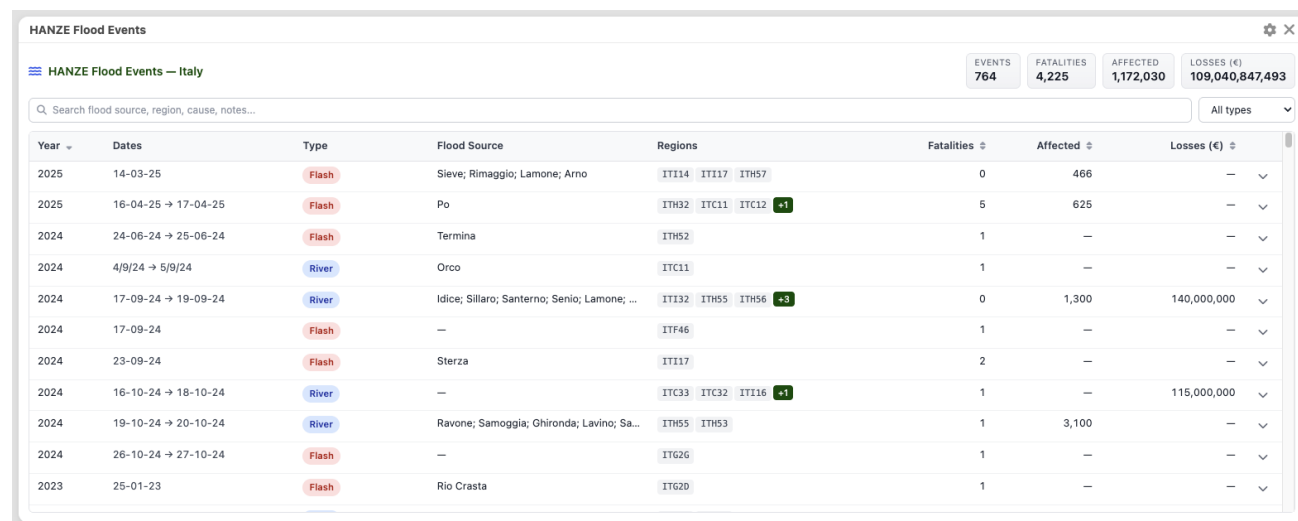
4.9.1 Objective

Provide a structured historical record of flood events affecting the user's country, supporting context for long-term flood risk assessment and comparative benchmarking against present-day conditions.

4.9.2 Methodology

The component renders flood event records from the **HANZE** (Historical Analysis of Natural Hazards in Europe) dataset as a sortable, filterable table. Each row corresponds to a documented flood event and includes year, dates, flood type, source, affected regions, fatalities, persons affected, and economic losses normalised to 2024 Euros. Aggregate totals are displayed in summary chips at the top of the component. A free-text search field and a flood-type dropdown allow users to narrow the dataset, and an expandable row reveals the cause, full list of affected regions, and contextual notes for each event. Data is sourced from the public HANZE dataset and is automatically scoped to the user's country.

4.9.3 Screenshot



Year	Dates	Type	Flood Source	Regions	Fatalities	Affected	Losses (€)
2025	14-03-25	Flash	Sieve, Rimaggio; Lamone; Arno	ITI14 ITI17 ITH57	0	466	—
2025	16-04-25 → 17-04-25	Flash	Po	ITH32 ITC11 ITC12 +1	5	625	—
2024	24-06-24 → 25-06-24	Flash	Termina	ITH52	1	—	—
2024	4/9/24 → 5/9/24	River	Orco	ITC11	1	—	—
2024	17-09-24 → 19-09-24	River	Idice; Sillaro; Santerno; Senio; Lamone; ...	ITI132 ITH55 ITH56 +3	0	1,300	140,000,000
2024	17-09-24	Flash	—	ITF46	1	—	—
2024	23-09-24	Flash	Sterza	ITI117	2	—	—
2024	16-10-24 → 18-10-24	River	—	ITC33 ITC32 ITI116 +1	1	—	115,000,000
2024	19-10-24 → 20-10-24	River	Ravone; Samoggia; Ghironda; Lavino; Sa...	ITH55 ITH53	1	3,100	—
2024	26-10-24 → 27-10-24	Flash	—	ITG26	1	—	—
2023	25-01-23	Flash	Rio Crasta	ITG20	1	—	—

