ICARIA
Improving climate resilience of critical assets

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D3.2 Holistic resilience methods

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D3.2: Holistic resilience methods

Summary

The present Deliverable 3.2 of project ICARIA is the main outcome of Task 3.2 (Holistic resilience methods). Its main objective is to provide a method for the holistic resilience assessment and the resilience assessment of critical assets and entities, comprising a detailed assessment for several urban services and a focused assessment for critical infrastructure.

Based on approaches developed in previous projects, the ICARIA methods are expanded to include all climate hazards studied in ICARIA, at asset and service level, at both urban and regional scale, and to specifically assess natural areas and critical assets. The tools that support the assessments are provided in the ICARIA Resilience Platform. The frameworks and the tools will be tested in following ICARIA activities with the case studies.

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List of Acronyms and Abbreviations

CER	Critical Entities Resilience Directive (Directive 2022/2557)
DR	Deliverable Responsible
DSS	Decision Support System
EC	European Commission
EU	European Union
EU-CIRCLE	Pan-European framework for strengthening Critical Infrastructure resilience to climate change – H2020 Project
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
RAF	Resilience Assessment Framework (holistic assessment)
RAT	Resilience Assessment Tool (critical infrastructure assessment)
RESCCUE	RESilience to cope with Climate Change in Urban arEas - a multisectorial approach focusing on water – H2020 Project
SSO	Specific Subobjective
SSP	Shared Socioeconomic Pathways
WP	Work Package

Executive summary

A resilience assessment is essential to identify the real needs for improving urban resilience, as well as the efficiency and effectiveness of planned or implemented actions. Therefore, an assessment of the current and expected future state of resilience provides a basis for cities, metropolitan areas, and regions to know where they stand, to identify strengths and weaknesses, and to support decisions on policies, actions, and measures to be adopted. The assessment supports planning for the short, medium, and long term and the evaluation of progress in between. Urban and rural areas are dynamic systems with changing risks and, in line with the principle of continuous improvement (ISO 9001, 2015), it is important that regular assessments of their resilience are carried out and that tools are available. Climate change is an additional and growing challenge that needs to be considered when assessing resilience.

This document is Deliverable D3.2 of Work Package 3 of the ICARIA project. The overall objective of WP3 is to support impact assessment within ICARIA and to develop decision support methods and tools. The specific objectives of this WP are to develop assessment frameworks and to design and develop a decision support system (DSS). A resilience assessment method was developed in Task T3.2 and D3.2 reports on this activity.

This deliverable focuses on the purpose, scope, and assumptions of the resilience assessment method. It presents the structure of the method and of the frameworks. Two frameworks are provided, the ICARIA RAF (Resilience Assessment Framework) for a holistic assessment and, as a starting point, the ICARIA RAT (Resilience Assessment Tool) for a specific assessment of critical infrastructure and critical entities. Their concepts, detailed structure, tools, and outputs are described in this deliverable. Details are given on data input (namely data from modelling activities) and data output (namely to the decision support system). User guidance is provided for the successful implementation of a resilience assessment.

D3.2 consists of this written document and the ICARIA Resilience Assessment Platform, the shell that hosts the web-based resilience assessment tools that enable the use of the developed method. Within this platform there are two applications, the ICARIA RAF App and the ICARIA RAT tool.

1 Introduction

1.1 Project ICARIA

The number of climate-related disasters has been steadily increasing over the last two decades, and climate change projections suggest that this trend could worsen dramatically in the medium and long term. It is estimated that between 2000 and 2019, 7,348 natural hazard related disasters occurred worldwide, causing losses of US$ 2.97 trillion and affecting 4 billion people (CRED, 2020). These figures represent a sharp increase in the number of recorded catastrophes compared with the previous twenty years. Much of this increase is due to a significant rise in the number of climate-related disasters (heat waves, droughts, floods, etc.), including combined events, whose frequency is increasing dramatically because of climate change and associated global warming. Looking ahead, by mid-century, the world will have lost around 10 per cent of its total economic value to climate change if temperature rises remain on their current trajectory and both the Paris Agreement and the 2050 net-zero emissions target are not met (WEF, 2021).

In this context, the overall objective of the ICARIA project is to promote the definition and use of a comprehensive asset-level modelling framework to achieve a better understanding of the climate-related impacts of complex, compound and cascading disasters and the possible risk reduction through appropriate, sustainable, and cost-effective adaptation solutions.

This project is particularly concerned with critical assets and infrastructures that are vulnerable to climate change, in the sense that its local effects can lead to significant increases in the cost of potential losses from unplanned failures and maintenance - unless efforts are made to make these assets more resilient. ICARIA aims to understand how the future climate could affect the lifecycle costs of these assets over the coming decades and to ensure that, where possible, climate proofing investments are made in advance in the form of adaptation measures to deal with these changes.

To achieve this objective, ICARIA has identified 7 Strategic Sub Objectives (SSO), each of which is linked to one or more work packages. They have been grouped into different categories: scientific, corresponding to research activities for advances beyond the state of the art (SSO1, SSO2, SSO3, SSO4, SO5); technological, proposing 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 dissemination and exploitation, aiming to bring ICARIA results to a wider audience and number of regions and communities to maximise the impact of the project (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 modelling 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 Objectives of the deliverable

This document corresponds to Deliverable D3.2 of Work Package 3 (WP3) - Impact evaluation and Decision Support System. The general objective of WP3 is to support the impact assessment in the scope of ICARIA and to develop decision support methods and tools. The specific objectives of this WP are the development of assessment frameworks and the conceptualization, development, and improvement of a Decision Support System (DSS).

Within the work of task T3.2 in WP3, this deliverable will specifically contribute to the SS05 - Better assessment of holistic resilience and climate-related impacts for current and future scenarios. In task T3.2 a method for resilience assessment was developed. D3.2 reports the method developed and the platform created for its implementation.

The ICARIA method for resilience assessment integrated existing methods and tools from the RESCCUE (Cardoso et al., 2020) and EU-Circle (Katopodis et al., 2018) projects, as a project's commitment, and promoted their improvement and enhancement. The previous approaches were revised, combined, and expanded to the scope of ICARIA, regarding climate hazards, geographic scale, and themes. The ICARIA method for resilience assessment now includes: all climate hazards studied in the project, namely flooding (rain induced, fluvial, and coastal), drought, heat wave, cold wave, windstorm, and forest fire; considers both urban and regional scales; addresses people, buildings, the urbanized and natural areas, and various urban services and assets. It also provides both a holistic assessment and an assessment focused on critical infrastructure.

D3.2 consists of this written document, which reports the assessment frameworks and provides guidance for users, and of the ICARIA Resilience Assessment Platform, the shell that hosts the web-based applications for resilience assessment, enabling the use of the developed method. In this platform, two applications are available, the ICARIA RAF App (the ICARIA Resilience Assessment Framework app), for a holistic assessment, and the ICARIA RAT (the Resilience Assessment Tool), for a specific assessment of critical infrastructures.

This deliverable will be used within the project to support the resilience assessment of the case studies (i.e. Barcelona Metropolitan Area, South Aegean Region, and Salzburg Region). In a first iteration, it will be used in T3.5 (the WP3 laboratory task) to test and validate its usefulness and appropriateness, in particular to ensure that the methods and tools are robust and ready for implementation in WP4, and that data are available for at least a preliminary assessment. Following this application in T3.5, refinements may be made and reported in deliverable D3.4.

This deliverable can also be used by any region, city, service, or organization intending to undertake a full-scale or tailored resilience assessment to climate change, within the scope of ICARIA.

1.3 Structure of the document

After this introduction, the structure of the deliverable is organized in sections as follows.

Section 2 presents a literature review. Section 3 focuses on the assessment method's main purpose, scope, and assumptions, the general structure of the method and frameworks and their connections. Section 4 presents an overview of the ICARIA RAF and of the RAT, describing their concepts, detailed structure, as well as the results provided. Section 5 describes the Resilience Assessment Platform, the ICARIA RAF App and the RAT, the tools to facilitate the assessment. Section 6 provides an approach for implementation of a resilience assessment with user guidance.

Annex A presents a data management statement.

In Annex B a detailed description of the ICARIA RAF is provided, which is complemented by Annex C, that presents the data sheets for the new metrics for the Natural Areas, by Annex D, showing the list of metrics included in the new filters, and by Annex E, listing the metrics in the whole ICARIA RAF framework that were revised or are new.

2 Literature review

2.1 Resilience assessment relevance

There is an inherent relationship between climate change and nature. If one is disturbed, the other will be affected. The interactions between climate change impacts, food security, natural resource use and biodiversity loss will increase the impact of natural disasters, accelerate the degradation of ecosystems, threaten food supplies and the stability of communities in climate-vulnerable economies, and limit progress on climate change mitigation unless significant policy or investment changes are made (WEF, 2023). The effects of climate change are intensifying and increasing the frequency of hazardous events worldwide. These effects, combined with other risks and threats such as conflicts, epidemics, or economic crises, create compound crises with serious human, economic and environmental consequences (UNDRR, 2023). Therefore, as reactive responses may lead to inappropriate decisions to ensure long-term resilience, it is essential to move from reactive responses to prevention, to ensure that sources of risk are properly addressed and to minimize the consequences of inappropriate decisions.

The concept of resilience has evolved over time and across disciplines (Patel and Nosal, 2016, Sharifi, 2016). For example, resilience refers to:

(i) the ability of human settlements to withstand, quickly recover from, and adapt to a full range of plausible hazards, and
(ii) the ability to reduce risk and damage from disasters and long-term disruptive events and to quickly bounce back to a stable state. Besides addressing disaster risk reduction, resilience includes changes in circumstances (RESCCUE, UN-Habitat, 2018; UNDRR, 2017a,b; ARUP, 2015);
(iii) the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt, transform and recover from the effects of hazards in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management (UNDRR, 2017a,b);
(iv) the ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions; includes the ability to withstand and recover from deliberate attacks, accidents or naturally occurring threats or incidents (NIPP, 2013);
(v) the ability to absorb and adapt to a changing environment. In the context of urban resilience, this is determined by the collective capacity of each component of an urban system to anticipate, prepare for and respond to threats and opportunities (ISO 22300:2021);
(vi) the ability of individuals, households, communities, cities, institutions, systems and societies to prevent, resist, absorb, adapt, respond and recover positively, efficiently and effectively in the face of a wide range of risks, while maintaining an acceptable level of functioning and without compromising long-term prospects for sustainable development, peace and security, human rights and well-being for all (UN, 2020).

Urban regions and larger areas are complex, fragile, and constantly changing. They have interacting and interdependent strategic services and assets, requiring the involvement of a variety of stakeholders who manage these areas. In addition, the significant impacts of climate dynamics (such as intense precipitation events, sea level rise, droughts, or heat waves) on strategic services, people, the natural environment and the economy, the exacerbation of current conditions and the emergence of new hazards or risk drivers need to be

considered. The increasing interdependence of ecosystems and humanity reinforces the need to increase the resilience of all systems (UNDRR, 2023).

The World Health Organization (WHO, 2009), in its five key conclusions of the Vision 2030 study, states that systematic resilience assessments to climate change of all utilities and rural water and sanitation programmes are needed, along with simple tools that can be used in different settings, such as for rapid assessment of the vulnerability of water utilities to climate change. To promote resilience, governments, the private sector, the civil sector, and civil society need to better understand how actions or inactions that promote social well-being (people), ecological or biosphere well-being (planet) and economic well-being (prosperity) interact to build or undermine resilience (UNDRR, 2023).

Strengthening resilience is critical to withstand and respond to shocks and to achieve a country's development objectives (UN, 2020). Building resilience helps to strengthen physical assets and create more sustainable systems. Understanding how to identify and measure vulnerabilities to resilience, and how to design interventions that meet current and future needs, is essential for sustainable development. These challenges require an integrated and forward-looking approach to resilient and sustainable urban development, considering the interdependencies between systems and the perceptions and needs of stakeholders and citizens. To achieve this, several long-term agendas have been adopted as part of the UN Agenda 2030 for Sustainable Development, such as the Sendai Framework for Disaster Risk Reduction 2015-2030, the Sustainable Development Goals, the New Urban Agenda, and the Paris Agreement (Panda, 2018), all of which consider assessment steps to track implementation (UN-GA, 2016).

Assessing current and future resilience is the basis for cities and regions to know where they stand, to support decisions on strategies, actions, and measures to be adopted, to plan in the long, medium, and short term, and to evaluate progress (Sharifi, 2016; Cardoso et al., 2020). In order to assess resilience, it is necessary to consider cities and regions as multidimensional entities, and therefore urban resilience needs to take into account multidisciplinary perspectives. In addition, resilience is determined by multiple interacting systems and their relationships. For this reason, resilience also depends on the overall performance and capacity of its systems, not just on their ability to cope with specific natural hazards or to adapt specific areas to the impacts of climate change (Brugmann, 2012).

Recognition of the relevance of resilience has led to the development of various tools and frameworks for assessing resilience, developed by different stakeholders in different disciplines, such as those by ICLEI 2010, UN-Habitat CRPT 2013, Rockefeller&Arup 2014, World Bank 2015, UNDRR 2015, EPA 2017, among others (Patel and Nosal, 2016; UNDRR, 2017a,b; Summers et al., 2017; EPA, 2017). Some were developed within projects funded by the European Union, e.g, the EU-Circle Resilience Assessment Tool (Katopodis et al., 2018), the RESCCUE Resilience assessment Framework (Cardoso et al., 2020), or Resiloc (Delprato et al., 2022), each with their focus, structure, and method for assessing resilience.

Resilience assessment tools provide decision support to managers, planners and decision makers in regions, cities, and urban services by identifying aspects that need improvement, prioritising interventions, identifying resilience strategies, developing resilience action plans, and predicting and monitoring the effectiveness and efficiency of their implementation (Sharifi, 2016, Cardoso et al., 2018). The development and implementation of the assessment process in collaboration with different stakeholders promotes their empowerment and enhance their role in decision making process (Cox and Hamlen, 2014), as well as in the implementation of improvement solutions.

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) (IPCC, 2022) highlights the importance of metrics for resilience assessment that go beyond measuring the impact reduction of mitigation actions, to capture their reduction of Greenhouse Gases (GHG) emissions and the related social, environmental, and economic co-benefits. AR6 uses as input climate models that apply the Shared Socioeconomic Pathways (SSPs). The SSPs translate how global society, demographics and economics might change over the next century. They are also being used to explore how societal choices will affect GHG emissions and, therefore, how the climate goals of the Paris Agreement could be met. The SSPs were initially published in 2016 but are only now beginning to be used in climate modelling (IPCC, 2023). Behavioural aspects are strictly connected with the time history in scenario analysis and resilience assessment in ICARIA (Turchi et al., 2023). Behavioural medium to long-term trends at the community level are associated with the different SSPs, potentially affecting the resilience capacity of critical assets and services. On the other hand, short-term "reactive" behaviours also affect exposure and vulnerability and the coping capacity (e.g. not following an evacuation order, spreading alarming messages, etc.). In ICARIA, the scenario analysis takes into account the socio-economic aspect also by considering compound events; these result from the combination of two or more natural events (causally correlated or not), which may i) occur simultaneously (i.e. compound coincident), ii) occur successively (i.e. compound consecutive), or iii) be combined with the evolutionary trends represented by the Shared Socioeconomic Pathways (SSPs) (Turchi et al., 2023).

As mentioned, climate change and nature are inextricably linked. Natural areas, both native and constructed blue-green infrastructure, either in a large or small scale, consist of natural and semi-natural systems within a given region. Several studies have highlighted the mitigation effect of climate change impacts due to natural areas. These studies are either focused on the urban heat island mitigation and stormwater management as potential benefits (Almaaitah et al., 2021), or they provide a more holistic approach. In the last case, the available studies detail the multiple ecosystem services, the socio-economic challenges (Beceiro et al., 2020; Sarabi et al., 2019; Cardinali et al., 2023), or embrace other contexts, such as earthquakes, fires, or hurricanes (EC, 2021a).

Natural areas in a region may comprise large reserves, forests, urban parks, and urban nature-based solutions (NBS) such as infiltration basins, green roofs and walls, vegetated swales, infiltration trenches, or porous pavements. NBS are man-made solutions based on natural processes aiming to solve problems people face, responding to the environmental, social and health concerns and hazards in the short- and long-term. Protected areas and forests are mostly native or have long existed. Urban parks, ponds, lakes, tree lines or vegetated squares were frequently designed and implemented to address a specific problem (environmental or urbanistic) but still provide several other co-benefits. The mitigation of climate change effects may occur, despite whether (or not) natural areas were designed and implemented with that specific purpose. For a holistic point of view, it makes sense to include both NBS and other existing natural areas in the same resilience assessment, to account for all the integrated co-benefits all natural areas have. Moreover, there's an added value when integrating all natural areas in a framework comprising other urban services. This enables the consideration of the interdependencies between the blue-green areas and the other services, such as water supply, stormwater, or mobility.

The consideration of natural areas as a service is also supported by the fact that a healthy natural environment provides a range of benefits, such as drinking water or clean air. The benefits that humans derive from nature are known as ecosystem services. They can be structured into four categories: provisioning services, regulating

services, habitat or supporting services, and cultural services. (Millennium Ecosystem assessment 2005; TEEB, 2011). In Figure 1, a detail on ecosystem services categories, namely those relevant to cities, is given.

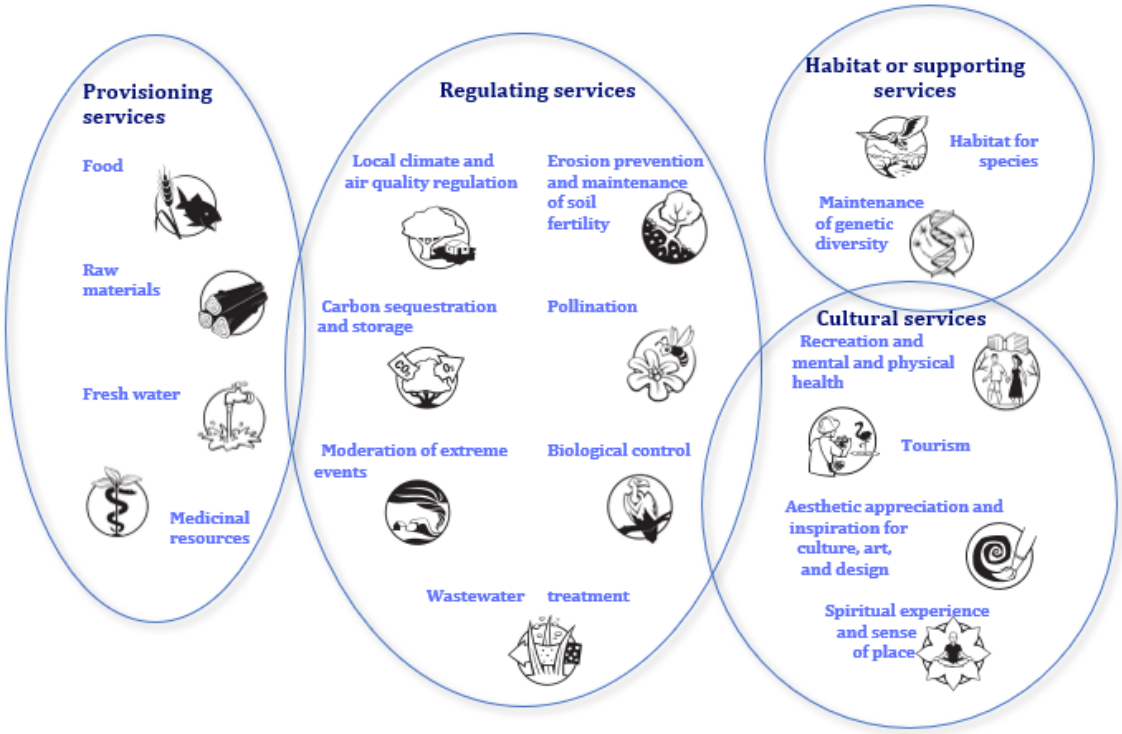


Figure 1. Ecosystem services categories relevant to cities (based on TEEB, 2011)

Almost every resource that societies use daily relies directly or indirectly on ecosystem services, either for human wellbeing or economic activities. Healthy natural areas must be a concern for all. A degraded natural area will cease to supply the ecosystem services that societies rely upon, and it can be extremely expensive, time-consuming, or even impossible to restore the ecosystems. For that reason, incorporating natural areas in city management is possible to be done and extremely beneficial (TEEB, 2011), and their condition ought to be monitored and maintained. Ecosystem services are, therefore, a core topic in natural areas' assessments.

The UN-Habitat resilience dimensions (UNHabitat, 2018) are a comprehensive approach that provides both an overview of the city as a whole and of each service in specific, by considering the resilience dimensions (organizational, spatial, functional, and physical) that were used in RESCCUE for several urban services (Cardoso et al, 2020). Natural areas may be considered as a service, a complementary and region-wide service provided by local authorities, in line with the UN-Habitat and RESCCUE approaches, that also requires to be integrated in a resilience assessment of a region or city. This way forward has the advantage of disaggregating the contribution of diverse aspects regarding the service and assets to the overall resilience.

The assessment of resilience is particularly important for critical infrastructure. The European Directive 2008/114/EC (ECI Directive) already envisaged that each Member State should identify potential critical infrastructure that is essential for the maintenance of vital functions for society, health, safety, security or economic or social well-being, and the disruption or destruction of which would have a significant impact on a

Member State. By then, the energy and transport sectors should be identified, but others could be included if deemed appropriate. This Directive, which set out obligations for the identification and designation of European Critical Infrastructure, has recently been repealed in the light of current developments and additional measures have been taken to protect critical infrastructure.

The already referred Sendai Framework (Sendai Framework for Disaster Risk Reduction 2015-2030) and its target four (Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030) lays down the foundation for the topic and is a central focus of ICARIA. The Sendai Framework proposes the following actions in relation to ICARIA's scope:

- integration of disaster risk reduction into laws and regulations applicable to publicly owned, managed or regulated services and infrastructure;
- investment in structural, non-structural and functional disaster risk prevention and reduction measures in critical infrastructure;
- promotion of resilience of new and existing critical infrastructure, including water, transport, telecommunications, and health infrastructure, to ensure that they remain safe, effective and operational during and after disasters to provide live-saving and critical services.

Within this framework, UNDRR (UNDRR, 2016; https://www.undrr.org/terminology/resilience) defines "Resilience" as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management."

Within the IPCC AR6 (IPCC, 2021), resilience has been defined as "the capacity of interconnected social, economic, and ecological systems to cope with a hazardous event, trend, or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/ or transformation.".

The EU adaptation strategy introduces the notion of 'just resilience', emphasizing that the impacts of climate change are not felt equally by all groups and that achieving resilience in a just and fair way is essential for the equitable distribution of climate adaptation benefits (EC, 2021b). Accordingly, the EU mission on adaptation to climate change sets out to accelerate a smart and systemic transformation to climate resilience in a just and fair way, through inclusive governance processes and supporting actions that protect the health and well-being of vulnerable people (EC, 2021c).

The Critical Entities Resilience Directive (Directive EU2022/2557, CER), repealing Council Directive 2008/114/EC, lays down obligations on EU Member States to take specific measures to ensure that essential services for the maintenance of vital societal functions or economic activities can be provided without disruption in the internal market. To address comprehensively the resilience of those entities that are critical for their undisrupted functioning, the CER establishes an overarching framework that addresses the *resilience of critical entities to all hazards, whether natural or man-made, accidental, or intentional*. CER defines 'resilience' as a critical entity's ability to prevent, protect against, respond to, resist, mitigate, absorb, accommodate, and recover from an incident.

