ICARIA
Improving climate resilience of critical assets

D3.3 Portfolio of adaptation solutions

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D3.3 Portfolio of adaptation solution

Presentation of the complete list of climate change adaptation measures collected and the method to create strategies and prioritise their implementation

Summary

This deliverable presents the process and methods used for the development of the ICARIA adaptation strategies platform. The web-based tool offers public access to a compendium of measures to achieve a climate adaptation of territories at different scales. Measures have been collected from previous projects of the Consortium Partners and relevant external sources to provide measures that tackle all hazards included in the ICARIA framework, also considering compound events and co-benefits of the selected measures. Additionally, the deliverable presents a method to design, evaluate and prioritise Adaptation Strategies, offering three different criteria to do so, which depends on the priorities of the decision makers (e.g. total cost, cost-effectiveness and co-benefits).

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Acronyms

AMB	Àrea Metropolitana de Barcelona (Barcelona Metropolitan Area)
CAPEX	Capital Expenditure
CC	Climate Change
CCA	Climate Change Adaptation
CICES	Common International Classification of Ecosystem Services
CIRIA	Construction Industry and Research Information Association
CoP	Community of Practices
CS	Case Study
CSO	Combined Sewer Overflows
DC	Direct Current
DSS	Decision Support System
EAC	Equivalent Annual Cost
EAD	Expected Annual Damage
EEA	European Environmental Agency
ERI	European Research Institute
ES	Ecosystem Services
EU	European Union
FAQs	Frequently Asked Questions
GDP	Gross Domestic Product
KTM	Key Type Measures
MCDA	Multi-Criteria Decision Analysis
NBS	Nature Based Solutions
OECD	Organisation for Economic Cooperation and Development
OIRA	Office of Information and Regulatory Affairs
OMB	Office of Management and Budget
OPEX	Operational Expenditure
SAR	South Aegean Region
SBG	Salzburg Region
SEEA	System of Environmental Economic Accounting
SQL	Structured Query Language
SSO	Strategic Sub Objectives
UNEXE	University of Exeter
URL	Uniform Resource Locator
WP	Work Package (Usually followed by a #number i.e: WP1)
WWTP	Waste Water Treatment Plant

Executive summary

This deliverable presents the ICARIA Adaptation Strategies Platform, which provides an open source database of characterised adaptation measures and a digital tool to support their prioritisation. It is expected to support decision makers and design teams in their processes to create and plan relevant Adaptation Strategies, suited to the community needs of their territory.

The platform has been developed taking references from existing Climate Change Adaptation platforms and databases (RESCCUE's Adaptation Strategies Platform, CLARITY and RECONNECT mainly), in terms of platform design, measures sources and methodologies to process the data. Constructing from proven sources provides a solid baseline to the platform and its content, which is expected to support the design and implementation of Strategic Climate Change Adaptation Plans, carried out by urban or regional planners.

The measures available in the platform and the characterization and assessment method presented are expected to support the development of adaptation scenarios for the 3 case studies included in the Project - the Metropolitan Area of Barcelona, the Salzburg Region and the South Aegean Region. In the forthcoming tasks of Project ICARIA, a number of impact assessments for the selected hazards, sectors and risks receptors (as presented in Deliverable D3.1) are going to be carried out. In this process, a sound selection of suitable measures for such tasks is needed to construct the scenarios and, in this sense, the content of this deliverable is going to be key.

As relevant aspects of the platform and the method proposed, a strong stakeholders engagement is suggested as a success factor for the design, prioritisation and implementation of measures. Additionally, there is a focus on Nature-based Solutions regarding measures's characterization, as well as the proposal of assessment of co-benefits and ecosystem services provision, in order to shed light on the aspects beyond the classic cost-effectiveness assessment for decision-making.

1. Introduction

1.1. Project ICARIA

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 (UNDRR, 2020). These numbers represent a sharp increase of the number of recorded disaster events in comparison with 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 (Zeppel, 2010). In 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 modelling framework to achieve a better understanding about climate related impacts produced by complex, compound and cascading disasters and the possible risk reduction provided by suitable, sustainable and cost-effective adaptation solutions.
This project will be especially devoted to critical assets and infrastructures that are susceptible to climate change, in a sense that its local effects can result in significant increases in cost of potential losses for unplanned outages and failures, as well as maintenance – unless an effort is undertaken in making these assets more resilient. ICARIA aims to understand how future climate might affect life-cycle costs of these 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.

To achieve this aim, ICARIA has identified 7 Strategic Subobjectives (SSO), each one related to one or several work packages. They have been classified according to different categories: scientific, corresponding to research activities for advances beyond the state of the art (SSO1, SSO2, SSO3, SSO4, SO5); 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); and related to dissemination and exploitation, aimed at sharing ICARIA results to a broader audience and number of regions and communities to maximize project impact (SSO7).

- SSO1.- Achievement of a comprehensive methodology to assess climate related risk produced by complex, cascading and compound disasters
- SSO2.- Obtaining tailored scenarios for the case studies regions
- SSO3.- Quantify uncertainty and manage data gaps through model input requirements and innovative methods
- SSO4.- Increase the knowledge on climate related disasters (including interactions between compound events and cascading effects) by developing and implementing advanced modeling for multi-hazard assessment

- SSO5.- Better assessment of holistic resilience and climate-related impacts for current and future scenarios
- SSO6.- Better decision taking for cost-efficient adaptation solutions by developing a Decision Support System (DSS) to compare adaptation solutions
- SSO7.- Ensure the use and impact of the ICARIA outputs

1.2. Main developments in the Portfolio of Adaptation Solutions

As part of the overall objective of ICARIA described above, there is the need to better understand the potential that different measures might have in the adaptation process of urban, rural and natural areas to reduce the impacts caused by the main hazards. This deliverable is therefore part of the Strategic Objective 6 SSO6.

To do so, a new web-based platform of adaptation strategies has been developed in T3.3 named ICARIA Adaptation Strategies Platform. It integrates the existing knowledge of previous projects (shown in Annex 1 & Table 4) carried out by Consortium members related to portfolios of climate adaptation solutions and prioritisation methods. Special attention has been paid to include nature based solutions (NBS), as measures to reduce climate change-related impacts with additional benefits to society and the environment.

The ICARIA platform includes a comprehensive database of climate adaptation measures with information relevant to decision makers, as well as state of the art references that allow to develop site-specific characterization for those indicators that can not be standardised. These measures are characterised based on their type (grey infrastructure, NBS, hybrid), hazard covered, sector targeted (e.g., water resources, agriculture, waste), and scale (e.g., local, regional, national). The details of the measures characterization and the summary of the proposed evaluation methods can be found in section 4.

The Adaptation Strategies platform also includes a measures prioritisation tool that follows the method proposed by Guerrero-Hidalga et al (2020) (section 5). The ICARIA platform is a catalyst to evaluate the impact of adaptation measures and strategies, as the information and process included in it will be connected to the Decision Support System (DSS) platform developed in T3.4. The ICARIA DSS is being designed as a toolbox and will allow comparison of several adaptation scenarios to improve climate planning on critical infrastructures offering a detailed asset-level approach and a holistic approach to support decision making at the relevant scale.

The proposed platform and the connected tools foster collaboration among experts from diverse disciplines, including climate science, environmental engineering, economics and policy. This interdisciplinary approach ensures that climate adaptation is addressed from a holistic perspective. Therefore, the structure of the platform is designed to be used by a multidisciplinary group of experts aimed to develop a Climate Adaptation Strategy Plan for a specific territory.

The present deliverable is structured as follows: it starts describing the climate adaptation framework of the Project ICARIA, followed by the measures characterization process. The following section (3) describes the prioritisation method followed by the platform and then the platform itself is presented.

2. Climate Change Adaptation Framework

The Project ICARIA's practical approach focuses on empowering asset-level modelling to foster the design and execution of Climate Adaptation Strategies, composed of cost-effective adaptation solutions. Adaptation Strategies are defined as programs, projects or approaches developed by the responsible authority to respond to anticipated climate change impacts in a specific area of potential concern (ERI, 2021). The strategies should be defined with a key objective that addresses a specific adaptation target, and composed by measures targeted to that objective. The measures are selected by the Strategy design responsible, named Adaptation Strategy Design Team (the group in charge of designing and evaluating an Adaptation Strategy for a particular territory), based on their potential to reduce the impacts and risks caused by the targeted hazard. Therefore, it is relevant to begin with the main characteristics of the Climate Change Adaptation Framework followed in ICARIA, before presenting the development of the platform. For a detailed description of the ICARIA's framework, the deliverable D1.1 is available in the Project's website.

Based on the previous experience of the Consortium members, the targeted hazards, assets or services, and risk have been selected based on the potential to reduce the impacts that currently caused the most damage in Europe. The following characteristics are the ones defined in the framework of ICARIA, which also support the measures characterization.

A. Hazards

The most relevant hazards included in the project ICARIA are shown in table 2.

Table 1. *Most relevant hazards included in the ICARIA project.*

					
Floods	Storm surges	Heat waves	Forest fires	Droughts	Storm winds

Combined sewer overflows (CSO) and sea level rise are not part of the ICARIA Framework, but they have been included in the platform to provide a broad scope of climate change hazards, available to all EU regions and users. Also, users are able to select various compound hazards events in order to characterise the hazards targeted by their strategies or measures.

B. Assets/services

Consortium members and the Communities of Practice of the case studies (Salzburg Region, Metropolitan Area of Barcelona and South Aegean Region) decided to focus on the following assets and services, as they are the ones of biggest concern for public authorities of the involved regions (see Table 3). These risk receptors could be affected directly by the considered hazards or due to cascading effects.

***Table 2**. Main assets of interest within the ICARIA project.*

Tourism	Properties	Natural areas	Transport	Water assets	Electricity assets	Waste assets

C. Tangible impacts

Considering the past experiences of ICARIA researchers in assessing the impacts of Climate Change, and the asset level modelling approach of ICARIA, it was established that mainly tangible damages were going to be included in the scope of the project. The most relevant are shown in the following Table.

***Table 3.** Main affected sectors in Project ICARIA.*

Properties	Water sector	Energy sector	Transport sector	Economic sectors	Natural areas	Human health	Information sector

The focus of ICARIA is on tangible impacts, with the exception of human health and safety, due to their relevance for heatwaves and floods. The consortium members of UNINA and AQUATEC. In this sense, there are many measures that reduce the impact to human health and safety, including those considered to improve the preparedness of the citizens, the governments or other organisations.

3. Adaptation measures characterization

The characterization process involves gathering information on the technical specifications, implementation requirements, and potential impacts of each measure. This information is used to feed the prioritisation process and support decision-making. The measures included in the platform are defined considering the previously described hazards, sectors of study (assets/services) and impacts, as well as the own characteristics of the measures themselves (i.e. key benefit, area type, scale, type of measure and cost) , as detailed in the following subsections.

A. Key benefits

In order to properly categorise the measures and, in particular, to combine them to create strategies that contribute to a common objective, it is important that they show the key benefit they offer if implemented (Leitner et al., 2021). It is worth mentioning that most of them are able to potentially offer more than one benefit. However, the design of a Climate Adaptation Strategy for any scale implies that it is necessary to address a specific climate adaptation goal. Considering the feedback received from CoPs (Communities of Practices) and literature (Woods Ballard et al., 2015), the following key benefits are presented in the platform:

- Citizens engagement

- Climate hazards reduction
- Exposure to climate hazards reduction
- Vulnerability to climate hazards reduction
- Governance improvements
- Efficiency gains (public or private service)
- Nature Positive
- Resource saving

B. Area Type

The type of area where the measure is designed to be applied is also relevant to provide information to the design team about the type of measures more suitable to their application case.