Figure 15: HANZE Historical Flood Events component (Italy) showing the summary chips (events, fatalities, affected, losses), the search and type filters

4.9.4 Execution Instructions

- Add the **HANZE Table** component to your dashboard from the Components Library (no configuration pop-up is required, the component automatically uses your account's country).
- The component loads the full set of historical flood events for your country and displays:
 - **Summary chips** at the top showing aggregate totals: total events, fatalities, persons affected, and economic losses in Euros.
 - **Filter controls**: a free-text search box (covering source, region, cause, and notes) and a flood-type dropdown.
 - **Event table** listing each flood event with year, dates, type, source, affected regions, fatalities, persons affected, and losses.

- Use the **search box** to filter events by keyword (e.g. region name, cause, or source).
- Use the **All types** dropdown to filter by flood type (e.g. Flash, River, Coastal, River/Coastal).
- Click the **x button** that appears when filters are active to clear them in one action.
- Click any column header marked with the sort icon (Year, Type, Fatalities, Affected, Losses) to sort the table ascending or descending by that column.
- Click the **chevron** (▾) at the end of any row to expand it and reveal additional details: cause, the full list of affected regions, and contextual notes for that event.

4.10 Social Media Components

4.10.1 Objective

Surface climate hazard-related social media activity from the ClimEmpower X (former Twitter) account as map pins, trend charts, and AI-generated hazard Q&A, providing real-time situational awareness alongside the quantitative data layers.

4.10.2 Methodology

Three sub-components work together:

- **Social Media Posts Map:** Overlays X posts as numbered map pins at their geographic location. Clicking a pin shows the post content and a link.
- **Social Media Chart:** Generates a bar chart of social media activity volume by hazard type (Fire, Flood, Weather, etc.) per time period. Available in standard and 3-column format.
- **FAQ (Common Hazard Questions):** Uses AI to generate context-based responses to pre-defined hazard questions (e.g. "What are people in Italy saying about recent flood incidents?"), drawing on X post data.

