

# D6.7 Innovation Management Report

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## D6.7: Innovation Management Report

### Summary

This Innovation Management Report presents proof of fulfillment of the multiple innovation objectives of project ICARIA collected in its Specific Subobjectives, mid-term Expected Outcomes and long-term Impact Pathways.

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Deliverable lead beneficiary	Deliverable author(s)	Contributor(s)
Aquatec (AQUA)	Alex de la Cruz (AQUA) Sofia Pacho (AQUA)	na
Internal reviewer(s)	External reviewer(s)	
Beniamino Russo (UPC)	Denis Havlik (AIT)	
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### Document history

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## List of Acronyms and Abbreviations

- **AI:** Artificial Intelligence.
- **AMB:** Barcelona Metropolitan Area.
- **BAU:** Business as Usual.
- **BNs:** Bayesian Networks.
- **CBA:** Cost-Benefit Analysis.
- **CER:** Critical Entities Resilience.
- **CMIP6:** Coupled Model Intercomparison Project Phase 6.
- **CoPs:** Communities of Practitioners / Practice.
- **CS:** Case Study.
- **DaaS:** Data-as-a-Service.
- **DoA:** Description of the Action.
- **DSS:** Decision Support System.
- **DV:** Dynamic Vulnerability.
- **EAD:** Expected Annual Damage.
- **EO:** Expected Outcomes.
- **GA:** Grant Agreement.
- **ICARIA:** Improving Climate Resilience of Critical Assets.
- **IMP:** Innovation Management Plan.
- **IMR:** Innovation Management Report.
- **IP:** Impact Pathways.
- **KERs:** Key Exploitable Results.
- **KPI:** Key Performance Indicators.
- **MCA:** Multi-Criteria Analysis.
- **NBS:** Nature-based Solutions.
- **RAF:** Resilience Assessment Framework.
- **RAT:** Resilience Assessment Tool.
- **RES-SCI:** Scientific Results.
- **RES-TEC:** Technical Results.
- **SaaS:** Software as a Service.
- **SAR:** South Aegean Region.
- **SBG:** Salzburg Region.
- **SOTA:** State of the Art.
- **SSH:** Social Sciences and Humanities.
- **SSO:** Strategic Subobjectives.
- **SSP:** Shared Socioeconomic Pathways.
- **TGM:** Trial Guidance Methodology.
- **TRL:** Technology Readiness Level.
- **WP:** Work Package.

## Executive summary

The Innovation Management Report provides evidence that the ICARIA project has successfully achieved its innovation objectives. As for the seven Strategic Sub-Objectives (SSOs), ICARIA has established a holistic asset-level modelling framework (SSO1) that accounts for the complexities of compound events and cascading effects. This scientific foundation is supported by tailored, high-resolution CMIP6 climate scenarios (SSO2) using innovative downscaling and AI-weighting techniques.

Through the open-access Jupyter Cookbook and targeted Lab Tests (SSO3), the project delivered reproducible methods for filling critical gaps such as infrastructure records and socioeconomic trajectories. These advancements enabled advanced multi-hazard modeling (SSO4) and the deployment of a unified Resilience Assessment Shell (SSO5) hosting the upgraded RAF and RAT applications. These tools are also integrated into a centralized Decision Support System (DSS) (SSO6), which supports multiple end users to compare "Business as Usual" scenarios against complex adaptation strategies using cost-benefit and multi-criteria analysis.

This document also reports the fulfillment of the project's three Expected Outcomes (EOs): delivering beyond-state-of-the-art models for critical infrastructure (EO1), enabling comparisons of adaptation approaches (EO2), and providing a systematic analysis of European data gaps (EO3). Furthermore, ICARIA has contributed to the EU Mission on Adaptation's Impact Pathways (IPs) by mobilizing a network of 7 follower regions and over 10 additional communities (IP1), providing open-access tools (IP2/IP3), and fostering a balanced portfolio of over 200 adaptation measures (IP4).

Finally, while D6.7 monitors these outputs, Deliverable 4.5 (Sustainability and Exploitation Plan) provides a robust foundation for the long-term use of the developed tools. In conclusion, ICARIA serves as a harmonization backbone, enabling European regions to manage complex disasters through a consistent and reproducible governance approach

# 1 Introduction

## 1.1 ICARIA in short

The number of climate-related disasters has been progressively increasing in the last two decades, and this trend could be drastically exacerbated in the medium- and long-term horizons according to climate change projections. It is estimated that, between 2000 and 2019, 7,348 natural hazard-related disasters have occurred worldwide, causing 2.97 trillion US\$ losses and affecting 4 billion people. These numbers represent a sharp increase of the number of recorded disaster events compared to the previous twenty years. Much of this increase is due to a significant rise in the number of climate-related disasters (heatwaves, droughts, flooding, etc.), including compound events, whose frequency is dramatically increasing because of the effects of climate change and the related global warming (IPCC, 2021; UNDRR, 2020) (UNDRR, 2020 and IPCC, 2021). For the future, by mid-century, the world stands to lose around 10% of total economic value from climate change if temperature increase stays on the current trajectory, and both the Paris Agreement and 2050 net-zero emissions targets are not met.

In this framework, **Project ICARIA** has the overall objective to promote the definition and the use of a comprehensive asset-level modeling framework to achieve a better understanding of climate related impacts produced by complex, compound, and cascading disasters and the possible risk reduction provided by suitable, sustainable, and cost-effective adaptation solutions.

Special regard is devoted to critical assets and infrastructures particularly susceptible to climate change, in the sense that their local effects can result in significant increases in the cost of potential losses for unplanned outages and failures, as well as maintenance, unless an effort is undertaken to make these assets more resilient. Therefore, ICARIA aims to understand how future climate might affect life-cycle costs of these infrastructures and assets in the coming decades and to ensure that, where possible, investments in terms of adaptation measures are made up front to face these changes. This requires forward planning that considers a comprehensive multi-risk assessment and the uncertainties associated with climate change, rather than reliance on models solely based on past events and single climate hazards.

## 1.2 Scope and Objectives

The present document corresponds to Deliverable 6.7 Innovation Management Report (IMR) of Work Package 6 (WP6) - Project Coordination and Management. It is the continuation of Deliverable 6.6 Innovation Management Plan (IMP).

The overall aim of the deliverable is to report the main innovations developed in the project ICARIA, generating knowledge and tools beyond the state of the art (SOTA) in the field of natural hazards impact assessment. Specifically, this document addresses and presents proofs of fulfilment of the matters stated in Deliverable 6.6: (1) relevant results (tools and methods) to be achieved within ICARIA; (2) indicate relevant results (tools and methods) to be achieved within ICARIA; (2) indicate how the

background SOTA contributed to the project; and (3) the fulfillment of all specific objectives. This document corresponds to the actions taken in Task 6.2: Quality assurance and innovation management.

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## 2 Innovation Management Strategy

Considering the overall objective of the ICARIA project (stated in Section 1.1), seven strategic subobjectives (SSOs) were defined. Each one represented a specific field of work to generate tangible results that represent progress beyond the current state of the art. According to their typology, the seven SSOs were classified into four categories:

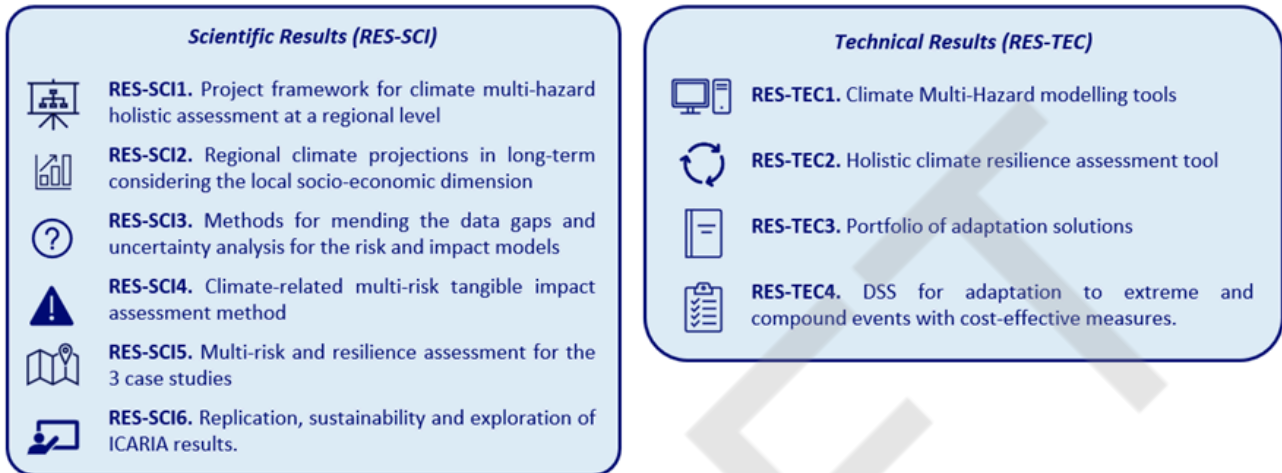
- **Scientific:** corresponding to research activities for advances beyond the state of the art (*SSO1, SSO2, SSO3, SSO4, SSO5*)
- **Technological:** suggesting and/or developing novel solutions, integrating state-of-the-art and digital advances (*SSO6*)
- **Societal:** contributing to improved dialogue, awareness, cooperation, and community engagement as highlighted by the European Climate Pact (*SSO7*)
- **Dissemination and exploitation:** aimed at sharing ICARIA results with a broader audience and a number of regions and communities to maximize project impact (*SSO7*)

In the Description of Action (DoA) of the project, a comprehensive description of the objectives and the current state-of-the-art knowledge and methods expected to contribute to each SSO was provided. The following figure depicts the main recent EU research projects that were planned to provide the required background to project ICARIA for it to achieve its innovation expected results.