- Urban areas
- Rural areas
- Natural areas

Due to the population density and the extent of potential damages caused by extreme events, Urban Areas usually receive most of the attention in Adaptation Strategies. The reason is that the urbanisation process alters natural surface and atmospheric conditions, increasing rainwater surface runoff, temperatures and decreasing evaporation (Zelenakova et al., 2015). Thus, it is understandable that a large share of measures have been designed for urban areas. However, a broader perspective reveals that rural areas have their unique vulnerabilities that warrant careful consideration (Aygün Oğur , 2023). In her study, Aygün Oğur , 2023, specifically examines rural and urban settlements, considering their economic, social, environmental, structural and governmental factors. The findings indicate that Rural Areas possess advantages, particularly in terms of environmental factors and, to some extent, social dynamics. However, these areas exhibit greater vulnerability in terms of infrastructure, connectivity and economic activities. Urban areas, characterised by diverse contexts, exhibit both vulnerabilities and advantages across all factors.
The climate change action towards restoring and increasing Natural Areas is a key driver of the EU policy, as well-managed Protected Areas safeguard biodiversity, natural processes and ecosystem services that are essential to support the adaptive capacity of ecosystems and human communities. The project Life NaturAdapt, as part of their recommendations to ensure better integration of climate priorities within nature conservation planning and management, published the following key points: 1. Protected Areas should be adequately involved in climate action planning. 2. All Protected Areas across Europe, including Natura 2000 sites, should integrate Climate Adaptation planning. 3. Climate change adaptation and nature restoration planning should integrate rigorous participatory processes, engaging communities, public and private sectors. 4. Protected Areas designation process should aim at nurturing future-proof ecosystems. Therefore, it is key that natural areas are included as part of the definition of ICARIA Adaptation Strategies.

C. Spatial Scale

The spatial scale of the Adaptation Strategy delimits the area of study and implementation of the interventions assessed. Depending on the scale, different measures apply and stakeholders involved in the decision making process of implementing and financing the measures also vary. The selected scales of adaptation measures are the following:

- Building
- Street
- Neighborhood
- City
- River Basin

- Metropolitan Area
- Region

In order to collect measures that facilitate the selection for diverse climate Adaptation Strategies designs, it was important to include the spatial scale classification. It is expected that the identification of the spatial scale in the measures' classification improves the information for a better decision making process.

D. Measure Type

The categorization of selected measures follows the one proposed by the European Environmental Agency, named Key Type Measures (KTM) (Leitner et al., 2021). The main goal of this labelling was to ease the reporting of Member States of their progress in the National Adaptation Plans (Leitner et al, 2021). It has been found relevant to use in the ICARIA Adaptation Platform, as follows the same logic sought in ICARIA, which is providing a correct definition of what adaptation measures are and therefore a correct labelling of them, to facilitate a "good catalogue of examples". However, the KTM identified below does not give an indication of priorities, meanwhile the ICARIA Platform guides the users to do their own prioritisation using the most relevant criteria for their territory.

- ***A: Governance and Institutional***
  - A1: Policy instruments
  - A2: Management and planning
  - A3: Coordination, cooperation and networks
- ***B: Economic and Finance***
  - B1: Financing and incentive instruments
  - B2: Insurance and risk sharing instruments
- ***C: Physical and Technological***
  - C1: Grey options
  - C2: Technological options
- ***D: Nature Based Solutions and Ecosystem-based Approaches***
  - D1: Green options
  - D2: Blue options
- ***E: Knowledge and Behavioural change***
  - E1 : Information and Awareness Rising
  - E2: Capacity Building, empowering and lifestyle practices

This comprehensive and well studied classification deserves to become the standard for climate adaptation strategies at European level. It is adopted by the platform Climate-ADAPT, which offers several resources for climate adaptation strategies design as well.

E. Co-Benefits

The co-benefits are understood as the additional positive externalities that a measure can provide, besides the key benefit that it was designed and implemented for. There are measures that can provide a wide range of co-benefits, for example NBS, that can provide an array of improvements to the ecosystem and quality of life of people that live or visit the site, besides their capacity to reduce the impacts of climate hazards. There are also negative externalities provided by certain measures, but they are not included in the scope of the project. When the impact is null or negative (also known as disbenefits), the given score to

that particular co-benefit is zero. More details about this are explained in Section 5. Following are the selected environmental, economic and social co-benefits. The sources of co-benefits were Projects Clarity and RESCCUE, and the selection of the final list of co-benefits available below was done by expert assessment of all researchers involved in WP3.

- ***Environmental***
  - Improved air quality
  - Improved biodiversity and ecosystems
  - Improved water quality
  - Improved water quantity (including aquifers)
  - Increased green area or green connectivity
  - Reduced land contamination
  - Improved Heat Island Effect
  - Reduced environmental impacts
  - Erosion control Environmental
- ***Social***
  - Noise abatement
  - Social cohesion and inclusion
  - Increased public space and accessibility
  - Reduced health impacts/mortality
  - Increased people's safety
  - Reduced number of property holders displayed
  - Effective/uninterrupted water collection and security
- ***Economic***
  - Cost savings
  - Increased property value
  - Job creation
  - Prices reduction
  - Increase resources efficiency

There are different methods to evaluate co-benefits, with different levels of detail and subsequent efforts to be obtained. The ICARIA Climate Adaptation strategies platform (ICARIA Climate Adaptation Strategies Platform) follows a scoring system that is explained in section 6.

F. Costs

The estimation of costs figures in a standardised manner, in terms of unit cost, which are relevant for all case studies, all contexts and countries across Europe, is something sought across the scientific and policy communities. It would ease the evaluation of climate change impact assessment, in particular the adaptation scenarios, where the comparison of the damage cost reduction and the measures implementation cost, help in deciding the adaptation investment plan.

However, to develop homogenous unit cost, there is the need for consensus across all stakeholders and a deep assessment that develops scientific evidence of the most appropriate estimated cost for each measure. Currently, there is no such a study, due to the complexity of generalising implementation and maintenance costs (Woods Ballard et al., 2015) .

To fill this data gap, the ICARIA team assessed the potential to adapt the study of Martinez-Gomariz et al. (2020), who developed a method to transfer the flood-depth damage curves (damage cost per depth of the flood event) studied for Barcelona, to all Spanish municipalities. The adaptation process of the method is thought to be based on site-specific costs estimation of the measures assessed and adapt them to different relevant regions in the European Union, using economic proxies that reflect the difference in costs levels across Europe. More details on the methodology can be found in Section 5.

Currently, the costs selector in the platform is presented as a qualitative assessment that is structured following the next categories:

- Low implementation and low maintenance costs
- Low implementation and average maintenance
- Low implementation and high maintenance
- Average implementation and low maintenance costs
- Average implementation and average maintenance costs
- Average implementation and high maintenance costs
- High implementation and low maintenance costs
- High implementation and average maintenance costs
- High implementation and high maintenance costs

This characterization allows a comparison between different levels of expenditure for both implementation and maintenance. It is thought to be a good approach to differentiate the general costs between measures, following an adaptation to the costs classification system proposed in the Project CLARITY (H2020, No 730355, 2017-2020).

4. Measures Sources

The ICARIA platform database has been populated with measures coming from a variety of sources (shown in Annex 1 & Table 5), from past and current projects of Consortium partners, as well as from external sources. These external sources have been crucial to count with a relevant number of NBS-type measures, which are at the core of the EU climate adaptation strategy and the ICARIA framework.

***Table 4**. Details of the main sources of data for the measures catalogue.*

Source		Main inputs	
ICARIA Partner	Project	Type of measures	Hazards targeted
AIT/UNINA	CLARITY	All	Heatwaves, pluvial and fluvial flooding
AQUA/AIT /UNININA	KNOWING	All	Floods, heatwaves
CET	RESCCUE	All for urban areas	Floods
CET	NATURE4CITIES	NBS	All ICARIA Project main hazards
CET	UNALAB Catalogue	NBS	All ICARIA Project main hazards
CET	Thinknature NATURE-BASED SOLUTIONS HANDBOOK	NBS	All ICARIA Project main hazards
CET	Urban greenup Catalogue	NBS for urban areas	All ICARIA Project main hazards
DMK	LIFE RESYSTAL	Healthcare infrastructure	Heatwaves, forest fires
DMK	EU CIRCLE	Training on Enhancing Resilience of Critical Infrastructure to Climate Change	Forest fires
UNEXE	RECONNECT	NBS	All ICARIA Project main hazards

The partner UNINA has provided inputs from the Project CLARITY (H2020, No 730355, 2017-2020). The project CLARITY focused on demonstrating the benefit of climate services for climate proofing of vulnerable large-scale investments such as urban infrastructure. In that context, the deliverable D3.3 Science support report (Goler et al., 2021) was a comprehensive catalogue of climate adaptation options and tools to measure them to help improve the efficiency and effectiveness of resilience measures. The measures included count with information about descriptive environmental, social and economic co-benefits, reference estimated level of costs (low, medium, high).

The University of Exeter (UNEXE) is a partner of Project RECONNECT (H2020, No 770142, 2018-2022) which explores the use of NBS as a means of adapting to and mitigating the impacts of climate change, with a particular emphasis on their potential benefits and applications in various contexts. The partner has provided a large number of NBS-type measures to the platform.

CETAQUA, UNEXE and AQUATEC, as partners of project RESCCUE (H2020, No 700174, 2016 - 2020), provided all measures collected for the project database. It specifically addressed the risks and challenges posed by floods in cites. Therefore, most adaptation measures were focused on enhancing resilience against flood events in urban areas.

AIT, as coordinator and AQUATEC, as partner of project KNOWING (Horizon Europe, No 101056841, 2022 - 2026) focuses on measures and strategies for both climate change mitigation (reducing greenhouse gas emissions) and adaptation (preparing for and responding to climate impacts). It aims to provide a comprehensive understanding of the available options and their potential benefits and trade-offs. At the time of writing, there are no available measures, but they will be integrated in the ICARIA platform if new measures arise from this project that are already not included.

Demokritos has contributed with measures focused to tackle forest fires and heatwaves, obtained, on the one hand, from the LIFE RESYSTAL project (LIFE, No 001787 2021 - 2025), which investigates climate change adaptation measures and strategies that are specifically applicable to healthcare infrastructure, such as hospitals and medical facilities, to ensure their resilience and continued operation in the face of climate-related impacts. On the other hand, the EU CIRCLE project (H2020, No 653824, 2015 - 2018) is also one the projects in which Demokritos is involved as coordinator. The project focuses on adaptation measures and strategies for addressing the risks and challenges posed by forest fires, which are expected to become more frequent and severe due to climate change.

There have been other EU projects, listed below, that have served as sources of measures.

- NATURE4CITIES (CER et al., 2016): This project explores the use of nature-based solutions (NBS) in urban environments, such as green infrastructure, urban forests and sustainable urban drainage systems, as a means of adapting to and mitigating the impacts of climate change.
- UNALAB Catalogue (Eisenberg, 2019): Building on the NATURE4CITIES project, the UNALAB Catalogue aims to create a comprehensive catalogue of measures and strategies for climate change adaptation, with a particular focus on nature-based solutions.
- Thinknature NATURE-BASED SOLUTIONS HANDBOOK (Somarakis et al., 2019): has been developed in the framework of the ThinkNature project. Its main objective is to gather and promote state-of-the-art knowledge regarding Nature-Based Solutions (NBS), comprising a comprehensive guide to all relevant actors. To this end, each aspect of NBS is investigated, from project development to financing and policy making, and is presented in a concise and comprehensive way, in order to be easily understandable. Regarding the EU agenda around NBS, this Handbook contributes to:
    - Expanding the knowledge base about the effectiveness of NBS, • Supporting the implementation of NBS through enhancing their replicability and upscaling,
    - Utilising the knowledge and experience of stakeholders, and
    - Proposing a comprehensive methodological approach for innovation.
- Urban greenup Catalogue (CAR et al., 2018): Similar to the UNALAB Catalogue, this project is developing a catalogue specifically focused on nature-based solutions for climate change adaptation in urban areas, providing guidance and best practices for implementing these measures in cities.

5. Method to Prioritise Adaptation Measures

One of the key features of the ICARIA Climate Adaptation platform is a prioritisation tool for the measures collected in its database as well as for future measures to be included by the users. In order to provide said tool, a prioritisation method that allows a pragmatic selection criteria is mandatory. The proposed method to prioritise adaptation measures is based in Guerrero-Hidalga et al. (2020). The method offers a flexible and practical approach that allows prioritising measures based on the most relevant criteria for each case, such as the cost-effectiveness, damage reduction or the welfare impact caused by the measures under assessment. It states that the most frequent criteria to select the implementation of one measure over another are damage and risk reduction, the cost-effectiveness of the measure in reducing those damages, the co-benefits offered by the measures and their estimated total costs.

In a nutshell, the methodology proposed follows a multi-phase structure to progressively narrow down the list of potential measures (as shown in Figure 1). The method is inspired by a Multi-Criteria Decision Analysis (MCDA). MCDA employs a scoring system to evaluate the potential achievement of policy objectives by assigning weights to different indicators (Zionts, 1979) (Weistroffer & Li, 2016), which are normalised beforehand to allow comparison. The scoring system allows to involve stakeholders in the process and include their valuable know-how that is not always considered.