4.10.3 Screenshot

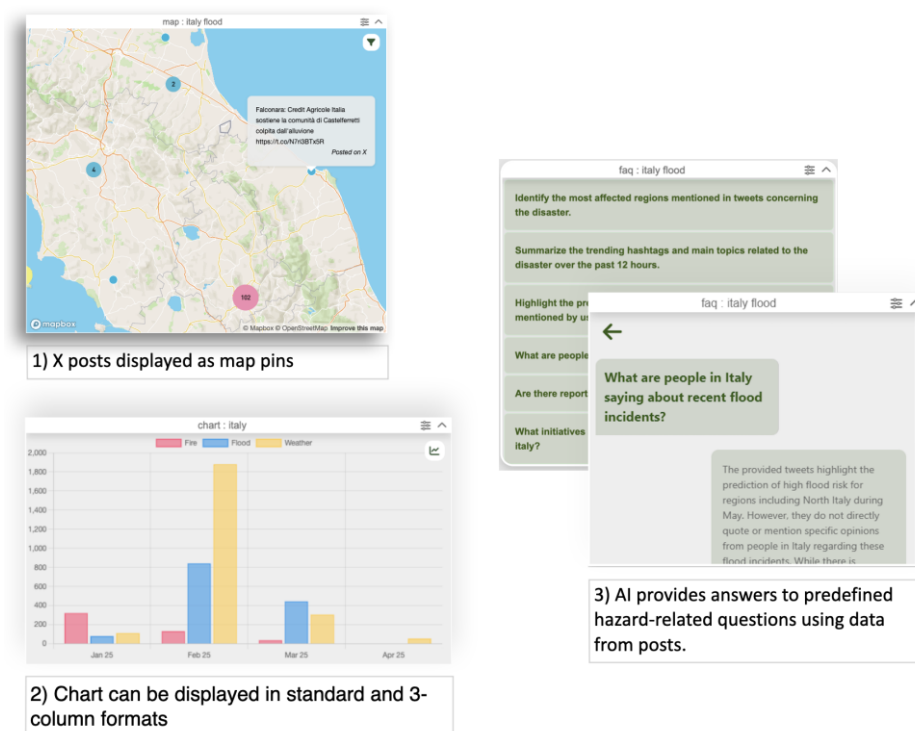


Figure 16: Social Media components: (1) Posts map with pins and post preview, (2) Social media activity bar chart by hazard, (3) AI FAQ panel with predefined questions and a context-based response

4.10.4 Execution Instructions

Social Media Posts Map:

- Add the Social Map component to your dashboard.
- The map loads automatically and shows X posts as numbered map pins.
- Click any pin to open a popup with the post content, timestamp, and a link to the original post.

Social Media Chart:

- Add the SM Posts Chart component to your dashboard.
- The chart renders automatically, showing post volume by hazard type over time.
- Use the component menu to toggle between standard and 3-column layout.

FAQ (Common Hazard Questions):

- Add the FAQ component to your dashboard.
- Select a pre-defined hazard question from the list (e.g. "Identify the most affected regions mentioned in tweets concerning the disaster.").
- The AI generates a context-based response using X post data for your region.

4.11 Resilience Recommendations Tab

4.11.1 Objective

Provide actionable, evidence-based intervention recommendations linked directly to the resilience indicators displayed on the Dashboard, bridging data analysis and climate adaptation planning.

4.11.2 Methodology

The Recommendations module uses a two-panel layout. The left panel presents a filterable list of interventions; the right panel displays the full details of the selected intervention. Users filter by Dimension (e.g. Health & Wellbeing) and Indicator (e.g. Life Expectancy) to narrow down relevant strategies. Each recommendation includes a strategic description, a step-by-step Policy Roadmap, identified Social & Environmental Co-benefits, and links to Best Practices and Learning Materials. The module is accessible from the top navigation bar and via shortcut buttons within the Resilience Map popup.

4.11.3 Screenshot

Resilience recommendations Tab

Centralized Access: Accessed via the button on the main Navigation Bar (with quick-routing links also available from within the Resilience Map).

Targeted Filtering: Users can easily pinpoint relevant interventions by selecting a specific **Dimension** and **Indicator** from the dropdown menus.

Comprehensive Insights: Selecting an intervention reveals practical data, including:

- Detailed strategic descriptions.
- A step-by-step **Policy Roadmap**.
- Identified **Social & Environmental Co-benefits**.
- Direct links to **Best Practices** and **Learning Materials**.

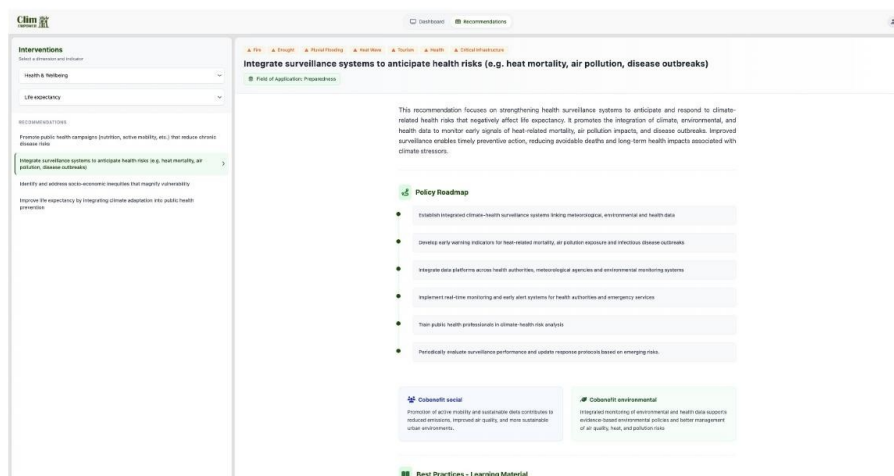


Figure 17: Resilience Recommendations tab: left panel with dimension/indicator filter and intervention list; right panel showing the full recommendation detail (description, Policy Roadmap, Co-benefits, Best Practices)