Critical entities must have a comprehensive understanding of the relevant risks to which they are exposed, and a duty to analyse all relevant risks that could disrupt the provision of their essential services (i.e., to conduct a

'critical entity risk assessment'). Critical entity risk assessments must consider all the relevant natural and man-made risks which could lead to an incident. These include those of a cross-sectoral or cross-border nature, accidents, natural disasters, public health emergencies and hybrid threats and other antagonistic threats, including terrorist offences as provided for in Directive EU 2017/541. Furthermore, the CER Directive recognizes an increased physical risk due to natural disasters and climate change, which is increasing the frequency and magnitude of extreme weather events and bringing long-term changes in average climate conditions. These can reduce the capacity, efficiency, and lifespan of certain infrastructure types if climate adaptation measures are not in place.

The CER Directive indicates that measures to increase the critical entities resilience ought to:

a) prevent incidents from occurring, duly considering disaster risk reduction and climate adaptation measures;
b) ensure adequate physical protection of their premises and critical infrastructure, duly considering, for example, fencing, barriers, perimeter monitoring tools and routines, detection equipment and access controls;
c) respond to, resist and mitigate the consequences of incidents, duly considering the implementation of risk and crisis management procedures and protocols and alert routines;
d) recover from incidents, duly considering business continuity measures and the identification of alternative supply chains, in order to resume the provision of the essential service;
e) ensure adequate employee security management, duly considering measures such as setting out categories of personnel who exercise critical functions, establishing access rights to premises, critical infrastructure and sensitive information, setting up procedures for background checks;
f) raise awareness about the measures referred to in points (a) to (e) among relevant personnel, duly considering training courses, information materials and exercises.

In 2023, the European Commission delegated regulation supplementing the CER Directive 2022/2557 by establishing a non-exhaustive list of essential services, in these sectors: energy; transport; banking; financial market infrastructure; health; drinking water; wastewater; digital infrastructure; public administration; space; food production, processing and distribution. Several subsectors are identified. For example, in the transport sectors, air, rail, water, road, and public transport subsectors are associated, and a description of each is provided.

Assessing resilience of critical infrastructures is, therefore, focused on these aspects, considering both the technological and physical protection of elements and the entities' management.

2.2 Framework for holistic resilience assessment | RESCCUE RAF

The RESCCUE RAF is a framework that facilitates a structured holistic assessment of urban resilience to climate change, with focus on water (e.g., earthquakes, economic crises are not taken into account for diagnosis). The emphasis of this framework, developed within the RESCCUE project (Velasco et al., 2020), is on city, services, and infrastructure resilience. For such, other aspects (e.g. social and political dimensions) are not the focus for diagnosis, but are considered whenever important for city, services, and infrastructure resilience (Cardoso et al., 2019; Cardoso et al., 2020). The RESCCUE RAF provides an objective driven diagnosis supported on the compliance of the resilience objectives for each resilience dimension, i.e., organisational (city governance), spatial (urban space and environment), functional (strategic services in the city) and physical (infrastructure of the services). The first two dimensions are mainly addressed by the city, and the last two are addressed by the services. The

strategic services/infrastructure already included in the RESCCUE RAF are water, wastewater, stormwater, waste, energy, and mobility.

The RESCCUE RAF has a hierarchical tree structure. In each dimension, the resilience objectives are assessed by criteria, expressing different points of view; each criterion is quantified by metrics; each metric is evaluated by reference values, providing an indication of the development level depending on the answer (incipient, progressing, or advanced). In the RESCCUE RAF, all the metrics are performance indicators. Metric's answer may be a figure or a pre-set list. The dimension of time is integrated within the metrics implicitly addressing it, by providing information about the city's ability to prepare for, respond to or recover from risk events or changes in circumstances.

The hazards considered in the RESCCUE RAF are flooding (of any origin), combined sewer overflows, heat waves, cold waves, windstorms, drought and other (to be defined by the user). These are characterized in the city / service profile, for the most probable and the most severe scenarios that must be established for the assessment. Metrics are generic to the hazard under assessment (e.g. "impact on urban footprint of the last climate related event, with similar or harsher climate variables than the most probable scenario").

To allow for a step-by step assessment, metrics have been assigned an *analysis level* (depending on the assessment purpose: *strategic, tactical*) and *a relevance level* (depending on the assessment maturity: *essential, complementary, comprehensive*, following more in-depth requirements) (Cardoso and Brito, 2019). Depending on city maturity, a given relevance level may be chosen. In total, the framework contains 719 metrics, of which 433 are essential, 202 are complementary and 84 are comprehensive. It includes some metrics specific to critical infrastructure.

The final assessment is based on the achievement of the resilience objectives, which is determined by the percentage of metrics in each *development level* (*incipient, progressing*, or *advanced*) for each criterion, objective, service, or dimension.

It should be noted that resilience depends on the specific context of each city and service. In this sense, the RESCCUE RAF considers the context of the city (city profile) and the services (service profile) under analysis, focusing on the relevant contextual information that supports the interpretation of the metric results (Cardoso et al., 2020). These profiles summarize a set of characteristics that provide a unique characterization of the city and services. The main characterization themes considered in the city profile are geography, climate, population, economy and governance, built environment and infrastructure, and identification of climate-related hazards in the city. The city profile identifies the services to be assessed. These are then characterized in more detail in the service profile. All services are described in a similar way regarding their context characterization, and in a specific way regarding the characteristics of their infrastructure. The main characterization themes in the service profile are the utilities involved in providing the service and the type of customers, the description of the assets, and the identification of the climate-related risks to the services.

The objectives within the organizational and spatial dimensions are described through and address the criteria presented in Table 1, identifying the number of metrics associated with each criterion, as well as the number of essential metrics. Overall, the organisational dimension in RESCCUE RAF considers 74 metrics in total, from which 50 are essential, 16 are complementary and 8 are comprehensive. The spatial dimension considers 29 metrics in total, from which 22 are essential, 4 are complementary and 3 are comprehensive.

The functional and physical resilience dimensions similarly unfold into objectives, associated with the scope of the assessment. The objectives are also described through and address the criteria presented in Table 1. Overall, depending on the services, the functional dimension considers between 42 and 69 metrics in total, from which between 24 and 39 are essential, between 5 and 28 are complementary and between 3 and 13 are comprehensive. Similarly, the physical dimension considers between 36 and 49 metrics in total, from which between 18 and 31 are essential, between 5 and 16 are complementary and between 4 and 13 are comprehensive.

It is important to emphasise that the scope and focus of the RESCCUE RAF do not integrate all potential resilience dimensions, all possible hazards that a city may face and all urban services available in the city.

Table 1. Overview of the resilience dimensions in RESCCUE RAF (Organisational, Spatial, Functional and Physical)

ORGANISATIONAL OBJECTIVE Criterion	No. PI	No. *essential* PI
COLLECTIVE ENGAGEMENT AND AWARENESS		
Citizens and communities' engagement	5	3
Citizens and communities' awareness and training	5	3
LEADERSHIP AND MANAGEMENT		
Government decision-making and finance	4	3
Coordination and communication with stakeholders	4	2
Resilience engaged area	19	13
CITY PREPAREDNESS		
City preparedness for disaster response	13	8
City preparedness for CC	7	6
City preparedness for recovery and build back	7	5
Availability and access to basic services	10	7

SPATIAL OBJECTIVE Criterion	No. PI	No. *essential* PI
SPATIAL RISK MANAGEMENT		
General hazard and exposure mapping	5	5
Hazard and exposure for CC	3	3
Resilient urban development	7	4
Impacts of climate-related event	2	2
PROVISION OF PROTECTIVE INFRASTRUCTURES AND ECOSYSTEMS		
Protective infrastructures and ecosystems services	9	6
Dependence and autonomy regarding other services considering CC	3	2

FUNCTIONAL OBJECTIVE. Criterion	No. PI	No. *essential* PI
SERVICE PLANNING AND RISK MANAGEMENT		
Strategic planning	5	5
Resilience engaged service	5-6	4-5
Risk management	7-12	2-7
Reliable service	6-11	1-5
Flexible service	4-6	1-4
AUTONOMOUS SERVICE		
Service importance to the city	2	1
Service inter-dependency with other services considering CC	2	0
SERVICE PREPAREDNESS		
Service preparedness for disaster response	0-4	0-4
Service preparedness for CC	6-8	4
Service preparedness for recovery and build back	0-15	0-8

PHYSICAL OBJECTIVE Criterion	No. PI	No. *essential* PI
SAFE INFRASTRUCTURE		
Infrastructure assets criticality and protection	5	5
Infrastructure assets robustness	10-14	4-6
AUTONOMOUS AND FLEXIBLE INFRASTRUCTURE		
Infrastructure assets importance to and dependency on other services	3-4	3
Infrastructure assets autonomy	1-6	0-4
Infrastructure assets redundancy	1-3	0-3
INFRASTRUCTURE PREPAREDNESS		
Contribution to city resilience	3-4	2-3
Infrastructure assets exposure to CC	3	0-3
Preparedness for CC	2	1
Preparedness for recovery and build back	7-9	2-4

To support the RESCCUE RAF usage, a tool – the RESCCUE RAF App – was developed as a web-based tool (Lopes et al., 2019), designed for an integrated assessment of the city and its services, for a given time and for a specific hazard. Access to the tool is available to users with login credentials.

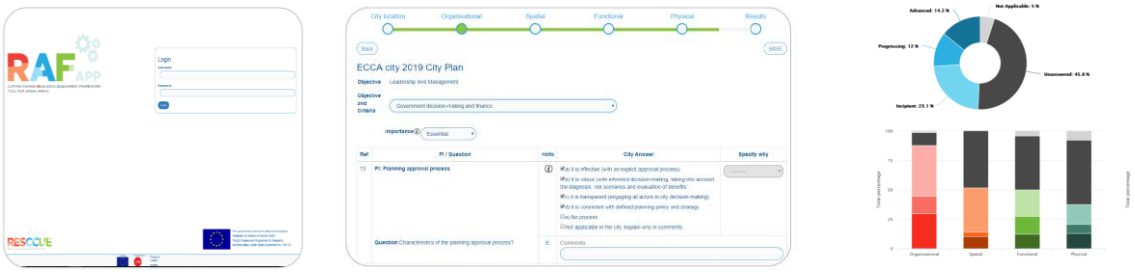
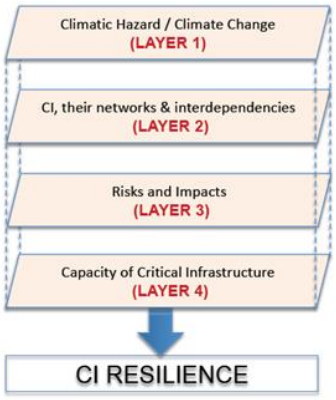


Figure 2. RESCCUE RAF App

The RAF App demonstrated to be a worthy solution to uptake the contributions from the cities, since it is a user-friendly tool facilitating metrics' inputs and providing an easy and dynamic visualization of results. Graphical aggregation, selecting the level of aggregation (such as for the whole city, for a given dimension, service, objective, or criteria, or for a given level of metrics' relevance or analysis level) is enabled. It provides a first identification of resilience strengths, gaps, and improvement opportunities, of progress achieved, and facilitates communication among all actors involved in the resilience enhancing process.

2.3 Framework for resilience assessment of critical infrastructure | EU-CIRCLE RAT

The EU-CIRCLE Resilience Assessment Tool (RAT) assesses critical infrastructures resilience to climate change, at asset level, network level and network of networks level. In summary, the EU CIRCLE resilience framework has multi-dimensional components, incorporating risks and capacities with the focus on critical infrastructure and climate hazards. These layers and components are illustrated in Figure 3.



1. Resilience for what – the disturbance, which is a Climatic Hazard (CH), including current and future climate change (Layer 1)
2. Resilience of what – the context, which is the Critical Infrastructure (CI), their networks and interdependencies (Layer 2)
3. Disaster risks and impacts (Layer 3)
4. Capacities of critical infrastructure (Layer 4)
5. Asset properties associated with Critical Infrastructure and Climate Hazards (contributes to Layers 1, 2 and 3)
6. Resilience parameters (Contributes to Layers 3 and 4)

Figure 3. Layers of information in EU-CIRCLE RAT (EU-CIRCLE D4.1, Sfetsos, A. et al., 2016)

The EU-CIRCLE RAT is a resilience capacity driven diagnosis. It is supported on the compliance of the following resilience capacities: anticipation, absorption, coping, restoration, and adaptation. For each resilience capacity, a set of points of view are identified, which unfold into specific ones. The answers are a pre-set list. Within EU-CIRCLE Resilience Assessment Tool, the following *infrastructure capacities* are considered:

- **Anticipatory capacity**: is the ability of a system to anticipate and reduce the impact of climate variability and extremes through preparedness and planning.
- **Absorptive capacity**: is the ability of a system to buffer, bear and endure the impacts of climate extremes in the short term and avoid collapse.
- **Coping capacity**: is the ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters.
- **Restorative capacity**: is the ability of a system to be repaired easily and efficiently.
- **Adaptive capacity**: is the combination of assets, skills, technologies, and confidence to make changes and adapt effectively to the challenges posed by long term trends, such as future climate change.

The EU-CIRCLE resilience framework recognizes five types of generic resilience parameters. These parameters correspond to the critical infrastructure capacities already referred to and outlined in Figure 4.

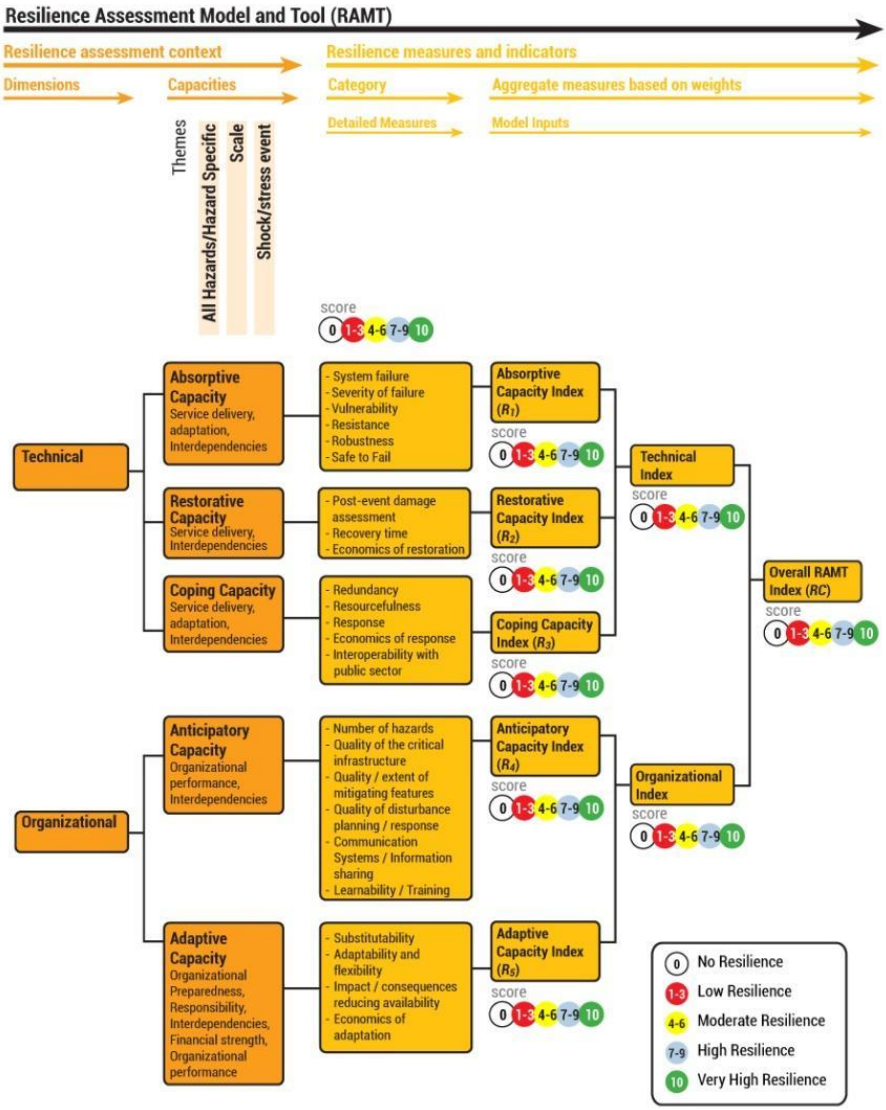


Figure 4. Resilience capacities in EU-CIRCLE Resilience Assessment Tool (EU-CIRCLE D4.5, Petrovic et al., 2017).

The EU-CIRCLE RAT is usable by several critical sectors, namely those addressed in ICARIA, but several other beyond ICARIA's scope: other energy services and assets (gas, oil, renewable energy), several transportation modes (road, rail, ports, airports), health sector, Information and communication technology sector or public administration).

2.4 Opportunities for development

It is clear from the bibliography review that diverse existing frameworks have been developed with different purposes, focusing on different themes, with distinct structures and formulations. The UN-Habitat CRPT was used as the basis for the RESCCUE RAF, and the European Directive on Critical Infrastructure Protection (2008/114/EC) was used as the basis for EU-CIRCLE RAT. The selection of these tools as a basis for ICARIA purposes was assumed in the project proposal and has the advantage of being widely available to regional, city and services managers.

The gaps between the available frameworks and the ICARIA's scope were assessed, regarding ICARIA assets, hazards, and geographic scale. Within ICARIA, as presented in **Table 2**, the assets, hazards, and geographic scale to be assessed are identified in the first column.

Indication of the ones already assessed by RESCCUE RAF or EU-Circle RAT is shown (√). For the others, some were identified as gaps to be filled, others as aspects to be revised, as they were somehow included in the previous frameworks but were not their central focus. EU-CIRCLE RAT does not cover some of the aspects listed as they are not considered critical infrastructure in the CER (N/I – not included).

Table 2. Synthesis of gaps to be addressed in ICARIA resilience methods

ICARIA Themes/Assets/services	RESCCUE RAF	EU-CIRCLE RAT
Water	√	√
Wastewater	√	√
Stormwater	√	√
Waste	√	√
Electricity	√	√
Natural areas	[gap]	N/I
Housing areas	[revise]	N/I
Tourism	[revise]	N/I
Social science and humanities	[revise]	N/I
ICARIA Hazards	RESCCUE RAF	EU-CIRCLE RAT
Floods	√*	√
Storm surges	√	√
Heat waves	√	√
Forest fires	[gap]	√
Droughts	√	√
Storm winds	√	√
Compound / multi-hazards	[revise]	[revise]
ICARIA Geographic scale	RESCCUE RAF	EU-CIRCLE RAT
Asset level	√**	√

ICARIA Geographic scale (cont.)	RESCCUE RAF	EU-CIRCLE RAT
Network level	√	√
Interconnected networks level	√	√
Urban	√	√
City area	√	√
Regional	[gap]	√

* Flooding is considered; however, rainfall induced, fluvial or coastal flooding are not distinguished
** Included as asset types or importance (e.g. pumps, solid waste containers) but not as individual assets, at operational level

Given the gaps identified, the efforts to develop the ICARIA resilience methods focused on the inclusion of natural areas and forest fires. Each method required specific development, e.g. for the RESCCUE RAF to include forest fires or the EU-Circle RAT to include compound hazards. Overall, each existing metric was re-examined with a view to broadening its application where deemed relevant. The set of metrics was also reviewed as a group to provide a comprehensive assessment of the global fit with ICARIA's objectives. For example, the social sciences and humanities metrics were fully scrutinised.

Naturally, even when a given topic is assessed by both frameworks, one must keep in mind that the RESCCUE RAF is more holistic, as it addresses city resilience as a whole and looks at all the infrastructure of the service, whilst the EU-CIRCLE RAT refers specifically to a subset – the critical infrastructure of that service.

3 Resilience assessment method

3.1 Main purpose, scope, and assumptions

The main purposes of the developed ICARIA resilience assessment method are to:

- provide a holistic resilience diagnosis of the regions, cities and strategic urban sectors, following an objective-driven approach (ISO 9001);
- provide a structured resilience diagnosis of the critical infrastructure or of the critical urban sectors in the region and city, following a resilience capacities-driven approach;
- identify, at both levels, data gaps and areas for resilience improvement;
- guide the development of an assessment tailored to each critical asset or service, region or city;
- support risk-informed decision-making, by comparing the contribute to resilience of different measures and strategies;
- monitor the progress of resilience over time;
- facilitate the communication among stakeholders.

It should be noted that the ICARIA resilience assessment method is not intended to provide a global resilience indicator or to undertake benchmarking but to support decision making. In fact, different cities have varied contexts, face different hazards, have diverse services provided, have distinct maturity levels regarding resilience and may intend to assess the resilience regarding a certain hazard or service. For these reasons, either using an overall figure or making comparisons between cities or regions must be made with caution.

The scope of ICARIA is considered – resilience to climate change (CC), meaning that diverse resilience drivers such as earthquakes, economic crises, or cyberattacks, are not contemplated; the emphasis is on the region, city, and critical infrastructure resilience, meaning that resilience aspects such as social and political are not fully developed for diagnosis, but they are incorporated whenever significant for the overall resilience.

Besides the scope, the ICARIA resilience assessment method considers the following assumptions:

- the services within the scope of the holistic assessment are the natural areas and the RESCCUE services (i.e. water supply, wastewater and storm water and those having interconnections and interdependencies, closely related with the water services: waste management, electrical energy supply and mobility);
- the resilience assessment of the critical infrastructure applies to several services: water supply, wastewater, stormwater, solid waste, energy (electricity), other energy services and assets (gas, oil, renewable energy), several transportation modes (road, rail, ports, airports), health sector, Information and communication technology sector or public administration); and it follows a structure that is independent of the geographical area, services, or hazards under assessment;
- the external context of the region, city, and services is considered by a standard characterization profile;
- the multi-scale, multi-sectoral, multi-hazards and interdependencies are addressed;
- the continuous improvement principle (ISO 9001) is pursued and, since resilience is dynamic, the assessment addresses:
  - progress of the strategies' implementation and of their effect;
  - before – during – after an event;
  - changes in the context;

- a tailored assessment is enabled, so guidance on the use of the method is required;
- the long, medium, and short terms are incorporated considering three different and aligned assessment levels for the city, services, and infrastructures while, as an integrated assessment, addresses the two first:
  - strategic – overlooking a long-term planning horizon (typically 15 to 20 years), requiring the involvement of the entire organisation, addressing the overall city and considering its vision;
  - tactical – overlooking a medium-term planning horizon (typically up to 3 to 5 years) and addressing departmental or sectoral activities in the city, services and infrastructure;
  - operational – referring to short-term horizon (typically 1 year), addresses the actions to be taken in the effective implementation of measures in the city, services, and infrastructure.

3.2 Structure of the proposed method

Two frameworks and tools with several similarities, but with different purposes, were identified as relevant for ICARIA's method for resilience assessment, the RESCCUE RAF and the EU-CIRCLE RAT. The developments to fulfil each specific identified gap or revision need (2.4) were identified. A detailed analysis of different possible solutions was carried out and it was decided to keep the frameworks and tools as stand-alone solutions, given their particular scope of application and complementarity.

The RESCCUE RAF is specifically dedicated to a holistic assessment (of the region and the services under assessment) while the EU-CIRCLE RAT is specifically dedicated to critical infrastructure, deepening the assessment for these specific assets. Links between the frameworks are emphasized, to ensure alignment between these complementary levels of assessment.

Although each framework is presented to the user through a specific App, both are included in a unique platform. To facilitate the use of either each app, or both in conjunction, user guidelines are provided.