Normalisation allows for variables of diverse nature and scales, such as monetary, quantitative or qualitative data, to be standardised and integrated into the same evaluation framework to compare and rank various adaptation measures, considering factors such as risks, costs and welfare impacts, thus facilitating informed decision-making processes. It is one of the key advantages of MCDA, its ability to integrate variables of diverse nature and scales into a unified framework. A drawback is the risk of loss of accuracy when simplifying and normalising different units and criteria for assessment. MCDA also implies the involvement of multiple stakeholders in the evaluation process, especially for indicators that are not based on quantitative data, ensuring impartiality and relevance of results when experts are unbiased. Overall, normalisation of indicators in MCDA's scoring system promotes consistency, comparability and objectivity in the evaluation process, enhancing the quality and reliability of the decision-making outcomes.

The proposed method begins using less resource-intensive techniques, to finally focus on the in-depth analysis on a narrower selection of measures. It involves evaluation of risks, costs, and welfare impacts, with strong focus on stakeholders' participation through the entire process. The methodology is adaptable to different contexts and objectives and it was tested in Barcelona and Bristol during the Project RESCCUE.

Before stepping into the main stages of the method, shown in Figure 1, it is important to define measure, strategy and scenario. A measure is a specific action taken to adapt to a specific Climate Change hazard. When a set of measures aimed to reduce the impact of a specific hazard are detailed in an official document, government policy, or strategic plan in a delimited political area, such a region or province, it is a strategy. Usually a strategy is designed and assessed by several stakeholders and experts in order to make it as effective as possible. A scenario is a combination of measures addressing usually one strategy (Climate Change hazard), where one or several are applied in order to fight against the pernicious effects of said events.

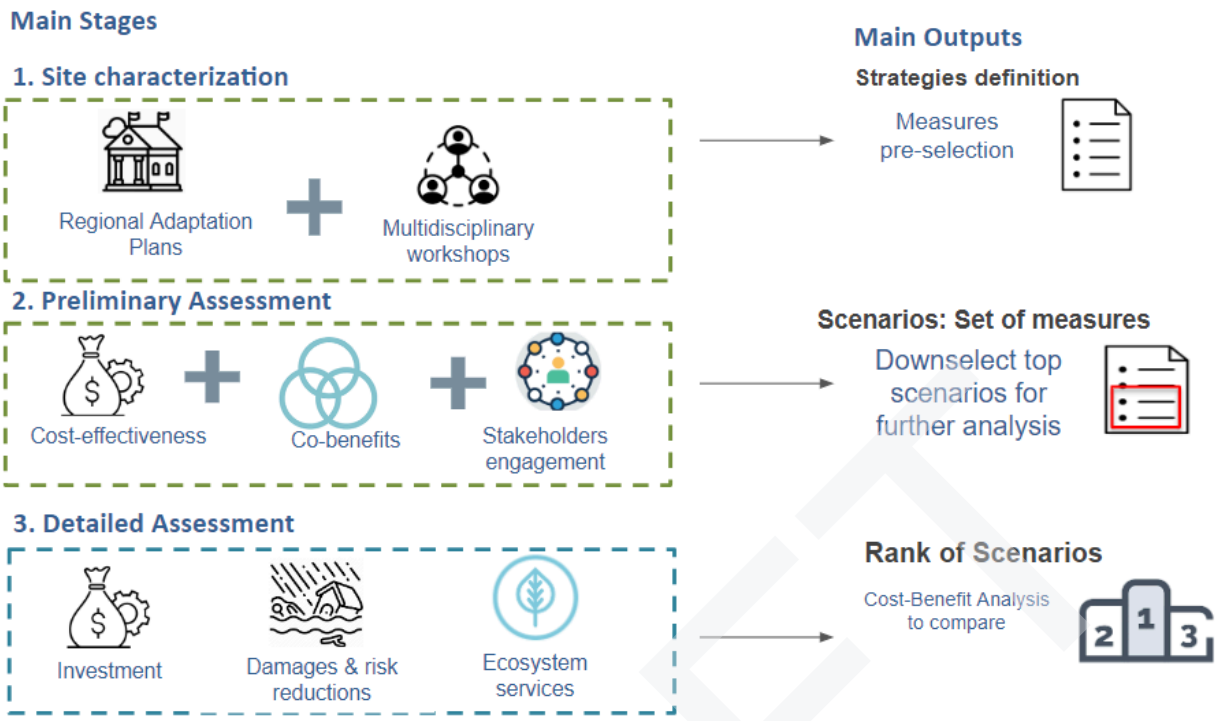


Figure 1. *Outline of the methodology stages and outputs. Retrieved from Guerrero-Hidalga (2020).*

As shown in Figure 1, the first stage consists of a characterisation of the major issues faced by the Regional or Local Administration, retrieved from their climate change strategic plans, and different multidisciplinary workshops. This phase is expected to define the main objectives of the Regional Adaptation Plan, which can have one or more strategies (one per hazard addressed), and the long list of measures to be assessed in the next stage. The output of stage 1 is the definition of the priorities to assess in terms of climate change hazards, the most relevant criteria to base the assessment's criteria and the preselection of measures that share a common adaptation objective.

The second stage is a preliminary assessment phase, aimed to downselect the number of measures within each strategy, using information not resource-intensive that serves to do a coarse comparison between . It involves an initial screening of adaptation measures based on cost-effectiveness and welfare aspects, covered through environmental, social and economic co-benefits. The cost-effectiveness uses an estimated annualised total cost per measure, obtained from previous projects or other contrasted references. Co-benefits are evaluated qualitatively through expert groups and stakeholders assessment. The output is a preliminary ranking of measures within each strategy.

The third stage is a detailed assessment of adaptation scenarios, using the preliminary ranking results as the source of scenarios. Measures are grouped by adaptation scenarios to understand the impact of implementing measures combined, against the baseline or do-nothing scenario. The prioritisation method proposes a series of methodologies to carry out a detailed analysis of the selected measures within specific scenarios for risks, costs and welfare impacts assessments. The assessment methodologies vary depending on the impact under study, the data available and the territorial scale. The results of the assessment provide inputs for a ranking of adaptation scenarios based on the most relevant criteria selected by the stakeholders (risk reduction, damage reduction, total annualised cost or welfare change).

1. Problem Characterization

Regional Adaptation Plans & Workshops

The first stage is an initial diagnosis that requires contributions from all members involved in the Regional Climate Adaptation Plan design task and stakeholders who have knowledge on policy making, the territory under assessment and specific strategic sectors. The first step is searching for existing documentation on Climate Change, Sustainability or relevant Public Policy Strategies for the area under assessment, and analyse it to understand the priorities already mentioned by the territory's policy makers. The output should be the key relevant criteria regarding Climate Change are indicated, including hazards, sectors, and territorial scope. The criteria selected will help to set up specific objectives that will support the creation of strategies.

Following, it is recommended to carry out workshops with stakeholders and validate the key objectives, criteria and strategies previously defined, obtaining consensus from stakeholders and further details. Once the diagnosis of the current situation within a regional context is done, the next step is to do an initial pre-selection of measures within each strategy. This can be supported by the ICARIA Adaptation Platform. It involves designing the strategy or strategies, by including descriptive details and all measures that can contribute to that strategy. The ICARIA platform aims to provide a structured approach to evaluate and prioritise adaptation measures based on multiple criteria, ensuring a comprehensive analysis of the measures' effectiveness and impact.

The Project ICARIA, following this approach, considers that integrating all relevant actors in the design process of the Climate Adaptation Strategy is key. In terms of Climate Adaptation, relevant actors include public administration representatives (e.g. regional adaptation commissions, urban sustainability representatives, climate action delegates), decision-makers from strategic sectors and public services (e.g. energy, water, waste, transport or insurance). Therefore, as a core part of the project there are the Community of Practices (CoPs) for each Case Study, where main representatives of territorial leaders and key sectors are included in periodical workshops where key details about challenges, approaches taken, data availability and other relevant issues are discussed and consensus is sought.

2. Preliminary Assessment

Once the strategic objectives about climate action are clear, and all related measures have been longlisted, the following step is to carry out a screening of the extensive list of adaptation measures considering cost, effectiveness, and welfare aspects. The process consists in a simple cost-effectiveness assessment and a qualitative co-benefits score, weighting these 2 factors in function of the stakeholders preferences. The output will be a preliminary ranking of measures for each strategy under consideration and will serve to down-select the measures more relevant to the case study before carrying out a detailed analysis.

a. Cost-Effectiveness Assessment

The cost-effectiveness assessment provides a comparison of the cost necessary to gain a unit of certain outcome - to be selected based on the selected objectives) (Van den Berg et al, 2008), and helps to quickly scan and compare the different measures of a strategy.

The OECD (2021) defines effectiveness as the extent to which the objectives of an intervention were achieved or are expected to be achieved. In the case of adaptation investment, effectiveness measures how

well the adaptation options reduce expected damages caused by climate change. That is, the effectiveness of an adaptation measure is the difference between the damages due to climate change and the residual damages after a climate change adaptation action is implemented.

The effectiveness indicator helps assess comparatively the success of the resources used in achieving the objective of each measure within a strategy (Guerrero-Hidalga et al., 2020). It's important to select one that is valid across measures of different characteristics and that requires available information.

In the context of Climate Adaptation in ICARIA, an effectiveness indicator could be the reduction in the risk of heatwaves-related reported health issues. The current risk of health issues caused by heatwaves in a territory can be found relatively easily, such as hospitalizations related to high temperatures health issues (for example, the Metropolitan Area of Barcelona has public heatwaves vulnerability maps), and there are several scientific publications that can estimate the measures' potential risk reduction (Qin-Mei Han et al., 2024; Kiarsi et al., 2023, Zuo et al., 2014). When a set of measures is modelled (i.e., adaptation scenario), a new number of hospitalizations can be estimated and compared with the non-adapted situation. This variation of number of hospitalizations could be used as an effectiveness indicator, indicating how effective a specific set of measures is. It is often estimated through simplified modelling, past experience in similar contexts, and/or expert opinion. Health issues directly impact the community's economic growth and social wellbeing.

The estimation of the total costs of the measures is needed to do the cost-effectiveness assessment and compare the costs of measures to achieve the same objective. Total costs include implementation (CAPEX) and operating and maintenance costs (OPEX) during the total lifespan of the asset or service. It is recommended to estimate the Equivalent Annual Cost (EAC), to do an homogenous cost comparison, as follows:

$$EAC = \frac{(CAPEX + OPEX) * Discount\ Rate}{1-(1+Discount\ Rate)^{-n}}$$

where n = periods

The discount rate is a complex topic, used to compare economic values over time, reducing the future value of an asset to its present value. The higher the discount rate, the more the value of the amount decreases over time (Valverde et al., 2022). There are recommendations from EU Projects that recommend a discount rate between 1 to 4 per cent for long term assessment (Rouillard et al., 2016).

Although costs are highly context-specific and vary significantly depending on site characteristics and the specific composition (Woods Ballard et al., 2015), it is recommended to find sources with estimated costs, relevant to the study site. There are public references available that can help to find reference costs (some unit costs available in D3.3 of Project Clarity, for example), although they should be used with careful consideration. They should be valid for a preliminary assessment, to give an order of magnitude to the different options, but accepting the high level of uncertainty. Therefore, it is recommended to find references as close as possible to the study site in terms of socioeconomic and technical characteristics, and time-wise. In Section 5.3 a proposed methodology to estimate the total costs of measures with more detail is proposed. There are other sources for unit cost information of NBS, such as Aerts (2018); Altamirano and de Rijke (2017); Ayres et al. (2014); NWRM (2015); World Bank (2021), as described in Ruangnpan et al. (2024), study carried out in the scope of project RECONNECT.

b. Co-benefits

Economic, social and environmental co-benefits are those positive effects generated in parallel to the main policy objective, understood as the specific climate change adaptation goal (Floater et al., 2016). The quantification and monetization of co-benefits is still complicated and uncertain; thus, the proposed accounting for co-benefits using a scoring system by Guerrero-Hidalga et al. (2020) is still valid.