4.11.4 Execution Instructions

- Click Recommendations in the top navigation bar, or use the ⓘ shortcut button inside any Resilience Map popup to go directly to a specific indicator's recommendations.
- In the left panel, select a Dimension from the first dropdown (e.g. Health & Wellbeing).
- Select an Indicator from the second dropdown (e.g. Life Expectancy).
- The RECOMMENDATIONS list populates with relevant interventions. Click any item to select it.
- The right panel displays the full intervention detail:
 - Strategic description explaining the rationale and scope.
 - Policy Roadmap a numbered list of concrete implementation steps.
 - Co-benefit social and Co-benefit environmental cards highlighting ancillary positive impacts.
 - Best Practices & Learning Material links for further reading.
- Use the hazard-type shortcut tabs at the top of the right panel (Fire, Drought, Flood Flooding, Heat Wave, Tourism, Health, Critical Infrastructure) to cross-filter recommendations across hazard types.

5 User Feedback and Improvements

5.1 User Acceptance Testing

A structured user acceptance testing round was conducted with pilot region representatives during WP4 workshops. Participants tested the deployed platform against their regional data and specific climate risk scenarios, covering the full range of dashboard components and the Resilience Recommendations module.

Nine usability and functionality issues were identified and documented in a feedback report. For each issue, the development team assessed feasibility, implemented a fix or workaround where possible, and provided a transparent resolution explanation in all other cases. Table 4 summarises all feedback items and their resolution status.

Table 2: User feedback items and resolution status

#	Issue	Context	Description	Status	Resolution
1	Missing Map Layer Information	Copernicus data map view	The map did not display information about what dataset/layer was being viewed; this was only available in edit mode.	Done	Layer and dataset information is now displayed directly on the component header and in a persistent legend.
2	Configuration Data Not Accessible	Configuration menu after map setup	Clicking the configuration gear did not show the original settings, making it impossible to identify what was displayed.	Done	Configuration options are now visible on the component; options are pre-selected when opening data-selection from the gear icon.
3	Limited Dashboard Grid Layout	Dashboard widget arrangement	The 8-column grid restricted layout options; three default CDS map widgets could not be placed side by side easily.	Done	One additional column has been added to the grid, increasing layout flexibility.
4	Map Panning Blocked by Popup	Maps with popup graph open	Popup graphs prevented map panning when clicking in the popup area, particularly affecting the lower-right graph.	Closed	Mapbox GL popups capture all clicks within their bounds by design. A close button was added to the popup so users can dismiss it and pan freely.
5	Popup Graph Size Cannot Be Adjusted	Popup graph widget	No option existed to resize popup graphs.	Not feasible	Popup graph resizing is not possible for the same reason as above. Zoom controls are already built into the graphs for closer data inspection.
6	Unintuitive Zoom Behaviour	Browser zoom vs. map zoom	Browser zoom (Ctrl +/- or mouse wheel) changed point sizes instead of widget sizes, with confusing behavior inside and outside the map.	Not feasible	Browser zoom is a browser-level feature scaling the entire page. Over the map, the scroll wheel triggers Mapbox geographic zoom by design. Users should use the dashboard edit/resize handles to resize widgets.
7	Missing Map Reset and Synchronization	Map navigation and comparison	Users could not return to the default zoom/pan position after exploring, and could not	Done	A re-centre button is now available for Risk

			synchronise views across multiple maps.		Maps, Vegetation Maps, and DSS maps.
8	Improved Widget Information Access	Risk maps and other widgets	Widgets lacked detailed information about displayed datasets and indicators. Users needed more context.	Partially done	Visible titles and tooltip-on-hover are implemented. Detailed information links (level 3) are pending an API update to provide the relevant resource URLs.
9	Redundant Heatmap / Pins Modes	CDS Dataset maps	The distinction between Heatmap and Pins views was confusing; both represented the same data but with different functionality, requiring mode switching.	Updated	Heatmap and Pins views have been merged into a single map view. Each point supports hover (value at selected date), click (full time-series graph), and a date slider at the bottom. Single-measurement datasets retain the heatmap view with hover/click value popups.