As ICARIA is intended to focus on critical infrastructures, it was decided that the EU-CIRCLE RAT should keep its emphasis, so as not to disperse this focus by being included in a holistic framework. It should also be revised considering the new CER Directive.

Figure 5 illustrates the components of the ICARIA resilience method and the articulation between them.

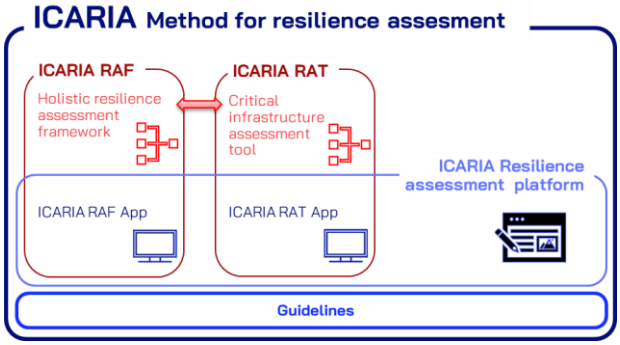


Figure 5. Components of ICARIA resilience method and their articulation

3.3 Build-up of the holistic assessment

The ICARIA RAF (holistic resilience assessment framework) keeps the hierarchical tree structure of the RESCCUE RAF (section 2.2). For each dimension (organizational, spatial, functional, and physical), resilience objectives are defined, representing the ambitions to be achieved in the medium–long term by the city and services. Each objective unfolds into a set of criteria, that translate the different points of view associated with it. Each criterion assembles the respective assessment metrics, enabling to classify the resilience development level by comparison with reference values. Metrics consist of questions, parameters or functions used to assess the criteria.

Even though ICARIA is not aimed to perform detailed resilience assessment of urban services and assets, it was decided that the full contents of the RESCCUE RAF should evolve to ICARIAS's purposes, while keeping the possibility of a service-driven assessment in case a city or region decides to do it. The ability of offering a step-by-step approach, with a deepening of the assessment from essential, to complementary, and then to comprehensive assessment levels, is kept. It enables a tailored assessment depending on the region, city, or service's resilience maturity. A tailored assessment can also be performed for individual services (e.g. urban waste, wastewater), as they might be selected or not for assessment. Herein, the evolvement of the RESCCUE RAF was mostly done to include natural areas and to permit a regional assessment. The inclusion of additional hazards (forest fires, and the disaggregation of the types of flooding), of housing areas and of tourism was performed using a simplified approach. These aspects were mostly included in the profiles and in existing metrics. For example, housing was already considered in the RESCUE RAF, particularly in the metrics addressing urban footprint; tourism is addressed as any other economic activity, already included in the RESCCUE RAF.

Some of the ICARIA RAF metrics correspond to or were adapted from existing frameworks, mainly from UNDRR framework (former UNISDR) and the RESCCUE project, found to be strongly linked to the ICARIA scope, and others were newly developed.

The RESCCUE RAF objectives, criteria, and metrics were fully revised to incorporate the regional scope, the housing areas and tourism, mainly in the profile and in the impact assessment. The city and service profiles were updated to include forest fires and metrics were revised to allow application to any hazard, and to include forest fires. Metrics were also revised to assess the need of complementing more specific aspects regarding the critical infrastructures.

The addition of a new layer of information to the RESCCUE RAF metrics, relating the metric to the type of information provided (e.g., modelling), supports identification of source of information and helps to ensure common data formats. With this new layer, several complementary aspects about the metrics are identified, namely whether the metric: has inputs from modelling; relates to critical infrastructure; relates to social aspects; is relevant as an output to the Decision Support System (DSS) in T3.4. A preliminary version of this information is provided in the ICARIA framework. This version and these specific contents will be validated in WP3 lab, in task T3.5. In the ICARIA RAF App, a filter (identified as *Additional Info*) was developed to allow to tag such metrics.

The RESCCUE RAF organisational and spatial dimensions were revised to guarantee that social sciences' and humanities' concerns are addressed, in the scope of ICARIA.

A specific and deeper development is required to include the natural areas. To fully consider their governance, management and operational aspects, natural areas are thought of as a strategic service, alike the others within the framework, with its assets that provides a service. As mentioned, this approach allows to disassemble and better understand the contribution of service and assets to the overall resilience of a region or city. For example, the functional dimension considers service planning and risk management, its flexibility, autonomy and interdependencies, and its preparedness to respond, endure and build back from stressful climate change events. From the infrastructure point of view, the physical dimension considers how safe, robust, and prepared for climate change the assets are, namely how autonomous, flexible, and redundant.

For a refinement of the metrics to include in the assessment framework for natural areas, it is important to clearly identify the ecosystem services provided and still necessary in the region. The ecosystem services are defined as the benefits that humans derive from nature, including direct and indirect contributions from ecosystems to human well-being, namely with regulating, provisioning, habitat or supporting, and cultural objectives (TEEB, 2011), as depicted in Figure 1. Metrics regarding natural areas and ecosystem services found great inspiration in TEEB (2011), EC (2021a) and Beceiro et al. (2020), among others.

3.4 Build-up of the assessment of critical infrastructure

Recent advances in assessing the resilience of critical assets require that increased levels of protection against multiple hazards and extreme events should be considered. This will support the integration of climate change considerations into future investments and infrastructure projects, from buildings or network infrastructure to a range of built systems and assets. In this respect, climate change should not be considered as an isolated challenge to critical assets, but in combination with other potential hazards and threats. Climate-resilient critical assets should be associated with an increased potential to improve the reliability of service delivery, extend asset life, and protect asset returns.

As the EU-CIRCLE Resilience Assessment Tool is more than 7 years old, the following set of actions has been implemented to upgrade it and provide the ICARIA RAT:

- Re-assess EU-CIRCLE RAT's conceptual validity with respect to existing International and EU framework, that are more recent.
- Re-evaluate the included capacity assessments in light of the CER Directive, linking them with the proposed resilience enhancement measures.
- Review existing resilience indicators.
- Update the tool from an excel file to a Web-app.

3.5 Links between the existing tools for resilience assessment

Overall, the EU-Circle RAT is a framework more adaptable to other services, infrastructure, hazards, and regional scale, with a focus on the assessment of critical infrastructures. It also provides a better insight into the evaluation of costs associated with improving resilience. RESCCUE RAF provides a deeper assessment for given services and infrastructure, namely including interdependencies and cascading effects for specific events, and for the governance, social and organisational aspects of resilience. RAT's anticipation and adaptation capacities relate to RAF's preparedness timeline; RAT's absorption, coping and restoration capacities relate to RAF's response or recovery timeline. Besides metrics specific related to critical infrastructure, in the RAT several

metrics relate to governance, financial and social aspects, as those found in the RESCCUE RAF organizational and spatial dimensions.

Besides this overall analysis, a thorough breakdown of the EU-CIRCLE RAT metrics correspondence with RESCCUE RAF metrics was done. Sixty-five of the EU-CIRCLE RAT metrics were pointed out. For the signed metrics, there is a correspondence, most often partial, with RESCCUE RAF metrics. In some cases, the RAT metrics are more generic and the RESCCUE metrics more detailed; in some other cases, it is the other way round. In some cases, more than two EU-CIRCLE RAT metrics' point of view are reflected in one RESCCUE RAF metric. In other cases, again, it is the other way round.

The overall conclusions are that the RESCCUE RAF App addresses the concerns of the RAT in circa 80% of the RAT questions regarding critical infrastructure; in some cases, RAF goes deeper, in others, RAT goes deeper; in most cases, even when the question is similar, the RESCCUE RAF refers to infrastructure that provides the service, as a whole, and the RAT refers specifically to critical infrastructure.

A more detailed analysis was made on the identification of metrics that could be parallel in both tools.

In the RESCCUE RAF, 38 metrics in the Organizational and Spatial dimensions and 39 metrics in the Functional and Physical dimensions (with the possibility of replication to 6 different services) were found to be parallel, with a similar depth in the required answer. A deeper analysis with the identification of the most relevant metrics in the RAF for critical infrastructure is presented in 4.1.7.

As a synthesis, the ICARIA resilience method was developed to extend the city-wide assessment to a regional scope, to address complementary assets (beyond those already covered in the previous frameworks and tools, such as those from water services, waste, energy, and mobility), namely natural areas, and to diagnose additional hazards beyond those already covered (flooding, storm surge, heat waves, drought, and windstorms), namely different types of flooding and forest fires. The RESCCUE RAF App has undergone a major development to include the specific aspects of ICARIA. It will not include all the concerns of the EU-CIRCLE RAT, as these are very well addressed in the EU-CIRCLE RAT. The intention was not to replicate the work already developed in either the RESCCUE RAF or the EU-CIRCLE RAT, but to incorporate new developments.

4 ICARIA frameworks detailed description

4.1 Holistic resilience assessment framework (ICARIA RAF)

4.1.1 Overview

As already referred, the ICARIA RAF considers the organisational spatial, functional, and physical resilience dimensions for assessment. When applicable, the dimensions unfold into sub-dimensions for each urban service under assessment.

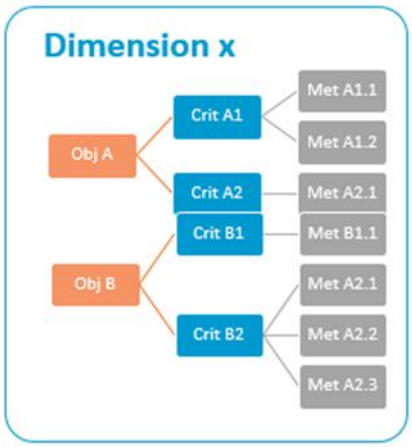
For each dimension, the resilience objectives identify ambitions to be achieved in the medium-long term by the city and services and are described through specified key criteria (expressing different points of view). Metrics are then defined through questions, parameters or functions used to assess the criteria. By comparing the result of metrics with reference values, it is possible to assign a classification to the responses, reflecting the resilience maturity of the city or of the service under assessment for that specific assessment. It is important to note that the classification of a given individual metric is of little value on its own. By itself, a metric does not reflect the entire point of view of the criterion, which it belongs to. The classification only allows an effective assessment when the metric is put into perspective within the criterion (i.e. linked to the corresponding criterion and objective), analysed together with the other metrics belonging to the same criterion, and framed by the context of the city and service under assessment.

For each metric, the classification is made by associating each answer to a resilience development level, related to the reference values mentioned above. The resilience development levels are classified as incipient (for results that are still non-existent or are at an early stage of development), progressing (for situations where significant steps have already been taken and the city or the service are still developing the specific aspect addressed by the metric), or advanced (for already consolidated results).

The metrics present a list of predefined answers, of which: (i) only one may be selected; or (ii) multiple answers may be selected. Depending on the metric's answer, a pre-defined resilience development level is assigned, based on the reference values: *incipient* (between 0 and 1), *progressing* (between 1 and 2) or *advanced* (between 2 and 3). These individual values for the metrics allow providing information on the percentage of metrics in each development level to assess a criterion, objective, or dimension.

The tree structure used in the ICARIA RAF (**Figure 6**) allows getting information on the development level for each criterion, considering the various metrics that contribute to it. Likewise, it is possible to know the development level of a given objective or, more aggregately, of a given service or resilience dimension. It is important to highlight that lack of information is also evidenced in the assessment and that data reliability should be mentioned, whenever it may compromise the assignment of a development level.

Each metric is also assigned to a relevance degree and to an analysis level. Three degrees of **relevance** are considered: *essential*, including all metrics with higher relevance, required to integrate the resilience assessment of any city or service; *complementary*, additional metrics to be considered whenever integration of a city or service specific aspects' is sought, corresponding to a more detailed resilience assessment; *comprehensive*, additional metrics recommended whenever a more in-depth assessment is aimed, for a city or service with higher maturity in its resilience path. Conversely, depending on the resilience maturity, the city or service aiming to apply the RAF may select a given set of metrics, according to their relevance.



Additionally, a metric might be *strategic* or *tactical*, depending on the **analysis level** the user wants to perform.

The RAF is built upon the assumption that it is feasible to give an answer to every metric. However, in the case a metric is not applicable to a city, for some specific reason, then the RAF provides the possibility to explain that reason (e.g., if a metric relates to coastal aspects and the city under assessment is in the hinterland). Some metrics precede others, meaning that if the city does not answer to the first one, the latter automatically does not apply (e.g., if a city answers negatively to a metric asking whether a plan is available, then any following metric concerning the contents of that plan is not applicable).

Figure 6. ICARIA RAF tree structure

In case the metric applies, but the city does not have an answer for it in the moment of the assessment, the reason why the metric is not answered should also be explained (e.g., if a metric relates to the impacts of an historical climate-related event and the city did not register the requested information).

Some metrics are scenario-specific, namely those that address preparedness for climate change, and that anticipate the regional and services' exposure or vulnerability to future scenarios. While some metrics relate generally to climate change scenarios, others are specific for the most probable or the most severe scenarios. In this case, the regional authorities and service utilities need to agree on those scenarios they want to be prepared for. From the CC projections, the most probable and most severe scenarios should be defined, to specify what it is being addressed in the assessment. The scenarios should be specified in the region's and in each service characterization profile, as they may differ for the area and for the services.

More than a tool for assigning a resilience grade, the main purpose of the ICARIA RAF is to identify those aspects in which the region or services already apply resilient practices and those in which there are still opportunities to improve resilience. In the latter case, the adverse results of the resilience assessment support the identification of strategies and the development of resilience action plans.

4.1.2 ICARIA RAF results

The ICARIA RAF is designed to be answered for an integrated assessment of the region and its services, for a given period and for a specific hazard or compound hazards (e.g. assessment for 2019 and flooding-related hazards) – this is considered as a study (study 2019/flooding). If the local authorities intend, for example, to compare the progress between the current status and a certain year in the past, then each one of these assessments corresponds to different studies (e.g. study 2014/flooding and study 2019/flooding). Similarly, when assessing more than one type of hazard, the assessment for each hazard corresponds to a different study (e.g. study 2019/flooding and study 2019/drought).

For each study, the ICARIA RAF's tree structure provides the percentage of total metrics results corresponding to each development level for the whole area and it is possible to get these results for each dimension, objective, and criteria. This information provides a progressively deeper insight into the regional and services

resilience strengths (provided by metrics with *advanced* results), opportunities for improvement (provided by metrics with *progressing* results) and major challenges to address (provided by metrics with *incipient* results).

In addition, the city may have different sources/variables of risk associated with each hazard. For example, flooding may be caused by rainfall or by sea level. When responding to the scenario metrics for flooding, if there are differences in impacts or consequences that depend on the type of variable, then the response should be made for the hazard/risk source that causes the most severe response to the metric, and the variable should be specified as a comment to the result. In this situation it is still possible to do another study if it deepens the assessment and facilitates the identification of solutions.

4.1.3 Updates to address ICARIA geographical scope

The ICARIA RAF can be applied to multiple dimensions in terms of geographical areas, namely to the city, a metropolitan area, or a region.

The user is required to first define the area under assessment, in the *profile*. The main characterization themes considered in the *profile* are geography, climate, population, economy, and governance, built environment and infrastructure, and the climate-related hazards in the area. In the ICARIA RAF the profile was enlarged to include regional features, as shown in **Figure 7**.

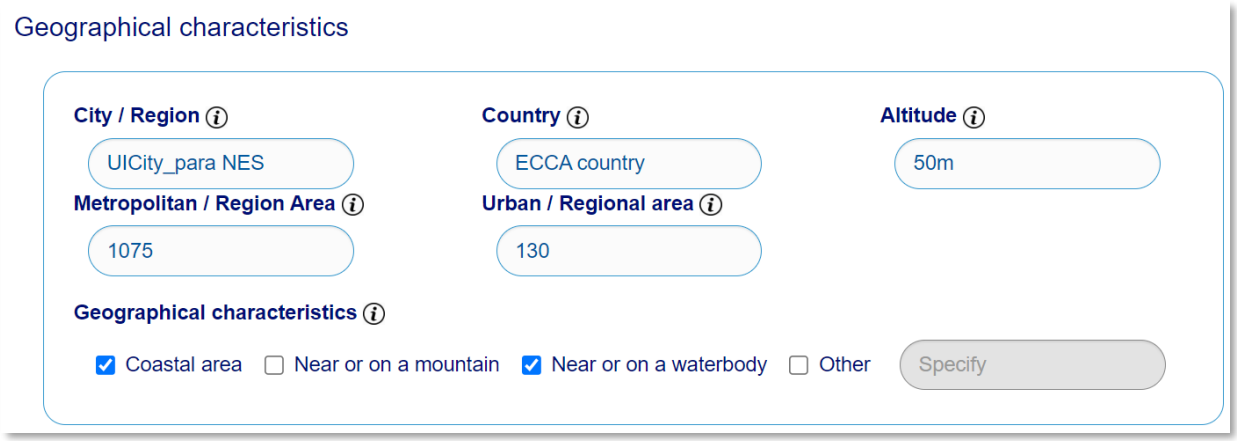


Figure 7. Assessment scope in the ICARIA RAF App

As mentioned above, each metric in the RESCCUE RAF was revised to include the possibility of applying it to a wider region, where this possibility was considered, or to include the option of multiple cities in the region. In total, 44 metrics were revised in the organisational and spatial dimensions, and 22 were revised for each service, in the functional and physical dimensions. In total, 176 metrics were revised to reflect the extension to a regional scope.

New metrics were added to distinguish the urban and the rural areas in the region. As an example, the detailed informative datasheets for metric 71 in the organizational dimension, and for metric 108b in the spatial dimension are presented in **Figure 8**. The complete list of metrics either new or revised to address ICARIA's geographical scope is presented in Annex E.

71 - Wastewater collection in the rural area (%)

Percentage of households in the rural area served by wastewater collection

Dimension	Organisational
Subdimension	-
Resilience objective	City preparedness
Criteria	Availability and access to basic services
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

If the percentage is not 100%, this metric allows to specify the reason in comments.Include the housing units located in the area for which collection and drainage service infrastructures through fixed networks are available or for which there are individual wastewater sanitation solutions (with the sludge and/or sewage removal service being provided) in locations without an available fixed network.

Development assessment rule	Development
70% - 100%	3
65% - 69%	2
51% - 64%	1
50% or less	0

108b – New rural development (-)

Is there a policy promoting physical measures in new development in rural areas that enhance resilience to one or multiple hazards?

Dimension	Spatial
Subdimension	-
Resilience objective	Spatial risk management
Criteria	Urban development
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Development assessment rule	Development
Clear policy exists. Guidance has been prepared for a range of practitioners (e.g. architects, landscape architects, engineers etc)	3
Policy exists but supporting guidance is inadequate	2
Resilience approaches are promoted, but not in a consistent manner, and not underpinned by policy	1
Little / no promotion of resilience in new rural development.	0

Figure 8. Examples of new metrics in the ICARIA RAF App to distinguish the urban and the rural areas

4.1.4 Updates to address social sciences and humanities' concerns

A common objective of the methods is to ensure that the behavioural aspects related to risk awareness and its impact on preparedness and response (short to long term) are integrated into the hazard/impact/resilience workflow.

The collaborative dimension, in terms of multi-stakeholder and community engagement, knowledge sharing and co-design of resilience strategies and actions, should also be integrated.

Social sciences and humanities (SSH) relevance for resilience was already present in the RESCCUE RAF. Nevertheless, a full revision of the contents on the topic was made, and the ICARIA RAF currently presents the metrics on the subject presented in Table 3. In the functional and physical dimensions, the metrics shown relate to the water supply service. Similar metrics exist for the other services.

Table 3. Overview of the metrics related to SSH in the ICARIA RAF

Organisational dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
COLLECTIVE ENGAGEMENT AND AWARENESS			
Citizens and communities' engagement	1	Community or "grassroots" organizations, networks and training	UNISDR
	2	Civil society links	UNISDR
	3	Engagement of vulnerable groups of the population	UNISDR
	4	Citizen engagement techniques	UNISDR
	5	Use of mobile and e-mail "systems of engagement" to enable citizens to receive and give updates before and after a disaster	UNISDR
Citizens and communities' awareness and training	6	Public education and awareness	UNISDR
	7	Training delivery	UNISDR
	8	Drills	UNISDR
	9	Social networks	UNISDR
	10	Validation of effectiveness of education	UNISDR
LEADERSHIP AND MANAGEMENT			
Government decision-making and finance	12	Consultative planning process	RESCCUE
	13	Planning approval process	RESCCUE
Coordination and communication with stakeholders	17a	Multi-stakeholder collaboration	RESCCUE
	17b	Access and use of digital services	RESCCUE
	17c	Collaboration mechanisms	RESCCUE
Resilience engaged area	23d	External support for the resilience plan	RESCCUE
	24	Robustness of resilience plan	RESCCUE
	27	Data sharing	UNISDR
	28	Integration	UNISDR
	30b	Critical infrastructure plan overview	UNISDR
	32	Learning from others	UNISDR
Preparedness for disaster response	33	Early warning	UNISDR
	34	Reach of warning	UNISDR
	43a	Existence of civil society focal points for citizens	UNISDR
	43b	Social connectedness and neighbourhood cohesion	UNISDR
AUTONOMOUS SERVICE			
Service importance to the area	340	Stakeholders' perception	RESCCUE

Table 3. Overview of the metrics related to SSH in the ICARIA RAF (cont.)

Functional dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SERVICE PREPAREDNESS			
Service preparedness for CC	352	Implemented measures to address climate change mitigation and adaptation	RESCCUE
	353	Planned measures to address climate change mitigation and adaptation	RESCCUE
Service preparedness for recovery and build back	356	Water service climate change recovery planning	UNISDR
Physical dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
INFRASTRUCTURE PREPAREDNESS			
Contribution to the area's resilience	1324	Other contributions to the area's resilience	RESCCUE

4.1.5 Inclusion of Natural Areas as a service

In the spatial dimension, several metrics have been either revised or included to address the overall contribution of the natural areas to urban resilience. This option allows natural areas to be included in the assessment even for users who chose not to include their full assessment as a service (i.e., in the functional and physical dimensions). In the spatial dimension, in metric 103 a new possible answer was added (f), new metrics 105b, 115b and 124b were included, and metrics 121, 122 and 129 were updated in several aspects. The detailed informative datasheets for some of these metrics are presented in **Figure 9**. The complete set is presented in Annex C.

103 - Damage and loss estimation (-)

Damage and loss aspects taken into account by risk assessments for key identified scenarios

Dimension	Spatial
Subdimension	-
Resilience objective	Spatial risk management
Criteria	General hazard and exposure mapping
Source	UNISDR Scorecard D2.2.2, adapted in ICARIA
Importance	Essential
Level	Tactical
Metric type	Multiple choice

Please select one or more of the options provided as answers. Sum of the selected answers and a scale to 3 is made.

Development assessment rule	**Development**
a) Changes in economic activities	**1**
b) Population at risk	**1**
c) Urban footprint at risk	**1**
d) Economic activities at risk	**1**
e) Natural areas at risk (green, blue or other, either natural or nature-based areas)	**1**
f) none of the above	**0**

105b – Natural areas at risk for climate change scenarios (%)

Percentage of natural areas at risk, according to climate change scenarios

Dimension	Spatial
Subdimension	-
Resilience objective	Spatial risk management
Criteria	Hazard and exposure for climate change
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Natural areas include green (e.g. forests, crops, urban parks, green roofs), blue (e.g. lakes, rivers) or other areas (e.g. ripples), either natural or nature-based

Development assessment rule	Development
No natural area at risk for "most severe" scenario	3
No natural area at risk for "most probable" scenario	2
Less than or equal to 2.5% of the natural area at risk for "most probable" scenario	1
Between 2.5% and 100% of the natural area at risk for "most probable" scenario	0

121 - Awareness and understanding of ecosystem services/functions (-)

Beyond just an awareness of the natural assets, is there an understanding of the functions that this natural capital provides?