Each category of co-benefits is composed of a set of positive effects, based on those proposed by Projects CLARITY (D3.3, Goler et al., 2019) and RESCCUE (D5.1, Martínez-Gomariz et al., 2017), under consensus of WP3 researchers. They were already mentioned in section 2 when describing the measures characterization and available also in the example provided in Table 5 . The method proposed to evaluate them is by the expert-based opinion of a multidisciplinary group of stakeholders. Each measure is presented to the experts group and they were asked to vote using a scoríng system from 0 to 10 for each category of co-benefits. The 0-10 scale was chosen as it is the most accepted system in behavioural science, due to its consistency, data diversity and provides a mid-point rate (Vall-Llosera et al., 2020).

The relevance of each co-benefit (Ürge-Vorsatz et al., 2014) is considered in a comparative manner between measures, establishing a matrix of weights of co-benefits related to each adaptation measure. This method also involves uncertainty but is less time-consuming and considers local knowledge.

***Table 5**. Example of a measure's co-benefits scoring results. Obtained from the ICARIA Adaptation Strategies Platform.*

Measure: Adding rain gardens before sewer inlet points	
Co-benefit	Weight
Economic	
Cost savings	3
Increase in resource efficiency	1
Increased property value	1
Job creation	0
Price reduction	0
Social	
Increased public space and accessibility	5
Noise abatement	0
Reduced health impacts/mortality	2
Reduced number of displaced property holders	0
Social cohesion and inclusion	5
Effective/uninterrupted water collection and security	0
Environmental	
Erosion control	0
Improved air quality	4
Improved biodiversity and ecosystems	8
Improved Heat Island Effect	0
Improved water quality	6
Improved water quantity (including aquifers)	2
Increased green area or green connectivity/diversity	8
Reduced environmental impacts	2
Reduced land contamination	2

The measures obtained from the projects CLARITY and RESCCUE were already scored in the previous process, and they were reviewed to update the scores with the new categorization of co-benefits presented in ICARIA. For the additional measures coming from the Project RECONNECT and the rest of the measures obtained from different sources, researchers involved in WP3 were asked to score the new measures through dedicated assessment sessions. Further dedicated sessions with experts will be conducted to update the co-benefit scores for the measures to be included. This ongoing process ensures that the co-benefits of all measures, both existing and future, are accurately evaluated and scored.

The evidence suggests that citizens are more likely to act on climate change, or more likely to support governments that act on climate change, if the wider co-benefits of those actions are emphasised (Bain et al. 2015). At the city level, the potential of co-benefits is particularly great as citizens can often witness the results of policy actions more directly in their daily lives (Floater et al., 2016). Several names for the same definition can be found in literature, such as win-win situations, life-cycle benefits, triple-win scenarios, consequential benefits, ancillary benefits, mutual benefit or, consequential life cycle impacts.

As a result of the preliminary assessment, a longlist of measures is selected to go under detailed assessment in the second stage. Following this first stage, the Adaptation Strategy Design Team will create a first engagement with stakeholders to involve them as part of the solution and obtain first hand information and low resources.

3. Detailed Assessment

The detailed assessment is the step to carry out when there is already a pre-selected number of measures, obtained from the preliminary assessment, since the final selection of measures and their prioritisation require a considerable amount of resources. In this subsection, a brief description of the methodology proposed for the detailed assessment is presented, including total estimation of costs, damages and risk reduction assessment, and analysis of Ecosystem Services.

a. Total Estimated Costs

In the previous subsection, the data requested for the cost-effectiveness assessment did not have to be accurate, it was more about a rough estimate to be able to compare between measures.

In section 3, an introduction to the proposed method was presented to estimate the unit cost for the measures. It follows the method to transfer the flood-depth damage curves studied in detail for Barcelona, to all Spanish municipalities, developed by Martinez-Gomariz et al. (2020) within RESCCUE project. The proposed method is based on site-specific costs estimation of the measures assessed, which needs t o consider the life cycle of the measure, as depicted in Figure 2, in order to address the following issues:

- The total cost of a proposed scheme over its lifetime, is composed of:
  - The likely capital cost
  - The likely operation and maintenance costs of a proposed scheme - annually or over the design life
- When and where costs might accrue to different stakeholders
- How costs of alternative green adaptation measures compare with one another or compare to a conventional measure
- How different elements of the measures contribute towards capital or maintenance costs and, therefore, how they might be optimised (Woods Ballard et al., 2015).

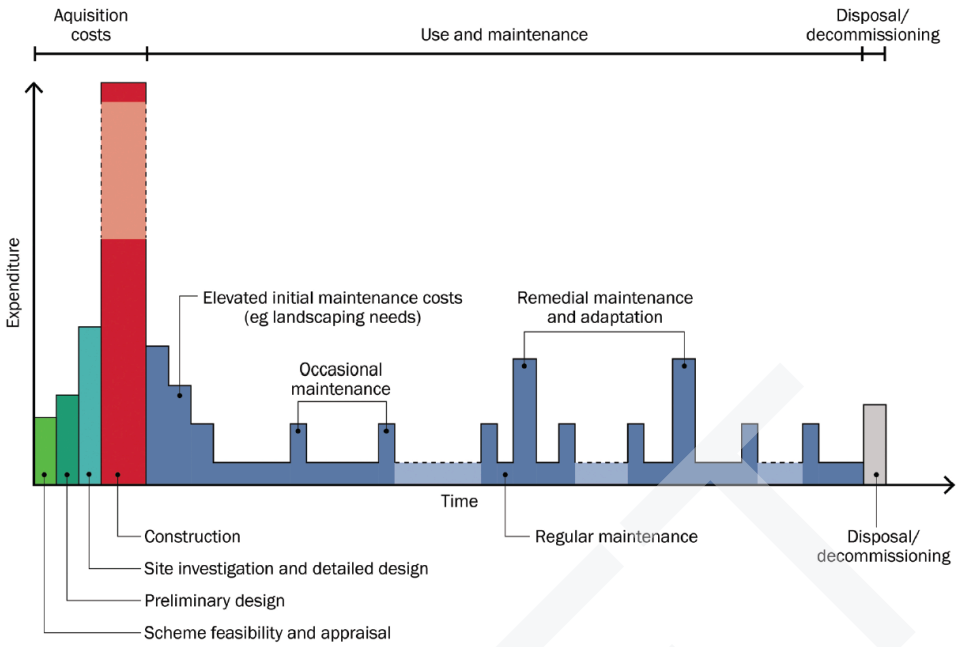


Figure 2. *Example of a measure's expenditure life cycle (Source: Woods Ballard et al., 2015).*

As can be seen, there are multiple challenges and considerations to estimate costs, such as the discount rate, the lifetime of the measure or the expected replacement cost, in particular to new adaptation measures whose details are not well known by design teams. The variation of the costs details among sites make it difficult to estimate the unit costs for all potential measures applications.

However, a potential solution can be using the cost curves methods to be assessed in detail for the study sites adaptation scenarios, and adapt them to different relevant regions in the European Union, using economic proxy indicators that reflect the difference in costs levels across Europe. They are indicators based on data that have to be available in both the study site and the rest of sites to be applied, so they can show the differences in economic value that can ultimately represent the total cost differences between the implementation of measures in different regions. The selected economic indicators used in the reference study focused on two main factors:

- Regional variability - addressed by different proxy indicators that can express the difference between regions in 3 key aspects:
    - the housing market (€/m2) - for the building value, regional average local revenues (€/year);
    - regional investments in tangible assets (€/year) and the average business revenues (€/year) - for the inventory value;
    - and average disposable income (€/year) - for the furniture and household value.
- Temporal variability - accounted for with the proxy of the OECD real GDP long-term forecast (%GDP/year)

This set of indicators seem to be valid for the difference in adaptation measures total costs. However, the data sources to transfer this approach from the Spanish to the European scale have to be verified. In addition, the proxies will be tested and if necessary, adapted to reflect the variation of measures' costs between EU regions.

Due to the high level of data requirements necessary to adapt the method to the new context (specific costs for selected measures, new regional transfers scale and transferred assets), unavailable at the moment, it was decided that the proposed adaptation of the Martinez-Gomariz et al (2020) measures costs transfer method is going to be carried out in the Adaptation Scenarios Assessment during T4.2 Trial implementation and assessment (starting in month 19). Once this exercise is carried out, and the methodology is adapted and validated, it will be included in the ICARIA Adaptation Platform, to be available to the public.

b. Damages and Risk Reduction Assessment

In regard to the assessment methodologies for the damage caused by the hazards as well as the damage and risk reduction given by the proposed measures, the proposed prioritisation methodology feeds from the outputs of other ICARIA deliverables.

In Deliverable D3.1 of Project ICARIA (Guerrero-Hidalga et al., 2024) there are several proposed methodologies to assess the tangible impacts for each relevant hazard, sector, asset (Table 3 & Table 4) and type of damage considered within the project ICARIA. A summary can be found in Table 6.

Table 6. *Summary of impact assessment methodologies (Retrieved from ICARIA D3.1).*

Hazard	Sector / Asset	Damage	Key parameter of the methodology	Trial
Flood	Properties	Direct	Depth-Damage curves & Estimated Annual Damage (EAD) function	AMB & SBG
	Economic sectors	Indirect	Input-Output Model /econometric regression	AMB
	Water Secto - WWTP	Direct / Indirect	Depth-Damage curves & EAD function	AMB
	Main Sewer	Direct	*Oceanographic range and level change intensity*-Damage curves & EAD function	AMB
	Electricity Sector	Direct	Fragility Curves and Intensity Duration Frequency Curves	SBG & AMB
		Indirect	Vulnerable points cascading effects evaluation starting from the direct impact assessment method	SBG
	Transport	Direct - Traffic	Combined flood velocity and depth impact assessment. Vehicular flow intensity (VFI)	SBG
		Direct - Railroads	Passenger flow intensity (PFI) and freight flow intensity (FFI) - Flood Depth	SBG & AMB

		Direct - Metro	Metro service disruption due to flooding - Flood Depth Ridership evacuation due to floodings - Flood Depth and Flood velocity	AMB
	Natural areas	Direct- agriculture	Depth - damage curves & EAD function	AMB
	Pedestrians	Direct	1D/2D urban drainage model + Pedestrian hazard classification	AMB & SBG
Drought	Economic sectors	Direct - aggregated economic sectors	Cobb douglas	SAR
		Indirect - all sectors	General equilibrium modelling	SAR
	Water sector	Direct	Drought risk assessment through the evaluation of the state of surface water reservoir	SAR
		Indirect - WWTP	Inflow-Operative extra cost curves	AMB
Heat Waves	Pedestrians	Direct	HWLEM simulations + UTCI indicator	SAR
	Electricity Sector	Direct	Electric demand oscillations related to Heatwave temperature variation.	SAR
		Indirect	Economic costs due to service disruption model	SAR
Forest Fire	Water Sector	Direct	Wildfire simulation from the WRF-FIRE	SAR
	Electricity Sector	Direct	Burned electricity network assets	SAR
Extreme Winds	Properties	Direct	CLIMADA Assessment model	SAR & SBG
	Electricity Sector	Direct	Fragility Curves of network components	SAR & SBG

Each impact assessment methodology proposed in D3.1 will be carried out during T4.2 and 4.3, for the different scenarios proposed- baseline, do nothing (business as usual, BAU) and different adaptation scenarios. The results will be used to continue with this third step of the prioritisation method of adaptation strategies.

The results of the scenarios from the aforementioned assessments will be published in the Project ICARIA's public website and made available to the users of the platform in order to use them during the execution of the prioritisation process. The future available references regarding the damage and risk reduction of adaptation measures, thus, will be limited to the results of the measures and scenarios selected in the Trials and Minitrials executed in WP4 "Case studies: implementation, replicability and exploitation".

c. Ecosystem Services

Ecosystem services, understood as the contributions to human welfare from the environment or ecosystems (Haynes-Young, R., & Potschin, M. (2017) ,UN SEEA, 2017), are key in the Adaptation Strategies evaluation, and therefore, a key aspect of ICARIA. Firstly, because for policy making, contributions to welfare have to be considered in investment decisions. Secondly, because most adaptation measures do

not have a direct or explicit monetary source of income, although they provide multiple benefits that refers to market and nonmarket goods and services deriving from the environment—for example health, visual amenities, and opportunities for outdoor recreation—that make these individuals better or worse off (UN SEEA, 2021).