Of the nine issues: six were resolved, one resolved partially pending an API update, and two were closed as not technically feasible due to constraints inherent to Mapbox GL JS or the browser platform. In each case the reasoning was communicated transparently to the pilot region representatives.

6 From Jupyter notebooks into workflow applications

This chapter describes the **efforts to transform Jupyter notebook-based workflows into self-contained, user-friendly applications**—a critical step in bridging the gap between research-oriented tools and operational decision-support systems.

In the course of project development, we realised that **Jupyter notebooks** are excellent tool for **rapid prototyping and collaborative development** (e.g., to prototype algorithms for hazard and risk modelling and discuss the results with regional users). Unfortunately, they are **not directly suitable as end-user applications** for regional stakeholders. Our users—local governments, planners, and policymakers—required **intuitive, click-based tools** rather than code-heavy notebooks.

To address this, we developed the **ClimEmpower mashup platform**, where simple, region-specific applications can be implemented with minimal technical effort. However, to ensure **scalability and robustness**, we also needed a way to **convert existing notebooks**, such as flood hazard/risk workflows from the CLIMAAX FLOODS repository, into **fully operational applications**.

To explore this transformation, we conducted experiments on **three distinct approaches**, using **two connected notebooks** as a case study:

- The **first notebook** prepares **flood-hazard data**, downloading high-resolution JRC flood maps for a user-specified bounding box, processing and comparing maps for different return periods, and saving the results for later use. It also incorporates **Aqueduct flood maps** to assess how projected flood depths may evolve under varying climate scenarios, years, and models.
- The **second notebook** builds on these outputs by combining the **JRC hazard maps with LUISA land-use data, JRC depth–damage curves, and locally adjusted economic information**. It spatially aligns these datasets, calculates potential economic damage using **DamageScanner**, and presents the results as **damage tables and maps**.

Our goal was to **evaluate the feasibility, trade-offs, and best practices** for converting research notebooks into **user-ready applications**, ensuring that the ClimEmpower platform could **leverage existing analytical workflows** while meeting the **usability needs of non-technical stakeholders**. The full findings from these experiments will be published as **educational material** to guide future climate service development.

6.1 Voila framework

As part of our effort to operationalize Jupyter notebooks for end-users, we first explored **Voila**, an open-source framework that converts notebooks into interactive web applications.

This approach was **particularly appealing for** rapid prototyping, as it allows data scientists to quickly transform existing notebooks into user-facing tools with minimal development overhead ([Figure 18](#)).

Interactive application

The controls below replace the original source-code parameter cells. Expensive downloads and processing start only when an action button is pressed. Use the three tabs from left to right. Prepared files retain the original workflow's names and remain compatible with the risk-assessment notebook.