Dimension	Spatial
Subdimension	-
Resilience objective	Provision of protective infrastructures and ecosystems
Criteria	Protective infrastructures and ecosystems services
Source	UNISDR Scorecard P5.1, adapted in ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Examples of functions or ecosystem services: mitigation of flooding, heat waves and land slides, provision of food, water, raw material or medicinal resources, habitat services, carbon sequestration, air regulation, pollination, aesthetic value, mental and physical health benefits and cultural services.

Development assessment rule	Development
The key stakeholders are familiar with the term ecosystem services and understand the economic value all of the functions provided by key local natural assets	3
The key stakeholders understand the majority of the functions provided by key local natural assets. These are not economically valued	2
There is an incomplete awareness and understanding of the functions delivered by the natural capital	1
Very little / no awareness of this topic	0

Figure 9. Examples of new or revised metrics in the spatial dimension of ICARIA RAF App to address natural areas

The inclusion of the natural areas as a service was mostly accomplished in the functional and physical dimensions. Table 4 shows the structure of the resilience assessment framework in the functional dimension. In this dimension, the resilience objectives aim to ensure that the natural services are properly planned and managed, that their autonomy is guaranteed, and that they are prepared for CC challenges. This dimension also allows to identify the contribution of the natural areas to city and regional resilience. Natural area's services are assessed as ecosystem services, namely: health and well-being, biodiversity, aesthetical and recreational activities, groundwater recharge, temperature reduction, air quality, carbon sequestration and storage, enhanced infiltration, water retention and evapotranspiration, regeneration of abandoned areas, and

land slide and erosion prevention. There is also an assessment on whether the existing and planned ecosystem services meet the expectations for the area.

Table 4. Functional dimension for Natural areas in the ICARIA RAF assessment framework

Functional dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SERVICE PLANNING AND RISK MANAGEMENT			
Strategic planning	900a	Natural areas governance	**ICARIA**
	900b	Integration of natural areas in policy and development projects	Beceiro (2021) & **ICARIA**
	900	Natural areas strategic plan making and implementation	RESCCUE
	901	Plan alignment with the City(ies) Master Plan	RESCCUE
	901a	Mitigation of perceived social detrimental effects of natural areas	**ICARIA**
	901b	Ecosystem services	Beceiro (2021) & **ICARIA**
	901c	Natural areas alignment with ecosystem services	Beceiro (2021) & **ICARIA**
	901d	Financial plan	RESCCUE, adapted in ICARIA
	901e	Financial support to private implementation of nature-based solutions	Beceiro (2021) & **ICARIA**
	902	Service plan monitoring and review	RESCCUE
	903	Exchange of information to the city(ies)	RESCCUE
	903b	Community engagement, networks, and training	RESCCUE, adapted in ICARIA
Resilience engaged service	905	Resilience in the strategy for natural areas and alignment with the strategic plan	RESCCUE, adapted in ICARIA
	905a	Health and well-being co-benefits	Beceiro (2021) & **ICARIA**
	905b	Biodiversity enhancement	Beceiro (2021) & **ICARIA**
	905c	Undesired species	Beceiro (2021) & **ICARIA**
	905d	Aesthetical and recreational importance	Beceiro (2021) & **ICARIA**
	905e	Groundwater recharge	Beceiro (2021) & **ICARIA**
	905f	Temperature reduction for local climate regulation	Beceiro (2021) & **ICARIA**
	905g	Air quality improvement	Beceiro (2021) & **ICARIA**
	905h	Carbon sequestration and storage	Beceiro (2021) & **ICARIA**
	905i	Estimated infiltration enhancement	Beceiro (2021) & **ICARIA**
	905j	Estimated water retention enhancement	Beceiro (2021) & **ICARIA**
	905k	Estimated evapotranspiration improvement	Beceiro (2021) & **ICARIA**
	905l	Regeneration of abandoned areas	Beceiro (2021) & **ICARIA**
	905m	Land slide and erosion prevention	Beceiro (2021) & **ICARIA**

Table 4. Functional dimension for Natural areas in the ICARIA RAF assessment framework (cont.)

SERVICE PLANNING AND RISK MANAGEMENT (cont.)			
Resilience engaged service (cont.)	906	Service resilience plan and Climate Change	RESCCUE
	907	Service financial plan and budget for resilience	RESCCUE
	909	Co-ordination with other services in the area	**ICARIA**
	910	Learning from other natural areas	RESCCUE, adapted in ICARIA
	910b	Integration with other neighbouring natural areas	**ICARIA**
Risk management	911	Risk information related to the natural areas	RESCCUE
	912	Damage and loss estimation	RESCCUE
	913	Area expected to be impacted according to climate change scenarios	RESCCUE
	915	Sensitive users expected to be impacted according to climate change scenarios	RESCCUE, adapted in ICARIA
	917	Other services expected to be impacted according to climate change scenarios	RESCCUE
	919	Households expected to be impacted according to climate change scenarios	RESCCUE
Reliable service	923	Area impacted last year	RESCCUE
	925	Sensitive users impacted last year	RESCCUE, adapted in ICARIA
	927	Other services impacted last year	RESCCUE
	929	Households impacted last year	RESCCUE
	933	Ecosystem services improvement	Beceiro (2021) & **ICARIA**
Flexible service	934	Water reuse	Beceiro (2021) & **ICARIA**
	935	Water uses	Beceiro (2021) & **ICARIA**
	939	Service management	RESCCUE
AUTONOMOUS SERVICE			
Service importance to the city	940	Stakeholders' perception	RESCCUE
	941	Cascading impacts	RESCCUE
Service inter-dependency with other services considering climate change	942	Critical services dependence on natural areas according to climate change scenarios	RESCCUE, adapted in ICARIA
	943	Natural areas autonomy from other services according to climate change scenarios	RESCCUE, adapted in ICARIA
SERVICE PREPAREDNESS			
Service preparedness for disaster response	944	Natural areas event management plans	RESCCUE, adapted in ICARIA
	945	Natural areas response in emergency	RESCCUE
	946	Natural area's early warning	RESCCUE
	947	Natural areas' service drills	RESCCUE
Service preparedness for climate change	948	Service commitment with mitigation of climate change effects	RESCCUE
	949	Existence of agreed climate change scenarios and alignment with the scenarios defined by the local authorities for the area	RESCCUE
	950	Knowledge of exposure and service vulnerability for climate change scenarios	RESCCUE, adapted in ICARIA
	951	Planning for adaptation to climate change	RESCCUE

Table 4. Functional dimension for Natural areas in the ICARIA RAF assessment framework (cont.)

SERVICE PREPAREDNESS			
	952	Implemented measures to address CC mitigation and adaptation	RESCCUE
Service preparedness for climate change (cont.)	953	Planned measures to address CC mitigation and adaptation	RESCCUE
	954	Equipment capacity of the service	RESCCUE
	955	Staffing capacity of the service	RESCCUE
Service preparedness for recovery and build-back	956	Natural areas climate change recovery planning	RESCCUE, adapted in ICARIA
	957	Natural areas damage and loss post-event assessment	RESCCUE, adapted in ICARIA
	958	Current post-event assessment system	RESCCUE
	959	Area impacted in the last relevant climate related event	RESCCUE, adapted in ICARIA
	961	Sensitive users impacted in the last relevant climate related event	RESCCUE, adapted in ICARIA
	963	Other services impacted in the last relevant climate related event	RESCCUE, adapted in ICARIA
	965	Households impacted in the last relevant climate related event	**ICARIA**
	969	Lessons learnt and learning loops	RESCCUE
	970	Insurance	RESCCUE

Table 5 shows the structure of the resilience assessment framework in the physical dimension. In this dimension, the resilience objectives aim to ensure that the natural assets (forests, green roofs, lakes, …) that provide the service are safe, properly maintained and monitored, autonomous and flexible, and prepared for CC challenges, namely in what regards to ecosystem services. This dimension also allows knowing the contribution of natural areas' assets to the resilience of both the respective service and of the city(ies) and region.

Table 5. Physical dimension for Natural areas in the ICARIA RAF assessment framework

Physical dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SAFE INFRASTRUCTURE			
Infrastructure assets criticality and protection	1900	Natural critical assets	RESCCUE, adapted in ICARIA
	1900b	Component importance	RESCCUE
	1900c	Critical natural areas mapping, review, and update	RESCCUE, adapted in ICARIA
	1901	Protective buffers mapping and information to the local authorities	RESCCUE, adapted in ICARIA
Infrastructure assets robustness	1902	Codes and standards for natural areas	RESCCUE, adapted in ICARIA
	1903a	Maintenance plan for natural areas	**ICARIA**
	1903	Maintenance of natural areas	**ICARIA**
	1903b	Monitoring program for natural areas	**ICARIA**
	1903c	Monitoring of ecosystem services in natural areas	**ICARIA**
	1903d	Monitoring of natural areas' condition	**ICARIA**

Table 5. Physical dimension for Natural areas in the ICARIA RAF assessment framework (cont.)

SAFE INFRASTRUCTURE (cont.)			
	1903e	Monitoring targets for natural areas	**ICARIA**
	1904	Natural areas out of service last year	**ICARIA**
	1905a	Ecosystem services provided last year	**ICARIA**
	1905b	Natural areas' condition last year	**ICARIA**
	1906	Coverage of expenditure in natural assets last year	RESCCUE, adapted in ICARIA
	1907	Time for restoration last year	RESCCUE
AUTONOMOUS AND FLEXIBLE INFRASTRUCTURE			
Infrastructure assets importance to and dependency on other services	1911	Cascading impacts	RESCCUE
	1912	Infrastructure of other services dependency on natural areas	RESCCUE
	1914	Dependency on infrastructures of other services	RESCCUE
	1914c	Level of dependency	RESCCUE
Infrastructure assets autonomy	1915	Autonomy from infrastructures of other services	RESCCUE
	1918	Water self sufficiency	**ICARIA**
	1919	Energy self-production	RESCCUE
Infrastructure assets redundancy	1920	Redundancy and easy access to natural areas	**ICARIA**
	1920b	Connection of natural areas	**ICARIA**
INFRASTRUCTURE PREPAREDNESS			
Contribution to the area's resilience	1923b	Greenhouse gas emission target	RESCCUE
	1924	Other contributions to city resilience	RESCCUE
Infrastructure assets exposure to climate change	1925	Level of exposure of natural areas to climate change scenarios	RESCCUE, adapted in ICARIA
	1926	Coverage of expenditure in natural areas for climate change scenarios	RESCCUE, adapted in ICARIA
	1927	Time for restoration for climate change scenarios	RESCCUE, adapted in ICARIA
Preparedness for climate change	1928	Implemented design solutions to address climate change mitigation and adaptation	**ICARIA**
	1928b	Planned design solutions to address climate change mitigation and adaptation	**ICARIA**
Preparedness for recovery and build back	1929a	Natural areas out of service in the last relevant event	**ICARIA**
	1929b	Ecosystem services provided in the last relevant event	**ICARIA**
	1929c	Natural areas' condition in the last relevant event	**ICARIA**
	1931	Coverage of expenditure in natural areas in the last relevant event	RESCCUE, adapted in ICARIA
	1932	Time for restoration in the last relevant event	RESCCUE

The detailed informative datasheets for the new metrics proposed for ICARIA are presented in annex C.

4.1.6 Outputs to the decision support system (DSS)

The RAF App provides a thorough and detailed assessment of the resilience of the city, region, and services, resulting in a comprehensive collection of data and several possible points of analysis are envisaged. The tree structure of the RAF allows for a structured collection of results, allowing the user to see the development opportunities and consolidated resilience aspects for each dimension (organisational, spatial, functional, or physical) or, within each dimension, for each service or objective, or within each objective, an insight into each resilience criterion is enabled.

Three different outputs to the DSS are proposed: a *summary report*; the results of a *pre-defined set of metrics*; the identification of the *metrics with low development level*.

A pre-defined *summary report* is a final output of the RAF app. This report highlights the most relevant graphs considering the structure down to the service level, as shown in **Figure 10**. Csv files containing the answers to the metrics and the development level are also provided.

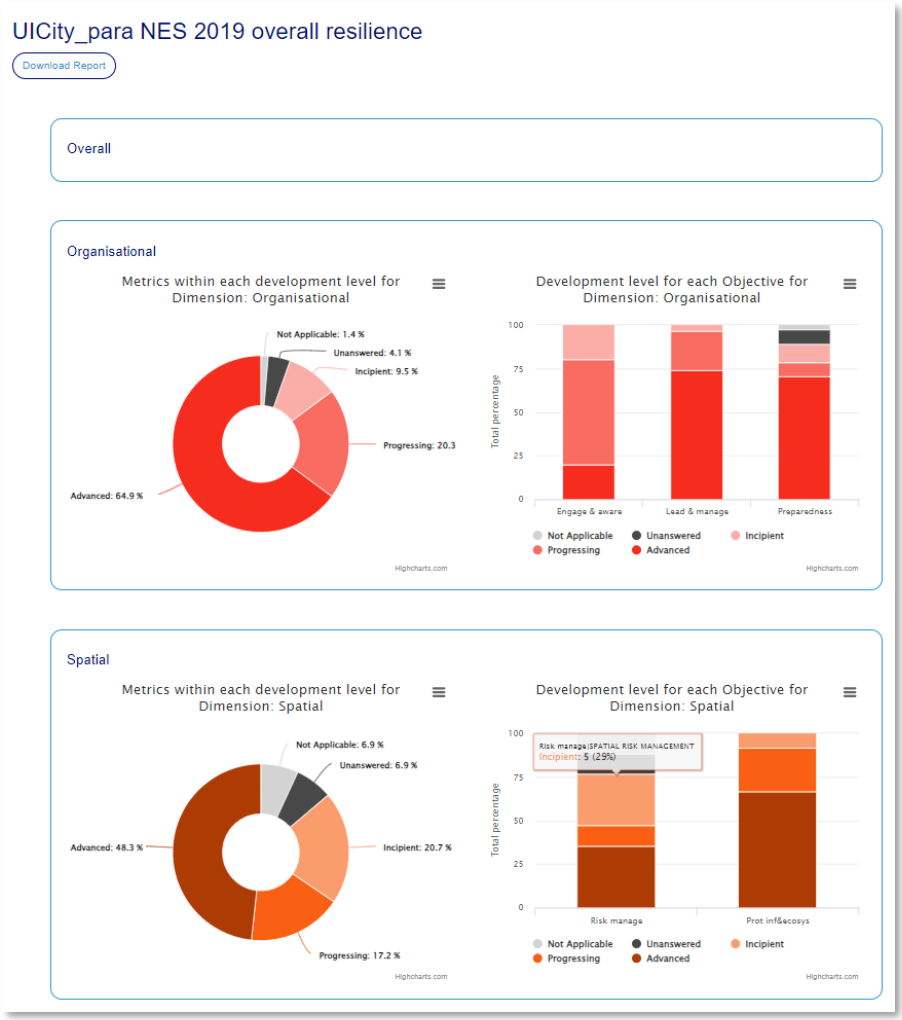


Figure 10. Example of a possible output to the DSS given by an overall report on the organizational and spatial dimensions from ICARIA RAF App

This report is proposed to serve as an output to the DSS. For more details, the user is invited to return to the ICARIA RAF App, and to navigate the Results page.

To complement this information, a *pre-defined set of metrics* was identified as an important output to the DSS, given their relevance for decision. The list of these metrics is presented in Table 6. For the functional and physical dimensions, examples are provided for the water service; similar metrics within the other services may also constitute an output to the DSS.

Table 6. Overview of the metrics from the ICARIA RAF that may output to the DSS

Organisational dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
LEADERSHIP AND MANAGEMENT			
Government decision-making and finance	15	Financial plan and budget for resilience, including contingency funds	UNISDR
Coordination and communication with stakeholders	17a	Multi-stakeholder collaboration	RESCCUE
Resilience engaged area	20	Hazard Assessment	RESCCUE
	21	Damage and loss estimation	RESCCUE
	23a	Plan for resilience	RESCCUE
	23b	Plan for resilience and Climate Change	RESCCUE
	26	Knowledge of resilience scenarios	UNISDR
	30b	Critical infrastructure plan overview	UNISDR
Preparedness for disaster response	33	Early warning	UNISDR
	40	Health care	UNISDR
	41	Food, shelter, staple goods, and fuel supply	UNISDR
Preparedness for recovery and build back	49	Post event recovery planning – pre-event	UNISDR
	50	Coordination of post event recovery	UNISDR
Spatial dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SPATIAL RISK MANAGEMENT			
Hazard and exposure for climate change	104	Potential population at risk of displacement for climate change scenarios	UNISDR
	105	Urban footprint at risk for climate change scenarios	RESCCUE
	105b	Natural areas at risk for climate change scenarios	**ICARIA**
	106	Economic activity at risk for climate change scenarios	UNISDR
Resilient Urban Development	109	Urban design solutions that increase resilience	UNISDR
	109b	Implemented design solutions to increase resilience	**ICARIA**
PROVISION OF PROTECTIVE INFRASTRUCTURES AND ECOSYSTEMS			
Protective infrastructures and ecosystems services	118	Existing protective infrastructure	UNISDR
	123	Trends in ecosystem services health	UNISDR
	125	Availability of green and blue infrastructures	**ICARIA**

Table 6. Overview of the metrics from the ICARIA RAF that may output to the DSS (cont.)

Functional dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
Under this line: detail for the water service; similar metrics apply in the other services			
SERVICE PLANNING AND RISK MANAGEMENT			
Resilience engaged service	306	Service strategic plan for resilience and Climate Change	RESCCUE
	307	Service financial plan and budget for resilience	RESCCUE
Risk management	313	Expected water supply interruptions, not caused by water quality, in the area, according to climate change scenarios	RESCCUE
	314	Expected water supply interruptions caused by water quality problems, in the area, according to climate change scenarios	RESCCUE
Reliable service	333*	Water losses last year	RESCCUE
Flexible service	334	Water uses	RESCCUE
	335	Water sources	RESCCUE
	338	Water sources' location	RESCCUE
AUTONOMOUS SERVICE			
Service inter-dependency with other services considering climate change	342	Critical services dependence on water service according to climate change scenarios	RESCCUE
	343	Water services autonomy from other critical services according to climate change scenarios	RESCCUE
SERVICE PREPAREDNESS			
Service preparedness for CC	352	Implemented measures to address climate change mitigation and adaptation	RESCCUE
Physical dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SAFE INFRASTRUCTURE			
Infrastructure assets criticality and protection	1301	Protective buffers mapping and information to the local authorities	RESCCUE
INFRASTRUCTURE PREPAREDNESS			
Contribution to the area's resilience	1321	Use of design solutions to improve the resilience of the area	RESCCUE
	1323	Greenhouse gas emissions	RESCCUE
	1324	Other contributions to the area's resilience	RESCCUE
Infrastructure assets exposure to climate change	1325	Level of exposure of critical infrastructure asset to climate change scenarios	RESCCUE
Preparedness for climate change	1328	Implemented infrastructural measures to address climate change mitigation and adaptation	RESCCUE

* Metric 333 is quite different in other services. For example, it addresses *Estimated undue inflows* into wastewater system, *Estimated undue wastes* into solid waste system or *Ecosystem services improvement* in natural areas.

To better support the selection of the actions to be taken to improve resilience, it is important to identify the weakest aspects of the assessment. The development level of every metric may also be sent to the DSS, and those with *low development level* (rated below or equal to 1) may be displayed, to support the decision.

4.1.7 Inclusion of new filters

To facilitate the use of the framework, it is important to allow the user to identify a subset of questions with the same underlying concern, or with a common input data source or output target. The RESCCUE RAF app already provided the ability to select only metrics for a particular dimension, service, objective, or criterion. It was also possible to view only metrics for a given level of relevance (*essential*, *complementary*, or *comprehensive*) or level of analysis (*strategic* or *tactical*).

Specifically for the purposes of ICARIA, the following subsets are also considered relevant:

- **M - Data from modelling**: metrics that either receive data produced in models or whose existence is relevant to modelling. The information the metric refers to might come from a database or service/infrastructure registry, or modelling (for example, water losses). This filter is especially relevant for modellers, to ensure common data formats, or for those willing to initiate modelling. The metrics can be based on data from a range of information sources and levels of complexity, allowing the framework to be used by cities with different levels of information maturity. The level of complexity increases depending on whether the metric is based on data commonly available in the city, on a procedure to be applied to such data, or, for example, on the results of complex monitoring campaigns, statistical data analysis or mathematical models. The model-based metrics are the most complex and require a significant amount of work by the city or region before the assessment methods can be applied. It was therefore considered relevant to identify the model-based metrics within the RAF to ensure user awareness of the effort required, or to take advantage of the modelling information in case the city or region already used mathematical models. The list of metrics in this subset is presented in Table 7.
- **CI - Related to critical infrastructure**: metrics that are specific to critical infrastructure or relate to a particular characteristic of critical infrastructure (e.g., for metrics related to sensitive users expected to be impacted). This filter provides an overview for users wishing to assess the resilience of critical infrastructure before applying the ICARIA RAT. The list of metrics in this subset is presented in Table 8.
- **SSH - Related to social sciences and humanities**: metrics that specifically refer to awareness and engagement, knowledge sharing and co-design of solutions. This filter is particularly relevant for users who are specifically interested in the societal aspects of resilience, rather than the governance, engineering, environmental or financial aspects. Aspects such as multi-stakeholder and community engagement, risk awareness, and participatory processes to streamline local planning and emergency preparedness are recognized as key factors supporting response, adaptive and transformative resilience capacities (Turchi et al., 2023). The list of metrics in this subset is presented in 4.1.4.
- **Sc - Associated with scenarios**: metrics related to the process of identifying, assessing, and planning for the climate change scenarios in the area, quantifying exposure, and vulnerability of urban and natural assets to them, preparing for their impacts (on people, buildings, the economic activities, natural areas and urban services and assets) and for mitigation and adaptation actions. The ICARIA RAF considers the time scale by integrating past experience (assessing the impact of a historical event with characteristics similar to the scenarios), the current situation (assessing the impact of everyday life, by assessing a year without historical events in the records), and future situation (regarding climate change scenarios). For users interested in planning for future resilience, for a given hazard or for setting actions, this filter is particularly relevant. The metrics might not all be determined for future

scenarios but might relate to knowledge regarding the scenarios or to a comparison with what is expected in the future. The list of metrics in this subset is presented in Table 9.

- **DSS - Relevant for the decision support system**: metrics that may be fed into the DSS, complementing the overall resilience assessment report and the highlights of lower resilience development. This filter is particularly relevant for users interested in an overview of resilience decision ingredients and in using the ICARIA DSS. The list of metrics in this subset is presented in 4.1.6.

A new layer of information has been added to the metrics, and a new filter was added to the RAF app to facilitate the quick identification of these subsets, as depicted in **Figure 11**.