The most extended classification for Ecosystem services is the one offered by CICES, that focus on final services, which are characterised by being the outputs of ecosystems (whether natural, semi-natural or highly modified) that most directly affect the well-being of people. (View Figure 3)

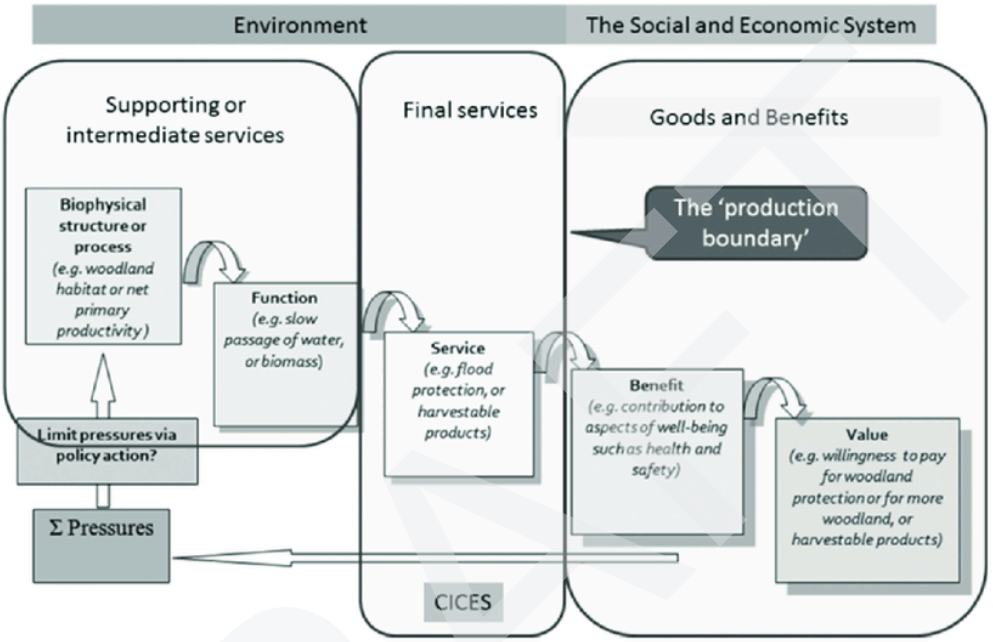


Figure 3. *The cascade model (Source: Potschin and Haines-Young, 2016b).*

The CICES classification for Ecosystem Services (ES) is as follows (UN SEEA, 2017):

- **Provisioning** - including all nutritional, non-nutritional material and energetic outputs from living systems as well as abiotic outputs (including water).
- **Regulation and maintenance**- All the ways in which living organisms can mediate or moderate the ambient environment that affects human health, safety or comfort, together with abiotic equivalents. Wetlands reducing flood risk is a clear example of this type of service.
- **Cultural** - All the non-material, and normally non-rival and non-consumptive, outputs of ecosystems (biotic and abiotic) that affect physical and mental states of people. Recreational activities in natural spaces are an example of cultural services.

Considering ecosystem services in adaptation strategies decisions, help regulators understand relevant trade offs or complementarities among different ecosystem services and with other costs and benefits. It also helps decision-makers avoid situations in which the value of specific ecosystem services are implicitly given no weight or disproportionate weight in an analysis.

There are many aspects of human welfare that can be affected by changes in ecosystem services. Some changes may result in positive impacts to human welfare, some may result in negative impacts, and some may result in transfers (e.g., offsetting increases and decreases in welfare for different groups of people). In

order to summarise these aspects of human welfare that can be affected by ecosystem service changes, the following list is presented (OIRA & OMB, 2023):

- Changes in mental health and physical health and safety can be connected to changes in aspects of the environment, often called environmental determinants of disease.
- Changes in property value can be tied to soil improvements, pollination or pest controls in farms, or changes in water bodies' pollution level can change home values.
- Changes in the production of goods and services are also tied to ecosystem services. Changes in the natural capital within the environment can alter production of fish, trees, or other resources that can be harvested for sale in a market or used for personal consumption.
- Changes in outdoor recreation, leisure, and other important forms of nature access and experiences are tied to ecosystem services. The types of experiences available and the quality of those experiences can be significantly affected by changes in water quality, forest health, natural views, and populations of species available for hunting, fishing, and viewing.
- Changes in non-use value can result from changes in the biodiversity of a forest. Individuals may simply value knowing that the natural asset—like that forest—exists, even if there are no plans for any current or future uses (i.e., existence value).
- Changes in culturally valued experiences, such as the opportunity for fulfilling a way of life, for example nature-related sports practitioners.

Therefore, there are different ways through which regulatory changes could affect the provision of ES. The value of an ES is influenced by changes in the amount and quality of service provided, the ability of people to access the service (physically and institutionally), the availability of substitute or complementary ecosystem or built goods or services, and people's preferences for a given amount or quality of that service. Therefore, the amount and importance of changes in ecosystem services caused by a regulation are a function of how the regulation changes the natural system, the built system, or the social system.

Changes in the natural system, such as the water cycle, affect the supply of an ecosystem service through the extent or quality of ecosystem elements, processes, or functions. For example, changes in hydrology that affect groundwater supplies and inflow to reservoirs often alter availability of irrigation water, affecting agricultural production (Congress Research Service, 2020),

Changes in the built system, affecting physical access to benefits (e.g., roads that provide access for recreation; dams that create reservoirs and reduce can alter how many and which people have access to ecosystem services- provision of energy for example, and how difficult or costly that access is to obtain.

Changes in the social system can also alter how many and which people have access to ecosystem services (by changing rights or norms related to access) and how much value people attribute to those services, or how much it costs to access them.

Due to the interconnectivity between systems, changes in one of these three systems can yield changes in other systems, sometimes resulting in feedback effects. All of these changes, alone or in combination, can affect human welfare that is associated with ecosystem services.

The recommended 5 steps for assessing ecosystem services from a policy-making perspective are:

- Step 1. Ensure that the scope (i.e. time and spatial scale) of the analysis is sufficiently broad to reflect important ecosystem services in the baseline and across alternative scenarios.
- Step 2. Describe the links between regulatory alternatives and likely changes to ecosystem services, and preliminarily determine which ecosystem services should be included in the analysis.

- Step 3. To the extent feasible and appropriate, monetize, quantify, or qualitatively describe the important effects of the regulatory alternatives on ecosystem services, and address uncertainty.
- Step 4. Aggregate estimated ecosystem-service changes and report them in a table, along with other benefits, costs, and transfers.
- Step 5. Incorporate monetized, quantified, and qualitatively described ecosystem-service benefits and costs into the assessment of the scenarios describing all benefits, costs, and transfers.

A detailed description of each step can be found in the reference document (Congress Research Service, 2020) and further details in the scientific publications released by the UN System for Environmental Economics Accounting (UN SEEA, 2021; UN SEEA 2017).

The project ICARIA has a strong focus on NBS, which is known to increase the provision of ES (EC, 2015). During the execution of Tasks T4.2 and T4.3 (4.2 Trial implementation and assessment and Replications and demos), an ES assessment will be conducted to estimate the welfare benefits provided by the different adaptation scenarios selected for each case study.

6. Platform design

1. Front End

The ICARIA Climate Adaptation platform (available at: ICARIAStrategies.eu) is a web-based application that is divided into two applications: A user front-end and a management back-end. There is an open area, a section that requires registration, to create tailored Strategies, apply the prioritisation method proposed and obtain downloadable graphs and tables. There is also an admin front-end to manage required changes on measures and other descriptive details.(View Figure 4)

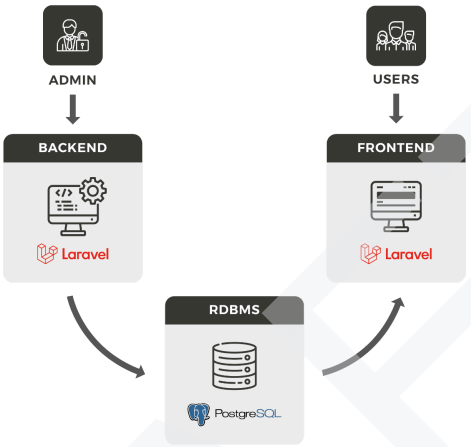


***Figure 4**. Scheme of the ICARIA climate adaptation strategies platform.*

The frontpage, publicly available, is formed by the Home, FAQs and measures database sections:

- **Project**: Home page describing Project ICARIA is presented in this section, including an introduction video as shown in Figure 5.

***Figure 5.** Screenshot of the Project description page.*

- **Measures**: A list of 228 adaptation measures is publicly available without any register required. A filter per several fields is provided for the user to easily find the desired measures (Figure 6). The filters available are climate hazard, key benefits, measure type, spatial scale, area type and target.

  It integrates a large set of measures, sourced from the aforementioned European (included in section 4 of this deliverable) projects that have researched previously Climate Change Adaptation, within the same framework of ICARIA (shown in Annex 1 & Table 4). It provides an open source

portfolio of adaptation measures with a search engine and filter to display the most relevant characteristics for measures, as described in Section 3, and reflected in Figure 6.

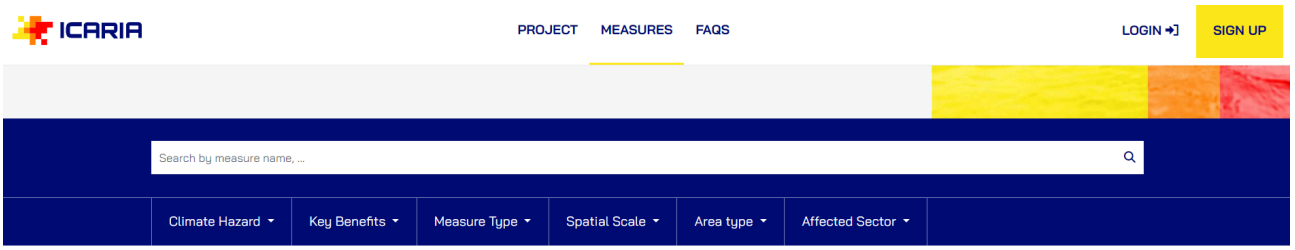


***Figure 6**. Filtering criteria for the different adaptation measures.*

The database used was Postgresql, a free and open-source relational database management system with extensibility and SQL compliance. It is a robust and quick system, and allows having JSON form fields.

After filtering the measures, a list with the measures formatted as informational cards is displayed allowing the user to access a more detailed view of the information related to each measure as shown in Figure 7. Below the general information, a table with the co-benefits is displayed, as shown in Figure 8. When a new measure is added to the platform, the criteria to evaluate the potential co-benefits is explained to the users, recommending multidisciplinary stakeholders assessment.

Figure 7. Specific Measure informative panel.

Co-Benefits

Climate actions are usually linked to co-benefits. In the report "Co-benefits of urban climate action : A framework for cities", the C40 Cities Climate Leadership Group (C40) aims to support cities to "understand value and then make the case for individual climate actions based on the environmental, economic and social costs and benefits" of those actions. Based on this report, a variety of co-benefits is provided here for each adaptation measure. A weight of 10 indicates that this co-benefit is highly relevant, while a 0 indicates that this co-benefit is not expected to occur.

Economic	Weight (1-10)
Cost savings	3
Increase resources efficiency	1
Increased property value	1
Job creation	
Prices reduction	

Social	Weight (1-10)
Effective/uninterrupted water collection and security	5
Increased public space and accesibility	
Noise abatement	
Reduced health impacts/mortality	2
Reduced number of propertyholders displayed	
Social cohesion and inclusion	5

Environmental	Weight (1-10)
Erosion control	
Improved air quality	4
Improved biodiversity and ecosystems	8
Improved Heat Island Effect	
Improved water quality	6
Improved water quantity (including aquifers)	2
Increased green area or green connectivity/diversity	8
Reduced environmental impacts	2
Reduced land contamination	2

CLOSE

Figure 8. Co-benefits scores panel.

FAQS: The most relevant characteristics of the platform are explained in this section in the form of questions and answers. There are citations to scientific evidence that the platform is based on and references to find further details to support the elaboration of an Adaptation Strategic Plan.

In addition, users can sign up to add new measures and design Adaptation Strategies, using the tool that guides users through the prioritisation method described above. Results are saved and can be retrieved to continue including new details, change variables and download the graphs and tables with the prioritisation results. To guide end-users through the prioritisation process, there is a sample strategy.

The initial step is characterising the site to be assessed, as depicted in Figure 9 below.