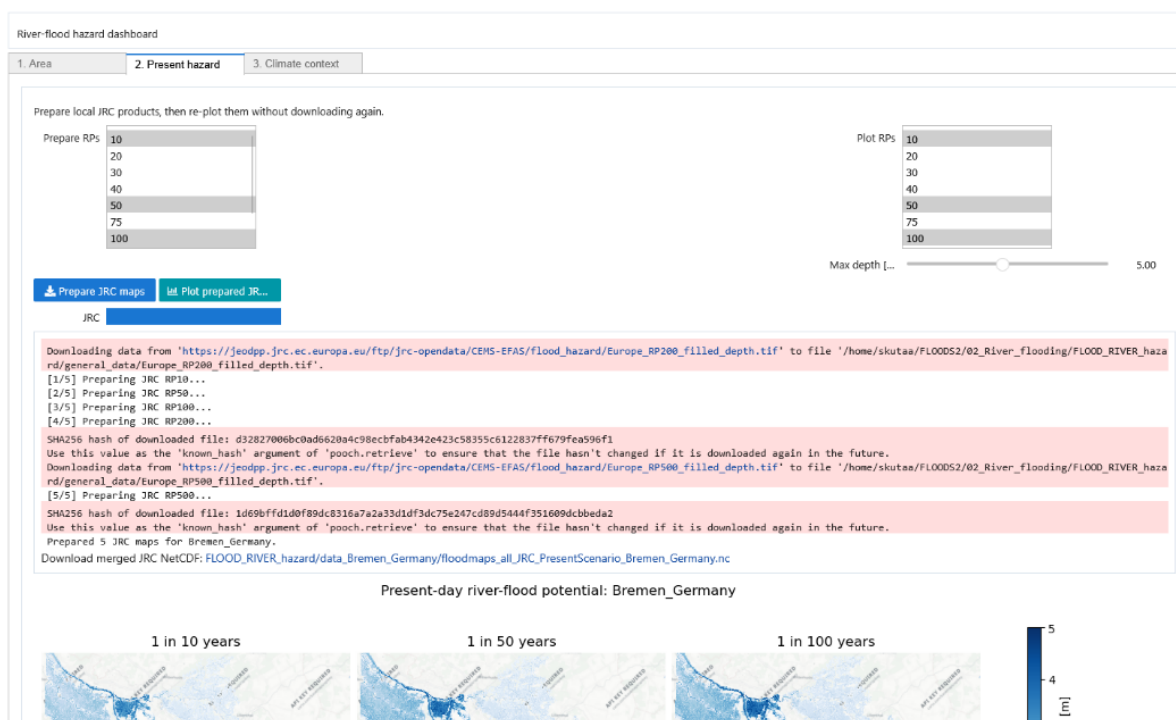


Figure 18: Hazard workflow represented as a voila enhanced notebook application. Notebook is presented as a three-step process. The present hazard step is currently shown, where users can choose which flooding maps they want to download and plot.

Voila executes the notebook when started, which posed a challenge for computationally expensive operations (e.g., downloading rasters, processing flood maps, or calculating damage). To address this, we restructured the notebooks to separate user inputs (e.g., bounding box selection, return period) from processing steps, replacing manual code edits with validated widgets and buttons. For example, in the flood hazard notebook, users could now select parameters via dropdowns and trigger calculations with a single click, rather than editing and running cells sequentially.

Voila provided a rapid transformation path from notebook to application, but offered limited control over UI design, navigation, and responsiveness. For instance, the resulting web apps lacked advanced customization options (e.g., dynamic layouts, real-time feedback), which are critical for non-technical users like regional planners.

Nonetheless, voila proved **valuable for quick testing of workflows and gathering early feedback** from pilot regions. The insights from this experiment informed the development of the mashup platform's widget-based approach, where users can assemble simple applications by combining pre-built components—an evolution of the Voila concept tailored to the needs of regional stakeholders.

6.2 Manual integration of algorithms in a workflow application

While Voila provided a **fast but limited** path to prototyping, we recognized that **complex workflows**—such as flood hazard and risk assessments—required **greater control over UI**,

validation, and user interactions. To explore this, we investigated the concept of **manual integration of notebooks into custom workflow applications.**

The underlying idea behind this approach is to **build a solid, well-engineered workflow application that could be brought to high Technology Readiness Levels (TRL), while still retaining the flexibility to rapidly develop, test, and integrate individual steps within the workflow.** This method is still faster than standard development practices but **prioritizes application robustness and user-friendliness over speed.**

While a **fully implemented workflow application was not delivered within ClimEmpower**, similar application has been **previously realized in the KlimaLinz project**, using React and FastAPI. In ClimEmpower, we **analysed and documented the feasibility** of transforming Jupyter notebooks into individual steps in this application, with following constrains:

- Replacing implicit notebook dependencies with **explicit, validated inputs and outputs** (e.g., user-selected regions, return periods, climate scenarios).
- Enabling **flexible area selection** (preconfigured regions, bounding boxes, or uploaded shapefiles) to accommodate diverse user workflows.
- Handling **data processing transparently** in the backend to reduce user errors (e.g., incorrect file paths or execution order).
- **Modularizing individual steps** (e.g., hazard data preparation, risk calculation) so they could be **developed, tested, and updated independently** before integration into the full workflow.