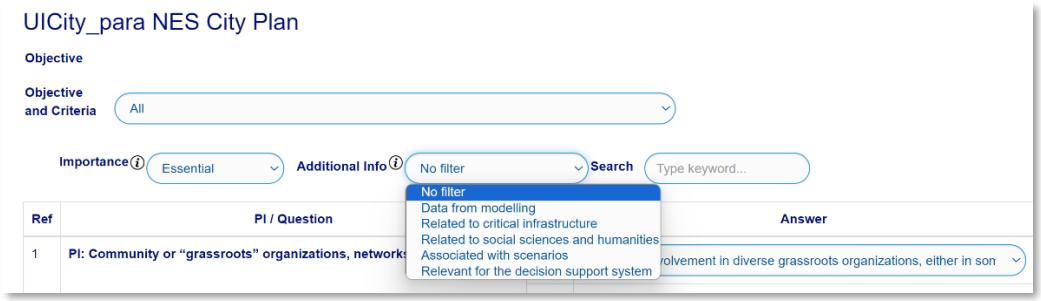


Figure 11. Filter in the ICARIA RAF App for identification of additional information in the metrics

Table 7. Overview of the metrics from the ICARIA RAF related to modelling activities

Organisational dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
LEADERSHIP AND MANAGEMENT			
Resilience engaged area	20	Hazard Assessment	UNISDR
	21	Damage and loss estimation	UNISDR
	26	Knowledge of resilience scenarios	UNISDR
	31	Cascading impacts	UNISDR
Spatial dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SPATIAL RISK MANAGEMENT			
General hazard and exposure mapping	101	Knowledge of exposure and vulnerability	UNISDR
	103	Potential population at risk of displacement for CC scenarios	UNISDR
Hazard and exposure for climate change	104	Potential population at risk of displacement for CC scenarios	UNISDR
	105	Urban footprint at risk for climate change scenarios	RESCCUE
	105b	Natural areas at risk for climate change scenarios	ICARIA
	106	Economic activity at risk for climate change scenarios	UNISDR
Impacts of climate related events	114	Human loss in the last events	RESCCUE
	115	Damages in urban footprint in the last events	RESCCUE
	115b	Damages in natural areas in the last event	ICARIA

Table 7. Overview of the metrics from the ICARIA RAF related to modelling activities (cont.)

Functional dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SERVICE PLANNING AND RISK MANAGEMENT			
Resilience engaged service	905e	Groundwater recharge	Beceiro (2021) & ICARIA
	905f	Temperature reduction for local climate regulation	Beceiro (2021) & ICARIA
	905g	Air quality improvement	Beceiro (2021) & ICARIA
	905h	Carbon sequestration and storage	Beceiro (2021) & ICARIA
	905i	Estimated infiltration enhancement	Beceiro (2021) & ICARIA
	905j	Estimated water retention enhancement	Beceiro (2021) & ICARIA
	905k	Estimated evapotranspiration improvement	Beceiro (2021) & ICARIA
Under this line: detail for the water service; similar metrics apply in the other services			
SERVICE PLANNING AND RISK MANAGEMENT			
Risk management	313	Expected water supply interruptions, not caused by water quality, in the area according to CC scenarios	RESCCUE
	314	Expected water supply interruptions caused by water quality problems, in the area according to CC scenarios	RESCCUE
	315	Expected water supply interruptions, not caused by water quality, for sensitive customers according to CC scenarios	RESCCUE
	316	Expected water supply interruptions caused by water quality problems, for sensitive customers according to CC scenarios	RESCCUE
	317	Expected water supply interruptions, not caused by water quality, for other services according to CC scenarios	RESCCUE
	318	Expected water supply interruptions caused by water quality problems, for other services according to CC scenarios	RESCCUE
	319	Expected water supply interruptions, not caused by water quality, for households according to CC scenarios	RESCCUE
	320	Expected water supply interruptions caused by water quality problems, for households according to CC scenarios	RESCCUE
	321	Expected total duration of water supply interruption, not caused by water quality problems, according to CC scenarios	RESCCUE
	322	Expected total duration of water supply interruption, caused by water quality problems, according to CC scenarios	RESCCUE
Reliable service	323	Water supply interruptions, not caused by water quality, in the area last year	RESCCUE
	324	Water supply interruptions caused by water quality problems, in the city last year	RESCCUE
	325	Water supply interruptions, not caused by water quality problems, for sensitive customers last year	RESCCUE
	326	Water supply interruptions caused by water quality problems, for sensitive customers last year	RESCCUE
	327	Water supply interruptions, not caused by water quality, for other services last year	RESCCUE

Table 7. Overview of the metrics from the ICARIA RAF related to modelling activities (cont.)

SERVICE PLANNING AND RISK MANAGEMENT			
Reliable service (cont.)	328	Water supply interruptions caused by water quality problems, for other services last year	RESCCUE
	329	Water supply interruptions, not caused by water quality, for households last year	RESCCUE
	330	Water supply interruptions caused by water quality problems, for households last year	RESCCUE
	333	Water losses last year	RESCCUE
SERVICE PREPAREDNESS			
Service preparedness for climate change	350	Knowledge of exposure and service vulnerability for CC scenarios	RESCCUE
Service preparedness for recovery and build back	359	Water supply interruption, not caused by water quality, in the city area in the last relevant climate related event	RESCCUE
	360	Water supply interruptions caused by water quality problems, in the city area, in the last relevant climate related event	RESCCUE
	361	Water supply interruptions, not caused by water quality problems, for sensitive customers in the last relevant climate related event	RESCCUE
	362	Water supply interruption caused by water quality problems, for sensitive customers in the last relevant climate related event	RESCCUE
	363	Water supply interruptions, not caused by water quality, for other services in the last relevant climate related event	RESCCUE
	364	Water supply interruptions caused by water quality problems, for other services in the last relevant climate related event	RESCCUE
	365	Water supply interruptions, not caused by water quality, for households in the last relevant climate related event	RESCCUE
	366	Water supply interruptions caused by water quality problems, for households in the last relevant climate related event	RESCCUE
Physical dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SAFE INFRASTRUCTURE			
Infrastructure assets robustness	1308	Real water losses	RESCCUE
	1309	Energy efficiency in pumping stations	RESCCUE
INFRASTRUCTURE PREPAREDNESS			
Infrastructure assets exposure to climate change	1325	Level of exposure of critical infrastructure asset to climate change scenarios	RESCCUE
	1327	Time for restoration for climate change scenarios	RESCCUE

Table 8. Overview of the metrics from the ICARIA RAF related to critical infrastructure

Spatial dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SPATIAL RISK MANAGEMENT			
General hazard and exposure mapping	101	Knowledge of exposure and vulnerability	UNISDR
PROVISION OF PROTECTIVE INFRASTRUCTURES AND ECOSYSTEMS			
Impacts of climate related events	118	Existing protective infrastructure	RESCCUE
	119	New protective infrastructure	RESCCUE
	120	Maintenance of protective infrastructure	RESCCUE
Protective infrastructures and ecosystems services	127	Critical services dependence of protective infrastructures and ecosystems under climate change scenarios	RESCCUE
Functional dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
Under this line: detail for the water service; similar metrics apply in the other services			
SERVICE PLANNING AND RISK MANAGEMENT			
Risk management	315	Expected water supply interruptions, not caused by water quality, for sensitive customers according to CC scenarios	RESCCUE
	316	Expected water supply interruptions caused by water quality problems, for sensitive customers according to CC scenarios	RESCCUE
Reliable service	325	Water supply interruptions, not caused by water quality problems, for sensitive customers last year	RESCCUE
	326	Water supply interruptions caused by water quality problems, for sensitive customers last year	RESCCUE
AUTONOMOUS SERVICE			
Service inter-dependency with other services considering CC	942	Critical services dependence on natural areas according to climate change scenarios	ICARIA (only for *natural areas*)
SERVICE PREPAREDNESS			
Service preparedness for climate change	350	Knowledge of exposure and service vulnerability for climate change scenarios	RESCCUE
Physical dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SAFE INFRASTRUCTURE			
Infrastructure assets criticality and protection	1300	Infrastructure critical assets	RESCCUE
	1300b	Component importance	RESCCUE
	1300c	Infrastructure critical assets mapping, review, and update	RESCCUE
	1300d	Exchange of information	RESCCUE
	1301	Protective buffers mapping and information to the city	RESCCUE
Infrastructure assets robustness	1305	Level of failure of critical assets last year	RESCCUE

Table 8. Overview of the metrics from the ICARIA RAF related to critical infrastructure (cont.)

AUTONOMOUS AND FLEXIBLE INFRASTRUCTURE			
Infrastructure assets redundancy	1320	Redundancy	RESCCUE
	1320b	Redundancy activation	RESCCUE
	1320c	Level of redundancy	RESCCUE
INFRASTRUCTURE PREPAREDNESS			
Infrastructure assets exposure to CC	1325	Level of exposure of critical infrastructure asset to climate change scenarios	RESCCUE
Preparedness for recovery and build back	1330	Level of failure of critical infrastructure asset in the last relevant event	RESCCUE

Table 9. Overview of the metrics from the ICARIA RAF related to scenarios

Organisational dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
COLLECTIVE ENGAGEMENT AND AWARENESS			
Citizens and communities' awareness and training	10	Validation of effectiveness of education	UNISDR
LEADERSHIP AND MANAGEMENT			
Resilience engaged area	23b	Plan for resilience and Climate Change	RESCCUE
	26	Knowledge of resilience scenarios	UNISDR
	31	Cascading impacts	UNISDR
City preparedness			
Preparedness for disaster response	37	Staffing / responder needs	UNISDR
Preparedness for climate change	97	Status when addressing contribution to CC (GHG emissions)	RESCCUE
	45	Knowledge of exposure and vulnerability for CC scenarios	UNISDR
Spatial dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SPATIAL RISK MANAGEMENT			
General hazard and exposure mapping	102	Scenarios and update process for risk information	RESCCUE
	103	Potential population at risk of displacement for CC scenarios	UNISDR
Hazard and exposure for climate change	104	Potential population at risk of displacement for CC scenarios	UNISDR
	105	Urban footprint at risk for climate change scenarios	RESCCUE
	105b	Natural areas at risk for climate change scenarios	ICARIA
	106	Economic activity at risk for climate change scenarios	UNISDR
Resilient urban development	107b	Land use plan monitoring and review	RESCCUE
	109b	Implemented design solutions to increase resilience	ICARIA
Impacts of climate related events	114	Human loss in the last events	RESCCUE
	115	Damages in urban footprint in the last events	RESCCUE

Table 9. Overview of the metrics from the ICARIA RAF related to scenarios (cont.)

SPATIAL RISK MANAGEMENT			
	115b	Damages in natural areas in the last event	ICARIA
	116	Economic Impact of the last events	RESCCUE
	117	Economic activities affected in the last events	RESCCUE
PROVISION OF PROTECTIVE INFRASTRUCTURES AND ECOSYSTEMS			
Protective infrastructures and ecosystems services	127	Critical services dependence of protective infrastructures and ecosystems under climate change scenarios	RESCCUE
	128	Autonomy from other services under climate change scenarios	RESCCUE
Functional dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
Under this line: detail for the water service; similar metrics apply in the other services			
SERVICE PLANNING AND RISK MANAGEMENT			
Risk management	312	Damage and loss estimation	RESCCUE
	313	Expected water supply interruptions, not caused by water quality, in the area according to CC scenarios	RESCCUE
	314	Expected water supply interruptions caused by water quality problems, in the area according to CC scenarios	RESCCUE
	315	Expected water supply interruptions, not caused by water quality, for sensitive customers according to CC scenarios	RESCCUE
	316	Expected water supply interruptions caused by water quality problems, for sensitive customers according to CC scenarios	RESCCUE
	317	Expected water supply interruptions, not caused by water quality, for other services according to CC scenarios	RESCCUE
	318	Expected water supply interruptions caused by water quality problems, for other services according to CC scenarios	RESCCUE
	319	Expected water supply interruptions, not caused by water quality, for households according to CC scenarios	RESCCUE
	320	Expected water supply interruptions caused by water quality problems, for households according to CC scenarios	RESCCUE
	321	Expected total duration of water supply interruption, not caused by water quality problems, according to CC scenarios	RESCCUE
	322	Expected total duration of water supply interruption, caused by water quality problems, according to CC scenarios	RESCCUE
AUTONOMOUS SERVICE			
Service inter-dependency with other services considering CC	942	Critical services dependence on natural areas according to climate change scenarios	ICARIA (only for *natural areas*)
	342	Critical services dependence on water service according to climate change scenarios	RESCCUE
	343	Water services autonomy from other critical services according to climate change scenarios	RESCCUE
SERVICE PREPAREDNESS			
Service preparedness for climate change	349	Existence of agreed climate change scenarios and alignment with the city climate change scenarios	RESCCUE
	353	Planned measures to address climate change mitigation and adaptation	RESCCUE

Table 9. Overview of the metrics from the ICARIA RAF related to scenarios (cont.)

Physical dimension			
OBJECTIVE / Criterium	**Metric ref.**	**Performance indicator**	**Source**
SAFE INFRASTRUCTURE			
Infrastructure assets robustness	1308	Real water losses	RESCCUE
	1309	Energy efficiency in pumping stations	RESCCUE
INFRASTRUCTURE PREPAREDNESS			
Infrastructure assets exposure to climate change	1325	Level of exposure of critical infrastructure asset to climate change scenarios	RESCCUE
	1326	Coverage of expenditure in infrastructure for climate change scenarios	RESCCUE
	1327	Time for restoration for climate change scenarios	RESCCUE

The complete list of metrics included in every subset is presented in Annex D.

4.1.8 Other updates

Several other updates were implemented to include the supplementary revisions required to meet ICARIA's scope, namely, to address forest fires, evaluate whether housing, tourism, multi-hazards, and other hazards (distinguish rainfall induced, fluvial or coastal flooding) were properly addressed. 10 metrics were adjusted. Depending on the metric, either the performance indicator's name, the question asked, or the list of possible answers were changed. 5 new metrics were added.

These aspects are also taken into consideration in the profile (**Figure 12**), in the adaptation of existing metrics or in the inclusion of new metrics.

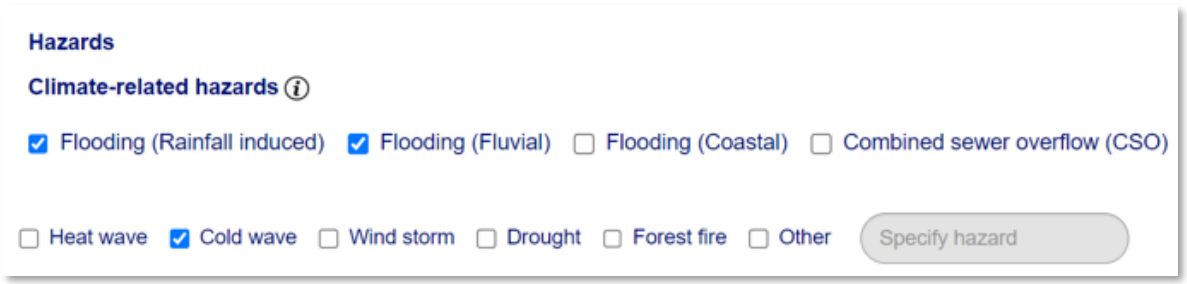


Figure 12. Climate related hazards in the ICARIA RAF App

Some examples of the adaptations made (e.g. in metrics 21 or 26, identified in italic bold) or of new metrics (e.g. metric 101b, 109b, or 1321), are presented in **Figure 13**. The list of all the revised or new metrics added to enlarge ICARIA's scope is included in Annex E.

21 - Damage and loss estimation (-)

Does risk assessment include estimations of damage and loss from potential disasters, based on current and future development changes ***(urban, population, tourism, green areas)?***

Dimension	Organisational
Subdimension	-
Resilience objective	Leadership and management
Criteria	Resilience engaged area
Source	UNISDR Scorecard D2.2.2 (adapted in RESCCUE and in ICARIA)
Importance	Essential
Level	Tactical
Metric type	Single choice

Development assessment rule	Development
Yes	**3**
Risk assessments focus mostly on spatial, physical assets at risk. Data is limited	**2**
There are plans to develop risk assessments	**1**
Risk assessments do not identify all risk areas or there are no plans to update them	**0**

26 – Knowledge of resilience scenarios (-)

Are there agreed scenarios for resilience (with relevant background information and supporting notes, updated at agreed intervals), setting out **area-wide exposure** and vulnerability from each hazard, **or multi-hazard**?

Dimension	Organisational
Subdimension	-
Resilience objective	Leadership and management
Criteria	Resilience engaged area
Source	UNISDR Scorecard D2.2.2 (adapted in RESCCUE and in ICARIA)
Importance	Essential
Level	Tactical
Metric type	Single choice

Development assessment rule	Development
Yes	**3**
A comprehensive suite of scenarios is available, but ***area-wide exposure*** and vulnerability are not available.	**2**
Some scenario information is available	**1**
No scenario information is available	**0**

101b - Knowledge of exposure and vulnerability to multihazards (-)

Existence of scenarios setting out area-wide exposure and vulnerability to multihazards

Dimension	Spatial
Subdimension	-
Resilience objective	Spatial risk management
Criteria	General hazard and exposure mapping
Source	ICARIA
Importance	Essential
Level	Tactical
Metric type	Single choice

Development assessment rule	Development
Comprehensive scenarios exist area-wide, for the "most probable" and "most severe" multihazard, updated in last 18 months and reviewed by a 3rd party.	3
Scenarios have shortcomings in terms of multihazard combinations, of coverage, when updated, level or thoroughness of review	2
Only a generalized notion of exposure and vulnerability, with no attempt systematically to identify impacts	1
No risk assessment	0

109b – Implemented design solutions to increase resilience (-)

Which of the following design solutions to increase resilience are implemented in the region?

Dimension	Spatial
Subdimension	-
Resilience objective	Spatial risk management
Criteria	Hazard and exposure for climate change
Source	ICARIA
Importance	Complementary
Level	Tactical
Metric type	Multiple choice

Please select one or more of the options provided as answers. Sum of the selected answers and a scale to 3 is made. In "other", some examples might be, among others: access to people with disabilities; creation of air ventilation corridors between buildings; water efficiency in internal water networks; overall energy efficiency of the buildings.

Development assessment rule	Development
Solar panels in most public buildings (over 60%)	1
Solar panels in many private buildings (over 30%)	1
Building insulation from external temperatures in most public buildings (over 60%)	1
Building insulation from external temperatures in many (over 30%) private buildings	1
Maintenance of existing water infiltration capacity in recent urban developments	1
Shadowing in pedestrian routes exposed to high solar radiation	1
Other	1
None	0

1321 – Use of design solutions to improve the *resilience of the area* (-)

The design of the infrastructure incorporate the use of the following solutions to improve the ***resilience of the area***

Dimension	Functional
Subdimension	Water supply
Resilience objective	Infrastructure preparedeness
Criteria	Contribution to the area's resilience
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Please select one or more of the options provided as answers. Sum of the selected answers and a scale to 3 is made.

Development assessment rule	**Development**
soakaways and porous pavement	**1**
underground parking garages used as holding tanks for storm water	**1**
parks that function as flood zones	**1**
green roofs	**1**
renewable energy generation	**1**
water reuse and recycling	**1**
Green areas	**1**
Shadowing	**1**
Public sprinklers	**1**
Protective walls against river or coastal high water levels	**1**
Control of vegetation growth in a buffer next to the facilities	**1**
Other	**1**
None	**0**

Figure 13. Examples of revised or new metrics to enlarge ICARIA RAF's scope

4.2 Critical infrastructure assessment (ICARIA RAT)

4.2.1 Conceptual analysis of EU-CIRCLE RAT

As mentioned in section 2.3, the EU-CIRCLE Resilience Assessment Tool is based on the assessment of the capacities of the critical infrastructures and entities. A similar definition of resilience is mentioned in the succeeding frameworks and, most importantly, in the IPCC, EU-Climate and CER Directives. Thus, the EU – CIRCLE Resilience Assessment Tool is still a viable way forward for implementing in similar studies.

4.2.2 Linking EU-CIRCLE RAT to CER Directive

In the CER Directive (Directive EU 2557/2022), as stated in section 2.1, resilience is defined as a critical entity's ability to prevent, protect against, respond to, resist, mitigate, absorb, accommodate, and recover from an incident. This directive also introduces several measures to enhance resilience. In Table 10 the measures of the CER Directive (Chapter 2.1.4) are mapped against the EU – CIRCLE RAT capacities. Some provide a direct link, whereas some others are closely related or are new, and are further developed in ICARIA RAT.

Table 10. EU-CIRCLE RAT and CER Directive alignment

Measures of the CER Directive	Resilience capacities | EU-CIRCLE RAT				
	Anticipatory	Absorptive	Coping	Restoring	Adapting
Prevent incidents from occurring	x				
Ensure adequate physical protection of their premises		x			
Respond to, resist and mitigate the consequences of incident			x		
Recover from incidents, duly considering business continuity				x	
Ensure adequate employee security management	x				x
Raise awareness	x				

Specifically, for each measure of the CER Directive (indicated by a direct transcript between "" below), the following alignments are given in Table 10:

a) "prevent incidents from occurring, duly considering disaster risk reduction measures and measures to adapt to climate change": there is a *direct link* with EU – CIRCLE RAT, as climate change should be an integral part of the risk assessment process.
b) "ensure adequate physical protection of their premises and critical infrastructure, duly considering, for example, fencing, barriers, perimeter monitoring tools and routines, detection equipment and access controls": this dimension assessment *is expanded* in the ICARIA RAT to include protective measures for people (employees and users of the critical assets) and physical assets, against climate change and extreme events (e.g. heatwaves, floods, wildfires, extreme winds).
c) "respond to, resist, and mitigate the consequences of incidents, duly considering the implementation of risk and crisis management procedures and protocols and alert routines": within EU – CIRCLE RAT, the coping dimension was *closely related* to the short-term response to the extreme event and crisis management procedures.
d) recover from incidents, duly considering business continuity measures and the identification of alternative supply chains, in order to resume the provision of the essential service: there is a *direct link* with EU-CIRCLE RAT, as the restorative capacities of EU-CIRCLE RAT directly addressed the climate business continuity element, which was a unique feature of EU-CIRCLE (Kazantzidou-Firtinidou, et al., 2019).
e) "ensure adequate employee security management, duly considering measures such as setting out categories of personnel who exercise critical functions, establishing access rights to premises, critical infrastructure, and sensitive information, setting up procedures for background checks": this is a *new dimension*. Additional provisions have been proposed in the ICARIA RAT, in particular on information security and on the avoidance of conflicts of interest, in the design and implementation of climate-related projects for critical assets.
f) "raise awareness about the measures referred to in points (a) to (e) among relevant personnel, duly considering training courses, information materials and exercises": there is a *direct link* with EU-CIRCLE RAT, as this has been a part of the initial framework, namely in the anticipatory and adaptive capacities of EU-CIRCLE.

4.2.3 Review existing resilience indicators

The ICARIA framework (Task 1.1) for identifying risk includes the building blocks for resilience capacities and accounts, among others, for the following: a) hazard characteristics, b) exposure, c) vulnerability and d) impacts (e.g. service levels). To not overestimate the importance of the said risk-related parameters in critical infrastructure, i.e., to avoid a bias in the risk assessment that could compromise the results validity, within the scope of the ICARIA RAT the EU – CIRCLE Resilience Assessment Tool was re-evaluated. The parameters linked only and exclusively to capacities were retained.

4.2.4 Complete RAT framework

Within the ICARIA project, a novel resilience categorization was followed, the "word ladder" approach (IAEA, 2015). This approach combines relative rating categories with narrative qualitative descriptions. It is a more sophisticated scaling of the qualitative rating, using descriptors or qualifiers to describe the resilience ratings, and allowing the use of expert judgement, a numerical value, etc.. In Table 11, the complete ICARIA RAT hierarchical characterization of the framework is depicted.