**Figure 1.** ICARIA Background of EU research projects

To clearly visualise the tangible outcomes expected from project ICARIA, ten specific results were defined. All were specifically associated with an SSO and a WP. The following figure depicts these results together with their classification: Scientific Results (RES-SCI) or Technical Results (RES-TEC).



**Figure 2.** ICARIA Progress beyond: Expected results

Regarding the mid-term horizon, three Expected Outcomes (EO) were defined according to the HORIZON-MISS-2021-CLIMA-02-03 topic. Specifically, these outcomes focused on Objective 2 of the Implementation Plan of Climate Change Adaptation Mission (Accelerating transformations to climate resilience).

**Table 1.** Summary of the mid-term pathway “Expected Outcomes”

Mid-term Expected Outcomes (EO)
<b>EO1.</b> Beyond state-of-the-art asset-level models for critical infrastructures will allow for a better assessment of adaptation options
<b>EO2.</b> Public authorities will be enabled to compare different adaptation approaches on the basis of a model information system on critical infrastructure
<b>EO3.</b> An analysis of gaps in European data regarding the assessment of direct and indirect economic consequences of damages to critical infrastructures.

Furthermore, ICARIA also addressed all Impact Pathways (IP) envisaged by Climate Change Adaptation Mission through a regional approach rooted in research and innovation and based on the above mentioned results and outcomes.

**Table 2.** Summary of the long-term Impact Pathways

Long-term Impact Pathways (IP)
<b>IP1.</b> Mobilize all actors, such as EU Member States, regional and local authorities, research institutes, investors and citizens to create real and lasting impact

## Long-term Impact Pathways (IP)

**IP2.** Provide general support to European regions and communities to better understand, prepare for and manage climate risks and opportunities. Accelerate transformations to climate resilience: cooperate with at least 150 regions and communities to accelerate their transformation to a climate resilient future, supporting them in the co-creation of innovation pathways and testing of solutions.

**IP3.** Demonstrate systemic transformations to climate resilience: deliver at least 75 large-scale demonstrations of systemic transformations to climate resilience across European regions and communities.

**IP4.** Foster the development of a balanced portfolio of solutions across the different climate risks, the different innovation areas as identified in the Mission Implementation Plan and the different biogeographical regions, as defined by the European Environment Agency

In order to measure the fulfillment of both the SSO and the expected results, a number of Key Performance Indicators (KPI) were defined in the project DoA. Each KPI was linked to a specific SSO and to a Deliverable, which correlated it with a tangible result. A table with the full list and description of the KPIs is provided in Annex I.

The following sections provide evidence of the planning and fulfilment of all SSOs, RES-TECs, RES-SCIs, EOs and IPs of the project.

### **3 Achievement of SSOs and development beyond the state of the art**

To accomplish its overall goals, ICARIA defined 7 Strategic Subobjectives (SSOs), each linked to specific activities and work packages. These SSOs adhere to the SMART framework: Specific (related to WPs), Measurable (through relevant KPIs), Achievable (the WPs in which they will be achieved are listed), Realistic (as they are referenced and explained within the methodology section), and Timebound (each KPI is related to a deliverable and a month of achievement). The SSOs were organized into categories: scientific, including research activities aimed at advancing beyond the current state of the art (SSO1, SSO2, SSO3, SSO4, SSO5); technological, focused on proposing and/or developing innovative solutions that integrate state-of-the-art and digital advancements (SSO6); societal, dedicated to improved dialogue, awareness, cooperation, and community engagement in line with the European Climate Pact (SSO7); and dissemination and exploitation, designed to share ICARIA's results with a wider audience across a greater number of regions and communities to maximize the overall impact of the project (SSO7).

The sections that follow outline the purpose of each SSO and how they were achieved to push beyond the existing state of the art.

#### **3.1 SSO1.- Achievement of a comprehensive methodology to assess climate-related risk produced by complex, cascading and compound disasters**

##### **a) SSO1 description**

A harmonized Risk/Impact modeling framework for climate-related hazards was developed, integrating multi-risk analysis, spatial visualization, and visual analytics to assess hazards, exposure, vulnerability, and socioeconomic impacts, supporting integrated adaptation actions across national to local scales.

##### **b) Proof of fulfilment and integration of methodological knowledge**

The achievement of SSO1 is evidenced by two main documents: ICARIA Deliverable 1.1 "ICARIA holistic modelling framework" (Truchi, et al., 2023) and the publication of the peer-reviewed article "A holistic asset-level modelling framework for a comprehensive multi-hazard risk/impact assessment: Insights from the ICARIA project" (Leone et al., 2025) in the Journal of Disaster Risk Management. This framework represents a significant advancement beyond the state-of-the-art by moving from traditional single-hazard assessments to a multi-hazard approach that accounts for the complexities of compound events (coincident or consecutive) and their cascading effects on socio-eco-technological systems.

The core of this innovation is the "elementary bricks" approach, which provides a harmonized modular structure for analysis. This knowledge is reflected in the framework through the following key integrations:

- **Dynamic Vulnerability (DV):** A critical component of the framework is the "procedure" to update the vulnerability of risk receptors following a sequence of events. The framework recognizes that a receptor's vulnerability is not static; for instance, a building's susceptibility to flooding may increase significantly if it has been previously damaged by extreme winds, a dynamic reflected in the framework's step-by-step updating of exposure and vulnerability data.
- **Comprehensive Risk Equation:** The framework operationalizes a probabilistic convolution of Hazard (H), Exposure (E), and Vulnerability (V), specifically adapted for multi-hazard scenarios where the cumulative impact may exceed the sum of individual hazard impacts.
- **Resilience and Human Behaviour:** To ensure a holistic assessment, the framework integrates Coping Capacity (CC), Adaptive Capacity (AC), and Transformative Capacity (TC), alongside human behaviour ( $\alpha$ ). Human behaviour is treated as a factor that can influence cascades, such as through non-compliance with evacuation orders or reactive decision-making during a crisis.
- **Spatiotemporal Event Trees:** The framework utilizes event trees to visualize and quantify hazard/impact interactions along a timeline. This allows for the identification of triggering mechanisms for cascades and the assessment of joint probabilities for coincident or consecutive extremes.
- **Decision Support Integration:** The methodology bridges quantitative modelling with decision-making by using Multi-Criteria Analysis (MCA) and Cost-Benefit Analysis (CBA). This enables the prioritization of adaptation strategies based on their ability to reduce damage while providing social, economic, and environmental co-benefits.

The practical fulfilment of these concepts has been validated through their application in the three ICARIA case studies (Barcelona, Salzburg, and the South Aegean Region), demonstrating the framework's ability to handle diverse hazards, from pluvial floods and storm surges to forest fires and droughts, even in contexts with varying data availability.

Furthermore, the results of the implementation of this framework in the three case studies are reported in Deliverable 1.5 (Leone et al., 2026). The practical validation of this methodological framework was conducted through a two-stage process involving Trials (under optimal data conditions) and Mini-Trials (addressing suboptimal data availability). This implementation experience demonstrated that the ICARIA framework effectively functions as a harmonization tool, aligning diverse hazard, exposure, and vulnerability models into a single consistent logic. A key outcome of these pilot applications was the transition from a purely hazard-driven modeling structure toward a risk-informed and decision-support-oriented architecture. By actively engaging local Communities of Practice (CoPs), the framework was refined to ensure that quantitative modeling results directly supported the co-design of local resilience strategies, making complex multi-hazard data more actionable for regional authorities and infrastructure operators.

However, the implementation phase also highlighted several critical limitations and operational challenges that must be addressed for future replicability. The most significant barrier encountered was data heterogeneity and availability gaps, particularly at the detailed asset level, which necessitated the use of simplified vulnerability representations and innovative gap-filling techniques in certain contexts. Furthermore, the project faced operational limitations in harmonizing diverse

hazard-specific models across different geographic regions. The modelling scope was also frequently shaped by stakeholder-driven prioritization, which redirected efforts toward the most policy-relevant impact chains rather than achieving theoretical completeness. These lessons emphasize that while the framework is theoretically robust, its successful deployment requires a flexible, modular approach that can scale based on local data maturity and institutional capacity.

### c) Methods contributing to the fulfillment of SSO1

The ICARIA framework overcomes the limitations of traditional single-hazard approaches. It was developed by synthesizing and advancing the state-of-the-art from several landmark EU research projects. The core starting points for these developments include:

- **RESCCUE:** Provided the foundations for urban water resilience (flooding, droughts, storm surges) and the Resilience Assessment Framework (RAF).
- **CLARITY:** Established the climate-proofing logic for heat and wind hazards based on IPCC AR5 risk-based approaches.
- **EU-CIRCLE:** Focused on the operational robustness and interconnectedness of critical infrastructures through the Resilience Assessment Tool (RAT).
- **SNOWBALL:** Introduced the theoretical "event tree" logic and probabilistic assessment of hazard transitions for cascading effects.