For example, in a hypothetical “flood workflow” application ([Figure 19](#)), users could first use the application to generate or upload and subsequently visualize high-resolution flood maps for their chosen area (hazard phase) and then proceed to next step(s) where the application would automatically combine the maps with land-use and economic data to calculate potential damages. The backend would ensure that intermediate files (e.g., GeoTIFFs) are validated and passed between phases, eliminating manual file management.

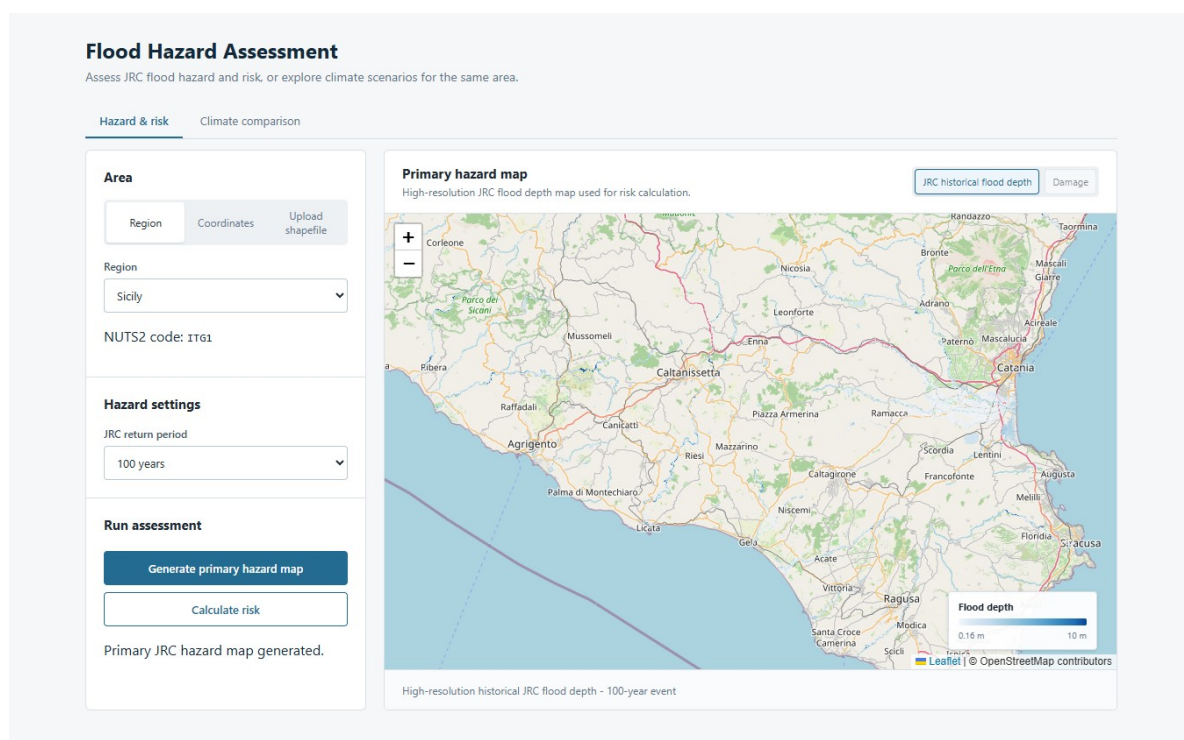


Figure 19: Flood-risk workflow application showing the user controls and generated map output

This method **delivers** the **most robust and user-friendly workflows** of the three approaches tested. By explicitly defining inputs, dependencies, and outputs, it **ensures reliability and reproducibility**—critical for tools used in decision-making. However, the **development effort is significant**, as translating notebooks into applications requires **manual engineering decisions** (e.g., reorganizing code, designing UIs, validating data handoffs).

This trade-off makes manual integration **ideal for high-priority workflows** (e.g., flood risk assessment) but **less scalable** for rapid prototyping across multiple hazards.