Table 11. Overview of the ICARIA RAT framework

Capacities	Category	Indicators
ANTICIPATORY	1.1. Number of hazards	1.1.1. Number of hazards related to asset (awareness)
	1.2. Quality / extent of mitigating features	1.2.1. Equipment and procedures for hazard mitigation exist
		1.2.2. Early warning system exists
	1.3. Risk Assessment	1.3.1. Risk Assessment
	1.4. Communication Systems / Information sharing	1.4.1. Plans of communication and information sharing between CI operators and public sector exist
		1.4.2. Communication system for communication and information sharing between CI operators and public sector exist
		1.4.3. Backup of communication system for communication and information sharing exist
	1.5. Learnability / training	1.5.1. Training system exist
		1.5.2. Number of trained people
		1.5.3. Training with other CI exist
	1.6 All hazards / threats	1.6.1 Integrated Governance Models
ABSORPTIVE	2.1 Protection	2.1.1 Physical protection / defense measures
	2.2. Vulnerability	2.2.1. Vulnerability assessment of asset to climate related hazards exist
	2.3. Resistance	2.3.3. Safety design standards for respective hazards are applied
		2.3.4. Regular maintenance of the asset is performed
	2.4. Robustness and redundancy	2.4.1. Asset backup exist
COPING	3.1. Response	3.1.1. Emergency plans under Climate Hazards (in the context of climate change) exists
		3.1.1. Business continuity plans under Climate Hazards (in the context of climate change) exists

Table 11. Overview of the ICARIA RAT framework (cont.)

Capacities	Category	Indicators
COPING	3.2. Availability of response	3.2.1. Cost of response
		3.2.2. Backup cost
		3.2.3 Response Means
	3.3. Interoperability with public sector	3.3.1. Procedures exist
		3.3.2. Communication system exist
		3.3.3. Joint action plans exist
RESTORATIVE	4.2. Recovery time	4.2.1. Recovery plan exist
		4.2.2. Time needed to recovery
	4.3. Economics of restoration	4.3.1. Cost of restoration availability
		4.3.4. Maintenance costs after hazard availability
		4.3.5. Cost of reputation provisions
		4.3.6. Insurance costs provisions
ADAPTIVE	5.1. Substitutability	5.1.1. Replacement of asset with other existing asset is possible
	5.2. Adaptability and flexibility	5.2.2. Climate Adaptation plan exist
	5.3. Impact / consequences reducing availability	5.3.1. Relocation of existing facilities is possible
		5.3.2. New investments take consider a climate change
		5.3.3. New facilities are built according to climate-ready standards
	5.4. Economics of adaptation	5.4.1. How many new clients can be reached by improving the service / climate adaptation policies
		5.4.2. Reputation is increased by implementing climate change adaptation options
		5.4.3. Decisions on adaptation adopt due to market forces
	5.5 Information Security	5.5.1 Climate Related Leakages

Given the tree structure of the ICARIA RAT, the indicators are aggregated into a final resilience indicator, using a simple and straightforward method that does not require additional end-user training, as shown in Table 12. The numerical value at the *indicator* level (scaled to 10) can be aggregated to quantify the resilience at the *Category* level (using a weighted averaging approach), aggregated again at the *Capacity* level (the five Capacity Indices) and finally producing the *Overall Resilience Index*. For the scope of ICARIA, each of the indicators and the higher level categories have been are given equal weight.

The final output of the ICARIA RAT is the Capacities Indices, which can provide an assessment of each resilience capacity (Anticipatory, Absorptive, Coping, Restorative, and Adaptive) in each application and the Overall Resilience Index, which can be used for an overall assessment of critical infrastructure resilience. This can be used as an output for decision making or in other policy making activities.

Table 12. Aggregation of results in the ICARIA RAT framework

Aggregation level		Aggregation method	Elicitation of weights
IV	Calculating Indicators from user provided values	Average value	Without weights
III	Calculating Category Index from Indicators	Sum of all simple weighted sums (equal weights as predefined)	End user prioritization input based on subject matter experts' opinion. Weight based sum of the indicators. In ICARIA, equal weights are used.
II	Calculating Resilience Capacities Indices from Category Indices		
I	Calculating Overall resilience index ORI from Capacities Indices		

4.2.5 Output to the decision support system (DSS)

The ICARIA RAT provides a detailed assessment of the resilience of critical infrastructures and entities, stemming from user feedback, resulting in a final resilience indicator and several possible views of the analysis:

a) The Overall Resilience Index of the critical infrastructures and critical entities;
b) The five individual Capacities Assessment.

This final output may be delivered to the DSS.

In this way, overall and individual resilience assessments of critical infrastructure and entities can be carried out, providing a landscape picture of the strengths and challenges faced by the CI in response to climate pressures. Within the scope of the project, proposed CCA / DRR (climate change adaptation /disaster risk reduction) interventions and technical solutions will be defined by the relevant stakeholders within the case studies and the communities of practice. These will be linked to specific resilience indicators, and their perceived changes will be used to inform "resilience-based", "risk-based" or cost-effectiveness analysis and prioritization studies.

As mentioned above, the structure of the ICARIA RAT allows the calculation of individual Capacity Indices in addition to the Overall Resilience Index. This allows potential users to identify targeted interventions to increase the lagging resilience Capacities of the examined CI.

As with any other set of intangible indicators, the values should be interpreted with caution and within a "comparative" scope between different interventions and solutions, which can be seen as a limitation of the ICARIA RAT. For this reason, the assumptions made by the users of the framework should be clearly identified and made available to users for future reference.

5 Resilience assessment platform

5.1 ICARIA shell

A shell was created to accommodate the resilience assessment platform, namely both resilience assessment tools, the ICARIA RAF App (holistic Resilience Assessment Framework) and the ICARIA RAT (critical infrastructure resilience assessment tool).

In Figure 14, the front page of the shell is presented. It can be found in **https://icaria.lnec.pt/**

Figure 14. ICARIA shell providing access to both resilience assessment tools

The shell uses a development framework DJANGO in Phyton, which includes tools to develop the database and associated software. The ICARIA RAF App and the RAT tool are nudged in the shell using html and javascript languages.

For the ICARIA RAF, access to the app is provided to the user by clicking on the lower side of the shell. The user must register to be able to access, namely, to have a username and a password to login to the app. To access the ICARIA RAF App**, a username and password were defined for reviewers**. These will be removed after the review process is finished. Similar username and passwords may be defined later, for any user wanting to access the ICARIA RAF app.

User: review_eu
Password: ICARIArevEU2024#
In case any difficulties arise, please contact rsbrito@lnec.pt.
(Registration is required before accessing the app through the email above)

The EU-CIRCLE Resilience Assessment Tool is provided without any registration through the following webpage. http://143.233.159.10:8003/icaria/questionnaire/

The user creates his studies and those are only accessible to the owner. Each tool administrator (LNEC, for the ICARIA RAF and Demokritus, for the ICARIA RAT) can see every created study.

5.2 ICARIA RAF App

Once the user is in the application, the next step is the creation of a new study. Studies are only available to the user that created them. During the creation of a new study for assessment, the user has to specify the dimensions to be assessed (organisational, spatial, functional and physical) and the services to be assessed (water, wastewater, storm water, waste, energy, mobility and natural areas) within the functional and physical dimensions (**Figure 15**). Subsequent tabs display the corresponding RAF structure for the selected dimensions and services.

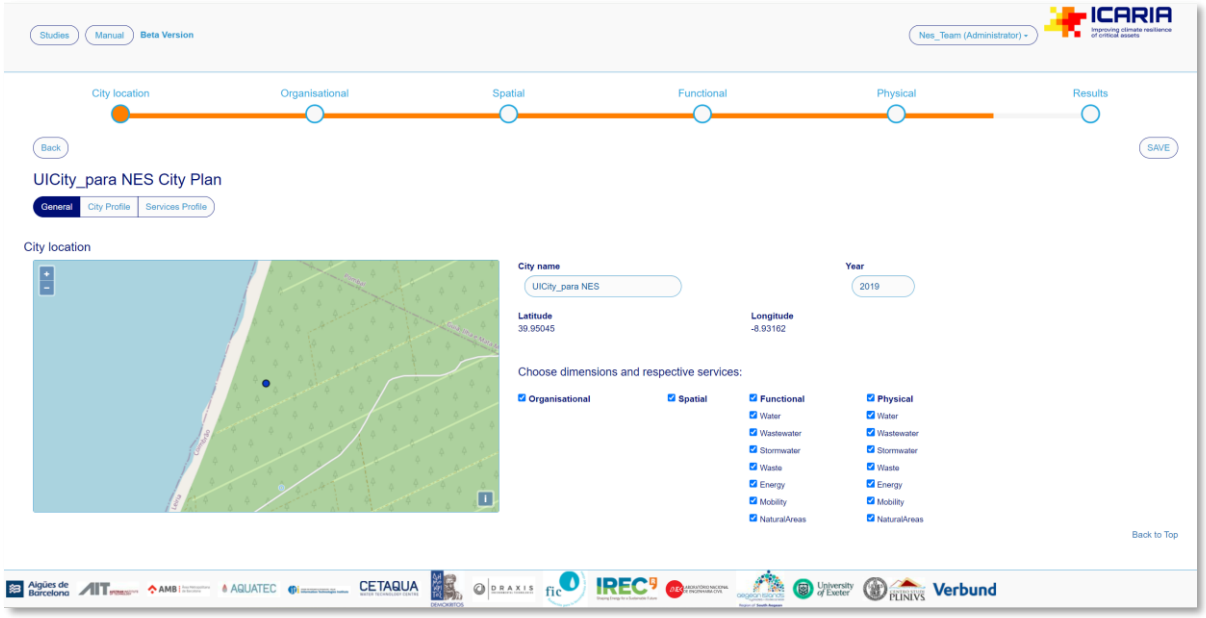


Figure 15. Front page of the ICARIA RAF App

A section on the profile of the area and services is available to provide context before entering the data for the resilience assessment.

As explained in 4.1.7, to facilitate and plan the input of responses to each metric, filters can be used to select a particular set of metrics, which may correspond to a particular criterion, objective, or level of relevance of a particular metric or additional information. The corresponding metrics are then displayed. Where applicable, the corresponding pre-defined responses and other inputs are also displayed (**Figure 16**).

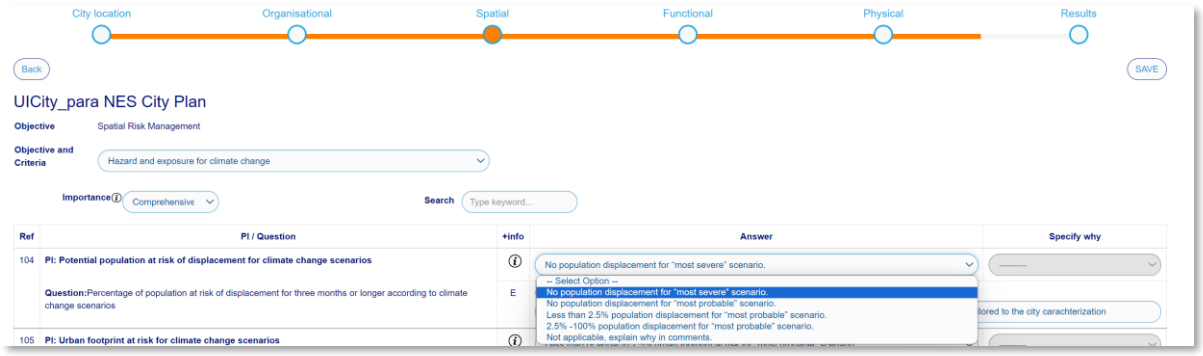
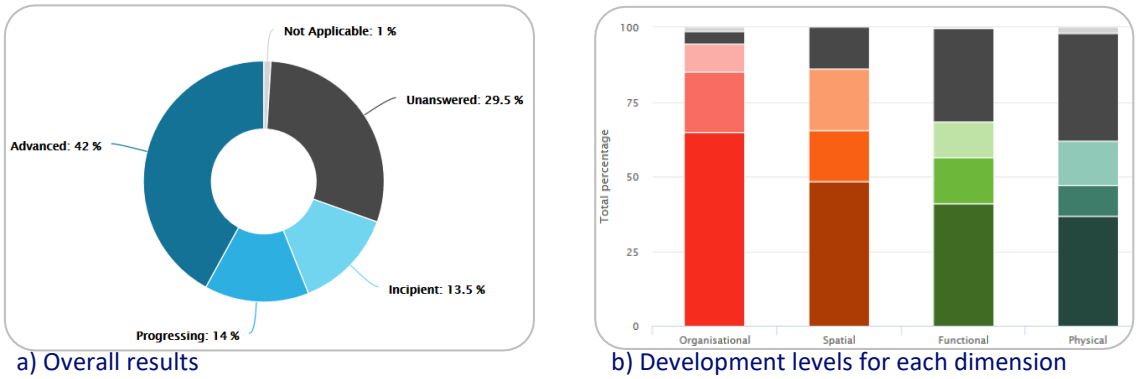


Figure 16. Example of data insertion in the ICARIA RAF App

The RAF app includes a module to explore the results graphically, allowing for user-friendly and dynamic visualization. This is possible for any level of aggregation, such as for the whole area (**Figure 17**); a given dimension, service (**Figure 18**), objective or criterium (**Figure 19**).

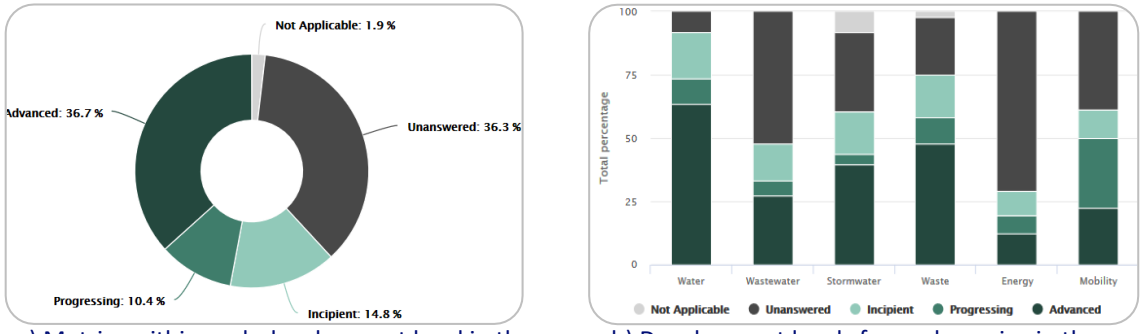
In each graph within the Results tab, the colour translates what is being assessed. The blue corresponds to the integrated assessments of the area; each different colour corresponds to a dimension (red for organisational, orange for spatial, light green for functional and petroleum green for physical), where darker shades relate to the percentage of metrics with an advanced level of development, medium shades to progressing and lighter shades to incipient. Dark grey refers to unanswered metrics and light grey to not applicable metrics.



a) Overall results

b) Development levels for each dimension

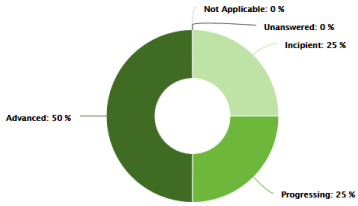
Figure 17. RAF App results: example of a regional integrated assessment



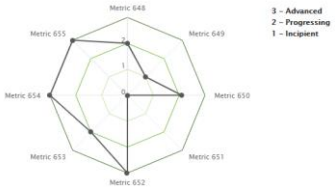
a) Metrics within each development level in the physical dimension

b) Development levels for each service in the physical dimension

Figure 18. RAF App results: example of a disaggregated assessment for a given dimension/service



a) Natural areas: metrics in the criterion "preparedness for CC"



b) Development level for each metric in this criterion"

Figure 19. RAF App results: example of a detailed assessment for Natural areas

Visual comparison between different assessment moments for the same region is possible. The RAF app makes it possible to monitor the progress of resilience in a given time window, both by visually comparing the diagnosis in different years and by identifying the progress through the variations in the percentages of each level of development.

The tool also allows visualizing the impact of the metrics affected by the resilience actions (in each criterion, objective, service or dimension) on the expected level of resilience development if the actions adopted by the city are implemented in a given planning horizon.

Finally, the tool provides an output in the form of a predefined summary report, highlighting the most relevant graphs.

In summary, as a tool that explores the RAF architecture, the ICARIA RAF App:

- assists in assessing, diagnosing and making decisions;
- monitors the progress of a region or service;
- compares different services;
- looks at how urban services contribute to making the area resilient to climate change;
- identifies opportunities for improvement to increase resilience;
- assists in the development of resilience plans;
- facilitates communication between the different stakeholders.

The ICARIA RAF app proved to be a valuable solution for capturing the resilience of a region or city, as a user-friendly tool that facilitates the input of metrics and provides easy visualization of results through graphical aggregation, as well as an initial identification of resilience strengths, gaps, and opportunities for improvement.

A detailed Manual is provided in the ICARIA RAF App for download.

5.3 ICARIA RAT web tool

The ICARIA resilience tool is designed as user-driven questionnaires in simple drop-down menus. The user provides two identification related parameters (**Figure 20**)

User name: identifies potential users
Scenario name: identification of resilience assessment

This information allows to a) create new scenario and b) retrieve old scenarios and assessments.

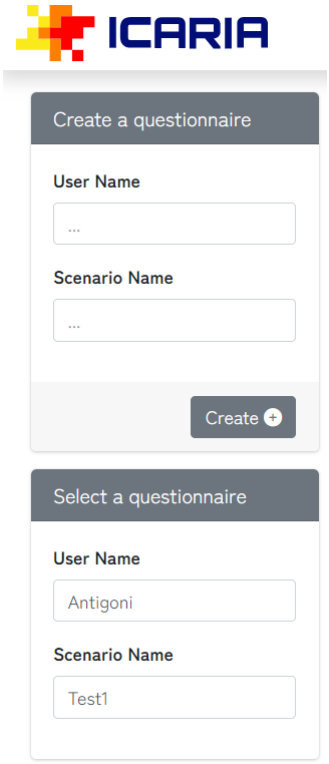


Figure 20. ICARIA RAT web-app user input menu

Afterwards, for each capacity, a new page opens and a series of drop down menus appear. For each question, the user inserts the information in the respective indicator category. For example, for the Adaptation capacity, **Figure 21** shows some of the questions to be answered (e.g. whether the adaptation of the asset under assessment is possible).

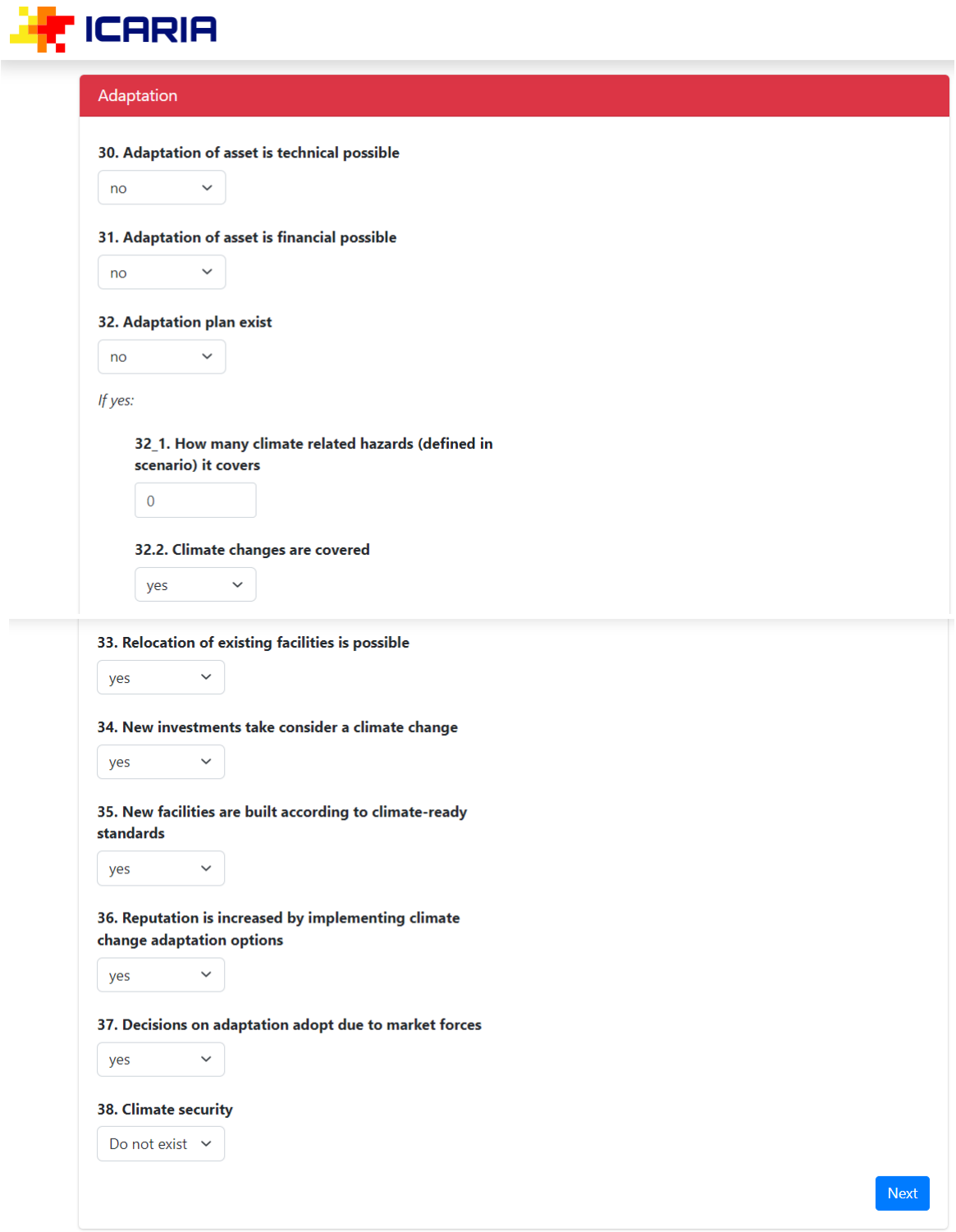


Figure 21. Capacity input menu example in the ICARIA RAT – Adaptive Capacity

After completion of the questionnaire, the outcomes are the individual Capacity Indices (e.g. for anticipation or absorption), and the Overall Resilience Index, as presented in **Figure 22**.

Figure 22. ICARIA RAT Capacity Indices and Overall Resilience Index

6 User guidance contribution

6.1 Overview

The resilience platform allows the user to decide whether to carry out a holistic assessment of resilience or an assessment that is focused on critical infrastructure.

In the case of a holistic resilience assessment, the user can decide whether to assess resilience at a regional or city level, or whether a specific assessment of selected urban services is required. In the first case, only the Organizational and Spatial levels might be assessed. In the second, the user might opt for Water supply, Wastewater, Stormwater, Solid waste, Energy, Mobility or Natural areas, for a group of these, or for all of them.

Regardless of the scope of the assessment, the RAF allows the assignment of a level of relevance to each metric: *essential*, *complementary,* and *comprehensive*, as mentioned above. Based on this feature, the assessment can be carried out first for the *essential* metrics when a city or region is just starting its resilience journey, then it can be deepened for the *complementary* metrics, and finally for the *comprehensive* metrics. The proposed RAF therefore allows for a tailored assessment of any region, city, or service, regardless of its resilience maturity. It supports the identification of a resilience development level for each dimension and for each service.

As this is a holistic assessment, and given the structure adopted, effective and robust implementation requires involving multiple parties in a collaborative process. Such a process allows for incorporating the best available information and different perspectives to be considered. It will also improve individual perceptions of the different resilience dimensions and interdependencies, and of the contribution of one's organization to the overall resilience. Coordination of the whole process is key to the successful implementation of the RAF. For this reason, the implementation of the proposed framework is based on a step-by-step approach.

In the case of critical infrastructure resilience assessment, many of these steps also ought to be taken.