ICARIA innovates by harmonizing these disparate methodologies into a modular "elementary bricks" approach. Moving beyond the SOTA, the framework introduces Dynamic Vulnerability (DV) to account for cumulative damage in consecutive events and incorporates Human Behaviour ( $\alpha$ ) as a variable influencing disaster propagation. Furthermore, by aligning with the IPCC AR6 approach, ICARIA shifts the focus toward Climate Resilient Development, enabling a holistic quantification of direct and indirect impacts to support more systemic and cost-effective adaptation strategies.

### d) Specific results achieved within SSO1

**RES-SCI1. Project framework.** The fulfilment of RES-SCI1, associated with SSO1 was fulfilled with the development of the ICARIA holistic multi-hazard risk assessment Framework. The primary scientific proof is provided by the peer-reviewed article published in the International Journal of Disaster Risk Reduction (Leone et al., 2025), which establishes the peer-validated methodological foundation for the holistic asset-level modelling framework. Complementing this scientific validation, the technical and operational fulfilment is formally documented in Deliverable 1.1 (Truchi, et al., 2023), which defines the framework's taxonomies and "elementary bricks", and Deliverable 1.5 (Leone et al., 2026), which details the implementation experience, validation across diverse regions, and the resulting lessons learned. Furthermore, the practical execution and quantitative outputs of the framework are evidenced in Deliverable 4.2 (A. De La Cruz–Coronas et al., 2026) and Deliverable 4.3 (Truchi et al., 2026), which report on the successful completion of the ICARIA Trials and Mini-trials.

## 3.2 SS02.- Obtaining tailored scenarios for the case study regions

### a) SS02 description

Near- and long-term climate projections (up to 2100) have been (statistically and dynamically) downscaled for the three ICARIA case studies based on the last emission scenarios used in the IPCC Sixth Assessment Report (IPCC, 2023). ICARIA has considered emissions scenarios without climate policies (baseline scenario) and with climate policies (mitigation scenarios). Climate change projections and socio-economic scenarios have been estimated at a local scale to evaluate climate-related impacts (business-as-usual scenarios) and adaptation/mitigation measures (adaptation scenarios).

### b) Proof of fulfillment and integration of methodological knowledge

The fulfillment of SS02 is substantiated by the generation of high-resolution, tailored climate scenarios for the Barcelona Metropolitan Area (AMB), Salzburg Region (SLZ), and South Aegean Region (SAR). All results were presented in Deliverable 1.2 (Paradinas Blázquez et al., 2024) and are openly available in ICARIA's Zenodo page (Bügelmayer-Blaschek, Hasel, & Gazzaneo, 2025; Paradinas et al., 2024).

This process successfully transitioned from theoretical "Climate Scenarios building" to the delivery of actionable local datasets. The methodological knowledge is integrated into the project results through four innovative pillars:

- **Dual-Method Downscaling:** ICARIA implemented a parallel approach using statistical (FICLIMA) and dynamical (RCMs) downscaling to capture different spatial and physical scales. As validated in *Environmental Research Communications* (Bügelmayer-Blaschek, Hasel, Redolat, et al., 2025), statistical methods proved superior for simulating historical temperature patterns, while dynamical models more accurately reflected precipitation in data-scarce regions like the South Aegean.
- **Convection-Permitting Resolutions:** To address complex topographies such as the Austrian Alps and fragmented island geographies, the project advanced dynamical downscaling to convection-permitting scales (2–5 km<sup>2</sup>). This resolves local physical processes, such as convective rainfall, which traditional models fail to represent accurately.
- **Sub-daily Precipitation Extremes:** Scientific advancements published in *Atmosphere* (Gacon et al., 2024) introduced a fractal-based modeling approach using the n-index to assess sub-daily rainfall regimes. This breakthrough allows daily climate projections to be extrapolated to hourly scales, enabling the creation of state-of-the-art Intensity-Duration-Frequency (IDF) curves essential for local urban flood and drainage modeling in Barcelona.
- **Uncertainty Management:** The results incorporate an ensemble strategy using 10 CMIP6 models. To reduce model-related biases, innovative weighting was applied, optimizing the combination of physical models to better represent regional future climates across short (2021-2050), mid (2041-2070), and long-term (2071-2100) horizons.

### c) Methods contributing to SS02

ICARIA's scenario building progressed significantly beyond the standard state-of-the-art (SOTA), which typically relies on **CMIP5/RCP** scenarios and regional models at resolutions of 12.5 km or coarser (e.g., EURO-CORDEX). The project established several innovative benchmarks:

- **Transition to CMIP6/SSP:** ICARIA is among the first projects to fully operationalize the latest CMIP6 generation models and Shared Socioeconomic Pathways (SSPs) at a local level. These scenarios replace static concentration pathways with narrative-driven "stories" of societal evolution, providing higher sensitivity to greenhouse gas forcing and more realistic impact assessments.
- **Resolution Breakthrough:** Moving from the standard 12 km grid to 2 km convection-permitting simulations resolved critical physical gaps in mountainous and coastal zones, effectively removing the need for error-prone parameterizations of convective systems.
- **Innovative n-index Methodology:** While SOTA IDF curves often rely on historical point data, ICARIA developed a methodology to bridge mono-fractal and multi-fractal behaviors in precipitation patterns. This enables a more precise climatology of precipitation structures, ensuring that sub-daily extremes are accurately projected even under shifting climate trends.
- **Physics-Aware Machine Learning:** Departing from traditional multi-model averages, the project applied Bayesian Neural Networks for ensemble weighting, enabling the capture of spatio-temporally varying model accuracy and significantly enhancing predictive performance for local temperature and wind variables.

#### d) Specific results achieved within SS02

**RES-SCI2. Climate scenarios methods and results.** This RES-SCI and the corresponding SSO have been fully achieved. This is evidenced by the comprehensive technical documentation in Deliverable 1.2, which provides the validated "Climate Signal" for all project case studies. The scientific validity of these tailored scenarios is further confirmed by peer-reviewed publications in Environmental Research Communications (Bügelmayer-Blaschek et al., 2025) and Atmosphere (Gacon et al., 2024), which detail the innovative downscaling and sub-daily extrapolation techniques used

### 3.3 SS03.- Quantify uncertainty and manage data gaps through model input requirements and innovative methods

#### a) SS03 description

ICARIA trials (implementation) and mini-trials (replications) in the case studies were carried out to define the minimum requirements in terms of input data needed to comprehensively analyze climate-related multi-hazard and risks on critical infrastructure and the effects of possible adaptation measures, as well as to determine how such data can be obtained, substituted or generated. ICARIA trials were carried out in "best case study scenarios", with good data availability, well-known climate hazards, and impact assessment methods. During the replication phase, key aspects of one trial were reproduced in other regions (mini-trials), with suboptimal data availability (e.g., coarse climate data, poor asset and economic data). Novel and robust approaches for filling data gaps and augmentations

(e.g., geographical and temporal downscaling, data substitution) were applied within the replication context, such as uncertainty propagation analysis.

### **b) Proof of fulfillment and integration of methodological knowledge**

The achievement of SS03 was established through the creation of a standardized, scalable workflow to identify and mitigate data scarcity, transitioning from theoretical data management to a validated gap-filling framework. This methodological knowledge is operationalized through two primary pillars: the ICARIA Jupyter Cookbook and the Validation via WP1 Lab Tests (Task 1.4). As part of this, a methodology to generate synthetic sewer networks was developed for the metropolitan area of Barcelona. It was published in a peer-reviewed journal (À. De La Cruz–Coronas & Russo, 2025).

The core technical innovation of SS03 is the ICARIA Cookbook, a modular repository designed for high transferability to other European regions. This resource was conceived as an open-source Jupyter Book, which enables the seamless integration of narrative text, executable code, and datasets (accessible at: [ICARIA Cookbook](#)). It is fully described in Deliverable 1.3 (Moumtzidou & Gialampoukidis, 2024b). The book categorizes solutions into five innovative streams: statistical methods, dynamical downscaling, data-driven/AI methodologies, expert elicitation, and uncertainty treatment

The practical validation of the data-gap filling framework was finalized through Deliverable 1.4 (Moumtzidou & Gialampoukidis, 2024a), which executed four targeted WP1 Lab Tests. These tests served as a crucial bridge to ensure that the methods listed in the Cookbook were robust enough for the subsequent full-scale Trials.

- **Test A (Barcelona):** Successfully downscaled Shared Socioeconomic Pathways (SSPs) to a regional scale using the ARSINOE method, integrating CORINE land cover data with GDP and population density to project future land-use dynamics.
- **Test B (Barcelona):** Addressed the absence of physical sewer records by applying synthetic data generation, allowing for urban drainage and flooding modeling despite critical infrastructure data gaps.
- **Test C (Salzburg):** Focused on windstorm risks by combining fragmented datasets to map tree locations and species, establishing a threshold-based methodology to estimate potential infrastructure disruption from fallen trees.
- **Test D (South Aegean):** Overcame the lack of public reparation cost data following wildfires by using taxable fair market values and average restoration costs per kilometer as economic proxies.

### **c) Methods contributing to SS03**

As an initial step, each case study responsible will elaborate an exhaustive list of all the input data requirements for all the models that will be used in the project. The list will indicate the necessary data resolution/quality and the sources available (if any) to obtain this information. This will provide a good picture of the data availability and the major gaps and uncertainties to be addressed. A trivial scheme for handling data gaps will include i) the description of the chosen methods, ii) the evaluation of the completeness of the datasets (for missing site-specific data in each case study), and iii) the proposal of tools and secondary surrogate data (if applicable) to fill the data gaps. Methodologies will include, but are not limited to, regression models, extrapolation methodologies, linear-scaling of

available compositional data and fitting of statistical distribution to a sample data frame. The relevance and importance of data gaps should be assessed depending on the contained impact methods and the weight of the missing data value, respectively. It should be considered that the trials setup aims for the highest possible quality of data so the results can be used “as they are” for operative/planning decision-making. On the other hand, the mini-trials replication foresees the use of suboptimal and/or limited datasets sourced both from open databases and national(local) authorities.