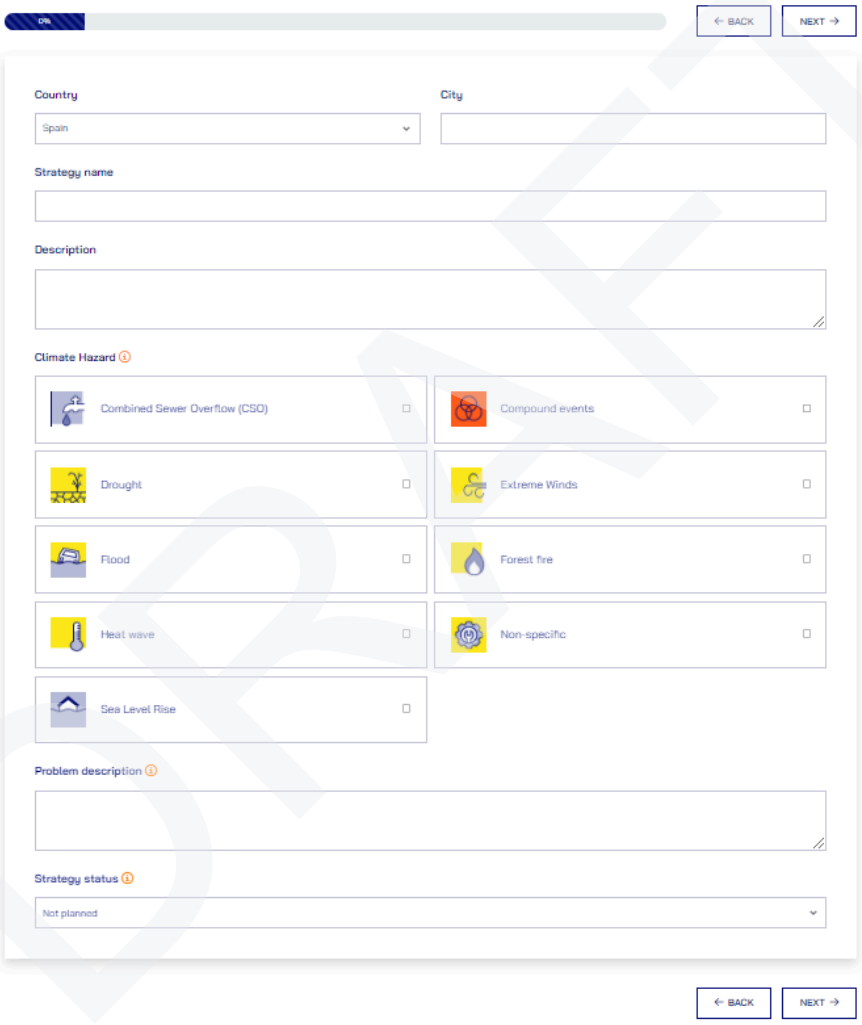


Figure 9. *Initial screen to create a new strategy.*

Then, the tool guides the users to select the existing measures related to the strategic adaptation objective that they are seeking for their regions. Measures can be filtered for each category (type, hazard targeted, etc.) by the users. Following, the effectiveness indicator has to be selected - for example for Heatwaves, an effectiveness indicator can be the temperature reduced (in Celsius, ºC), so the cost-effectiveness criterion will show the impact of the measures in terms of cost per Celsius degree

(€/ºC). Illustrative costs are requested by the tool, although considering the barriers expressed above, it is recommended to the users to provide a rough estimate that serves as figures relative to the other measures. Existing co-benefits of the selected measures are displayed and they can be adapted to the case study, if they differ from the initial scores proposed.

The weights assigned to each evaluation criterion can be adapted, as it is shown in Figure 10, in order to follow the relevance of each criterion for the Adaptation Strategy Design Team.

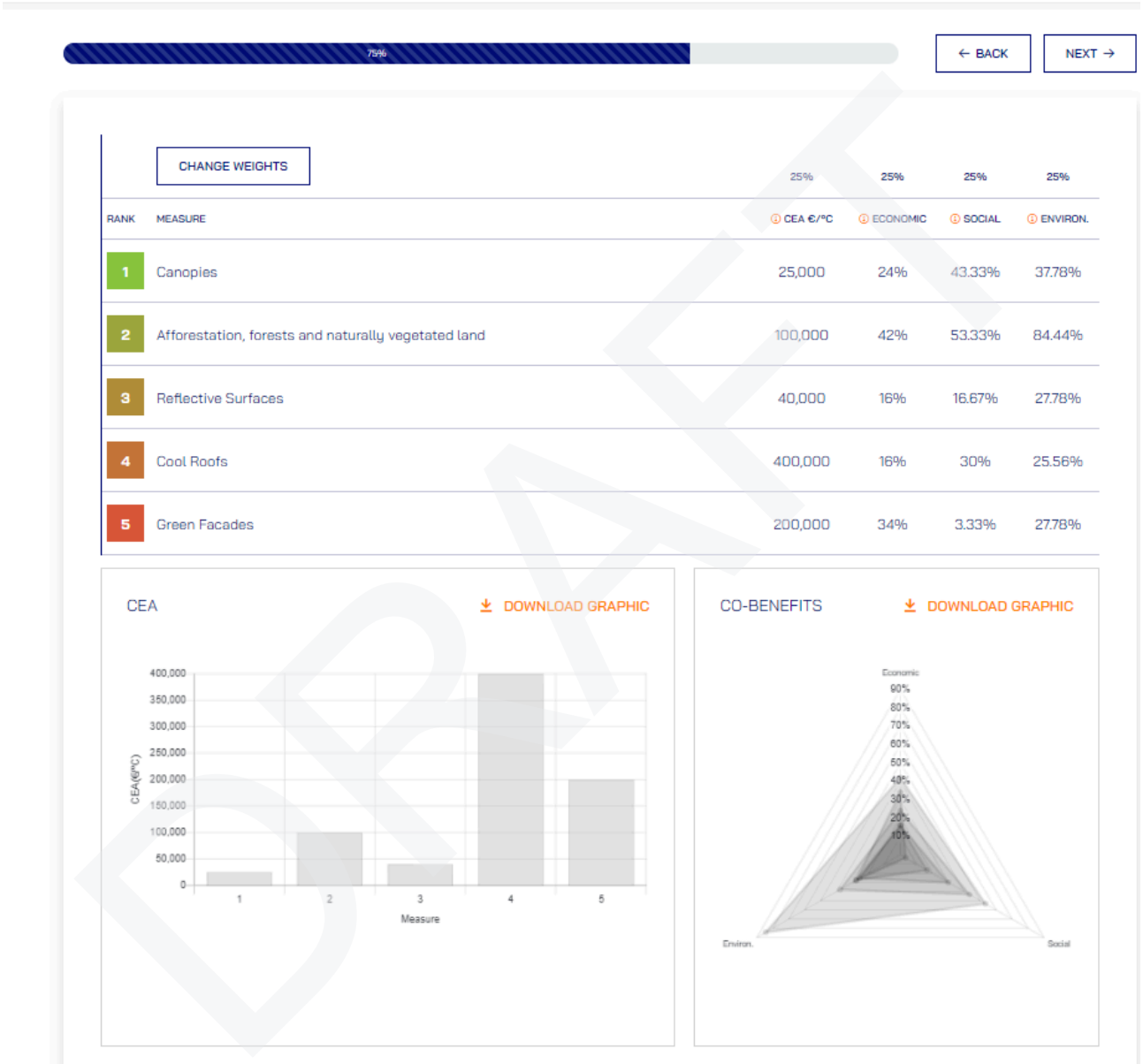


Figure 10. *Results of preliminary assessment for a Strategy to reduce Heat Waves impacts.*

Once the preliminary assessment has been completed, more prioritisation criteria can be added to give space to those case studies where deeper damage assessment studies have been carried out as in those within the ICARIA project (Barcelona, Salzburg, South Aegean Region) . Similarly, more adaptation scenarios can be added, so new sets of measures can be compared.

2. Back end

The back end is the website that allows the administrator to manage user profiles, characteristics and descriptions of the measures and strategies. Its access is only gained through a user and password access and it is stored in a private URL that is only known by the team members of D3.3.

Through the back end, there is the register of users, including their company and sector and the date of the creation of their profile. In addition, there is also a register of strategies and measures included in the database, that can be reviewed, modified or deleted. In the configuration section, administrators can modify the items that characterise the measures, in order to update new items if found necessary. The FAQs section can be updated as well.

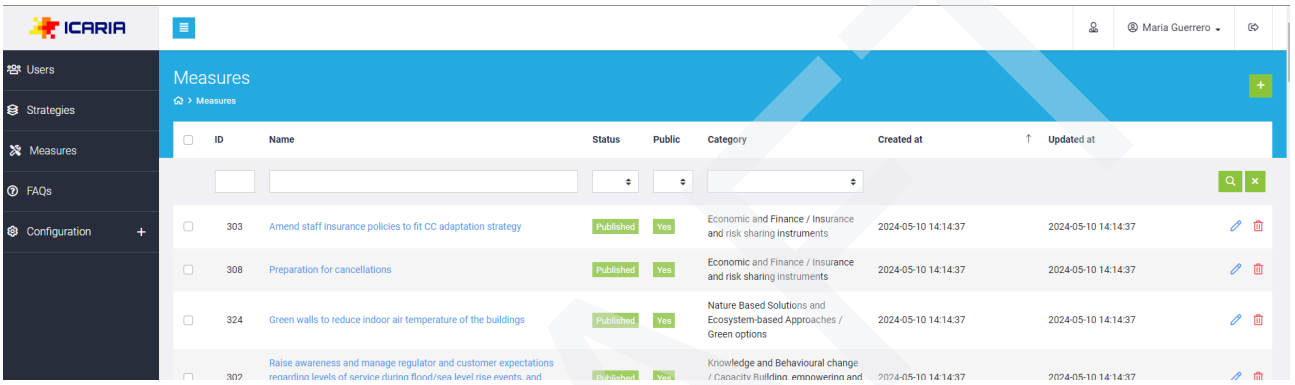


Figure 11. *Screenshot of the view of the administrator profile.*

Following, there is a summary statistics of the existing measures, presented by the number of measures' main and secondary hazards (Figure 11 and 12). Compared to the platforms previously developed, the ICARIA Climate Adaptation platform allows to select more than one targeted area, as it is understood that the same measure can target more than one hazards, as for example, a green roof can help to reduce the heatwave impacts as well as supports the reduction of the runoff caused by flood events.