The proposed step-by-step approaches will be validated in the sequential ICARIA activities with the case studies.

6.2 ICARIA RAF implementation step by step

Several actions are required to ensure the successful application of the RAF.

Overall, steps to be taken are shown in Figure 23 and detailed below. The main path is shown in darker arrows. Interactive connections are shown in lighter arrows.

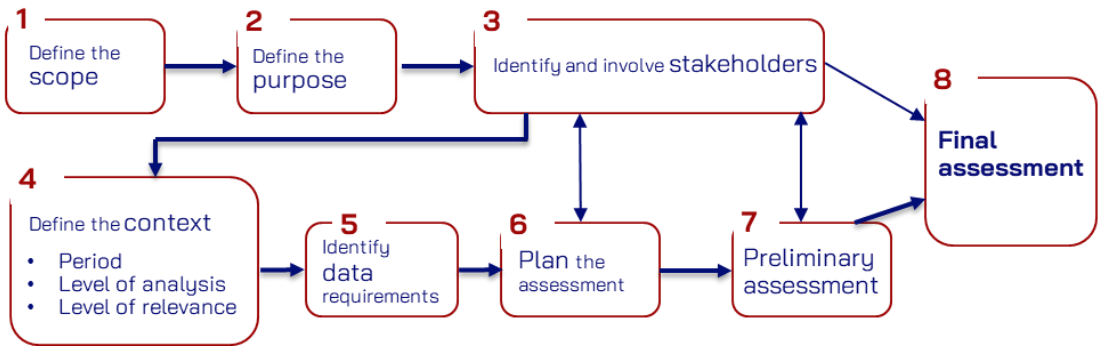


Figure 23. Step by step implementation of a holistic resilience assessment using the ICARIA RAF

Step 1. Define the scope of the assessment, i.e. the geographical area, hazards, services, and infrastructure to be covered. Fill in the city profile and/or the service(s) profile(s).

Step 2. Define the purpose of the assessment.

Step 3. Identify and involve stakeholders relevant for the scope and the purpose, assemble teams, assign responsibilities, and establish guiding principles for cooperation and coordination. Define a coordinator for the assessment.

Step 4. Define the context of the application, including the time period, the level of analysis (*strategic* or *tactical*) and the level of relevance (*essential*, *complementary* or *comprehensive*).

Step 5. For each dimension/service/type of infrastructure of the assessment, identify data requirements and select analytical tools to support the application; use the filter on Modelling (see Table 7) and on Scenarios (see Table 9) to identify the aspects that might require more complex data sets and previous work.

Step 6. Establish a programme for the application of the RAF by each member of the team, with assigned responsibilities and timeline.

Step 7. Perform the preliminary assessment and evaluate the results in the RAF App. This ought to be done by the coordination team and informed to the team members.

Step 8. Using the feedback from the team, prepare the final version of the assessment.

Feedback loops should be considered whenever applicable or deemed necessary by the team members.

Defining the purpose of the assessment (step 2) can be determining for the following steps.

Several examples of purposes (from A to E, listed below) are considered, and for those some recommendations are made.

Other purposes might be defined.

A: Perform an overall resilience assessment of a region, for a preliminary evaluation

For a preliminary evaluation of an overall resilience assessment of a region, there are a few details that should be noted and carried out. Steps to be taken are highlighted in Figure 24 and detailed below.

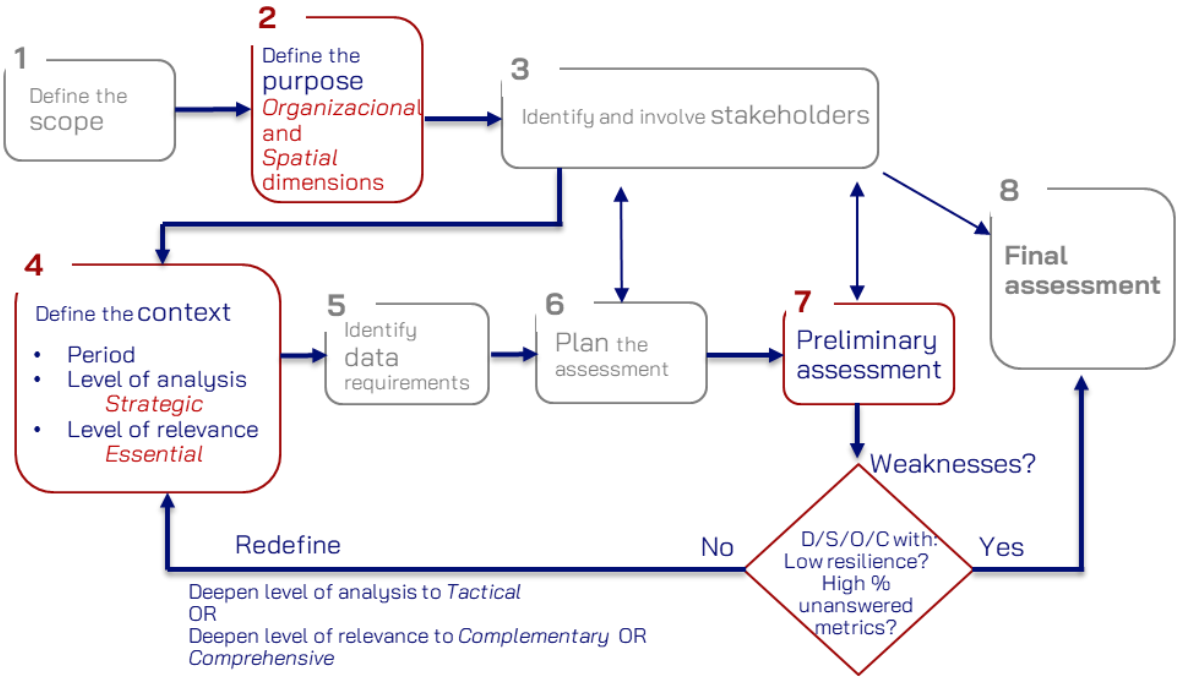


Figure 24. Step by step overall resilience assessment of a region

1. In step 2, define that the assessment will be made for the organizational and spatial dimensions.
2. In step 4, define the level of analysis as *strategic* and the level of relevance as *essential*.
3. In step 7, identify the dimensions/services/objectives/criteria (D/S/O/C) which have low resilience (lower than 1). These are your weaknesses.
4. Identify the dimensions/services/objectives/criteria (D/S/O/C) which have a high percentage of unanswered metrics (higher than 20%). These are also your weaknesses, as data was not available.
5. If you did not identify relevant weaknesses, consider going back to step 4 and defining the level of analysis as *tactical*.
6. After that, if you did not identify relevant weaknesses, consider going back to step 4 and defining the level of relevance as *complementary.*
7. After that, if you did not identify relevant weaknesses, consider going back to step 4 and defining the level of relevance as *comprehensive.*

B: Compare the evolution of resilience between 2019 and 2024

To compare the evolution of resilience for the same area our service(s) in a given time frame (e.g. from 2019 to 2024), there are also some details that should be noted and carried out. Steps to be taken are highlighted in Figure 25 and detailed below.

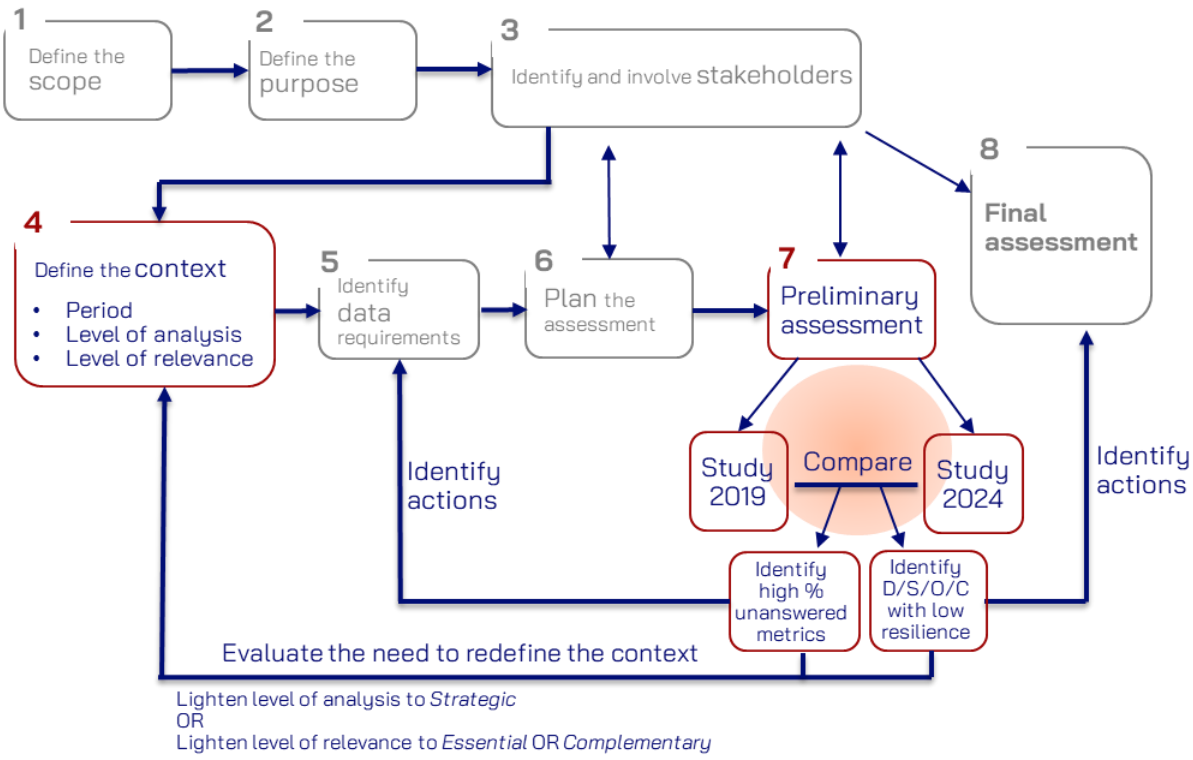


Figure 25. Step by step comparison of resilience in a given time frame

1. In step 7, create a study for 2019 and answer, for the situation in 2019, to the set of metrics/ level of analysis /level of relevance considered appropriate in previous steps; if data was not available for some, leave them unanswered.
2. Copy the study and name it 2024 and, for the situation in 2024 (to the same set of metrics/ level of analysis /level of relevance), correct the metrics that changed over time.
3. Compare both studies in the Results page.
4. Identify the dimensions/services/objectives/criteria (D/S/O/C) which resilience improved.
5. Identify the dimensions/services/objectives/criteria (D/S/O/C) which resilience decreased.
6. Identify the metrics with low development level (1 or lower) in 2024, for the criteria with an overall lower level. Identify actions to be taken to improve such metrics.
7. Identify the unanswered metrics in 2024, for the criteria with an overall greater percentage of unanswered metrics. Identify actions to be taken to collect such data.
8. For 6 and 7, evaluate whether most low development level/unanswered metrics are *comprehensive* or *complementary*, or *tactical*, meaning that perhaps the level of relevance or analysis was too

advanced/detailed for the resilience status of the area under assessment. If so, go back to step 2 and redefine the level of relevance or the level of analysis.

C: Compare resilience to different hazards

To compare the resilience of an area or service to different hazards, comparative studies can also be prepared. Steps to be taken are highlighted in Figure 26 and detailed below.

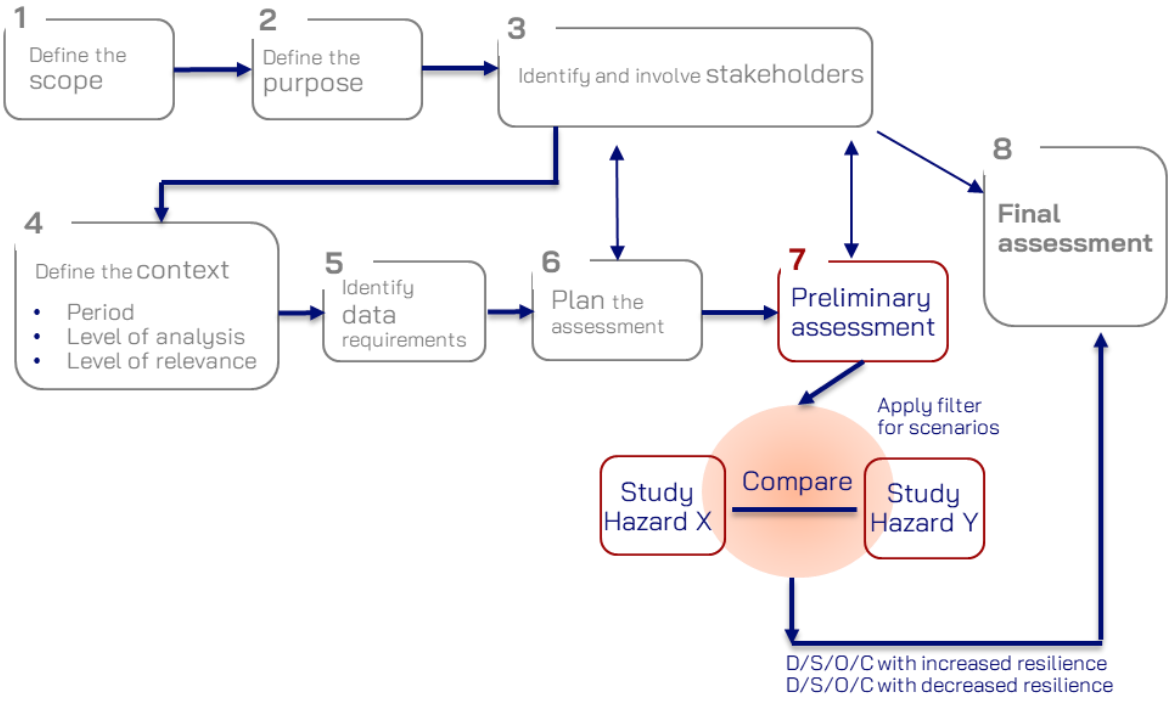


Figure 26. Step by step comparison of resilience to different hazards

1. In step 7, create a study for Hazard X and answer to the set of metrics/ level of analysis /level of relevance considered appropriate in previous steps; if data was not available for some, leave them unanswered.
2. Copy the study and name it Hazard Y, apply the filter for Scenarios (see Table 9) and correct the metrics that change for Hazard Y.
3. Compare both studies in the Results page.
4. Identify the dimensions/services/objectives/criteria (D/S/O/C) which resilience improved from Hazard X to Hazard Y.
5. Identify the dimensions/services/objectives/criteria (D/S/O/C) which resilience decreased from Hazard X to Hazard Y.

D: Compare how resilience changes when different actions are taken

That RAF App can also be used to compare possible changes in resilience in the case specific actions are put in place. Again, comparative studies can be prepared. Steps to be taken are highlighted in Figure 27 and detailed below.

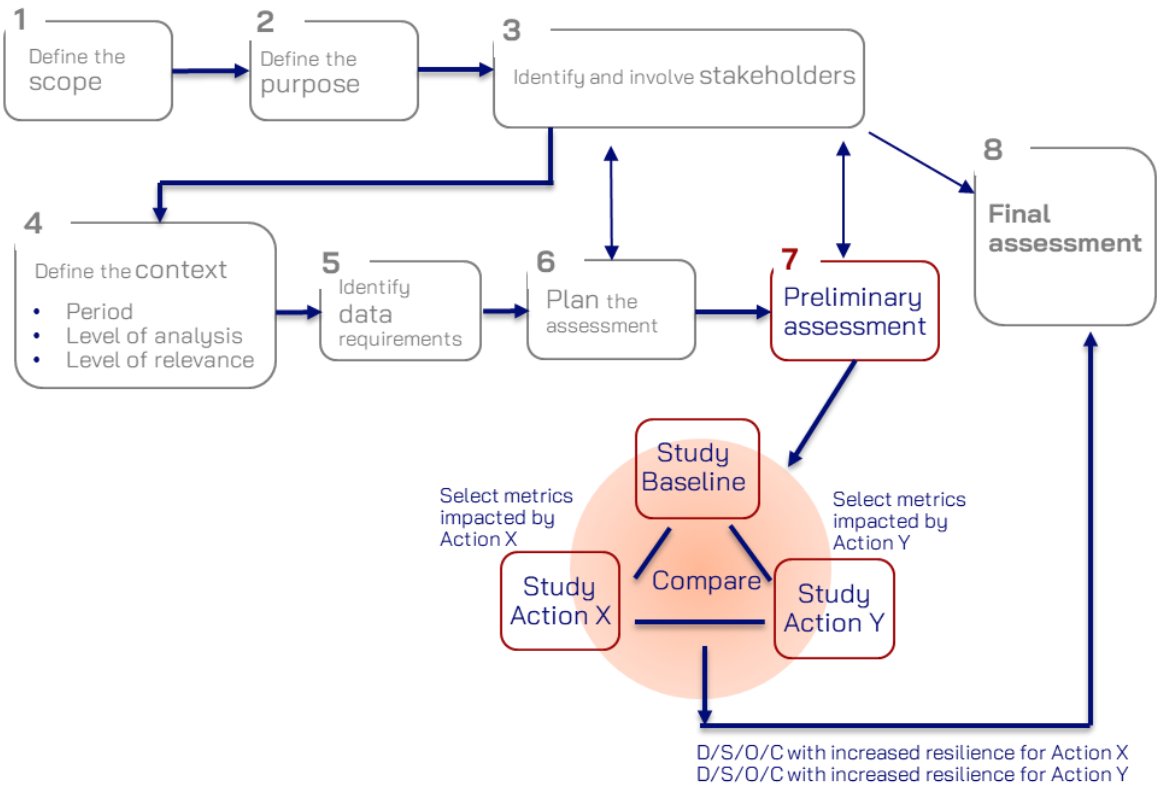


Figure 27. Step by step comparison of resilience when faced with different actions

1. In step 7, create a baseline study (for business as usual, with no actions implemented) and answer to the set of metrics/ level of analysis /level of relevance considered appropriate in previous steps; if data was not available for some, leave them unanswered.
2. Copy the study and name it Action X. Depending on the type of action, select the objective/criteria most impacted with such type of action, and correct the metrics that change if action X is implemented.
3. In the Action X study, apply the filter for Scenarios (see Table 9) and correct the metrics that change if action X is implemented.
4. Copy the study and name it Action Y. Repeat the procedure applied for Action X.
5. Compare the studies X and Y, one by one, with the Baseline study, in the Results page.
6. Identify the dimensions/services/objectives/criteria (D/S/O/C) which resilience improved with any Action.
7. Identify the dimensions/services/objectives/criteria (D/S/O/C) which resilience improved specifically with Action X.
8. Identify the dimensions/services/objectives/criteria (D/S/O/C) which resilience improved specifically with Action Y.
9. Compare the overall resilience improvement between Actions X and Y, in the Results page.

E: Overall resilience of critical infrastructure (CI)

That RAF App can be used to assess if there is an overall resilience problem with critical infrastructure (or service), so as the user can be directed to the RAT tool in such case. Steps to be taken are highlighted in Figure 28 and detailed below.

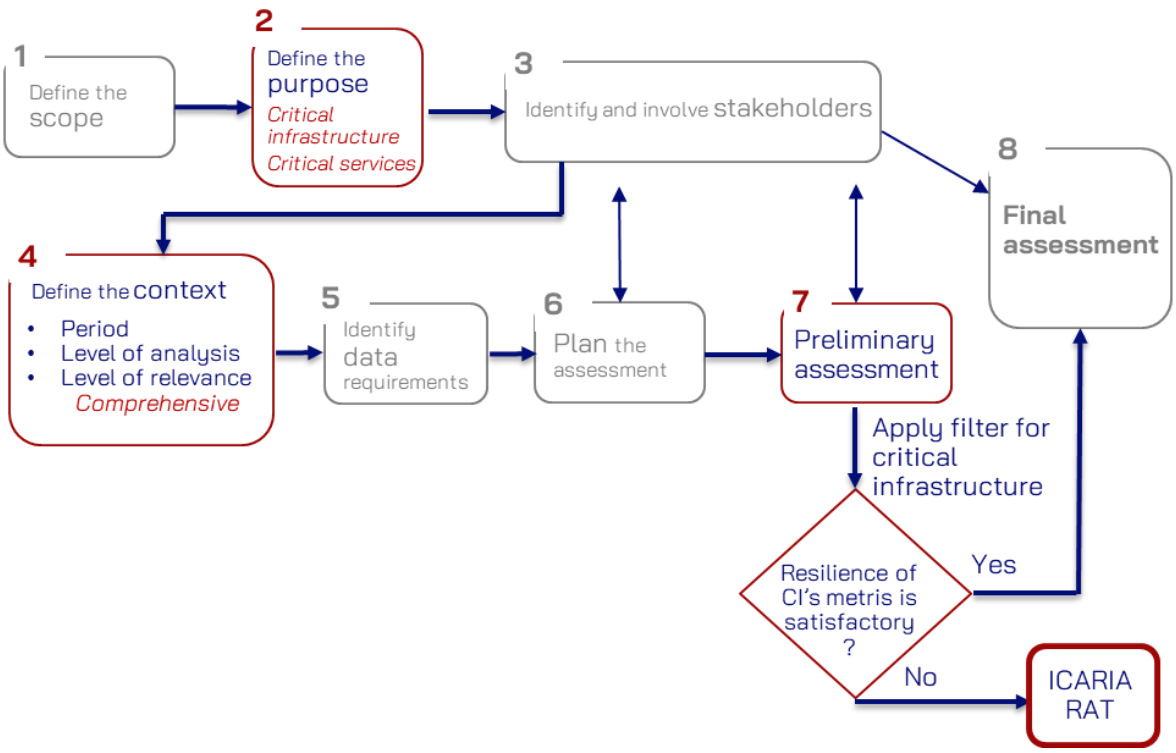


Figure 28. Step by step assessment of overall resilience of critical infrastructure

1. In step 2, define that the assessment will be made for the metrics regarding critical infrastructure. Define which services the critical infrastructure refers to.
2. In step 4, define the level of relevance as *comprehensive*.
3. In step 7, apply the filter for critical infrastructure (see Table 8).
4. In the Results page, assess the overall resilience for these metrics.
5. If the result in not satisfactory, go to the ICARIA Shell and proceed to the ICARIA RAT, for a detailed analysis of the resilience of critical infrastructure.

6.3 ICARIA RAT implementation step by step

The following guideline presents a step-by-step guidance for potential implementation of the ICARIA RAT within a more generic CI assessment framework:

Step 1 *Identify the Resilience Assessment Team*, the people that will be involved in the process of answering the questions and the indicators.

Step 2 *Contextualise the Resilience Assessment*. Put into context the following questions:

1. Resilience for what – identify the disturbance, which is a Climatic Hazard (CH), including current and future climate change (Layer 1)
2. Resilience of what – identify the context, which is the Critical Infrastructure (CI), their networks and interdependencies (Layer 2)
3. Disaster risks and impacts (Layer 3)
4. Capacities of critical infrastructure (Layer 4)
5. Asset properties associated with Critical Infrastructure and Climate Hazards (contributes to Layers 1, 2 and 3)
6. Resilience parameters (contributes to Layers 3 and 4)

Step 3 Determine the existing operational resilience and climate adaptation *local legislative and operational environment*.

Step 3a: Analyse existing CCA / DRR frameworks considering the CI of interest and/or generic local/regional/national response frameworks and obtain related information that could be useful for the scope of the resilience assessment.

Step 3b: Identify existing levels of “acceptable risk” and “acceptable resilience”.

Step 4 [Optional]: *Frame stakeholder collaborative environment*.

In the case that multiple stakeholders participate in the assessment, establish the collaborative framework and process.

