



# REUSABLE LIBRARIES AND SERVICES FOR CLIMATE FEATURE EXTRACTION, DATA PROCESSING AND INDICATOR BUILDING

ClimEmpower Work Package 3, D3.2



Project ClimEmpower: User Driven Climate Applications Empowering  
Regional Resilience

Work package 3, Deliverable D3.2

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# List of Acronyms

Acronym	Meaning
AIT	Austrian Institute of Technology GmbH
API	Application Programming Interface
CC	Climate Change
CDS	Climate Data Store
CLIMAAX	CLIMAtE risk and vulnerability Assessment framework and toolboX (CLIMAAX)
CLMS	Copernicus Land Monitoring Service
CoP	Community of Practice
ECMWF	European Centre for Medium Range Weather Forecasting
EDR	Environmental Data Retrieval
EUROSTAT	European Statistical Office
FE	Feature Extraction
GDP	Gross Domestic Product
GRIB	GRIdded Binary
GUI	Graphical User Interface
IPCC	Intergovernmental Panel on Climate Change
ISF	Indicator Service Framework
KPI	Key Performance Indicator
MIKE	Water modelling and simulation suite developed by DHI, named after Professor Mike Abbott
MU	Mission Users
NUTS	Nomenclature of Territorial Units for Statistics
OGC	Open Geospatial Consortium

Acronym	Meaning
PLINIVS	PLINIVS - Centro Studi per l'Ingegneria Vulcanica Sismica e Idrogeologica
RA	Regional Authorities
SO	Strategic Objectives
TMRT	Mean Radiant Temperature
UNDRR	United Nations office for Disaster Risk Reduction
WP	Work Package

## Glossary

Glossary term	Meaning
<b>Climate impacts</b>	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)
<b>Climate Resilience</b>	The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.
<b>CLIMAAX</b>	CLIMAtE risk and vulnerability Assessment framework and toolboX (CLIMAAX) is a 4-year Horizon Europe project that will provide financial, analytical, and practical support to improve regional climate and emergency risk management plans. It offers a toolbox that integrates the components of risk (Hazard, Exposure, Vulnerability) into an integral risk assessment and visualizes risk information to develop regional risk profiles.
<b>CoverageJSON</b>	A web-friendly geospatial format for representing spatiotemporal “coverage” data with rich metadata, facilitating interoperability with OGC APIs and web applications; used here as a target format converted from GRIB/NetCDF.
<b>Covjsonkit</b>	An open-source library for encoding/decoding CoverageJSON and converting GRIB/NetCDF to CoverageJSON; includes utilities for transforming data to xarray and for mapping/regridding workflows.
<b>Datacube</b>	A multidimensional data structure typical of meteorological and climate datasets, enabling extractions along spatial, temporal, and other axes.
<b>Earthkit</b>	An ECMWF open-source Python project that streamlines access, processing, analysis, and visualization of meteorological/climate data; integrates Polytope-based requests and CoverageJSON reading (with covjsonkit), with planned extensions for regridding, aggregation, and transformations.
<b>Effort level</b>	A qualitative attribute assigned to recommendations (e.g., low to high) to support prioritization, resource planning, and communication with local stakeholders.
<b>ERA5</b>	A multi-decadal global atmospheric reanalysis distributed via the CDS; employed to estimate climate-related hazards and indicators within the project’s applications.
<b>Exposure</b>	Exposure is the situation of people, infrastructure, housing, production capacities and other tangible (human) assets located in hazard-prone areas.

Glossary term	Meaning
<b>GeoJSON</b>	An open format for representing geospatial geometries and features on the web; used to define areas of interest for spatial subsetting.
<b>Geospatial vs non-geospatial data</b>	The described services are designed for geospatial datasets (gridded or vector). They are not applicable to non-geospatial datasets (e.g., many EUROSTAT tables).
<b>GRIB/NetCDF</b>	Standard formats for gridded meteorological/climate data provided by the CDS; in this workflow they are converted to CoverageJSON to enhance usability and interoperability.
<b>Hazard</b>	Hazards have the potential to cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation.
<b>Indicator</b>	An indicator is a measurement or value which gives you an idea of what something is like.
<b>Jupyter notebooks</b>	Interactive computational notebooks used for demonstrative analyses of extreme events and for integrating the Polytope DSS into analytical pipelines.
<b>NUTS level</b>	The European statistical territorial unit level to which indicator resolution is often aligned, depending on the availability of input data. <ul style="list-style-type: none"> <li>• NUTS 0 – Countries</li> <li>• NUTS 1 – Major socio-economic regions</li> <li>• NUTS 2 – Basic regions for regional policies</li> <li>• NUTS 3 – Small regions for specific diagnoses</li> </ul>
<b>Python</b>	Python is a high-level, general-purpose programming language.
<b>Shapefile</b>	A file format for vector geospatial data, used to delimit regions for subsetting.
<b>Vulnerability</b>	Vulnerability refers to the conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards.

## Executive summary

The ClimEmpower project is dedicated to advancing practical, scalable solutions for climate risk management across European regions. **This deliverable presents the strategic progress made in the development of data services and user-oriented frameworks designed to support reliable, transparent, and flexible approaches to climate risk assessment and decision support.**

A key achievement is the provision of **interoperable, open-source libraries and modular data access and pre-processing services**. These services allow regional users, analysts, and planners to efficiently access and process climate data from major providers such as Copernicus and ECMWF, as well as from their local repositories. Tools for streamlined extraction, subsetting, and data conversion, alongside user-friendly APIs, ensure that essential climate information becomes directly usable for a wide spectrum of applications, eliminating many traditional technical bottlenecks.

Alongside these data solutions, it introduces a structured **indicator service framework that links climate risk to specific resilience recommendations**. The framework allows for the routine classification and harmonization of risk measures at multiple spatial and administrative scales, ensuring that recommendations are robust, transparent, and easily updated as science and policy evolve. The process emphasizes flexibility, collaboration, and traceability so that all partners, including those without technical backgrounds, can review, adapt, and co-manage both risk classifications and recommended actions as new knowledge or needs emerge.

Finally, the deliverable also introduces the **methodology used to implement and develop the climate risk maps** in the project and illustrates the anticipated results of this work on example of the Sicily region.

These results are designed not only for current project sites but also for straightforward transfer and integration into new regions and applications, extending value across Europe. The system's emphasis on accessibility, modularity, and open documentation creates a user environment where everyone, from local policymakers to technical developers, can move confidently from climate risk analysis to well-grounded, context-specific recommendations.