6.3 AI-assisted development

The **manual integration pathway** described in the previous section requires **engineering decisions** about how to translate notebook elements (e.g., code cells, dependencies, outputs) into functional components of an application. This involves **analysing the notebook code** to determine its purpose, inputs, processing stages, dependencies, outputs, exploratory operations, and inter-notebook connections. For **complex or multi-file notebooks**, this process can be **time-consuming and labour-intensive**.

To accelerate this work, we investigated the feasibility of **LLM-assisted code analysis**. The analyser we implemented ([Figure 20](#)) can process **up to four Jupyter notebook files** or links to notebooks hosted on supported public GitHub repositories. It first validates the notebook format, then reads the **code and Markdown cells without executing them**. If multiple notebooks are provided, they are analyzed together in a **single LLM request**, allowing the tool to examine workflows and relationships across files in a unified context.



Figure 20: Notebook analyser showing the hazard and risk workflows and their evidence linked relationship

The analyser generates a structured engineering description of the workflow, including:

- The **apparent purpose** of the workflow.
- **Inputs, configuration, and processing stages.**
- **Dependencies, intermediate/final outputs, and exploratory cells.**
- **Imported libraries and unresolved questions.**

Rather than treating each cell as a separate stage, the analyser **groups related cells into meaningful workflow stages** and cites the specific notebook cells that support each stage. This allows the interpretation to be **verified against the original source**. For multiple notebooks, cells are assigned **global indexes** while retaining their original filenames, enabling the tool to **track relationships between files**. A connection between notebooks is only reported if there is **evidence in both the producing and consuming notebooks**.

The **semantic interpretation** is performed by the LLM, while a **deterministic backend** validates the response's structure and traceability. These checks ensure that:

- Step identifiers and dependencies are **valid**.
- Cited cell indexes **exist and are correctly attributed**.
- Cross-notebook connections **refer to both notebooks involved**.

However, **while this approach speeds up the analysis**, it **requires careful design of the GenAI workflow and prompts, as well as human oversight**. The backend **cannot guarantee** that the LLM's interpretation is **scientifically or semantically correct**, and the **output can vary** depending on the LLM, instructions, notebook content, and context provided.

In short, **AI can help accelerate the understanding of notebook workflows**, but **it is not a fully automated solution**—it reduces manual effort but still demands **expertise and validation**.

7 Conclusions

This document reports on the successful realization of Task T3.4, which focused on configuring, testing, validating, and improving the ClimEmpower platform (developed in Task T3.3) for use in the five pilot regions (Andalusia, Croatia, Cyprus, Central Macedonia, and Sicily). The **key outcomes of T3.4** are:

- A **containerized backend stack** (FastAPI, MongoDB, GeoServer) deployed on the project's production virtual machine, fully integrating the T3.1 data access services and the T3.2 Indicator Service Framework.
- **Regional configuration and deployment of the mashup platform**, tailored to the specific needs of each pilot region,
- **User acceptance testing** with pilot region partners, yielding **nine feedback items**, six of which were resolved, one partially addressed, and two closed with technical explanations. This process confirmed that the **configured platform meets the operational requirements** of local government practitioners with varying levels of data literacy.
- **Improvements to the platform** based on user feedback, enhancing usability, performance, and regional relevance.
- **Exploratory work on workflow application prototyping** to investigate methods for **accelerating and improving the development process** of future climate services. This included experiments with three approaches for transforming Jupyter notebooks into operational applications and provided **valuable insights into trade-offs between speed, customization, and reliability** for future development efforts.

The five regional configurations of the ClimEmpower platform show how open-source web technologies combined with Copernicus climate data services and a structured indicator framework can provide climate decision-support tools tailored to the needs of local governments in vulnerable regions.

The workflow prototyping experiments highlight the potential for more efficient and robust development processes, ensuring that future climate services can be adaptable, scalable, and accessible to diverse stakeholders.

8 References

IPCC. (2018). Annex I: Glossary. In *Global Warming of 1.5°C* (S. pp. 541–562). Cambridge University Press. doi:<https://doi.org/10.1017/9781009157940.008>