The model's sensitivity to data lack and uncertainties will be estimated by cross-validation, measuring the effects of existing and/or introduced data gaps.

Given ICARIA's resources and constraints, the bridging of data gaps will be based on inexpensive methodologies that are either well-documented or in the literature or well-known by the team members, rather than developing novel data gap bridging techniques. Existing techniques that could be used for this purpose are: data augmentation, crowdsourcing and AI tools.

#### **d) Specific results achieved within SS03**

**RES-SCI3. Methods for mending the data gaps and uncertainty analysis.** SS03 has been fully realized through the delivery of a comprehensive methodological and technical ecosystem for managing data uncertainty. The formal proof of fulfillment is provided by Deliverable 1.3, which established the ICARIA Cookbook and its associated Jupyter Book landing page, and Deliverable 1.4, which documents the successful application of these gap-filling methods in the Barcelona, Salzburg, and South Aegean Region.

### **3.4 SS04.- Increase the knowledge on climate-related disasters by developing and implementing advanced modelling for multi-hazard assessment**

#### **a) SS04 description**

This SSO increased understanding of climate-related disasters and multi-hazard events by identifying triggering mechanisms behind cascading catastrophes and applying SS01's holistic modeling framework to analyze the consequences of such events.

#### **b) Proof of fulfillment and integration of methodological knowledge**

The fulfillment of SS04 has been proofed through the successful operation of the holistic multi-hazard framework across the project's three case studies (AMB, SBG, and SAR). This framework was developed in Deliverable 1.1 (Truchi, et al., 2023), implemented based on the hazard assessment methodologies established in Deliverable 2.1 (A. De La Cruz–Coronas et al., 2023) and achieved by the validated results presented in Deliverable 4.2 (A. De La Cruz–Coronas et al., 2026) and Deliverable 4.3 (Truchi et al., 2026). As part of WP2, the joint probability occurrence of multi-hazard events was evaluated through a copula model methodology. This provided the CS with a knowledge basis to simulate realistic multi-hazard scenarios (Chen et al., 2025). The following sections summarize the specific multi-hazard models and scenarios implemented in each case study as proof of fulfillment:

**Barcelona Metropolitan Area (AMB):** Compound Coastal-Pluvial Flooding in the AMB focused on the joint occurrence of coincident extreme precipitation and storm surges. This scenario addresses a

critical physical interaction where elevated sea levels create "change conditions" by reducing the drainage capacity of the metropolitan sewer network and causing backflow in low-lying urban areas.

- **Model/Scenario:** The study used a coupled 1D/2D urban drainage model (Infoworks ICM) to simulate pluvial flooding under various climate change projections (SSPs) and return periods, paired with data on extreme sea level (ESL) for storm surges.
- **Framework Connection:** This implementation directly applied the framework's ability to model physical interactions at the land-sea interface, using joint probability assessment to represent the probability distribution of the hazards involved.

**Salzburg Region (SBG):** Fluvial Flooding and Extreme Windstorms. The Salzburg case study assessed the impacts of longer-lasting fluvial rain events combined with high-intensity windstorms on critical assets, specifically the electricity and transport networks.

- **Model/Scenario:** River flood hazards were assessed using the HydroMT-SFINCS hydrological model. Extreme wind speeds and gusts were simulated using WRF and COSMO-CLM regional climate models at high spatial resolutions (up to 1 km<sup>2</sup>) to account for complex Alpine topography. The physical hazard interaction focused on the representation of wood deribs in riverbeds during winds storms, worsening flood conditions of subsequent rain events.
- **Framework Connection:** This study validated the framework's scalability by adopting the Decision Support System (DSS) workflow originally developed for the AMB and using generalized European flood-damage curves to overcome asset-specific data gaps.

**South Aegean Region (SAR):** The SAR trials on the islands of Rhodes and Syros addressed the "worst-case scenario" of the compound dry hazards of heatwave, drought and wildfire where prolonged heatwaves and droughts create optimal conditions for wildfires.

- **Model/Scenario:** The HWLEM (Heat Wave Local Effect Model) was used to analyze urban microclimate variability and health impacts. For wildfires, the framework used the Fire Weather Index (FWI), integrating "fuel moisture codes" derived from drought scenarios to predict fire ignition likelihood and rate of spread.
- **Framework Connection:** This case study demonstrated the framework's capacity to simulate complex chains where one hazard (drought) alters environmental conditions to increase the probability of a secondary hazard (wildfire).

### c) **Methods contributing to the fulfillment of SS04**

The original objective of SS04 was to move beyond traditional "silo" single-hazard assessments. To achieve this, ICARIA generated specific multi-hazard and risk assessment results, through the implementation of the RES-TEC1 modeling framework. The following methods were applied as part of this approach:

- **Elementary Brick Framework:** ICARIA created a harmonized modular structure, decomposing multi-hazard risk into Hazard (H), Exposure (E), Vulnerability (V), and Resilience. This systematic approach integrates time and space variables for assessing disaster propagation.
- **Spatiotemporal Event Trees:** The innovative use of "event trees" simulates complex event chains by acting as a "storyline" to map all hazard/impact interactions over time.

- **Coupled Multi-Hazard Modeling Chains:** The project developed modeling chains capable of spatial and temporal coupling of multi-hazards. This included modelling physical mechanisms for interactions, such as "change conditions" (where one hazard alters the environment to increase a secondary hazard's probability) and "association" (where multiple hazards share a single triggering event).
- **Joint Probability Quantification (Bayesian Networks and Copulas):** use of advanced mathematical approaches to quantify dependencies like Bayesian Networks (BNs) and Copula models (Chen et al., 2025).

#### **d) Specific results achieved within SS04**

**RES-TEC1. Multi-Hazard modeling tools.** RES-TEC1 is fulfilled by the development and deployment of asset level multi-hazard models for all three case studies. The integration of the results into the ICARIA DSS proves their validity to carry climate risk assessments.

ICARIA will integrate the modelling tools established in previous projects (RESCCUE for flood and storm surges, CLARITY for wind and heat waves, GRIDWATCH for forest fire and windstorm on electrical infrastructures, etc.) to create a holistic modelling framework by considering the interactions among different hazards and assess the related impacts. These tools will be improved to cover a wider range of hazards (including compound disasters) and scopes (from local to regional) and their results will be used in the DSS.

### **3.5 SS05.- Better assessment of holistic resilience and climate-related impacts for current and future scenarios**

#### **a) SS05 description**

The aim of this SSO was to increase knowledge on multi-risk and resilience assessment of critical infrastructures, including compound events, climate drivers, cascading effects, and tangible impacts, under various socio-economic and climate scenarios, supporting both short-term impact mitigation and long-term adaptation strategies.

#### **b) Proof of fulfillment and integration of methodological knowledge**

The scientific objective SS05 was achieved through the development and delivery of the resilience assessment methodology detailed in Deliverable 3.2 (Brito et al., 2024). This included the ICARIA Resilience Assessment Platform, a web-based tool that hosts two interconnected applications:

- **ICARIA RAF** maintains the tree structure of the original RESCCUE RAF but extends its capabilities to a regional and metropolitan scale, moving beyond a purely urban focus. A key scientific advancement is the inclusion of Natural Areas as a strategic service, enabling the assessment of ecosystem services within the same framework as traditional infrastructure. The framework now also integrates Social Sciences and Humanities (SSH) metrics to capture community risk awareness and has been updated to address additional hazards such as fires.

- **ICARIA RAT** updates the EU-CIRCLE RAT into a web application, meeting critical infrastructure assessment needs by aligning its resilience indicators (anticipatory, absorptive, coping, restorative, and adaptive) with the new CER Directive (2022/2557). The fulfillment of SS05 is further demonstrated by the platform's integration in the Decision Support System (DSS).
- **Implementation of tailored impact assessment methods** to assess the damage caused by extreme events (including multi-hazards) on specific risk receptors. This included the inhabitants of affected areas, critical infrastructures and relevant assets and services. This knowledge supported the assessment of chains of cascading effects too. This work has been published into a scientific journal special issue focused on the ICARIA results.

### c) **Methods contributing to the fulfillment of SS05**

The methods contributing to fulfill SS05 were as follows:

- **Regional Scale and Metric Revision:** To address the transition from urban to regional scope, 176 metrics within the original RAF tree structure were revised or added. This included new metrics specifically designed to distinguish between urban and rural areas and to assess regional governance and infrastructure connectivity.
- **Inclusion of Natural Areas:** Natural Areas are treated as a strategic service, equivalent to traditional utilities. This involved developing entirely new assessment metrics to evaluate ecosystem services such as groundwater recharge, temperature regulation, and carbon sequestration.
- **Social Sciences and Humanities (SSH) Integration:** The methodology was updated to include behavioral aspects of resilience. New metrics were integrated to capture community risk awareness, short-term "reactive" behaviors during disasters, and long-term societal trends associated with Shared Socioeconomic Pathways (SSPs).
- **Tangible Impact Assessment (RES-SCI4):** ICARIA developed a comprehensive method to monetize climate-related losses. This work uses hazard-damage curves to estimate reconstruction costs and hazard-disruption curves to quantify the economic cost of service interruptions and cascading effects.
- **RAT Alignment with the CER Directive:** The ICARIA RAT was methodologically upgraded by aligning its resilience capacities (Anticipatory, Absorptive, Coping, Restorative, and Adaptive) with the requirements of the CER Directive (2022/2557). It also adopted a "word ladder" approach, which translates qualitative expert descriptions into quantitative resilience indices.