# 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).

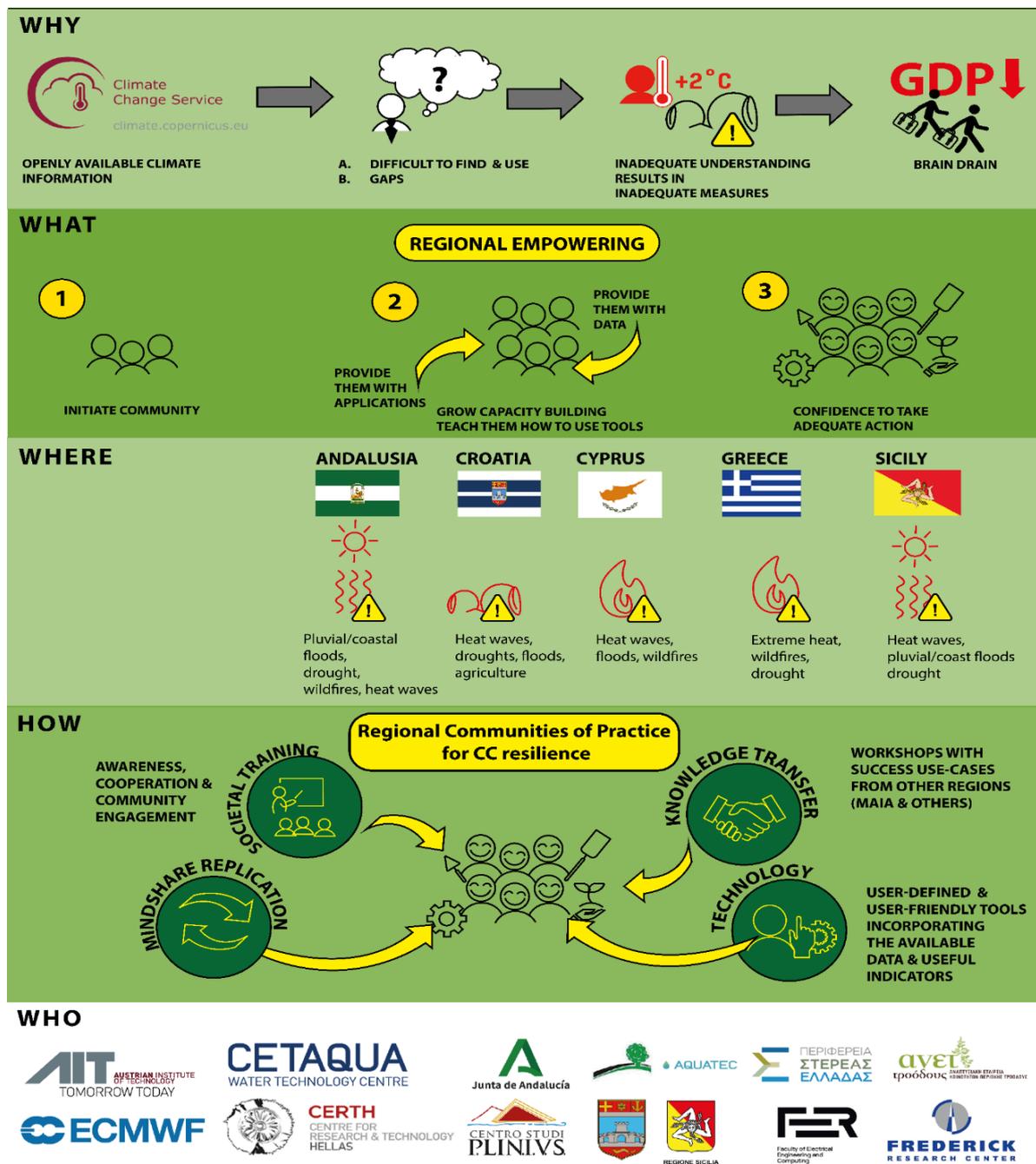


Figure 1: ClimEmpower at a glance: why, what, where, how and who.

## 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).

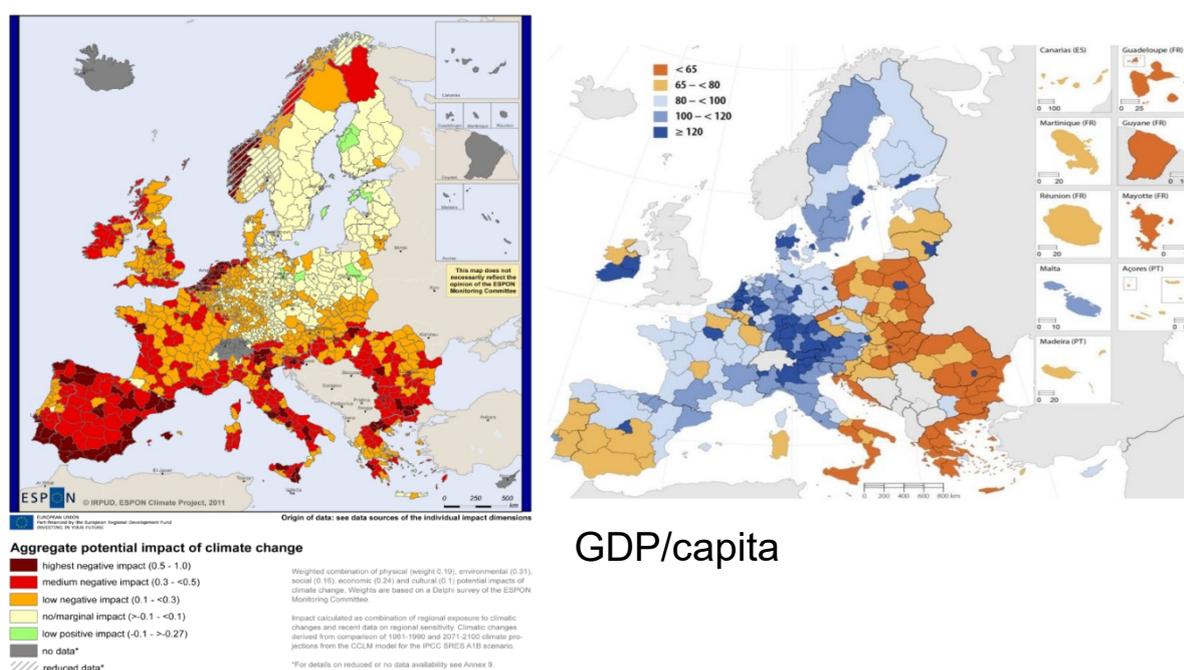


Figure 2: Aggregated potential impact of climate change<sup>2</sup>

**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.

<sup>2</sup> Source: (<https://www.espon.eu/climate-2012>); GDP/capita (based on <https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210303-1>)

## 1.2 Project Objectives

To achieve this overarching goal, **ClimEmpower has identified six SMART<sup>3</sup> 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).

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

<sup>3</sup> 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 report documents the development and integration of reusable climate data libraries, feature extraction tools, and methodological frameworks in the framework of the ClimEmpower project. Intended end result of this work is a software suite supporting the development of tailored climate resilience assessment and adaptation planning solutions across diverse European contexts. The work emphasizes two tightly connected tracks: first, the creation of interoperable services and open-source libraries to simplify the access, extraction, and processing of high-quality climate data, from sources such as Copernicus and ECMWF, at scales relevant to regional users; second, the definition of transparent procedures and collaborative frameworks (including the Indicator Service Framework) to efficiently translate climate risk indicators into science- and policy-driven adaptation recommendations.

The core **data access and processing services** address common technical barriers through streamlined APIs, subsetting, and geospatial data conversion. Tools such as Polytope, Earthkit, Polytope FE, and Polytope DS2 allow regional, municipal, and technical users to retrieve only the climate data needed for their applications. This modular approach ensures flexibility and integration with a wide variety of external platforms or analytical workflows.

The **Indicator Service Framework** provides a structured, auditable process for classifying and standardizing climate risk indicators developed in WP2, covering a range of hazards such as heat waves, pluvial flooding, wildfires and droughts. The deliverable builds upon the outcomes of WP2 (notably D2.1, D2.2 and D2.4), which provided the inventory of datasets and the initial set of resilience indicators, and prepares the ground for WP4, where the classified indicators and recommendations will be tested and applied in regional co-design activities. While it anticipates future automation, its emphasis is on accessibility, ease of collaboration, and ongoing refinement based on scientific evidence and stakeholder input. These two tracks, together, establish a foundation for scalable, transparent, and transferable climate adaptation solutions both within the project and for broader adoption.

Finally, the deliverable also introduces the **methodology used to implement and develop the climate risk maps** in the project and illustrates the anticipated results of this work on example of the Sicily region.

In this sense, D3.2 ensures methodological continuity across work packages and delivers operational outputs that are transparent, reproducible, and directly usable by stakeholders.

### 2.2 End-users for ClimEmpower services

ClimEmpower's outputs are designed to address the needs of a diverse array of end users across the climate adaptation spectrum. These include technical actors, such as data scientists, regional analysts, platform developers, and infrastructure managers, who require flexible, performant libraries and open APIs to ingest, process, and interpret climate data as part of risk modeling, policy assessment, or operational decision support.

In parallel, public authorities, municipal planners, community stakeholders, and practitioners in urban development or public works benefit from the project's transparent procedures, low technical barriers, and collaborative tools for co-creating and updating adaptation strategies.

The modular frameworks and clear documentation ensure that both expert and non-expert users can review, validate, or adapt risk indicators, classification criteria, and the resulting recommendations, regardless of technical background.

Finally, the ClimEmpower platform and its underlying methodologies are built for alignment with a variety of external applications, supporting not only project partners but also future adopters at the local, regional, or cross-national scale. The overarching goal is to empower all stakeholders to efficiently connect scientific climate knowledge with context-specific, actionable adaptation planning, ultimately boosting resilience across regions with varying capacities and needs.

## 2.3 Relation to other work

D3.2 builds directly on the previous work of WP2 and WP1 and provides the technical foundation for subsequent implementation and co-design activities in WP3 and WP4.

In particular, it operationalises the outcomes of D2.1 (availability of climate datasets and services) and D2.2/D2.4 (selection and structuring of climate resilience indicators) by implementing the WP2 core indicator set as service-ready computations, structured into three families, hazard (climatic extremes and trends), exposure (assets, services, and populations at risk), and vulnerability/adaptive capacity (sensitivity and readiness to respond), consistent with IPCC/UNDRR frameworks, and organised across priority sectors (e.g., health and social, ecosystems/environment, infrastructure and urban systems, water/energy/agriculture), as catalogued in D2.2. The data sources screened and documented in WP2, mainly the Copernicus Climate Data Store (CDS) and other ECMWF datasets, constitute the primary input for the service components described in this deliverable. The data sources analyzed and documented in WP2, primarily the Copernicus Climate Data Store (CDS) and other ECMWF datasets, constitute the main input for the service components described in this document. The indicators defined and selected by WP2 are documented in D2.2 and are accessible and partially computable.