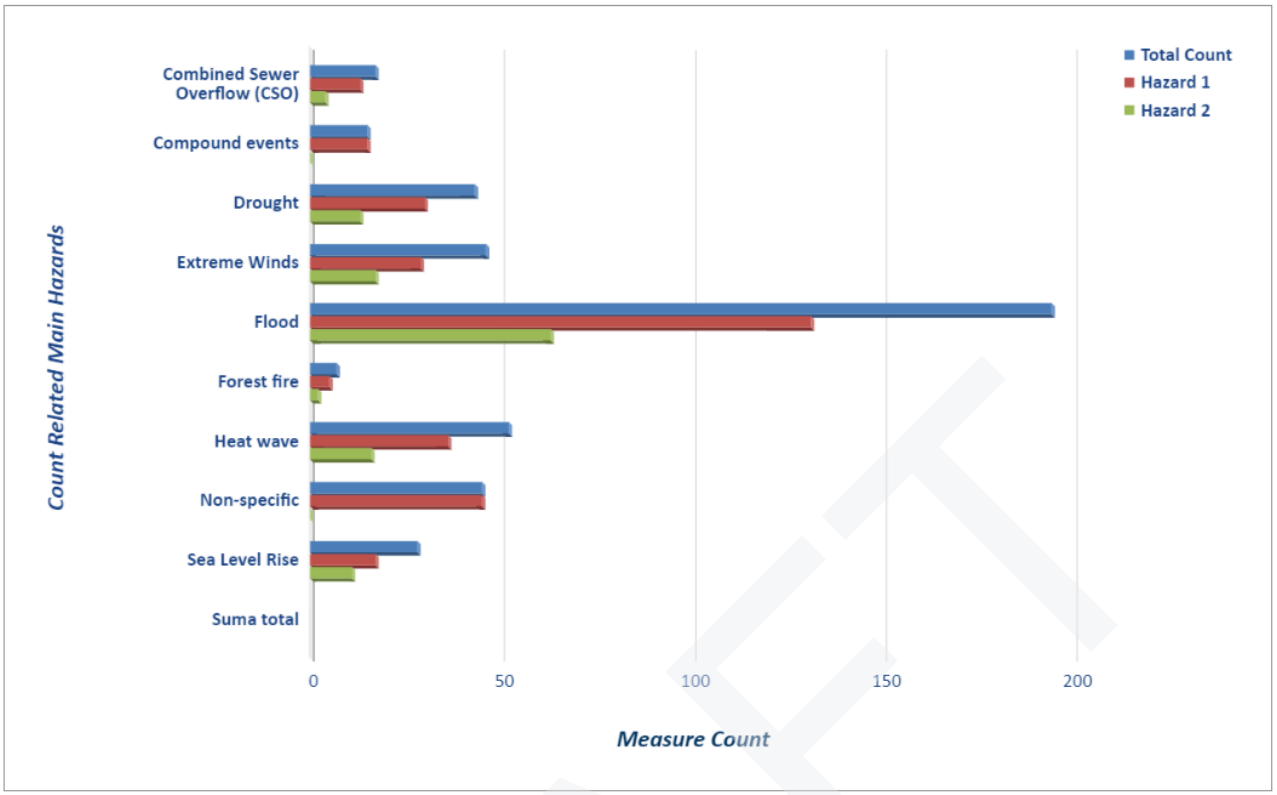


Figure 12. *Count and proportion of measures by role.*

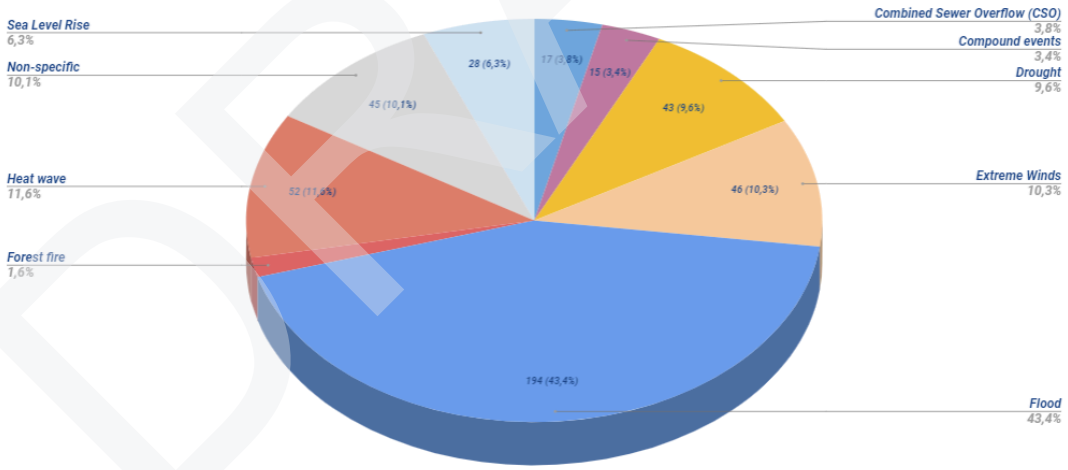


Figure 13. *Percentage and count of measures classified by hazard types.*

3. Connection to other platforms

The design of the ICARIA platform is inspired by existing platforms derived from previous EU-funded projects. Part of the projects mentioned in Annex 1 & Table 4, as sources of measures, were also sources of the platform design. They were RESCCUE Adaptation Strategies Platform, CLARITY Catalogue of adaptation options, and RECONNECT measure selector tool. In addition, a strong reference for Adaptation Strategies platform is the Climate-Adapt Platform, designed by the European Environmental Agency. In particular their Urban Climate Adaptation Tool offers a guide to urban planners to develop

their Adaptation Strategies, providing a series of references for methods and other EU-funded projects. All of them have served as a foundation to develop the new platform, improving the existing ones. This tool will be also connected with the Decision Support System (DSS) developed in Task 3.4 (deadline on month 33) and it will be allowed to extract the results obtained by the prioritisation tool and integrate them in the DSS as part of the multi-tool development that it is. At the time of writing the present deliverable, the DSS is under development, but in the conceptualization phase, the inputs form T3.3 have been considered, including the type of data, outputs and potential interaction with other tools, as represented in the following diagram of the DSS design (Figure 13).

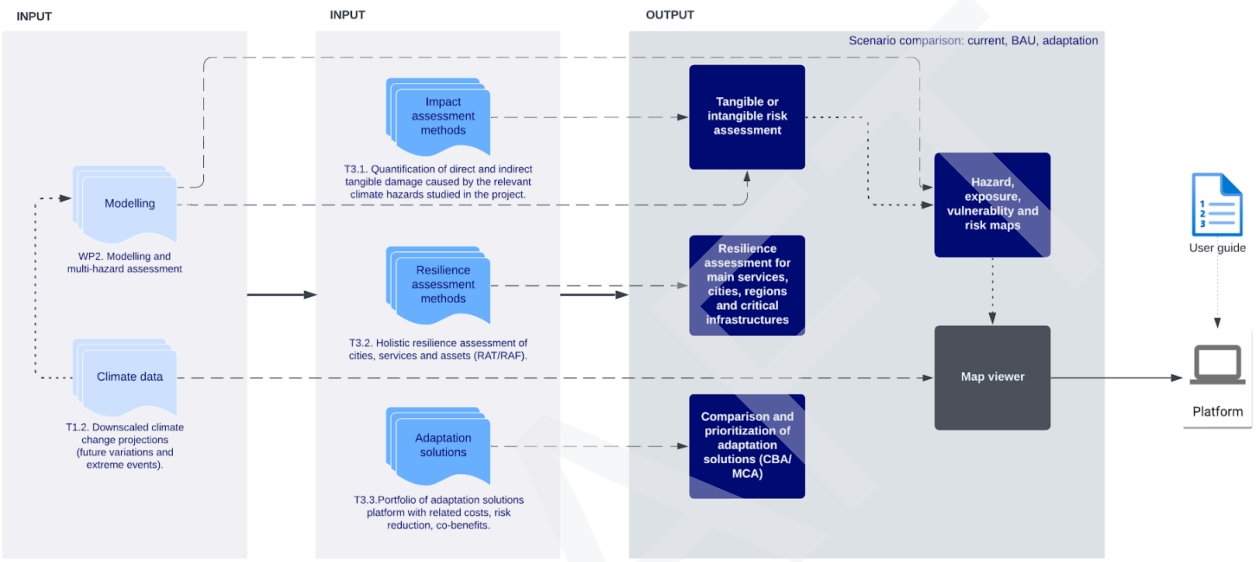


Figure 14. *Diagram of the DSS Design (retrieved from Draxis, T3.4).*

In addition, the project MAIA (Horizon Europe, No 101056935, 2022-2025), coordinated by BC3- Basque Center for Climate Change, aims to act as an impact multiplier of completed or ongoing climate research projects funded under the Horizon Europe and Horizon 2020 programmes. It is focused on establishing connections and fostering collaboration between different platforms and initiatives related to climate change adaptation and resilience. This includes sharing knowledge, resources and best practices across various stakeholders and projects.

In this sense, MAIA and ICARIA members will assess the capability of the Artificial Intelligence platform developed in MAIA to draft application descriptions in the form required for input in the ICARIA Portfolio of Solutions (including e.g. characterization of key benefits and co-benefits).

This assessment will be performed in cooperation with the MAIA team, during the final project year and at least involve:

1) Re-creating the definitions of three to six measures that are already described in a portfolio of solutions by AI and comparing the results.
2) Drafting the measure descriptions for additional three to six measures from documents describing such measures discovered on the web and assessing the usability of the results by the Portfolio editors.

This exercise will be done under the cooperation between EU projects activity, covered by the disseminating activities in WP5.

7. Example of the application of the prioritisation method for adaptation measures

In order to show how the proposed prioritisation method is applied in the ICARIA platform, this section presents an example to explain the step by step process summarised in Figure 1 and explained throughout this deliverable. The exemplification is carried out using a sample site, named Region X.

Step 1. Site Characterization

The Region X has been grappling with more frequent and severe extreme events over the past decade. In particular, the increasing frequency and intensity of extreme high temperatures, flood events and dry periods have caused damages to different economic sectors, such as the water, agriculture, electricity sectors and society, disrupting the regional economy, and threatening the wellbeing of its residents. To tackle this pressing problem, the regional authorities launched a thorough assessment to identify and implement an effective drought adaptation strategy.

As a starting point, the regional government asks for the formation of a Climate Change Adaptation Design Team, formed by a project manager in charge of designing the strategy for Region X, and a group of multidisciplinary experts that support the project execution. They include hydrologists, economists, agricultural engineers, public policy experts and civil engineers with expertise in NBS.

The first step is to review public documentation from Region X's arcade, with explicit policy objectives, strategies and assessment of any topic related to climate change hazards management, strategies and implementation plans, such as flood, drought, . Secondly, the design team checks with representatives of relevant sectors (agriculture, water, energy and health, among others), through workshops and interviews, their feedback on actual damages, risks and impacts perceived and registered in the past in their respective sectors and facilities. Finally, the team carries out a review exercise of the state-of-the-art in drought adaptation plans published in scientific articles and drought strategies established in other regions with similar characteristics, regarding climate, demography, hydrology and geomorphology.

After compiling all required documentation, a multidisciplinary stakeholder workshop is done to obtain consensus in the Strategic Objective of the Adaptation plan. The Design Team presents to all participants, from politicians to economic sectors and society representatives the main findings. It is decided that the first Climate Change hazard to target is drought, due to the pressing damages caused to the society and the economy, and the potential to reduce the wellbeing of the region if no action is taken. It can be introduced in the platform as is shown in Figure 14 below.

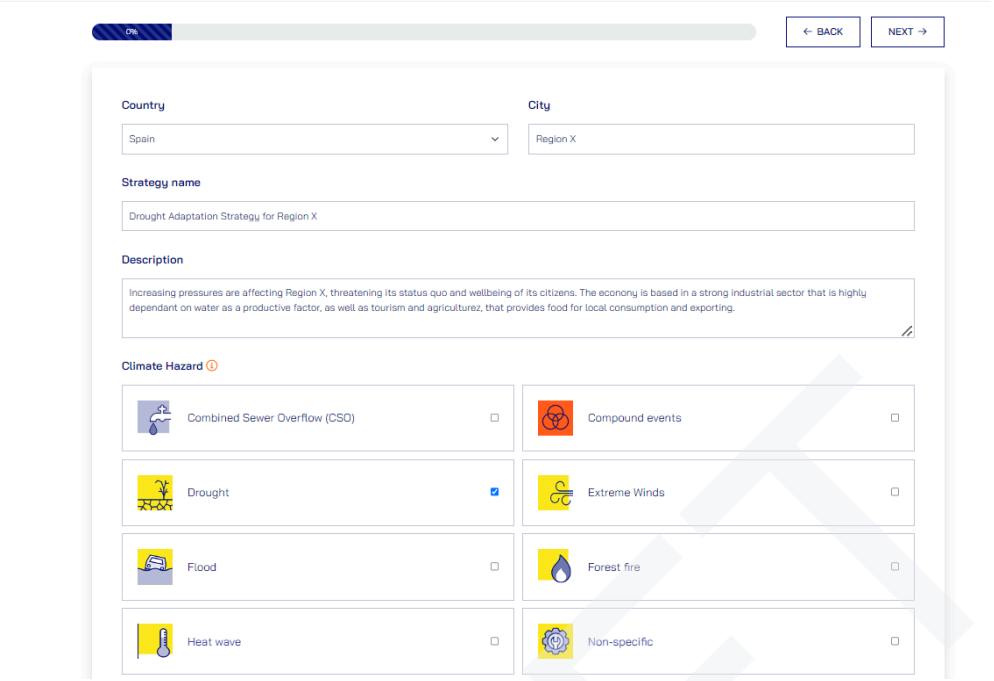


Figure 15. *Screenshot of the data entry for the creation of a Adaptation Strategy in the platform.*

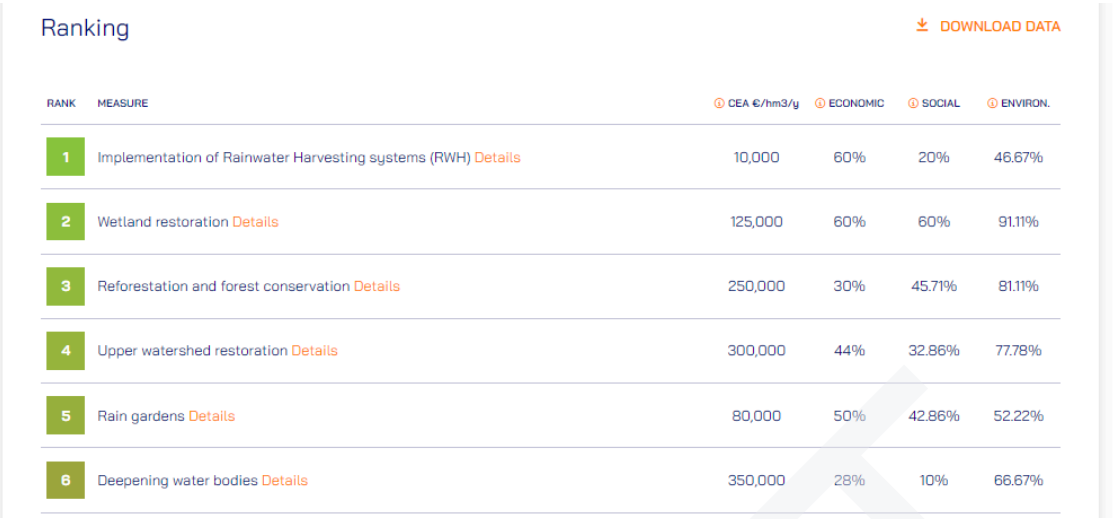
Using ICARIA Adaptation Strategies Platform, the Design Team selects all available measures in the platform, compiling a list of 25 potential drought adaptation measures. The measures selected include actions in the fields of governance, engineering, economy, ecology, knowledge and behavioural change. The 25 measures go to the second step, to be assessed preliminarily, which will allow to down-select them to the ones with more potential effectiveness and positive impact in Region X.