### d) **Specific results achieved within SS05**

**RES-SCI4. Climate-related multi-risk tangible impact assessment method.** RES-SCI4 is achieved by applying multiple methods to quantify direct and indirect tangible economic losses for assets and critical infrastructure. Deliverable 3.1 presented a portfolio and application guidelines of such measures (Guerrero-Hidalga et al., 2024).

**RES-TEC2. Holistic climate resilience assessment method.** For RES-TEC2, the project successfully delivered a unified "Resilience Assessment Platform" that hosts the upgraded ICARIA RAF and ICARIA RAT within a single web-based platform.

### 3.6 SS06.- Better decision-making for cost-efficient adaptation solutions by developing a DSS to compare adaptation solutions

#### a) SS06 description

A Decision Support System (DSS) was developed, enabling multiple endusers to compare adaptation solutions for climate planning on critical infrastructures. It integrates hazard modeling, climate projections, impact and resilience assessments, and adaptation solutions. Users can access risk assessment results, evaluate the co-benefits of adaptation solutions.

#### b) Proof of fulfillment and integration of methodological knowledge

The fulfillment of SS06 has been achieved through the conceptualization, development, and deployment of the ICARIA Decision Support System (DSS). This tool materializes technical result RES-TEC4, as a centralized web-based toolbox that integrates climate hazard modeling, risk assessment, and resilience metrics to facilitate informed decision-making. Its main features are:

- **Centralized Project and Scenario Manager:** Users can create, manage, and collaborate on resilience projects, allowing the comparison of "Business as Usual" (BAU) scenarios against various adaptation strategies.
- **Adaptation Measures Portfolio:** A comprehensive database (RES-TEC3) has been integrated, allowing users to evaluate, create, and prioritize solutions. The system includes an automated Multi-Criteria Prioritization tool that reorders measures based on user-defined weights for economic, social, and environmental co-benefits.
- **Risk and Impact Assessment Engine:** The DSS calculated expected impacts on strategic assets, transforming quantitative hazard data into actionable decision ingredients such as expected annual damage (EAD) or service disruption percentages.
- **Interactive Map Viewer:** A GIS-based explorer facilitates the management and visualization of geospatial data layers, allowing decision-makers to interact with hazard and risk maps.
- **Holistic resilience assessment:** is includes reduced versions of RAF and RAT.

The ICARIA DSS allows the Multi-Criteria Analysis (MCA) and Cost-Benefit Analysis (CBA) of adaptation scenarios thanks to the combination of its multiple functionalities. Both the Trial and Mini-Trial phases ensured that the system is robust even in contexts with suboptimal data availability.

#### c) Methods contributing to the fulfillment of SS06

Key methodological contributions include:

- **Expansion of Risk Receptors:** Unlike traditional tools focused only on infrastructure, the ICARIA DSS integrates a broader range of receptors, including housing, tourism, and natural areas. This results in a more holistic assessment of adaptation impacts.
- **Monetization of Risk:** The system quantifies climate impacts in monetary terms, specifically through the calculation of Expected Annual Damage (EAD). This allows for direct comparison between "Business as Usual" (BAU) and adaptation scenarios, providing clear evidence for the cost-efficiency of proposed measures.

- **Multi-Criteria and Cost-Benefit Analysis (MCA/CBA):** These methods were included in the DSS to help decide which adaptation strategies are best, considering not only how much damage they prevent but also their positive social, economic, and environmental co-benefits.

**d) Specific results achieved within SS06**

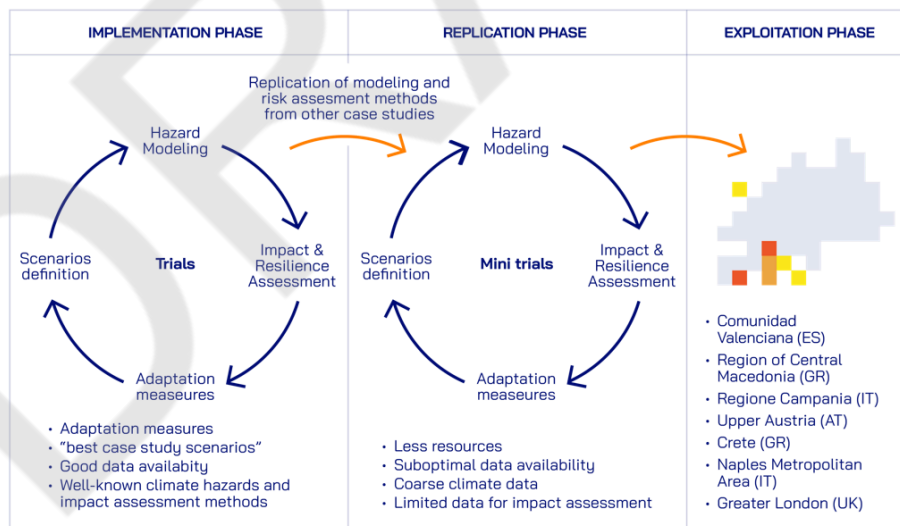
**RES-TEC3. Portfolio of adaptation solutions.** The RES-TEC3 result is an open-source, web-based dataset of over 200 climate adaptation measures sourced from previous EU projects focusing on Nature-based Solutions (NBS). Each measure includes detailed technical specifications, implementation requirements, and costs. A key feature is a prioritization method allowing users to evaluate strategies based on total cost, cost-effectiveness, and quantified co-benefits (economic, social, environmental), helping decision-makers select solutions with the highest systemic value.

**RES-TEC4. ICARIA DSS.** The RES-TEC4 was materialized as a centralized web-based Decision Support System designed to assist authorities in climate resilience decision making. The DSS serves as the final integration point for the project’s modeling chain, with inputs from climate projections (WP1), multi-hazard impact models (WP2), and the resilience indicators generated by the ICARIA RAF and RAT apps (WP3).

**3.7 SS07.- Ensure the use and impact of the ICARIA outputs**

**a) SS07 description**

ICARIA methods and outputs were successfully implemented, replicated, and exploited through a participatory process that engaged local stakeholders both within and outside the project framework.



**Figure 3.** Scheme of the implementation, replication and exploitation phases of project ICARIA

## b) Proof of fulfillment and integration of methodological knowledge

The fulfillment of SS07 has been achieved through multiple participatory process designed to bridge the gap between scientific research and practical application by regional authorities and infrastructure operators.

- **Establishment and Activation of Communities of Practice (CoPs):** As defined in the Stakeholder Engagement Plan (Deliverable 5.4) , local CoPs were successfully established in the three study regions: the Barcelona Metropolitan Area (AMB), the Salzburg Region (SBG), and the South Aegean Region (SAR). These communities have served as the primary instrument for co-creation, ensuring that ICARIA's tools and methods align with the actual needs and expectations of multi-disciplinary stakeholders.
- **Validation via Trial Guidance Methodology (TGM):** Following the design outlined in Deliverable 4.1 (Havlik et al., 2024), the project adapted the TGM methodology to the climate adaptation domain. The deliverable Deliverable 4.2 (A. De La Cruz–Coronas et al., 2026) serves as the formal proof of fulfillment, documenting that the ICARIA Decision Support System (DSS) and resilience assessment tools (RAF/RAT) were tested and validated by stakeholders in all three regions.
- **Integration with the Replicability and Outreach Strategy:** In alignment with the Communication and Dissemination Plan, the project has moved beyond the trial phase into mini-trials and the involvement of seven "follower regions". This structured approach connects the initial trials (conducted under optimal data conditions) to replication scenarios with suboptimal data availability, proving the transferability of ICARIA's results to a broader number of communities across Europe.

## c) Methods contributing to the fulfillment of SS07

The strategy for achieving SS07 was based on shifting the classical cooperation model toward a collaborative co-creation process. The original plan outlined the use of CoPs to bridge the research community with regional institutions and the adaptation of the TGM to validate project results. It also defined the involvement of seven "follower regions" as a key mechanism to ensure the replicability and exploitation of the project's methodologies across different European contexts.

## d) Specific results achieved within SS07

**RES-SCI5. Multi-risk and resilience assessment for the 3 EU case studies.** The ICARIA framework was successfully integrated and validated operationally in three case study regions (Barcelona Metropolitan Area, Salzburg, and South Aegean Region). As established in Deliverable 4.2 (A. De La Cruz–Coronas et al., 2026), project methodologies were integrated into the Decision Support System (DSS) and tested by stakeholders with optimal data.

**RES-SCI6. Replication, sustainability and exploitation of ICARIA results.** The achievement of this result is centered on Trials, Mini-trials, and Demonstrators. While the Trials validated technical performance, the Mini-trials served to test the transferability of ICARIA's tools to scenarios with suboptimal data availability. Furthermore, the project successfully engaged seven "follower regions" across Europe to ensure that the developed methodologies are applicable in diverse geographical and socioeconomic contexts beyond the initial case studies.