D3.2 also aligns with D1.2 ClimEmpower Scenarios, which established the conceptual pathways and resilience narratives. The Indicator Service Framework presented here translates these conceptual pathways into an operational structure, enabling reproducibility, traceability, and transparent handling of classification methods and mapping tables. This strengthens the link between scenario-building (WP1) and technical implementation (WP3).

The outputs of this deliverable are critical for ongoing work in WP3 (T3.2, T3.4), where they serve as the backbone for implementing the user-centric ClimEmpower Platform, and in WP4 (T4.1, T4.3, T4.4), where regional co-design activities require reliable, open, and auditable services for data access and indicator generation. By deploying the Polytope DS2 and related libraries on ECMWF infrastructure, D3.2 ensures long-term sustainability and alignment with European open data and climate service standards.

In summary, D3.2 bridges the methodological developments of WP1–WP2 with the technical implementation in WP3 and the participatory processes in WP4, grounding the platform in the sectoral and risk-dimension structure of the WP2 indicator set and thereby consolidating ClimEmpower’s capacity to provide interoperable, transparent, and societally relevant climate services to the Communities of Practice and beyond.

## 2.4 Data, security, and ethics

In line with the project's other deliverables, D3.2 adheres to three data principles: KISS (simple and transparent processes), FAIR (Findable, Accessible, Interoperable, Reusable), and Societally Responsible (maximum openness except for justified ethical or commercial exceptions; explicit verification of ethical issues regarding data, algorithms, and outputs). These principles guide the design of services, documentation, and the release of software and information artifacts.

### 2.1.1 Data Context and Interoperability

D3.2 describes reusable libraries and services for extracting climate features and accessing geospatial data primarily from the Copernicus Climate Data Store (CDS) and ECMWF resources (e.g., ERA5), exposed via APIs (REST) and, where appropriate, OGC EDR standards. The libraries are modular and open source (e.g., Polytope, polytope-mars, covjsonkit, Earthkit, polytope-client, Polytope DS2). The use of standard formats and interfaces (e.g., CoverageJSON via covjsonkit) facilitates integration and reuse in external workflows.

Consistent with the analysis in WP2, typical data formats for climate/gridded datasets include NetCDF/GRIB; for vector and tabular data, shapefiles/CSV and statistical tables are used. D3.2 primarily works with climate geospatial datasets. The service is not applicable to non-geospatial datasets (e.g. most of EUROSTAT).

### 2.1.2 Accessibility and reuse

The D3.2 architecture favours selective access (subsetting) to reduce bandwidth, processing time, and costs, with reusable and open services and libraries.

The Polytope DS2 component is already deployed on the ECMWF infrastructure and available via REST, with maintenance planned beyond the project's lifespan.

### 2.1.3 Data and service security

The datasets discussed in D3.2 are environmental and geospatial, free of personal data; therefore, the activities described are not considered sensitive from an ethical or security perspective. The use of standardized services (EDR) and deployment on ECMWF infrastructures contribute to operational robustness and access control to third-party resources (CDS).

### 2.1.4 Ethics and responsibility of use

The methodological framework introduced in this deliverable requires transparency and traceability in technical and methodological choices, with particular attention to documenting procedures (e.g., versioning systems and auditing of data and algorithms). This ensures verifiability, reproducibility, and the possibility of collaborative adjustments.

From an ethical perspective, the work is committed to ensuring that the data and tools developed are used responsibly and inclusively, avoiding the risk of bias or disproportionate effects on vulnerable groups. The focus is on promoting a just transition, in which the climate services produced support fair and transparent decisions that benefit the community.

### 2.1.5 Licensing and reuse of outputs

This deliverable is published under the CC BY 4.0 license; the libraries cited are released as open source, encouraging reuse within and beyond the project, in compliance with third-party licenses and Copernicus/ECMWF policies.

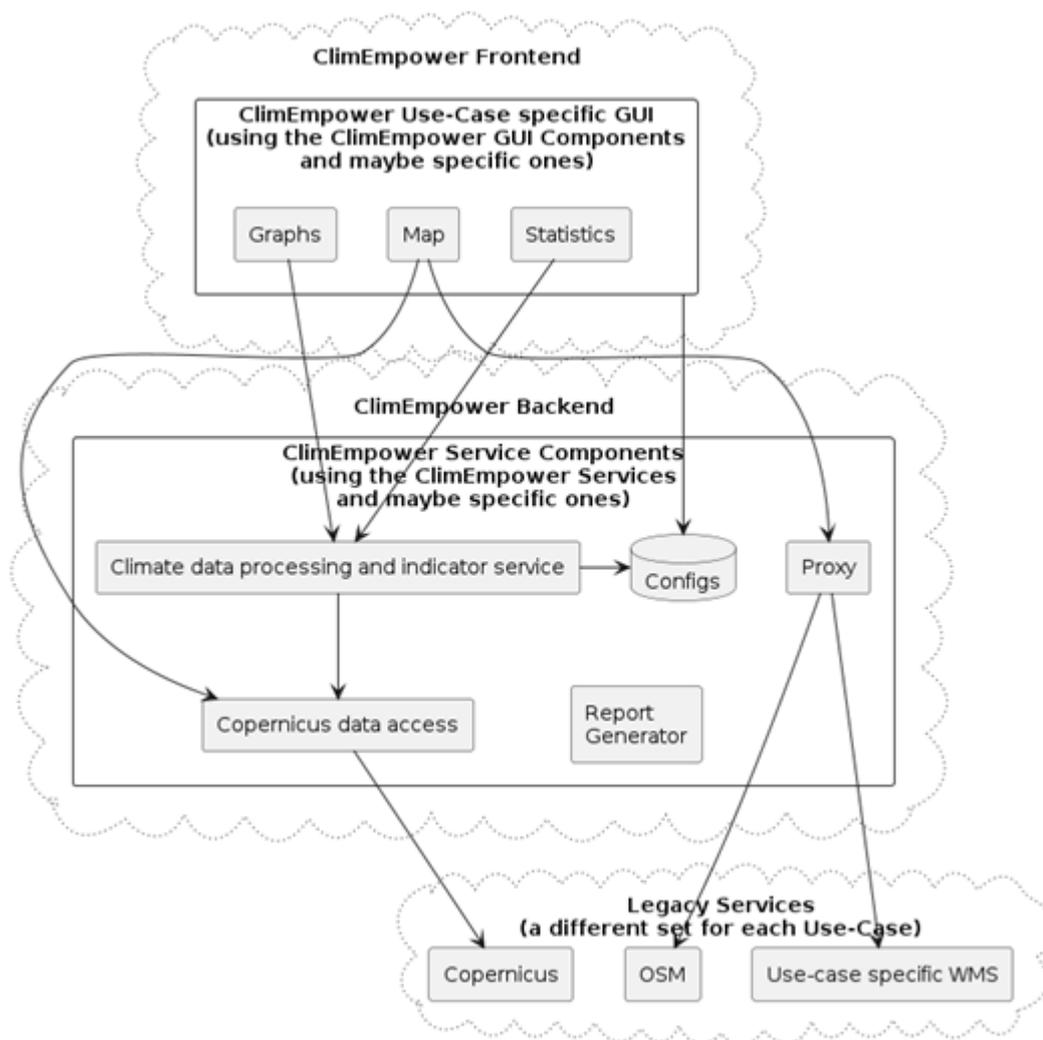
## 3 Climate feature extraction

Data access is integral to the ClimEmpower project. Without data tailored to users' needs the goals of the project become much more difficult to attain if not impossible. We intend to provide data that is easy to access, understandable and tailored to the region's needs. These data access services will also be supported and maintained post the ClimEmpower project by ECMWF. The main users of the data services are the data scientists, modellers, and the service developers in other tasks such as task 3.3 and task 3.4.

ClimEmpower addresses these challenges in a number of ways. Firstly **the project implements a new way for accessing the Copernicus data store (CDS, <https://cds.climate.copernicus.eu/>)**, which contains numerous datasets such as ERA5, a reanalysis for the global climate and weather for the past eight decades, as well as many other useful datasets that can be used by the regions in this project to estimate hazard and risk assessment at a more granular level. While a data access API for these datasets already exists, the new API developed in T3.1 “Develop feature extraction library and service for Copernicus data” of WP3 is **more powerful and allows the users to easily retrieve the part of the data that is relevant for their region and use case, rather than downloading an entire global or European dataset and extracting the required parts of it locally**. This will lower the transfer bandwidth required for retrieving the data and allow us to utilise Copernicus data services more efficiently, while increasing the speed of service development and lowering their complexity and processing needs.