Step 2. Preliminary assessment

The preliminary assessment aims to select the most viable options from the initial list, using a moderate amount of resources for the exercise. The Design Team evaluates each measure on the following criteria: cost-effectiveness and environmental, social and economic co-benefits. Following the methodological recommendations from section 5, the expected total cost for the selected measures in Region X is estimated, using references from previous research projects. The effectiveness indicator selected in cubic hectometers per year.

The measures are presented by the Design Team to relevant stakeholders in workshops dedicated to the assessment of the co-benefits of each measures. There is a scoring system, from 1 to 10 to each of the specific parameters selected to define the three co-benefits categories (specified in section 3).

A sample of the results is presented in the following capture from the ICARIA Adaptation Strategies platform. The top 6 measures of the preliminary ranking are displayed, with information about the CEA and the qualitative co-benefits assessment.



Ranking

DOWNLOAD DATA

RANK	MEASURE	CEA €/hm3/y	ECONOMIC	SOCIAL	ENVIRON.
1	Implementation of Rainwater Harvesting systems (RWH) Details	10,000	60%	20%	46.67%
2	Wetland restoration Details	125,000	60%	60%	91.11%
3	Reforestation and forest conservation Details	250,000	30%	45.71%	81.11%
4	Upper watershed restoration Details	300,000	44%	32.86%	77.78%
5	Rain gardens Details	80,000	50%	42.86%	52.22%
6	Deepening water bodies Details	350,000	28%	10%	66.67%

Figure 16. *Sample of the preliminary ranking of measures obtained from the ICARIA Adaptation Strategies Platform.*

Following the preliminary assessment, the list with the preliminary results was shared with the stakeholder group, in order to narrow down the number of measures. Following the prioritisation method, 15 measures were selected to be assessed in detail for the Drought Adaptation Plan in Region X.

Step 3. Detailed Assessment

The next phase involves a detailed assessment to thoroughly understand the damage reduction and welfare impact of the 15 downselected measures. The Design Team identifies advanced assessment methods from ICARIA's D3.1, which require high expertise to carry out.

Two scenarios are designed, dividing the 15 measures in 3 groups, one with more physical and grey infrastructure measures, known as classical engineering, one scenario more oriented to NBS and one focused on governance and behavioural change. This will allow to assess and compare three different policy styles.

Figure 17. *Sample of scenarios of measures designed in the ICARIA Adaptation Strategies Platform.*

Once the damage modelling of drought under the 4 scenarios in Region X is assessed (business as usual (BAU), classical engineering, NBS and governance), the results can be added to the platform as new prioritisation criteria in the Strategy. This will provide downloadable graphs and visual prioritisation lists of the scenarios and single measures if needed, as shown in the following figure.

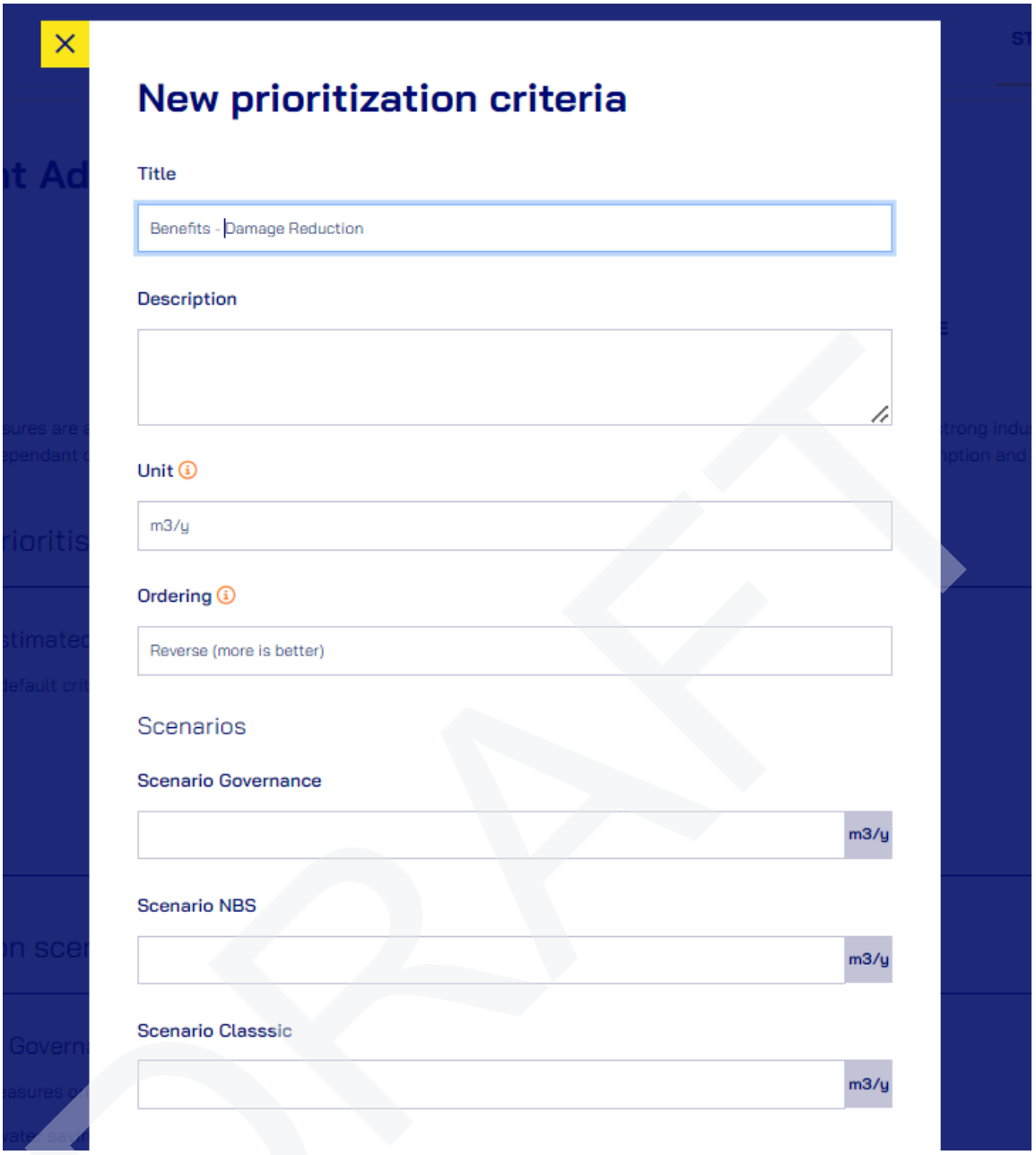


Figure 18. *Sample of new prioritisation criteria that can be included in the scenarios comparison in the ICARIA Adaptation Strategies Platform.*

The last step is the **Cost-Benefit Analysis** (CBA). Economic evaluations are conducted to compare the long term implementation and maintenance costs against the expected benefits, particularly in terms of reduced damages, enhanced community resilience and welfare variations provided by the changes in ecosystem services provision levels. An example of the summarised results of a CBA are displayed. Please note that this is just an example and prices do not represent any real scenario. Numerical values provided next are just a numerical exemplification to show future steps in the development of these tools, at the moment the ICARIA platform only provides a qualitative category for each measure as already mentioned.

Figure 19. *Sample of CBA potential results using the MCA prioritisation tool included in the ICARIA Adaptation Strategies Platform.*

Throughout the process, it is still recommended to maintain continuous engagement with regional and local communities and other civil society stakeholders. Regular consultations ensure that the selected measures are aligned with community needs and preferences, fostering a sense of ownership and cooperation among residents.

The detailed assessment reveals that each strategic scenario of measures offers different benefits at different costs, and the decision makers should use the results to take action in the implementation of measures that alleviate the impacts of drought in Region X.

In conclusion, the comprehensive assessment proposed in ICARIA for Region X highlights the importance of preliminary evaluations to assess all potentially relevant measures without using excessive resources, and the detailed assessment to study with the required detail the top measures. It has highlighted the need for stakeholder engagement in crafting a robust adaptation strategy. By combining advanced analytical methods with active community engagement, Region X is better prepared to build a safer, more resilient future in the face of increasing climate change risks.

8. Conclusions

As part of the ICARIA's objectives, the platform of adaptation solutions presented in this deliverable, offers a compilation of the latest advances in adaptation measures, collected from related EU-financed Projects, scientific publications, and other relevant official documents. The portfolio of solution counts with more than 200 measures covering a wide range of hazards, measure types, and different pertinent classification criteria to facilitate the selection and assessment of measures by end users. The existing reference adaptation solution tools, coming from projects such as RECONNECT, RESCCUE and CLARITY, have served to offer an improved version of them, with a larger number of measures, better classification, wider scope and new functionalities, such as the downloadable visualisation and connection trough AI to other platforms and the final ICARIA DSS.

Expected end users of the platform are the denominated Adaptation Strategies Design Teams and policy makers seeking details on potential adaptation strategies, or researchers looking for potential measures to assess in a research context. As mentioned in the web platform, the Project ICARIA has an applied approach, and offers additional resources that facilitate the design and implementation of their Strategic Adaptation Plans. Therefore, it is expected that the Adaptation Platform serves as a gateway to the rest of Adaptation tools offered by the project. It has been emphasised the relevance of stakeholders and community engagement to develop strategies that really suit the adaptation and socioeconomic sustainable development needs of the regions. Their inputs must be taken to succeed from the design phase.

The prioritisation method will be tested in Tasks T4.2 and T4.3 during the application of the methodologies presented in D3.1 to assess impacts under different scenarios (business as usual and adaptation scenarios) in the three case studies. The data outcomes obtained from these tasks will feed the platform with representative figures that will serve as reference for replication sites that are not able to carry out impacts and risks studies with the same level of detail.

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Annex 1: Data Management Statement

Dataset name	Format	Size	Owner and re-use conditions	Potential Utility within and outside ICARIA	Unique ID
CLARITY	PDF	19,8 Mb	CLARITY Consortium / Open Source / **D3.3 Annex Adaptation measures**	Collection of adaptation measure to various climate hazard events	-
RECONNECT measures	Excel Datasheet	32 Kb	RECONNECT Consortium / Open Source	Collection of adaptation measure to various climate hazard events	-
Adaptation measures RESCCUE	Excel Datasheet	189 Kb	RESCCUE Consortium / Open Source	Collection of adaptation measure to flood related events	-

Table A1. *Data used in preparation of ICARIA Deliverable D3.3*

Dataset name	Format	Size	Owner and re-use conditions	Potential Utility within and outside ICARIA	Unique ID
ICARIA D3.3 Measures	Excel Datasheet	271 Kb	ICARIA Consortium	Compilation of Measures employed in ICARIA Web Platform as a data set	-

Table A2. *Data produced in preparation of ICARIA Deliverable D3.3*

ICARIA
Improving climate resilience of critical assets

More info: **www.icaria-project.eu**

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