### 3.8 Fulfillment of the technical results of ICARIA (RES-TEC)

The technical results (RES-TEC) of the ICARIA project represent the tangible tools and software platforms developed to advance the state of the art in climate resilience. The fulfillment of these four results is evidenced as follows:

- RES-TEC1 Multi-Hazard modeling tools:** This result was satisfied through the development of state-of-the-art multi-hazard models for each CS using best-fit existing commercial software (see Section 3.4). The models implementation and results validity is documented in Deliverable 4.2 (A. De La Cruz–Coronas et al., 2026).
- RES-TEC2 Holistic climate resilience assessment method:** ICARIA delivered a unified "Resilience Assessment Shell," a web-based platform that hosts the upgraded ICARIA RAF and ICARIA RAT applications. This result fulfills the project's aim to provide a versatile tool capable of performing assessments from urban to regional scales ([RAF & RAT access link](#)).
- RES-TEC3 Portfolio of adaptation solutions:** This result was achieved through the creation of a comprehensive web-based platform serving as an open-source database of over 200 climate adaptation measures. The portfolio includes Nature-based Solutions (NBS) and a prioritization method that enables decision-makers to evaluate solutions based on total cost, effectiveness, and multi-perspective co-benefits ([Adaptation portfolio access link](#)).
- RES-TEC4 ICARIA DSS:** The ICARIA Decision Support System was materialized as a centralized web-based integration point for the project's entire modeling chain, including climate projections and multi-hazard impact models. It allows authorities to compare "Business as Usual" scenarios against various adaptation strategies ([DSS access link](#)).

### 3.9 Summary of achievements

The following tables summarize the achievements for the project.

**Table 3.** Achievement of Strategic Subobjectives

Strategic objectives		
Number	Title	Category
SS01	Achievement of a comprehensive methodology to assess climate-related risk produced by complex, cascading and compound disasters	Scientific
SS02	Obtaining tailored scenarios for the case study regions	Scientific
SS03	Quantify uncertainty and manage data gaps through model input requirements and innovative methods	Scientific
SS04	Increase the knowledge on climate-related disasters by developing and implementing advanced modelling for multi-hazard assessment	Scientific
SS05	Better assessment of holistic resilience and climate-related impacts for current and future scenarios	Scientific
SS06	Better decision-making for cost-efficient adaptation solutions by developing a DSS to compare adaptation solutions	Technological

Strategic objectives		
SS07	Ensure the use and impact of the ICARIA outputs	Dissemination and exploitation

**Table 4.** Achievement of technical results

Code	Objective	Description	Justification of novelty	Mechanisms of validation
RES-TEC1	Multi-hazard modeling tools	ICARIA will integrate and improve existing modeling tools (RESCCUE, CLARITY, GRIDWATCH, etc.) to create a holistic framework that assesses impacts by considering interactions among a wider range of hazards, including compound disasters, across local to regional scopes. The results will feed into the DSS.	These tools move beyond "silo" assessments by using spatiotemporal event trees to map hazard interactions and Bayesian Networks/Copulas to quantify dependencies between events like heatwaves and wildfires.	<b>Met by deploying multi-hazard asset models across all CS. Integrating these results into the DSS validates their use for climate risk assessments.</b>
RES-TEC2	Holistic climate resilience assessment tool	Integrating the RAF App (from H2020 RESCCUE for urban water resilience, TRL7) and the RAT tool (from EU-CIRCLE for critical infrastructure resilience, TRL5). It will enhance these solutions by covering larger areas (up to regional level) and multiple hazards/compound events, reaching TRL7. This output will feed into the DSS.	It expanded the assessment scope from urban to metropolitan/regional scales and integrated Natural Areas as a strategic service. The tool was methodologically upgraded to align with the new EU CER Directive (2022/2557).	<b>Delivered as a unified web-based "Resilience Assessment Shell" hosting upgraded RAF and RAT applications.</b>
RES-TEC3	Portfolio of adaptation solutions	The ICARIA portfolio will integrate the RESCCUE Adaptation Platform, RECONNECT NBS portfolio, CLARITY Catalogue, and DRIVER+ Crisis Management solutions. ICARIA will work closely with the KNOWING and MAIA projects (involving AQUA and AIT) to build adaptation measure portfolios. The ICARIA team will focus on ensuring project adaptation solutions (TRL 5 to 7) are well-represented in the portfolio, including impact modeling information, for use by the ICARIA DSS.	An open-source database of over 200 measures that uniquely integrates Nature-based Solutions (NBS) alongside traditional infrastructure. It includes an automated Multi-Criteria Prioritization tool based on socio-economic and environmental co-benefits.	<b>Solutions were applied and assessed in the project's case studies, with technical performance validated during stakeholder trials.</b>
RES-TEC4	ICARIA DSS	The ICARIA DSS is a toolbox integrating existing modelling and risk assessment methods (all ICARIA results). This web-based, user-friendly platform, supported by GIS platforms from CRISI-ADAPT II and CLARITY, will enable easy comparison and selection of the most cost-effective adaptation strategies and measures (TRL 3 to 7).	A centralized platform serving as the final integration point for the entire modeling chain. It features a Scenario Manager that allows users to compare "Business as Usual" scenarios against complex adaptation strategies using MCA and CBA	<b>Tested and validated by stakeholders across three regions through the Trial Guidance Methodology (TGM), documented in Deliverable 4.2</b>

**Table 5.** Achievement of scientific results

Code	Objective	Description	justification of novelty	Mechanisms of validation
RES-SCI1	Project framework	ICARIA will establish a climate-change multi-hazard framework for holistic regional assessment, including cascading and compound effects. This framework addresses hazards impacting any service or CI, though ICARIA will focus implementation on selected single or compound hazards affecting a variety of assets and services.	This framework moves beyond traditional single-hazard assessments to a multi-hazard approach accounting for compound events and cascading effects. It introduces "elementary bricks" for harmonized modular analysis, Dynamic Vulnerability (DV) to track cumulative damage, and integrates human behavior as a factor in disaster propagation.	<b>Validated through its application in three diverse case studies (Barcelona, Salzburg, and South Aegean) and published in the peer-reviewed <i>International Journal of Disaster Risk Reduction</i>.</b>
RES-SCI2	Climate scenarios methods and results	Downscaling methods will be proposed, applied to three case studies, and tailored for local climate projections up to 2100 (long-term) and 15 days to 6 months (short-term). These projections will integrate large-scale climate and local socio-economic emission scenarios.	ICARIA operationalized the latest CMIP6 models and Shared Socioeconomic Pathways (SSPs) at a local scale. It utilized a dual-method downscaling approach (statistical and dynamical) and a fractal-based n-index methodology to extrapolate daily projections to hourly scales for urban flood modeling.	<b>Confirmed by peer-reviewed publications in <i>Environmental Research Communications and Atmosphere</i>, with all datasets made openly available on Zenodo.</b>
RES-SCI3	Methods for mending data gaps and uncertainty analysis	Data gaps and associated uncertainty will be addressed by defining and testing methods, including cross-validations, across regional data availability scenarios (best-case with full data to worst-case with minimum data).	The project established a standardized, scalable workflow for identifying and mitigating data scarcity. This includes the ICARIA Jupyter Cookbook, which offers innovative streams like synthetic data generation for missing infrastructure records and AI methodologies.	<b>Validated through four targeted WP1 Lab Tests addressing specific gaps in the case study regions, such as absence of sewer records or restoration cost data.</b>
RES-SCI4	Climate-related multi-risk tangible impact assessment method	Building on projects like RESCCUE, ICARIA will deliver an improved, comprehensive method to assess direct and indirect tangible losses for critical assets and infrastructure due to climate extremes. This includes reconstruction costs, service interruption costs, and knock-on effects.	This method allows for the monetization of climate-related losses by using hazard-damage and hazard-disruption curves to quantify direct reconstruction costs and the economic impact of service interruptions.	<b>Documented in Deliverable 3.1 with application guidelines and further validated through results published in a specialized scientific journal.</b>

Code	Objective	Description	justification of novelty	Mechanisms of validation
RES-SCI5	Multi-risk and resilience assessment for the 3 EU case studies	ICARIA's existing methods and tools will be tested, implemented, and replicated across the three case study regions for various hazards and assets to demonstrate their versatility. For all three regions, the most cost-effective adaptation solutions will be selected based on the evaluated hazards and assets.	Represents the first integrated application of the project's multi-hazard and resilience methodologies within real-world operational contexts across three high-contrast European regions.	<b>Operationally validated through Trials involving local stakeholders and Communities of Practice (CoPs), as documented in Deliverable 4.2.</b>
RES-SCI6	Replication, sustainability and exploitation of ICARIA results	The results from a case study on hazard-asset combinations and cost-effective adaptation measures will be replicated in other regions, but with fewer resources. Replication guidelines, along with a sustainability and exploitation plan, will be created to detail how these outcomes will be improved, used by case studies, and extended across Europe to help at least 150 European regions achieve climate resilience by 2030 (KPI 7.3).	Focused on proving the transferability of ICARIA tools to regions with suboptimal data availability through "Mini-trials" and the engagement of seven "follower regions".	<b>Success was measured by the feedback from the follower regions and over 10 additional communities during the project's final event</b>

## 4 Contribution to objectives beyond the project duration

The SSOs reflect the main objectives to be achieved within the time-span of ICARIA. However, the project ambitious mid and long term impacts beyond its end as reflected in the Expected Outcomes (EOs) in Table 1 and Impact pathways (IP) in Table 2. This section highlights how ICARIA contributes to their fulfillment.