This functionality is available both as a **python library** and as a **REST API**, and already deployed at <https://polytope-dss.ecmwf.int/>. These developments aren't directly targeting the end users or scientists and instead target the software developers and data scientists that are comfortable with use of python for data processing. They integrates with the data processing, visualisation and GUI developments in tasks 3.2, 3.3 and 3.4 (Figure 3).

CDS and the ClimEmpower python/REST API service are both developed and hosted by ECMWF and part of the European Copernicus program. **The code for the libraries developed within ClimEmpower will be published as open source with ongoing maintenance from ECMWF and the Copernicus program.**



**Figure 3: ClimEmpower architecture – component view**

The library is modular and flexible enough that other datasets or data sources can be added in the future as backends with minimal need to change the underlying code. Complete data access and pre-processing services software stack developed by ECMWF is shown in the Table 1 below.

**Table 1: Overview of data access service stack**

Service/tool name	Purpose	Further information	Version
Polytope Feature Extraction	Polytope is a library for extracting complex data from datacubes. It provides an API for non-orthogonal access to data.	<a href="https://github.com/ecmwf/polytope">https://github.com/ecmwf/polytope</a>	1.1.1
Polytope-mars	This library provides a higher-level API to allow requests for features such as time series and vertical profiles.	<a href="https://github.com/ecmwf/polytope-mars">https://github.com/ecmwf/polytope-mars</a>	0.3.4

Service/tool name	Purpose	Further information	Version
Covjsonkit	Covjsonkit is a library for encoding and decoding coverageJSON files/objects of meteorological features such as vertical profiles and time series.	<a href="https://github.com/ecmwf/covjsonkit">https://github.com/ecmwf/covjsonkit</a>	0.2.3
Polytope-client	Polytope-client provides a REST API and python interface for access to hypercube data, stored in various data sources.	<a href="https://github.com/ecmwf/polytope-client">https://github.com/ecmwf/polytope-client</a>	0.7.7
Earthkit	A python library providing powerful tools for speeding up weather and climate science workflows by simplifying data access, processing, analysis, visualisation and much more.	<a href="https://earthkit.readthedocs.io">https://earthkit.readthedocs.io</a>	0.16.5 (EarthKit-Data)
Polytope DS2	Polytope DS2 (Data Store Service) combines most of the above libraries into a single deployable service.	<a href="https://polytope-dss.ecmwf.int/docs#/">https://polytope-dss.ecmwf.int/docs#/</a>	Prototype Deployed

While the CDS, Polytope Feature Extraction, and Polytope-client were developed under other European projects, Covjsonkit, Polytope-mars, and Polytope-DS2 have been specifically developed in ClimEmpower. All libraries are open source and available on github. These libraries are intended to be modular and reuseable and do not need to be used together, with each component being using as an independent library. We will now go further into each of these reusable components for climate feature extraction.

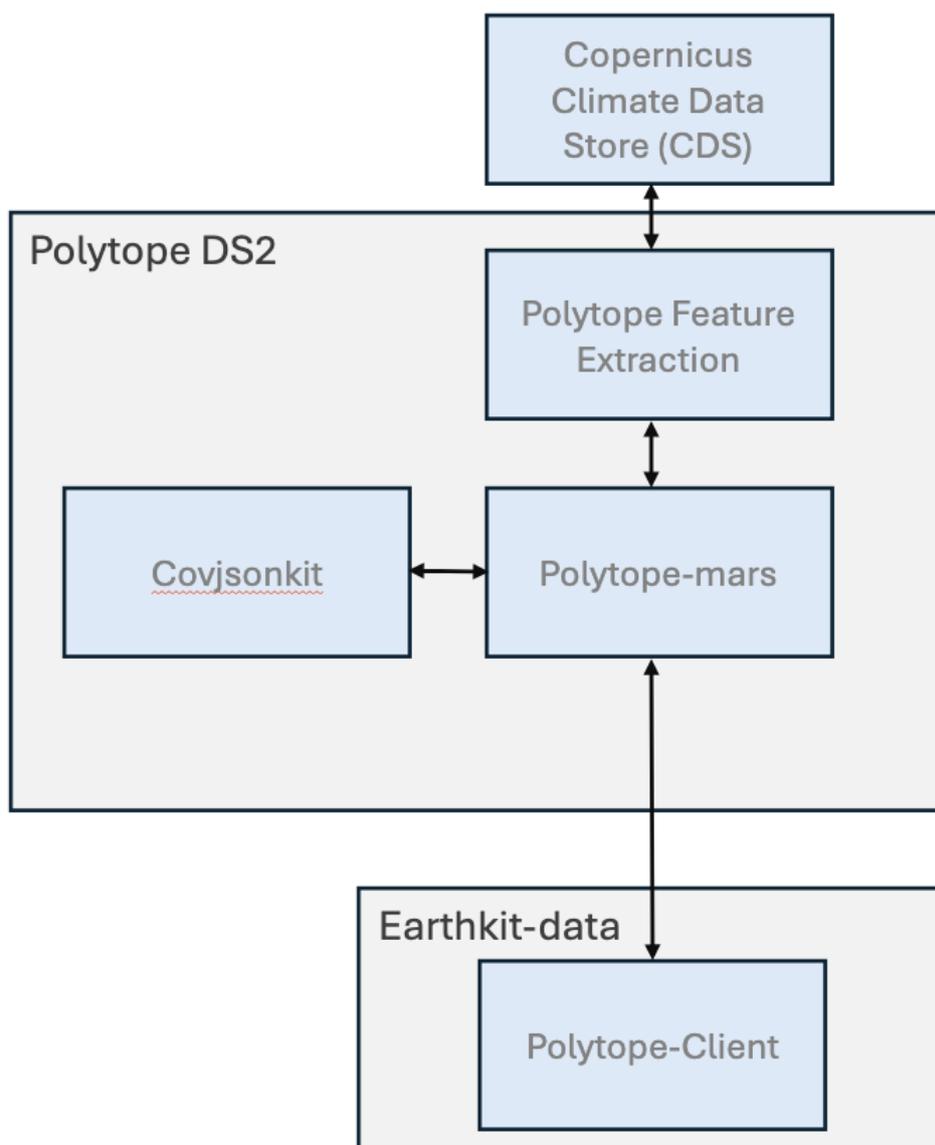


Figure 4: Overview of Software Component interactions

### 3.1 Polytope Feature Extraction

The Polytope Feature Extraction (FE) library is used for extracting complex data from datacubes. It provides an API for non-orthogonal access to data, where the stencil used to extract data from the datacube can be any arbitrary  $n$ -dimensional polygon (called a *polytope*). This can be used to efficiently extract complex features from a datacube, such as polygon regions or spatio-temporal paths. Previously when providing data, we only returned global fields which users would have to process for their local area, however Polytope FE allows us to return arbitrary cut outs from our data cubes allowing the regions to only receive data tailored to their needs and removes the need for post processing on their end.

An easy-to-use interface for Polytope FE, Polytope-mars has been developed to allow users to more easily request features that otherwise would be more difficult using Polytope FE alone. Polytope-mars provides an interface that can return features such as time series, vertical

profiles and cut outs of countries of regions via shape files or GeoJSON geometries. This library will be integrated with the Polytope client to expose the interface in the future and consolidate interfaces, for this project however it will be hosted separately as a REST interface.

## 3.2 Covjsonkit

Data formats are integral to data services. If users do not receive a format they can work with, they will not use the data service. The existing formats such as GRIB and NetCDF provided by the CDS are specific to the meteorology and climate communities and while they are useful in that context users in ClimEmpower may not be familiar with these data formats, so we intend to use an open and user-friendly format.

In this case we are providing a community standard data format that is interoperable with existing tooling, and we are providing our own custom tooling to convert and interpret the data in other popular formats that users are likely to be familiar with, currently the main format to convert to is xarray, and GeoJSON. This tooling provides a number of other utility functionalities such as plotting, mapping and regridding tools.

CoverageJSON is an OGC community standard that is web friendly, human-readable, geospatial data format. CoverageJSON can encode spatial and temporal data with aggregated metadata. This format is widely adopted in the geospatial and climate communities and integrates with other OGC standards and APIs.

To facilitate the easy use of the CoverageJSON we have created the Covjsonkit library. This open source library is intended for use by the entire OGC and CoverageJSON community but has been created for users of ClimEmpower. The library converts bytes retrieved from underlying Global fields data in the GRIB or NetCDF format and converts it into CoverageJSON.

The library allows users to create or read a CoverageJSON file and manipulate its data. It can also be used to convert the data into other formats such as xarray for ease of use.

## 3.3 Earthkit

Earthkit is a new open-source Python project led by ECMWF, providing powerful tools for speeding up weather and climate science workflows by simplifying data access, processing, analysis, visualisation and much more. Both the Polytope data service and Covjsonkit are integrated with the Earthkit library ecosystem.

In particular, Earthkit allows users to make requests directly in python using Polytope and is then able to interpret the CoverageJSON data directly using Covjsonkit. This is then integrated with Earthkit's plotting tools that can be used for visualisation of the data all in the same library.

We intend to integrate the Polytope data service further in the future with other Earthkit features such as regridding of data, and aggregation and transformation of data. This will allow users to write all their workflows in a single library.

## 3.4 Environmental Data Retrieval (EDR)

EDR (Environmental Data Retrieval) is an OGC API standard that allows users to query resources for different types of features such as areas, trajectories and positions. Implementing the EDR interface allows users to adapt existing workflows that already use EDR

in an easy way, lowering the effort required. EDR as an already existing standard has been shown to be a robust way of accessing geospatial data.

This interface gives users extra options on how they would like to retrieve data from ClimEmpower and CDS sources. It also provides a base to build off for implementing other standard OGC API's and services. This is currently in development and will be finished before the end of the ClimEmpower project.

### 3.5 Copernicus Climate Data Store (CDS)

The Copernicus Climate Data Store (CDS) is a central repository for storing climate and extreme event datasets primarily relating to Europe but also to the rest of the world. These datasets include ERA5 a global reanalysis of the state of the global atmosphere dating back decades, climate projections from various models, as well as indexes and hazard datasets for many extreme events such as fires, droughts, floods, and heatwaves. These datasets are invaluable to calculating risk and hazard indicators for the users of ClimEmpower.

Users can currently retrieve data from the CDS using the CDS API, however these datasets are usually large, covering all of Europe or the whole globe. We intend to improve upon this by allowing users to sub select on this data for only the data that is relevant to their region. Reducing the amount of data that needs to be stored and improving the speed of requests made, via the Polytope tools described above.

### 3.6 Polytope DS2 Prototype

Polytope DSS (Data Store Service) combines all the software stack into a deployable service which provides a REST API that can be queried to retrieve subsections of datasets from the CDS. The service is deployed via Kubernetes on ECMWF servers from a Docker image. This allows updates of the underlying libraries to be made and versions in the image updated easily and then redeployed quickly.

The Polytope DSS service is currently up and running at <https://polytope-dss.ecmwf.int/docs/> and can be queried by users of ClimEmpower and the other tasks. It is currently being integrated with other tasks in WP3 and by users from the other work packages.

The Polytope DSS service will be used in the Jupyter notebooks that have been created for various Extreme events from the CLIMAAX project. It will also be used in the GUI to provide data for plots and visualisations.

## 4 Indicator Service Framework (ISF)

The Indicator Service Framework (ISF) establishes a common methodological and operational reference for transforming climate-related risk assessments into actionable adaptation and resilience recommendations at multiple administrative levels. It can be considered an evolution of the Service as originally described in Deliverable 3.1 (paragraph 4.2), designed to meet partners’ usability needs and deliver genuine value to end users. At this stage, the framework is intentionally designed to provide principles, guidance, and procedural steps that will underpin a future operational service.

Its primary use is to support both technical and non-technical partners in reliably translating climate indicators, selected through scientific analysis in WP2 (Figure 5) and stakeholder consultation, into a systematic, transparent portfolio of recommendations tailored to each territorial context. Throughout its design, the ISF prioritizes scientific rigor, transparency, collaborative review, and the ability to evolve as project needs, knowledge, or stakeholder requirements change. It is not a finalized software product or a static tool, but a foundational platform from which iterative development and integration can proceed.

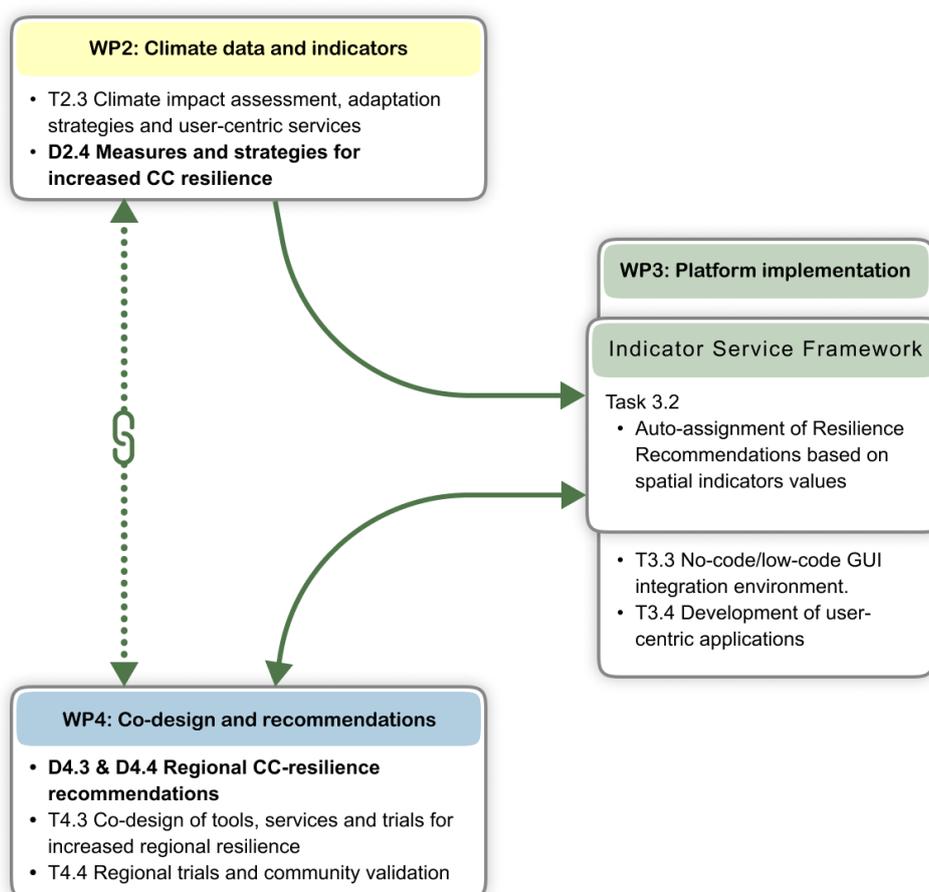


Figure 5:Relation to other Work Package

## 4.1 Multi-Scale, Data-Agnostic Architecture and Spatial Intelligence

### 4.1.1 Spatial and Administrative Adaptability

The ISF is explicitly built to be spatially and administratively agnostic, prioritizing inclusion and usability across diverse regional realities. It is not constrained to a single spatial format. WP2 selects the geographic resolution, grids, city blocks, districts, municipalities, or provinces, that best reflect their operational needs, data availability, and governance structures. However, it is important to acknowledge that, in most cases, the spatial dimension of the indicator, its resolution, is determined by the availability of input data, which ultimately dictates its final NUTS level.

### 4.1.2 Data Structures and Usability

A fundamental priority is to keep the technical barrier as low as possible for all partners. The framework prescribes the use of accessible, tabular data structures (Table 2) for associating climate indicators with spatial units and recommendations. This design choice enables collaborative editing, auditable workflows, and scalable management by both technical and non-technical users. Guidance is detailed for populating, versioning, and reviewing these tables in a way that ensures a common understanding among partners, thus preventing any loss of information or methodological drift during future code or platform development.

## 4.2 ISF Complexity Levels and Indicator Classification and Standardization

The ISF is designed to be used at three distinct levels of complexity or applicability (Figure 6), decided by various factors. This ensure that even when there is a lack of knowledge, spatial resolution, or simply regional needs, there can still be resilience recommendations acting as general guidelines based on the input indicator(s).