### 4.1 Achievement of Expected Outcomes

#### **EO1: Beyond state-of-the-art asset-level models for critical infrastructures**

The contribution to EO1 is evidenced by the development of the ICARIA holistic asset-level modelling framework (Section 3.1) and its subsequent operationalization through advanced multi-hazard models (Section 3.4).

- The ICARIA Framework: methodological approach for the holistic modeling framework to assess the impacts of multi-hazard complex events, including cascading effects. It was published in the *International Journal of Disaster Risk Reduction* (Leone et al., 2025).
- State-of-the-art asset-level models: In Barcelona, a hydrodynamic 1/2D coupled models developed in Inforworks Ultimate addressed compound coastal-pluvial flooding at the metropolitan level. Based on it, impacts on electricity distribution elements and waste management assets were assessed. In Salzburg, the HydroMT-SFINCS model was used to assess river flood and windstorm impacts on electricity and transport assets. In the South Aegean, a GIS-based model quantified impacts of combined forest fires and heatwaves in multiple risk receptors.

The publication of the methodology and its implementation in three different European regions illustrate how the achievement of EO1 can support the assessment of natural hazard impacts on critical assets.

#### **EO2: Model information system for comparing adaptation approaches**

EO2 is covered by the delivery of the ICARIA Decision Support System (DSS) and the comprehensive Portfolio of Adaptation Solutions.

- The ICARIA DSS is a centralized web-based platform that serves as the "model information system" required by EO2. Its core functionality is the Scenario Manager, which allows public authorities to create and compare "Business as Usual" (BAU) scenarios and compare it against multiple adaptation strategies. The comparison is multiperspective (total impacts, holistic resilience, adaptation measures in place) and is supported by an interactive map viewer interface, numeric results and summary graphs.
- The Adaptation Portfolio (RES-TEC3) is an expanded portfolio of measures covering multiple natural hazards, including heatwaves, floods, and forest fires. A significant innovation is the inclusion of Nature-Based Solutions (NBS) and ecosystem services for natural areas, which were traditionally excluded from infrastructure-focused tools. Users can filter measures by

typology, scope, estimated cost and multiple co-benefits to identify the most adequate options.

Since both tools are open web-base platforms, they are accessible for users beyond the end of ICARIA.

### **E03: Analysis of gaps in European data regarding economic consequences**

The project documented that the primary barrier to assessing the impacts of extreme and complex events on critical assets is data heterogeneity and availability gaps. In particular, socioeconomic and infrastructure exposure and vulnerability data are often scarce, outdated, or restricted due to proprietary and security constraints.

- Task 1.3 developed the ICARIA Jupyter Cookbook providing multiple for data-gap filling methods like Taxable Fair Market Values (used in the South Aegean to estimate building repair costs when official disaster loss records were unavailable) and GIS Analytics and Buffer Zones (utilized in Salzburg to map tree species and density as a proxy for estimating windstorm-induced infrastructure disruption).
- A methodology for synthetic sewer network generation was developed for the AMB CS to reconstruct missing drainage systems layouts essential for pluvial flood modeling.
- Generic fragility curves were used to compute the damages of wind-storms in the electricity transmission lined of the Salzburg CS.
- Synthetic national-level flood depth damage curves were integrated in the DSS to provide a generic but solid approach to quantify the economic impact of this hazard on buildings across Europe.

The mentioned data-gap filling methods and the use of alternative data sources contributed to E03.

## **4.2 Contribution to long-term Impact Pathways**

### **Contribution to IP1: Mobilizing actors for lasting impact**

ICARIA has successfully engaged a large network of stakeholders to create a real and lasting impact on climate risk governance. At the core of it, each CS created a local community of practice including 8 to 15 regions actors in the field of climate adaptation and critical infrastructures. They included regional administrations, research community and asset operators. In addition 7 follower regions (including diverse EU regions such as the Region of Valencia or the city of Naples), acted as early adopters and provided feedback on the transferability of the project's methodologies. Mobilization was fostered through targeted events, including a mid-project information session specifically for follower regions to align technical developments with their local needs. This network was significantly expanded during the project final event, which brought together the follower regions along with more than 10 additional European regions and infrastructure operators from across the continent to learn from ICARIA outcomes, acknowledge its long-term lasting tools, and share best practices in climate-proofing critical assets.

### **Contribution to IP2 and IP3: Support and demonstration of systemic transformations**

The project contributes to the Mission goal of supporting at least 150 regions by providing a suite of fully open-access tools designed to accelerate transformations to climate resilience: the ICARIA Decision Support System (DSS), the Resilience Assessment Platform (RAF/RAT), and the Jupyter Cookbook. By delivering large-scale demonstrations in three high-contrast European contexts—Barcelona (urban/coastal), Salzburg (Alpine), and the South Aegean (archipelago)—ICARIA has validated that systemic transformation is achievable through a harmonized methodology even in data-scarce or sub-optimal conditions. As explained for IP1, the existence and applicability of the tools was presented to multiple potential end users all over Europe through the project final event.

#### **Contribution to IP4: Fostering a balanced portfolio of adaptation solutions**

ICARIA has directly fostered the development of a portfolio of solutions (RES-TEC3) that addresses a wide spectrum of climate risks including heatwaves, floods, forest fires, and droughts. A significant innovation is the integration of Nature-Based Solutions (NBS) and ecosystem services alongside traditional grey infrastructure, ensuring that adaptation strategies provide cross-sectoral co-benefits. It enables authorities to prioritize these solutions through Multi-Criteria Analysis (MCA) by considering implementation costs, maintenance demands and co-benefits associated with each measure.

## 5 Exploitation of ICARIA results

The ICARIA project's exploitation strategy is centered on transforming its eight Key Exploitable Results (KERs) into actionable tools for public authorities, infrastructure managers, and the scientific community. The core of this effort is the DSS, which serves as the central platform integrating hazard models, resilience frameworks, and adaptation portfolios into a single digital environment.

An extensive Sustainability and exploitation plan – Final version (Deliverable 4.5) (Lavasa, 2025) details how to achieve this and the product exploitability assessments carried out. This section summarises its main conclusions.

### 1. Sharing via Open Access and Scientific Transfer

ICARIA ensures the long-term impact of its scientific findings through an open and collaborative sharing model:

- **Public Repositories:** Scientific datasets and methods, such as climate scenario methods (KER 1), multi-hazard modeling results (KER 2), and tangible impact assessment methods (KER 3), are made available through Zenodo. This allows researchers and authorities to use validated climate projections and hazard maps for their own independent analyses.
- **Free Tools for Non-Commercial Use:** The Resilience Assessment Framework (RAF/KER 4) and the Resilience Assessment Tool (RAT/KER 5) are provided as open services for non-commercial research and practical applications. These tools allow users to self-diagnose resilience maturity levels and plan improvements.
- **Guides and Methodologies:** The "Portfolio of Adaptation Solutions" (KER 6), which includes over 320 curated measures, and the "Trial Guidance Methodology" (KER 7) are shared to help stakeholders validate and implement innovative solutions in real-world contexts.

### 2. Commercial and Joint Exploitation Strategy

The DSS is positioned as the consortium's primary commercial asset under a model led by DRAXIS and supported technically by other partners.

- **Business Model:** A "pilot-first" strategy has been defined, where potential clients test the tool in their operational context before transitioning to a Software as a Service (SaaS) subscription model.
- **Revenue Structure:** The model includes tiered subscription levels for small municipalities, medium regions, and large critical infrastructure operators. This is complemented by project-based consulting and premium Data-as-a-Service (DaaS) offerings.
- **Regional Reach:** Beyond the primary case studies, ICARIA has engaged seven "follower regions" across Europe (including regions in Italy, France, and Germany) to ensure methodologies are exportable to diverse geographic and climatic contexts.

### **3. Stakeholder Engagement (Outreach)**

Exploitation is reinforced through the activation of Communities of Practice (CoPs) in each region, facilitating a co-creation process that ensures tools meet the real needs of end-users. This approach has transformed research outputs into knowledge capable of sustaining project impact far beyond its initial funding period.

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## 6 Conclusions

The Innovation Management Report (D6.7) provides evidence that the ICARIA project has achieved its innovation objectives. Looking into its Strategic Sub-Objectives (SSOs), ICARIA has established a holistic multi-hazard framework (SSO1), developed high-resolution CMIP6 climate scenarios (SSO2), and a reproducible Jupyter Cookbook for managing data scarcity (SSO3). Also, it has advanced in multi-hazard modeling (SSO4) and integrated resilience assessment platforms (SSO5). All methods and tools have been integrated in a Decision Support System (DSS) (SSO6) and ensured broad stakeholder impact (SSO7).

The project has achieved its three mid-term Expected Outcomes (EOs): delivering beyond-state-of-the-art asset-level models for critical infrastructure (EO1), enabling public authorities to compare adaptation approaches via a model information system (EO2), and providing a systematic analysis of European data gaps regarding economic consequences (EO3). Furthermore, ICARIA has actively contributed to the EU Mission on Adaptation's four Impact Pathways (IPs). This includes mobilizing a network of follower regions (IP1), providing open-access tools for regional risk management (IP2), demonstrating systemic transformations across diverse topographies (IP3), and fostering a balanced portfolio of over 200 adaptation measures (IP4).

In this context, Deliverable 4.5 (Sustainability and Exploitation Plan) provides a clear plan for the long-term exploitation of the tools and results developed. This ensures that ICARIA's methodologies remain actionable for European communities.