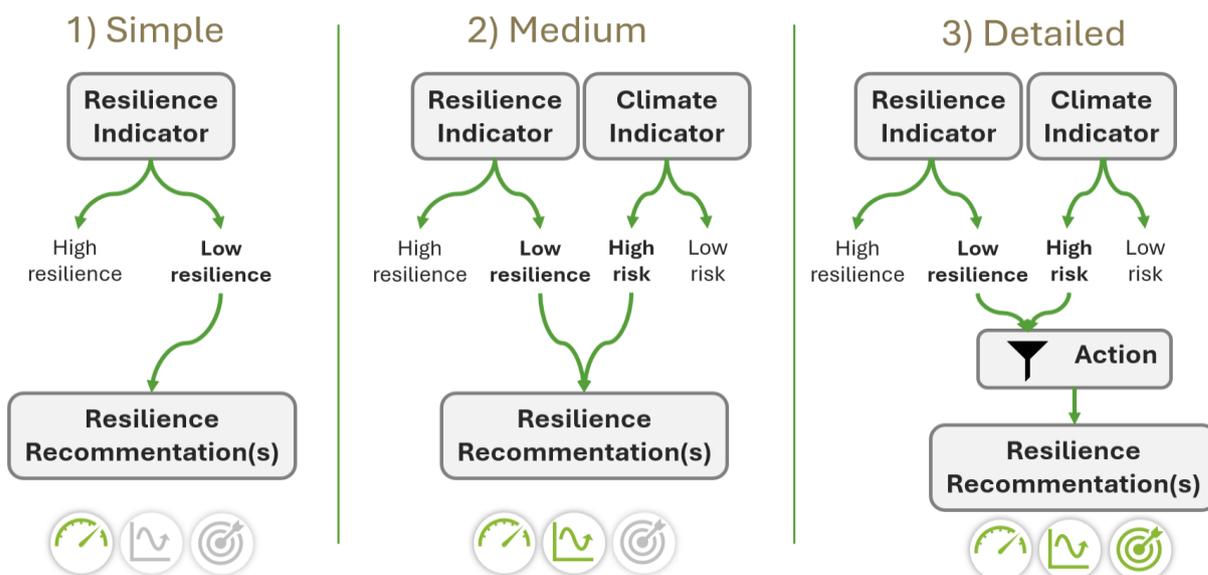


Figure 6: Diagram showing the possible levels of applicability and complexity in using the ISF

The three levels of complexity are designed to allow for addressing resilience even in contexts where, due to a lack of scientific literature, it is not possible to discern the different levels of “severity” of the indicators.

Specifically, the three levels of applicability are intended as such:

**1. Simple:** the most direct implementation based on the Resilience Indicators identified by WP2 and described in Deliverable 2.4. The threshold for activating the recommendation comes from literature reviews, or decided by the regional authority or, in the absence of both, the recommendation would always activate, thus simply represent a general guideline, independent of the current status of the indicator.

**2. Medium:** This intermediate level should be used to provide end users with more contextualised information and recommendations. In particular, it requires a Resilience Indicator and an associated Climate Indicator as input (the association should be decided with stakeholders or by expert guidance in WP2) and returns Resilience Recommendations that respond separately to both indicators.

**3. Detailed:** The third level is also the most specific and contextual of the three, including a potential ‘Action’ based on the needs expressed by the regions (WP4). An example could be the Sicily Region, who needs to discriminate recommendations based on six possible types of interventions on the territory in order to carry out preliminary Climate Proofing, but this level of applicability would be suitable for any region where necessary and required. In particular, the end user should first select the Action of interest, at which point the process is similar to the Medium level, but the recommendations in this case must be adapted to be action-specific.

A key methodological advance of the ISF is the requirement for a two-step process in preparing indicators for use in mapping and recommendation assignment.

### 4.2.1 Step 1: Indicator-Specific Classification Method Selection

For every indicator, the process requires to:

The **intended use** (regional governance, local action, building design, etc.) must always guide both indicator and classification choice, and this reasoning is to be recorded alongside indicator definitions, to ultimately ensure final user effortless understanding of the entire process (Moreira, 2021).

### 4.2.2 Step 2: Value Standardization for Mapping

After case-specific classification:

The raw or classified indicator values are mapped onto a set of standardized classes (e.g., 0,1,2,3,4 or similar, depending on indicator granularity). This harmonization is necessary to:

- Enable automatic recommendation assignment,
- Enable transparent status mapping throughout the platform,
- Allow meaningful regional and cross-region comparisons for not-strictly regional indicators,
- Permit subsequent modification of the original ranges without modifying the standardized classes, avoiding the need to act at the code level each time.

This process ensures that, for instance, a TMRT (Mean Radiant Temperature) value in degrees Celsius is converted to a discrete class (e.g., “>70°C = class 4, 65-70°C = class 3” etc.) before recommendations are assigned.

### 4.2.3 Documentation Requirement

All decisions on classification methods and value-to-class mappings must be documented within the mapping tables and in associated meta-documentation. This traceability allows for review, joint revision, and eventual external audit, as well as supports future adaptation to new indicators or knowledge.

**Table 2: Example table for the first level of implementing complexity of the ISF**

Percentage of properties with insurance coverage for high-risk hazards	Class (standardized value range)	Recommendation	Effort level	Notes
>50	1	No recommendation	N/A	Not needed
<=50	2	- Expand access to affordable insurance products for high-risk areas. - Encourage mandatory insurance schemes for properties in hazard-prone regions.	N/A	Not needed

As in the sample Table 2, the structure should, at a minimum, include:

- Indicator original value,
- Standardized class (numeric or categorical),
- Full text of recommendation (if needed),
- and some non-mandatory:
- Effort level (qualitative or quantitative scale: e.g., low to high),
- Additional notes if relevant.

The Table 2 represents the Simple implementation of the ISF (Figure 6) but for the Medium level of complexity, instead of a single table, it is sufficient to have two tables associated with each other; the layout and operation remain the same.

For the Detailed level of complexity, on the other hand, a preliminary step is required, a filter that discriminates the indicators to be included in the process and also determines the Action-specific recommendations.

## 4.3 Systematic Mapping Logic: From Indicator Class to Recommendations

### 4.3.1 Structure and Dimensions of Mapping

One of the foundational aspects is the *systematic mapping* table or matrix, which assigns each standardized class of each indicator to a set of one or more recommendations. **Categorization should include at least:**

- Risk type (e.g., heat wave, pluvial flood),
- Resilience domain (or dimension),
- Level of implementation effort, thus in which class they fall.

**Effort levels** are included methodologically (ranging from low effort to high effort); these support prioritization, resource planning, and communication to local actors. The mapping table must make visible which recommendations are low-effort “quick wins” versus which are high-effort, long-term structural changes (Figure 7).

### 4.3.2 Assignment Process

For each spatial unit:

- Once an indicator’s value is classified and standardized, its class is looked up in the mapping table to yield one or more pre-defined recommendations.

The recommendations should match the specific risk, spatial scale, and capacity, as determined via the previous step. All of this can be region-specific. In absence of regional



Figure7: Empirical representation of the assignment of recommendations based on the “severity” represented by the indicator and the effort required to implement them

recommendation, a default recommendation is used.

### 4.3.3 Examples and Expected Use

This logic supports a transparent, automated linkage between data and action: for example, all units flagged as “class 4 – highest heatwave risk” may receive a standard suite of recommendations (e.g., “install passive ventilation, invest in high solar reflectance pavements,” etc.), all clearly listed with effort level.

*Note for composite indicators:* At present, to maintain transparency and avoid methodological ambiguities, the framework does not include composite indicators for recommendation

assignment. Future methodological updates may revisit this decision considering additional research or innovation in the field.

### 4.3.4 Versioning and Audit

All mapping and recommendation tables should be versioned, with reasons for changes or new entries always recorded. Annual or milestone-based reviews are recommended, in which partners jointly evaluate the continued scientific and practical suitability of thresholds and actions.

## 4.4 Documentation, Automation, and Integration: Principles for Sustainable Implementation

This IDF is designed to ensure both immediate usability and long-term adaptability, supporting stakeholder collaboration, technological transitions, and seamless platform integration. All configuration tables and mapping logic developed within the framework are maintained in formats that are both human-readable and machine-readable, such as standardized spreadsheets or structured text files (e.g., JSON or YAML). This dual accessibility guarantees that any participant, regardless of technical skills, can review, edit, or propose modifications, while ensuring the same data can be directly referenced or processed by automated systems.

Although the current implementation emphasizes manual and semi-automated editing, making adjustments accessible to all project partners, the framework is explicitly future-oriented. Its structure acts as a blueprint for full digital automation: all mapping logic, thresholds, and classification rules are unambiguously translatable into code, ready for deployment as independent microservices, APIs, or modules within the ClimEmpower digital ecosystem. This design eliminates ambiguity and reduces the risk of misinterpretation during future upgrades or integration phases. Future enhancements require only updates to specific configuration tables (such as adding new indicators or recommendations), rather than overhauling the underlying codebase or architectural logic, preserving both forward and backward compatibility.

Integration into the broader ClimEmpower platform is a core ambition for the framework. The ISF is built to operate as a versatile module within the project’s data hub and decision-support dashboards. This makes its outputs, well-defined climate adaptation and resilience recommendations linked to standardized indicator classes, accessible across multiple scales, supporting flexible reporting and cross-scale analysis for policy makers, technical experts, and regional users alike.

Looking ahead, the framework is designed to be a living system, sustained by a dynamic and participatory environment. Its long-term relevance and credibility are anchored by two core principles:

- **Collaborative Improvement:** Open documentation and workflows empower all project participants, from technical experts to regional stakeholders, to contribute updates as new data, scientific insights, or local priorities emerge.
- **User-Centric Feedback:** A continuous feedback loop with both technical and non-technical users is essential for refining recommendations and ensuring the tool remains practical and effective over time.

This combined approach ensures lasting traceability and accountability, anchoring future improvements in both scientific validation and real-world user experience. In summary, the Indicator Service Framework’s design preserves its methodological rigor, transparency, and collaborative ownership throughout its entire lifecycle, from initial configuration to fully automated service deployment and its potential transferability to other contexts.

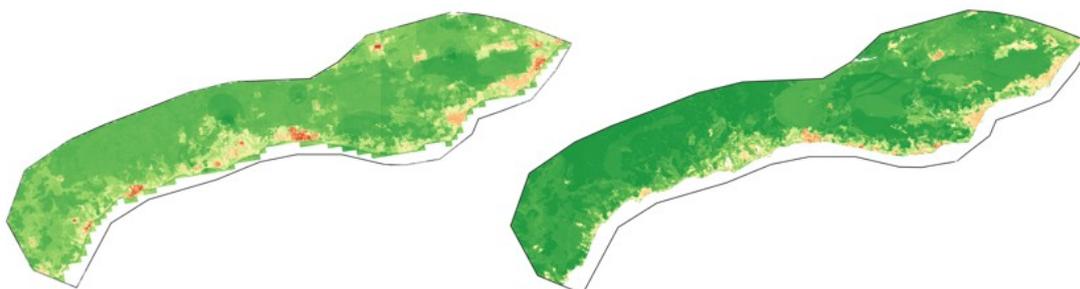
## 5 Climate risk maps

Within ClimEmpower, climate risk mapping constitutes one of the central climate services provided through the platform. The risk maps are designed to offer a harmonised, transparent and user-oriented representation of how different climate hazards may affect people, buildings, critical infrastructure, natural systems and economic sectors across the participating regions, as well as possible adaptation measures.

The methodology follows a coherent multi-hazard approach rooted in established frameworks (UNDRR, IPCC), expert consultations, and resources developed within CLIMAAX, while also remaining flexible enough to integrate region-specific information when available.

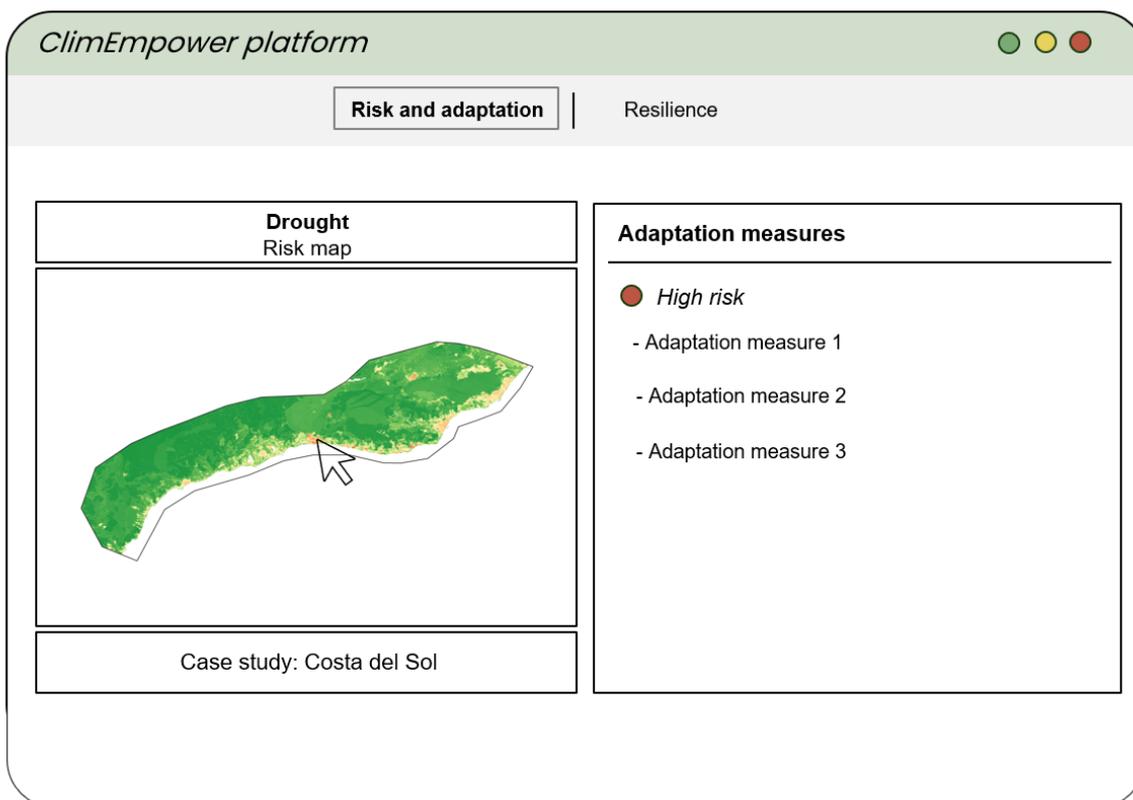
### 5.1 General methodological approach

All risk maps follow a consistent structure based on the three core components of risk: hazard, exposure and vulnerability. Each component is developed as an independent spatial layer using open datasets at the European scale whenever possible. When additional regional or local datasets are available, especially those emerging from interactions with the Communities of Practice (CoPs), these are incorporated to improve local relevance and increase map resolution (see **Error! Reference source not found.** below). This two-tier approach (European baseline + local enhancement) ensures comparability across regions while enabling tailored insights where detailed data exist.



**Figure 8:** Preliminary computed results of drought risk using European datasets (left) and local region-specific datasets (right) in Costa del Sol (Andalusia) Case Study

Hazard, exposure and vulnerability layers are normalised and combined using an equal-weighting scheme (1/3 each), unless one component is not applicable (in which case the remaining two are weighted by 1/2). Within each component, the individual datasets are internally weighted so their combined contribution equals 1. Risk is ultimately computed using the selected methodology for each hazard, and translated into standardised categories displayed on the platform using a common colour scale, ranging from low to very high risk. Each risk level is also linked to recommended adaptation measures within ClimEmpower, ensuring that the maps directly support decision-making processes. **Error! Reference source not found.** illustrates the conceptual idea



**Figure 9: Overview of risk maps and associated adaptation measures in the ClimEmpower platform**

All risk maps will be computed using GIS or similar spatial analysis software,

The following sections summarise the methodological principles for the four risk types implemented in ClimEmpower: heatwaves, droughts, floods, and wildfires. The technical details for each step are fully documented in Deliverable 2.4.

Hazard-specific risk assessments

## 5.1.1 Heatwaves

### 5.1.1.1 Hazard

Heatwave hazard is derived from region-specific heatwave definitions provided by the pilot regions. Climate simulations (e.g., EURO-CORDEX) and other existing local datasets are processed to count heatwave days under historical and future scenarios.

### 5.1.1.2 Exposure

Exposure is defined in terms of population, including population density, touristic accommodation and social facilities such as hospitals and kindergartens. Point datasets are treated as binary values (present/not present), while population density is normalised to the regional distribution.

### 5.1.1.3 Vulnerability

Vulnerability reflects access to cooling resources (proximity to green areas and water bodies) and population age structure, with higher sensitivity assigned to children and elderly people. Distance-based classes are converted into a 0–5 scale, and all variables are normalised before integration.

## 5.1.2 Drought

### 5.1.2.1 Hazard

Drought hazard is captured using two climatic indicators:

- SPI-12, representing long-term precipitation deficit,
- NDMI, representing soil and vegetation moisture.

Both are standardised into a common 1–10 scale.

### 5.1.2.2 Exposure

Exposure includes population density, social facilities, tourist accommodation and golf courses, as well as crop types for agricultural drought risk. These datasets reflect the variability of water demand across sectors.

### 5.1.2.3 Vulnerability

Vulnerability is characterised by water demand, soil imperviousness and groundwater storage potential. These factors capture the sensitivity of ecosystems and human activities, and the capacity of the system to buffer drought impacts.

## 5.1.3 Wildfire

### 5.1.3.1 Hazard

Wildfire hazard is computed by combining:

- Fire Weather Index (FWI): seasonal mean as a proxy for meteorological fire danger;
- Burnable vegetation: derived from CORINE Land Cover.

The hazard layer is the product of both, rescaled to 0–1.

### 5.1.3.2 Exposure

Exposure depends on the asset and includes buildings, infrastructure, touristic facilities, agricultural areas, forests and population density. Boolean or fractional methods are applied depending on the dataset type. All exposure layers are added and capped at 1.

### 5.1.3.3 Vulnerability

Vulnerability is constructed using components such as WUI fraction, protected area importance, and population density in WUI zones. Each variable is normalised (if needed), added and capped at 1. Asset-specific layers may use a single dataset if it sufficiently represents vulnerability.

## 5.1.4 Pluvial flood

Flooding is one of the highest-impact climate hazards in Europe, and its relevance has been emphasised by multiple ClimEmpower CoPs, particularly in regions recently affected by severe flood events.