## Bibliography

- Brito, R., Cardoso, M. A., Mendes, A., Matos, R., & Oliveira, A. (2024). *ICARIA Deliverable 3.2: Holistic resilience methods*.
- Büegelmayer-Blaschek, M., Hasel, K., & Gazzaneo, P. (2025). *ICARIA: Dynamically downscaled climate projections using two regional climate models* [Dataset]. Zenodo. <https://doi.org/10.5281/ZENODO.14937417>
- Büegelmayer-Blaschek, M., Hasel, K., Redolat, D., Paradinas, C., & Monjo, R. (2025). Future climate projections for South Aegean and Salzburg region based on statistical and dynamical downscaling—Similarities and discrepancies. *Environmental Research Communications*, 7(6), 065003. <https://doi.org/10.1088/2515-7620/addc3f>
- Chen, A., Evans, B., De La Cruz–Coronas, A., Russo, B., Büegelmayer-Blaschek, M., & Zarios, I. (2025). *ICARIA Deliverable 2.4: ICARIA multi-hazards modelling tools and application guidelines – Version 2*.
- De La Cruz–Coronas, A., Evans, B., Truchi, A., Addabbo, N., Büegelmayer-Blaschek, M., & Zarikos, I. (2023). *ICARIA Deliverable 2.1: Holistic modeling framework for multi-hazard events*.
- De La Cruz–Coronas, A., Pacho, S., Büegelmayer-Blaschek, M., Hasel, K., Berg, R., Havlik, D., Duro, R., Zarikos, I., Pradell, P., Cantó, N., Baraibar, S., Leone, M., & Brito, R. (2026). *ICARIA Deliverable 4.2: Trial Assessment*.
- De La Cruz–Coronas, À., & Russo, B. (2025). Synthetic Sewer Networks for Pluvial Flood Assessment in Urban Areas: A Data Gap Filling Methodology. *Hydrological Processes*, 39(12), e70365. <https://doi.org/10.1002/hyp.70365>
- Gacon, B., Santuy, D., & Redolat, D. (2024). Temporal Distribution of Extreme Precipitation in Barcelona (Spain) under Multi-Fractal n-Index with Breaking Point. *Atmosphere*, 15(7), 804. <https://doi.org/10.3390/atmos15070804>
- Guerrero-Hidalga, De La Cruz–Coronas, Flor, G., Evans, B., & Gili, A. (2024). *ICARIA Deliverable 3.1 Tangible Impact Assessment Methods*.
- Havlik, D., Fotcha, V., De La Cruz–Coronas, À., Büegelmayer-Blaschek, M., & Zarikos, I. (2024). *ICARIA Deliverable 4.1: Trial Design*.
- IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (V. Masson-Delmotte, A. P. Zhai, S. L. Pirani, C. Connors, S. Péan, N. Berger, Y. Caud, L. Chen, M. I. Goldfarb, M. Gomis, K. Huang, E. Leitzell, J. B. R. Lonnoy, T. K. Matthews, T. Maycock, O. Waterfield, R. Y. Yelekçi, & B. Zhou, Eds.). Cambridge University Press.
- IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (C. W. Team, H. Lee, & J. Romero, Eds.). IPCC. <https://doi.org/10.59327/IPCC/AR6-9789291691647>
- Lavasa, A. (2025). *ICARIA Deliverable 4.5: Sustainability & Exploitation Plan*.
- Leone, M. F., Zuccaro, G., De Gregorio, D., Turchi, A., Tedeschi, A., Büegelmayer-Blaschek, M., Sfetos, A., Zarikos, I., Coronas, A. D. L. C., & Russo, B. (2025). A holistic asset-level modelling framework for a comprehensive multi-hazard risk/impact assessment: Insights from the ICARIA project. *International Journal of Disaster Risk Reduction*, 119, 105319. <https://doi.org/10.1016/j.ijdr.2025.105319>
- Leone, M., Truchi, A., Tedeschi, A., & Zuccaro, G. (2026). *ICARIA Deliverable 1.5: Implementation of ICARIA Holistic modelling framework—Lessons learnt*.
- Moumtzidou, A., & Gialampoukidis, I. (2024a). *ICARIA Deliverable 1.4 – WP1 lab testing results*.
- Moumtzidou, A., & Gialampoukidis, I. (2024b). *ICARIA Deliverable 1.3: Impact modelling data requirements and methods to treat data gap filling and data uncertainty*.
- Paradinas Blázquez, C., Büegelmayer-Blaschek, M., Galiano Sánchez, L., Redolat Negro, D., Prado López, C., Hasel, K., Züger, J., Lampert, J., & Thiele, P. (2024). *ICARIA Deliverable 1.2: Climate projections and hazard scenarios* (p. 210).
- Paradinas, C., Galiano, L., Redolat, D., Prado, C., Gaitan, E., & Monjo, R. (2024). *ICARIA: Climate projections from statistical downscaling outputs* (Versión 1.0) [Dataset]. Zenodo. <https://doi.org/10.5281/ZENODO.10964397>
- Truchi, A., Tedeschi, A., Leone, M. F., De Gregorio, D., Zuccaro, G., De La Cruz–Coronas, A., Büegelmayer-Blaschek, M., & Zarikos, I. (2023). *ICARIA Deliverable 1.1: ICARIA holistic modelling framework*.
- Truchi, A., Tedeschi, A., Leone, M., Pacho, S., De La Cruz–Coronas, A., Büegelmayer-Blaschek, M., Havlik, D., & Zarikos, I. (2026). *ICARIA Deliverable 4.3: Replicability recommendations*.

UNDRR. (2020). *Human cost fo disasters: An overview of the last 20 years*.  
<https://www.undrr.org/publication/human-cost-disasters-overview-last-20-years-2000-2019>

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## Annex I: ICARIA project KPIs

KPI*	SSO*	Corres. deliv.*	Dead-line	Description	Probability of timely achievement
KPI 1.1	SSO 1	D1.1	M9	Framework (aligned with EC technical guidance on climate proofing of infrastructure 2021-2027) presented, at least, in 1 international conference and 1 open access scientific journal	Medium
KPI 1.2		D4.3	M36	Testing methodology in all ICARIA implementations (3 trials) and replications (3 mini-trials)	High
KPI 1.3		D1.3	M18	Four data collection templates (1. hazard, 2. exposure, 3. vulnerability, 4. socio economic impact)	High
KPI 2.1	SSO2	D1.1	M12	Finalized concept of combination of the different approaches (at least 2) to obtain downscaled scenarios with uncertainty measurement for the near and long term	Medium
KPI 2.2		D1.2	M12	Number of CMIP6 climate models (at least 10 using the statistical approach, at least 2 using the dynamical approach**) downscaled at a local*** scale (points) to feed asset risk assessment	Medium
KPI 2.3		D1.2	M12	The method and results will be discussed within at least 1 open-source publication and 1 conference	High
KPI 3.1	SSO3	D1.3	M18	Use of data gap filling and data uncertainty methods recommended in D1.3 in all the three ICARIA case studies during the replication phase (mini-trials)	High
KPI 3.2		D4.3	M36	Satisfactory validation (75% satisfaction in Communities of Practice (CoP) poll results) of data gap and uncertainty methods recommended in D1.3 in the ICARIA case studies during replication phase (mini-trials)	High
KPI 4.1	SSO4	D4.2	M36	Successful implementation and assessment of ICARIA modeling framework through 3 trials	High
KPI 4.2		D4.2	M36	Successful replication of ICARIA modeling framework in at least 3 mini-trials	High
KPI 4.3		D4.3	M36	More than 3 publications on analyzing the interactions between multi-hazards and critical infrastructures, the knock-on effects of compound/cascade disasters, and the ICARIA modeling framework applications	Medium

KPI*	SSO*	Corres. deliv.*	Dead-line	Description	Probability of timely achievement
KPI 4.4		D4.3	M36	Presenting the methods and results in, at least, 15 specialized journals / forums / conferences	Medium
KPI 5.1	SSO5	D4.2 & D4.3	M39	More than 3 scientific publications on peer-reviewed indexed and open access journals about the holistic resilience assets and tangible impact assessment methods and their implementation within ICARIA case studies	Medium
KPI 5.2		D4.3	M36	Successful implementation and replication of the multi-risk and resilience assessments in the 3 ICARIA sites (average of 75% satisfaction on poll results among CoPs)	High
KPI 6.1	SSO6	D3.3	M18	For each of the asset categories that are investigated in the project, a minimum of 3 relevant adaptation solutions of ICARIA portfolio, applied and assessed in at least one of the case studies	High
KPI 6.3		D3.5	M36	Satisfactory implementation of the DSS (75% satisfaction on CoP poll results)	High
KPI 6.3		D3.5	M36	Use of DSS in all the 3 ICARIA case studies for trials and mini-trials	High
KPI 7.1	SSO7	D5.3	M39	Availability of ICARIA website with more than 250 visits/month from M12 to M36	Medium
KPI 7.2		D5.5	M39	Minutes of the CoPs workshops during the project (3 minutes for each case study)	High
KPI 7.3		D5.5	M39	More than 10 regions (including followers) interested in ICARIA demos participating in final event	Medium
KPI 7.4		-	M39	Organization of Final Conference on climate-proofing infrastructures with more than 200 attendances	Medium

\* KPI: Key Performance Indicator; SSO: Specific sub-objective; Corres. deliv.: Corresponding deliverable

\*\* Dynamically downscaled climate projections based on at least 2 different CMIP6 and 2 different RCM models

\*\*\* High-level, hazard climate projection based on statistical approaches and AI-improved dynamical projections

More info: [www.icaria-project.eu](http://www.icaria-project.eu)



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