### 5.1.4.1 Hazard

Flood hazard is derived from fluvial and coastal flood maps following CLIMAAX/CLIMADA methodologies. These maps represent inundation depth for selected return periods. When

regional maps do not exist, global high-resolution datasets are used as first approximations but interpreted with caution, as they do not include local protective infrastructures.

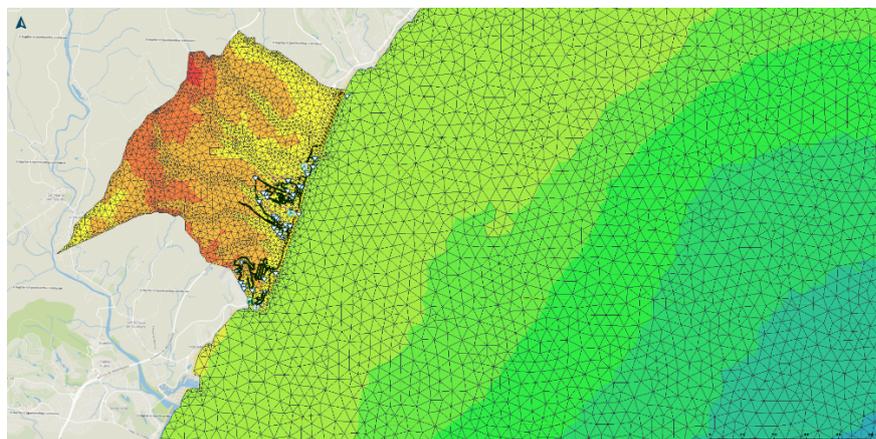
Extreme precipitation is treated separately: rather than being directly converted into pluvial flood hazard, it is used to assess changes in intensities and extremes (e.g., RX1day), acknowledging the need for local thresholds and hydrodynamic modelling for pluvial flood risk.

### **Special case: Andalucía (Costa del Sol)**

In addition to the common approach applied across regions, Andalucía has expressed specific concerns regarding pluvial flooding, driven by recent damaging events (such as Valencia and Málaga in 2024) and stakeholder priorities. To address this, it ClimEmpower is developing a dedicated high-resolution pluvial flood model using local drainage network data provided by municipalities. Regarding the final map:

- These drainage data themselves will not be displayed, as they are not public.
- The resulting hazard maps will be openly accessible through the platform.
- This local model complements the European-scale datasets and significantly improves the representation of pluvial flood dynamics, which are often underestimated or absent in existing regional or EU-level flood maps.
- Additionally, compound flooding (interaction between pluvial and coastal flooding) will be studied given its relevance in the region.

The pluvial flood model for Andalucía is being developed using the MIKE (DHI) hydrodynamic modelling suite<sup>4</sup>. This modelling effort provides added value to the existing fluvial flood maps, as it captures pluvial and surface-runoff mechanisms that are currently not represented in regional datasets.



**Figure 10: Development of the MIKE 21 hydrodynamic model in a municipality of the Costa del Sol. The pluvial flood model has been coupled with a coastal model to study compound flooding events**

Since this constitutes a pilot study within ClimEmpower, the project will also evaluate the potential replicability of the methodology. If successful, key steps, recommendations, and good

<sup>4</sup> <https://www.dhigroup.com/technologies/mikepoweredbydhi>

practices can be summarised at the end of the project, allowing similar analyses to be reproduced using the same software or other non-licensed and open-source tools (e.g., IBER-SWMM). This will enhance the applicability of the approach across other regions, should similar data become available in the future.

#### 5.1.4.2 Exposure

Exposure depends on the asset considered: Buildings (building footprints and types), Population (population density) and Critical infrastructure (location of facilities from OSM).

#### 5.1.4.3 Vulnerability

For buildings, vulnerability can be quantified using JRC depth-damage curves and reconstruction costs. For population displacement, vulnerability is represented by flood-depth thresholds (e.g., >1 m). Finally, for critical infrastructure risk is based solely on hazard × exposure, as no suitable vulnerability information exists.

## 5.2 Heatwave and Pluvial Flood hazard maps for Sicily

This section illustrates how the methodology described in section 5.1 will be implemented, on example of the Sicily case study.

Regarding the primary hazards identified for the Sicilian territory, heat waves and pluvial floods, specific indicators were utilized to establish temperature and precipitation thresholds representative of reference events under future climate scenarios. These events were classified into 27 distinct hazard permutations, resulting from the intersection of three core variables:

- **Temporal Horizons:** 2011–2040, 2041–2070, and 2071–2100.
- **Emission Scenarios (RCPs):** RCP 2.6 (ambitious mitigation), RCP 4.5 (intermediate stabilization), and RCP 8.5 (high-emissions/worst-case scenario).
- **Event Frequency:** “Frequent” (1-year return period), “occasional” (5-year return period), and “rare” (20-year return period).

The modeling framework relies on the Heat Wave Local Effect Model (HWLEM) and the Flood Local Effect Model (FLEM), originally developed by the UNINA-PLINIVS Study Centre within the CLARITY project. However, their application at the regional scale for the ClimEmpower project necessitated significant methodological adaptations to accommodate such an extensive geographic scope.

Key enhancements include:

- **High-Resolution Land Cover Development:** To overcome the absence of pre-existing regional data, a bespoke, detailed land cover dataset was constructed (Figure 11). Every individual surface was meticulously classified and parameterized, ensuring that the local physical characteristics of the built and natural environment are accurately represented.
- **Multi-Input Model Recoding:** While these models typically process a single input value from climate scenarios (which is sufficient for urban-scale analysis using 12km x 12km grids), the model code was re-engineered for ClimEmpower. This allows the

simulation to simultaneously process a multitude of different temperature and precipitation inputs for the same scenario, reflecting the climatic heterogeneity across the entire region.

- **Standardized Spatial Resolution:** For the regional analysis, a 1km x 1km spatial resolution grid, specifically derived from the EUROSTAT grid, was adopted. This ensures not only high-resolution regional hazard mapping but also the ability to seamlessly compare and integrate climate data with demographic indicators for future multi-risk assessments. This made it possible to calculate indicators for a total of approximately 13 cells covering the entire region.



**Figure 11:** Images extracted from the high-resolution regional land cover developed by PLINIVS for climate simulations in Sicily.

To ensure a comprehensive assessment of the territory, simulations are currently being executed at two distinct spatial scales:

- **Regional Scale:** Utilizing 1km x 1km cells to provide a consistent overview across the entire Sicilian region, as said before.
- **Urban Scale:** Utilizing high-resolution 250m x 250m cells specifically for the Functional Urban Areas (FUAs) of Palermo, Messina, and Catania, where the complexity of the built environment requires finer granularity.

Upon completion, these simulation outputs will be fully integrated into the ClimEmpower platform. This integration will provide the Regional Authority and the specific FUAs with a robust, evidence-based scientific framework. By accounting for micro-climatic dynamics under diverse future climate scenarios, this toolset enables stakeholders to take more informed decision thanks to high-fidelity territorial evaluations and develop targeted, climate-resilient adaptation strategies.

## 6 Conclusions

ClimEmpower prioritizes long-term usability and stakeholder co-creation. Solutions described in this deliverable are designed not only for current project sites but also for straightforward transfer and integration into new regions and applications, extending value across Europe. The system's emphasis on accessibility, modularity, and open documentation creates a user environment where everyone, from local policymakers to technical developers, can move confidently from climate risk analysis to well-grounded, context-specific recommendations.

In sum, this deliverable describes a coordinated, durable approach to operational climate risk management, building capacity for effective adaptation and resilience planning among all project partners and future users.

The **Polytope climate feature extraction service** has now been deployed and is available for users. We will now integrate the service with T3.3 and T3.4 to enable the visualisations and GUI components for the regions. Further improvements can be made with feedback from the regions and the associated tasks and training materials, and code examples will be provided to ease users experiences with the service. The service currently works on datasets from the CDS but can also be adapted to other geospatial datasets depending on their format, it cannot be applied to non-geospatial datasets such as most EUROSTAT datasets.

The **Indicator Service** should be considered as a general working framework for the coming months. An updated and final version will be provided between March and April 2026, when the Indicator Service will have been discussed among the partners and its development defined in detail, together with the first results.

Finally, **the risk maps** will be developed for each of the five ClimEmpower regions and integrated into the ClimEmpower applications using a common visualisation approach:

- A colour gradient representing the full range of risk from low to high,
- Interactive display of hazard and risk layers
- Associated adaptation measures that help users interpret and act upon the identified risks.

## 7 References

Moreira, L. L. (2021). Effects of Different Normalization, Aggregation, and Classification Methods on the Construction of Flood Vulnerability Indexes. *Water*, 13(1), 98.  
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