Step 5 *Data collection* from diverse sources.

Collect data from multiple sources (climate, CI, CI operation, potential impacts, historic events post action reports, etc) that will help frame the resilience assessment.

Step 6 *Prepare different tools*.

Prepare the ICARIA - RAT and potentially other tools that could be needed for conducting the analysis (e.g. wildfire, flood)

Step 7 *Multi-hazard assessment*.

Conduct a multi-hazard assessment to obtain an initial understanding of a) present and future levels of critical hazard thresholds for the operation of the CI, and b) critical assets for the business continuity of the CI.

Step 8 Identify *CI assets* and characterize them.

Quantify their exposure to analysed multi-hazards.

Characterize their resilience capacities and their criticality in business continuity.

Step 9 Conduct *Risk and Resilience Assessment*.

Apply the ICARIA-RAT using the data collected in the previous steps and stakeholder feedbacks.

Step 10 *Assessment of risk and resilience* quantifiable results

Gather stakeholder feedback on the obtained results, comparison against acceptable levels of resilience and risk.

Identify capacities that could be prioritised for improvement, and potential solutions and interventions.

Step 11 *Re-evaluate CI asset resilience* based on proposed interventions / adaptive measures.

Step 12 Report *Results and Recommendations*.

7 Final remarks

The ICARIA's resilience assessment method extended existing frameworks and tools, to support structured assessment of urban or regional resilience to climate change, both holistically and specifically for critical infrastructure. Replication was inherent in the method, as it is based on previous European projects, although it has been extended to support ICARIA's objectives and case studies. Due to its flexibility to be tailored, it can be used by any region, city, organization, or utility that wishes to carry out a resilience assessment or develop an action plan with this scope and focus, regardless of its level of resilience maturity.

Both the ICARIA RAF and the ICARIA RAT are flexible frameworks that allow for including additional dimensions, such as social or economic, and other objectives, criteria, and metrics related to the services already addressed. As demonstrated by the inclusion of the CER Directive innovative aspect in the ICARIA RAT and the natural areas as a service in the ICARIA RAF, they can also be strengthened by the inclusion of other concerns or services such as telecommunications, education, or health. Consideration of other hazards, such as earthquakes, or other risks, is another area for development. These developments are encouraged to be incorporated into the platform, given the user-friendliness of the ICARIA RAF and RAT applications. Additionally, through the link with the DSS it is expected that it may contribute and facilitate an informed decision on the best solutions to build resilience. Testing of the ICARIA platform with the case studies will provide an opportunity for refinement and improvement of the frameworks and tools.

Given that it will be freely available, there is significant potential for the platform to be used in the near future. Combined with the identified possible developments of the framework, shell and tools, there is also a potential for academic research on the ICARIA resilience methodologies. Considering also the internationally recognised concerns about urban and regional resilience and the challenges of climate change, and the numerous potential users involved, a wider interest in the ICARIA Resilience Assessment Platform is expected from regional, city and service managers, consultants, academics, and researchers.

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Annex A: Data Management Statement

Table 13. Data used in preparation of ICARIA Deliverable 3.2

Dataset name	Format	Size	Owner and re-use conditions	Potential Utility within and outside ICARIA	Unique ID
RESCCUE RAF	Framework and document	-	LNEC	Used as a basis for ICARIA RAF	-
RESCCUE RAF App	Web app tool	-	LNEC	Used as a basis for ICARIA RAF App	-
EU-CIRCLE RAT	Framework and excel file	-	DEMOKRITUS	Used as a basis for ICARIA RAT	

Table 14. Data produced in preparation of ICARIA Deliverable 3.2

Dataset name	Format	Size	Owner and re-use conditions	Potential Utility within and outside ICARIA	Unique ID
ICARIA RAF	Framework and document	-	LNEC	Can be accessed in D3.2 and in ICARIA RAF app	
ICARIA RAF App	Web-based tool	-	LNEC	Can be accessed in the ICARIA Resilience Assessment Platform Register is mandatory	
ICARIA RAT framework and tool	Web-based tool	-	DEMOKRITUS	Can be accessed in the ICARIA Resilience Assessment Platform	
ICARIA Resilience Assessment Platform	Web-based shell	-	LNEC	Can be accessed in https://icaria.lnec.pt/	

Annex B: ICARIA RAF assessment framework

Organisational dimension

Table 15. Resilience assessment framework: organisational dimension

OBJECTIVE Criterion PI		PI unit[1]	Changes in ICARIA
Obj.O1 - COLLECTIVE ENGAGEMENT AND AWARENESS			
Citizens and communities engagement			
1	Community or "grassroots" organizations, networks and training	(-)	Adapted
2	Civil society links	(-)	Adapted
3	Engagement of vulnerable groups of the population	(-)	
4	Citizen engagement techniques	(-)	Adapted
5	Use of mobile and e-mail "systems of engagement" to enable citizens to receive and give updates before and after a disaster	(-)	Adapted
Citizens and communities awareness and training			
6	Public education and awareness	(-)	
7	Training delivery	(-)	
8	Drills	(-)	
9	Social networks	(-)	Adapted
10	Validation of effectiveness of education	(-)	Adapted
Obj.O2 LEADERSHIP AND MANAGEMENT			
Government decision-making and finance			
12	Consultative planning process	(-)	
13	Planning approval process	(-)	Adapted
14	Public finances	(-)	Adapted
15	Financial plan and budget for resilience, including contingency funds	(-)	Adapted
Coordination and communication with stakeholders			
16	Co-ordination with other government bodies	(-)	Adapted
17a	Multi-stakeholder collaboration	(-)	Adapted
17b	Access and use of digital services	(-)	Adapted
17c	Collaboration mechanisms	(-)	Adapted
Resilience engaged area			
18	Master Plan making and implementation	(-)	Adapted
19	Master Plan monitoring and review	(-)	Adapted

[1] (-) means without unit or dimensionless

OBJECTIVE Criterion PI		PI unit[1]	Changes in ICARIA
20	Hazard Assessment	(-)	
21	Damage and loss estimation	(-)	Adapted
22	Shared understanding of infrastructure risk	(-)	
23a	Plan for resilience	(-)	Adapted
23b	Plan for resilience and Climate Change	(-)	
23c	Plan integration in the City(ies) Master Plan	(-)	Adapted
23d	External support for the resilience plan	(-)	Adapted
24	Robustness of resilience plan	(-)	Adapted
25	Resilience Plan monitoring and review	(-)	
26	Knowledge of resilience scenarios	(-)	Adapted
27	Data sharing	(-)	Adapted
28	Integration	(-)	Adapted
29	Organization, coordination and participation	(-)	
30a	Critical infrastructure as a priority	(-)	Adapted
30b	Critical infrastructure plan overview	(-)	Adapted
31	Cascading impacts	(-)	Adapted
32	Learning from others	(-)	Adapted
Obj.O3 CITY PREPAREDNESS			
Preparedness for disaster response			
33	Early warning	(-)	
34	Reach of warning	(-)	
35	Communications	(-)	Adapted
36	Event management plans	(-)	Adapted
37	Staffing / responder needs	(-)	
38	Equipment and relief supply needs	(-)	
39a	Definition of human resources, equipment and supply needs, and availability of equipment	(-)	
39b	Existence of agreements	(-)	
40	Health care	(-)	
41	Food, shelter, staple goods and fuel supply	(-)	Adapted
42	Interoperability and interagency working	(-)	
43a	Existence of civil society focal points for citizens	(-)	
43b	Social connectedness and neighbourhood cohesion	(%)	

OBJECTIVE Criterion PI		PI unit[1]	Changes in ICARIA
Preparedness for climate change			
44a	Management plans for climate-related events	(-)	Adapted
44b	Implementation of management plans for climate-related events	(-)	
44c	Management plans for climate-related events monitoring and review	(-)	
45	Knowledge of exposure and vulnerability for climate change scenarios	(-)	Adapted
97	Status when addressing contribution to climate change	(-)	Adapted
98	Commitment with mitigation of climate change effects	(%)	Adapted
99	Planning for mitigation of climate change effects	(-)	Adapted
Preparedness for recovery and build back			
49	Post event recovery planning – pre event	(-)	
50	Coordination of post event recovery	(-)	Adapted
51a	Lessons learnt	(-)	
51b	Learning loops	(-)	
52	Insurance	(-)	Adapted
53a	Damage and loss post-event assessment	(-)	Adapted
53b	Current post-event assessment system	(-)	
Availability and access to basic services			
54	Water supply in the urban area	(%)	Adapted
70	Water supply in the rural area	(%)	**NEW**
55	Wastewater collection in the urban area	(%)	Adapted
71	Wastewater collection in the rural area	(%)	**NEW**
55ba	Wastewater treatment in the urban area	(-)	Adapted
72	Wastewater treatment in the rural area	(-)	**NEW**
56a	Urban waste collection in the urban area	(%)	Adapted
73	Urban waste collection in the rural area	(%)	**NEW**
56b	Urban waste treatment	(-)	
57	Urban electrical energy network	(%)	Adapted
58	Urban electrical energy alternative source	(%)	Adapted
59	Urban gas energy network	(%)	
60	Urban mobility accessing collective transportation	(%)	Adapted
61	Urban cycling mobility	(-)	Adapted

Spatial dimension

Table 16. Resilience assessment framework: spatial dimension

OBJECTIVE Criterion PI		PI unit	Changes in ICARIA
Obj.S1 SPATIAL RISK MANAGEMENT			
General hazard and exposure mapping			
100a	Presentation process for risk information	(-)	Adapted
100b	Update process for risk information	(-)	
101	Knowledge of exposure and vulnerability	(-)	
101b	Knowledge of exposure and vulnerability to multihazards	(-)	**NEW**
102	Scenarios and update process for risk information	(-)	
103	Damage and loss estimation	(-)	Adapted
Hazard and exposure for climate change			
104	Potential population at risk of displacement for climate change scenarios	(-)	
105	Urban footprint at risk for climate change scenarios	(-)	
105b	Natural areas at risk for climate change scenarios	(-)	**NEW**
106	Economic activity at risk for climate change scenarios	(-)	
Urban development			
107a	Land use zoning and planning	(-)	
107b	Land use plan monitoring and review	(-)	
107c	Land use zoning implementation	(-)	Adapted
108	New urban development	(-)	
108b	New rural development	(-)	**NEW**
109	Design solutions that increase resilience	(-)	Adapted
109b	Implemented design solutions to increase resilience	(-)	**NEW**
109c	Planned design solutions to increase resilience	(-)	**NEW**
110	Building codes and standards	(-)	Adapted
111	Application of building codes	(-)	
Impacts of climate-related event			
114	Human loss in the last events	(-)	
115	Damages in urban footprint in the last events	(%)	
115b	Damages in the natural areas in the last events	(%)	**NEW**
Obj.S2 PROVISION OF PROTECTIVE INFRASTRUCTURES AND ECOSYSTEMS			
Protective infrastructures and ecosystems services			
118	Existing protective infrastructure	(-)	Adapted
119	New protective infrastructure	(-)	Adapted
120	Maintenance of protective infrastructure	(-)	
121	Awareness and understanding of ecosystem services / functions	(-)	Adapted

OBJECTIVE Criterion PI		PI unit	Changes in ICARIA
122	Awareness of the role that assets providing ecosystem services play in the area's resilience	(-)	Adapted
123	Trends in ecosystem services health	(-)	
124	Maintenance of ecosystem services	(-)	
124b	Effective protection of protected areas	(-)	**NEW**
125	Availability of green and blue infrastructures in the city	(m^2/inhabitant)	Adapted
126	Integration of green and blue infrastructure into city policy and projects	(-)	
Dependence and autonomy regarding other services considering climate change			
127	Critical services dependence of protective infrastructures and ecosystems under climate change scenarios	(-)	Adapted
128	Autonomy from other services under climate change scenarios	(-)	Adapted
129	Transboundary environmental issues	(-)	Adapted

Functional dimension

Table 17. Resilience assessment framework: functional dimension for the Water Service

Structure for Wastewater, Stormwater, Solid waste, Energy and Mobility are similar (for example, metric 304 in Water Suply will be similar to 404 in Wastewater service, and to 504 in storm water service, etc)
Structure for Natural Areas is presented in section 4.1.5

OBJECTIVE Criterion PI		PI unit	Changes in ICARIA
Obj.FW1 WATER SERVICE PLANNING AND RISK MANAGEMENT			
Strategic planning			
300	Water service strategic plan making and implementation	(-)	
301	Plan alignment with the City(ies) Master Plan(s)	(-)	Adapted
302	Service plan monitoring and review	(-)	
303	Exchange of information to the city(ies)	(-)	Adapted
304	Land use zoning compliance	(-)	
Resilience engaged service			
305	Resilience in water service strategy and alignment with the strategic plan	(-)	Adapted
306	Service resilience plan and Climate Change	(-)	Adapted
307	Service financial plan and budget for resilience	(-)	
308	Water service business continuity	(-)	
309	Co-ordination with other water services in the area	(-)	Adapted
310	Learning from other water services	(-)	

OBJECTIVE Criterion PI		PI unit	Changes in ICARIA
Risk management			
311	Risk information related to the water service	(-)	Adapted
312	Damage and loss estimation	(-)	
313	Expected water supply interruptions, not caused by water quality problems, in the area according to CC scenarios	(% area)	Adapted
314	Expected water supply interruptions caused by water quality problems, in the area according to CC scenarios	(% area)	Adapted
315	Expected water supply interruptions, not caused by water quality problems, for sensitive customers according to CC scenarios	(% sensitive customers)	
316	Expected water supply interruptions caused by water quality problems, for sensitive customers according to CC scenarios	(% sensitive customers)	
317	Expected water supply interruptions, not caused by water quality problems, for other services according to CC scenarios	(% customers other services)	
318	Expected water supply interruptions caused by water quality problems, for other services according to CC scenarios	(% customers other services)	
319	Expected water supply interruptions, not caused by water quality problems, for households according to CC scenarios	(% households)	
320	Expected water supply interruptions caused by water quality problems, for households according to CC scenarios	(% households)	
321	Expected total duration of water supply interruption, not caused by water quality problems, according to CC scenarios	(Days)	
322	Expected total duration of water supply interruption, caused by water quality problems, according to CC scenarios	(Days)	
Reliable service			
325	Water supply interruptions, not caused by water quality problems, in city area last year	(% area)	Adapted
324	Water supply interruptions caused by water quality problems, in the area last year	(% area)	Adapted
325	Water supply interruptions, not caused by water quality problems, for sensitive customers last year	(% sensitive customers)	
326	Water supply interruptions caused by water quality problems, for sensitive customers last year	(% sensitive customers)	
327	Water supply interruptions, not caused by water quality problems, for other services last year	(% customers other services)	
328	Water supply interruptions caused by water quality problems, for other services last year	(% customers other services)	
329	Water supply interruptions, not caused by water quality problems, for households last year	(% households)	
330	Water supply interruptions caused by water quality problems, for households last year	(% households)	

OBJECTIVE Criterion PI		PI unit	Changes in ICARIA
331	Total duration of water supply interruption, not caused by water quality problems, last year	(Days)	
332	Total duration of water supply interruption, caused by water quality problems, last year	(Days)	
333	Water losses last year	(m^3/(km.day))	Adapted
Flexible service			
334	Water uses	(% drinking water)	
335	Water sources	(-)	Adapted
338	Water sources location	(-)	Adapted
339	Service management	(-)	
Obj.FW2 AUTONOMOUS WATER SERVICE			
Service importance to the city			
340	Stakeholders perception	(-)	
341	Cascading impacts	(-)	
Service inter-dependency with other services considering climate change			
342	Critical services dependence on water service according to CC scenarios	(-)	Adapted
343	Water services autonomy from other critical services according to CC scenarios	(-)	Adapted
Obj.FW3 WATER SERVICE PREPAREDNESS			
Service preparedness for disaster response			
344	Water service event management plans	(-)	Adapted
345	Water services interdepartmental collaboration for emergency	(-)	
346	Water services early warning	(-)	Adapted
347	Water service drills	(-)	
Service preparedness for climate change			
348	Service commitment with mitigation of CC effects	(% reduction GHG)	
349	Existence of agreed CC scenarios and alignment with the city CC scenarios	(-)	Adapted
350	Knowledge of exposure and service vulnerability for CC scenarios	(-)	
351	Service planning for adaptation to CC	(-)	
352	Implemented measures to address CC mitigation and adaptation	(-)	Adapted
353	Planned measures to address CC mitigation and adaptation	(-)	Adapted
354	Equipment capacity of the service	(-)	
355	Staffing capacity of the service	(-)	
Service preparedness for recovery and build back			
356	Water service CC recovery planning	(-)	
357	Water service damage and loss post-event assessment	(-)	
358	Current post-event assessment system	(-)	

OBJECTIVE Criterion PI		PI unit	Changes in ICARIA
359	Water supply interruption, not caused by water quality problems, in the city area in the last relevant climate-related event	(% area)	Adapted
360	Water supply interruptions caused by water quality problems, in the city area, in the last relevant climate-related event	(% area)	Adapted
361	Water supply interruptions, not caused by water quality problems, for sensitive customers in the last relevant climate-related event	(% sensitive customers)	
362	Water supply interruptions caused by water quality problems, for sensitive customers in the last relevant climate-related event	(% sensitive customers)	
363	Water supply interruptions, not caused by water quality problems, for other services in the last relevant climate-related event	(% customers other services)	Adapted
364	Water supply interruptions caused by water quality problems, for other services in the last relevant climate-related event	(% customers other services)	
365	Water supply interruptions, not caused by water quality problems, for households in the last relevant climate-related event	(% households)	
366	Water supply interruptions caused by water quality problems, for households in the last relevant climate-related event	(% households)	
367	Total duration of water supply interruption, caused by water quality problems, in the last relevant climate-related event	(Days)	
368	Total duration of water supply interruption, caused by water quality problems in the last relevant climate-related event	(Days)	
369	Water service lessons learnt and learning loops	(-)	
370	Insurance	(-)	

Physical dimension

Table 18. Resilience assessment framework: physical dimension for the water infrastructure

Structure for Wastewater, Stormwater, Solid waste, Energy and Mobility are similar (for example, metric 1304 in Water Suply will be similar to 1404 in Wastewater service, and to 1504 in storm water service, etc)
Structure for Natural Areas is presented in section 4.1.5

OBJECTIVE Criterion PI		PI unit	Changes in ICARIA
SAFE WATER INFRASTRUCTURE			
Infrastructure assets criticality and protection			
1300a	Water infrastructure critical assets	(-)	
1300b	Component importance	(-)	
1300c	Water infrastructure critical assets mapping, review and update	(-)	

OBJECTIVE Criterion PI		PI unit	Changes in ICARIA
1300d	Exchange of information	(-)	Adapted
1301	Protective buffers mapping and information to the local authorities	(-)	Adapted
Infrastructure assets robustness			
1302	Codes and standards for infrastructure	(-)	
1303	Maintenance of infrastructure	(-)	
1304	Water pump failures last year	(Days)	
1304b	Water mains bursts last year	(No./100 km)	
1304c	Water service connections bursts last year	(No./1000 connections)	
1304d	Hydrant failures last year	(No./1000 hydrants)	
1304e	Power failures last year	(Days)	
1304f	Water quality last year	(%)	
1305	Level of failure of critical infrastructure asset last year	(%)	
1306	Coverage of expenditure in infrastructure last year	(-)	
1307	Time for restoration last year	(Days)	
1308	Real water losses	(m^3/(km.day))	
1309	Energy efficiency in pumping stations	(kWh/m^3.100m)	
1310	Pollution prevention	(% appropriate sludge disposal)	
AUTONOMOUS AND FLEXIBLE WATER INFRASTRUCTURE			
Infrastructure assets importance to and dependency on other services			
1311	Cascading impacts	(-)	
1312	Infrastructure of other services dependency on water infrastructure	(-)	
1314	Dependency on infrastructures of other services	(-)	
1314c	Level of dependency	(% customers affected)	
Infrastructure assets autonomy			
1315	Autonomy from infrastructures of other services	(% infrastructure)	
1316	Level of autonomy	(% customers)	
1316b	Autonomy activation	(-)	
1316c	Autonomy period	(Days)	
1317	Water storage autonomy	(Days)	
1319	Energy self-production	(%)	
Infrastructure assets redundancy			
1320	Redundancy	(-)	
1320b	Redundancy activation	(-)	
1320c	Level of redundancy	(% customers)	

OBJECTIVE Criterion PI		PI unit	Changes in ICARIA
WATER INFRASTRUCTURE PREPAREDNESS			
Contribution to city resilience			
1321	Use of design solutions to improve the resilience of the area	(-)	Adapted
1323b	Greenhouse gas emission target	(-)	Adapted
1324	Other contributions to city resilience	(-)	Adapted
Infrastructure assets exposure to climate change			
1325	Level of exposure of critical infrastructure assets to the most probable scenario	(-)	
1326	Coverage of expenditure in infrastructure for most probable scenario	(%)	
1327	Time for restoration for most probable scenario	(Days)	
Preparedness for climate change			
1328	Implemented infrastructural measures to address CC mitigation and adaptation	(-)	
1328b	Planned infrastructural measures to address CC mitigation and adaptation	(-)	
Preparedness for recovery and build back			
1329	Water pump failures in the last relevant event	(Days)	
1329b	Water service mains failures in the last relevant event	(No./100 km)	
1329c	Water service connection mains bursts in the last relevant event	(No./1000 connections)	
1329d	Hydrant bursts in the last relevant event	(No./1000 hydrants)	
1329e	Power failures in the last relevant event	(Days)	
1329f	Water quality compliance in the last relevant event	(%)	
1330	Level of failure of critical assets in the last relevant event	(%)	
1331	Coverage of expenditure in infrastructure in the last relevant event	(%)	
1332	Time for restoration in the last relevant event	(Days)	

Annex C: ICARIA RAF new metrics for Natural Areas

Spatial dimension

103 - Damage and loss estimation (-)

Damage and loss aspects taken into account by risk assessments for key identified scenarios

Dimension	Spatial
Subdimension	-
Resilience objective	Spatial risk management
Criteria	General hazard and exposure mapping
Source	UNISDR Scorecard D2.2.2, adapted in ICARIA
Importance	Essential
Level	Tactical
Metric type	Multiple choice

Please select one or more of the options provided as answers. Sum of the selected answers and a scale to 3 is made.

Development assessment rule	Development
a) Changes in economic activities	1
b) Population at risk	1
c) Urban footprint at risk	1
d) Economic activities at risk	1
e) Natural areas at risk (green, blue or other, either natural or nature-based areas)	1
f) none of the above	0

105b – Natural areas at risk for climate change scenarios (%)

Percentage of natural areas at risk, according to climate change scenarios

Dimension	Spatial
Subdimension	-
Resilience objective	Spatial risk management
Criteria	Hazard and exposure for climate change
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Natural areas include green (e.g. forests, crops, urban parks, green roofs), blue (e.g. lakes, rivers) or other areas (e.g. ripples), either natural or nature-based

Development assessment rule	Development
No natural area at risk for "most severe" scenario	3
No natural area at risk for "most probable" scenario	2
Less than or equal to 2.5% of the natural area at risk for "most probable" scenario	1
Between 2.5% and 100% of the natural area at risk for "most probable" scenario	0

115b – Damages in natural areas in the last event (-)

Impact on natural areas of the last climate related event, with similar or harsher climate variables than the most probable scenario

Dimension	Spatial
Subdimension	-
Resilience objective	Spatial risk management
Criteria	Impacts of climate-related events
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Natural areas include green (e.g. forests, crops, urban parks, green roofs), blue (e.g. lakes, rivers) or other areas (e.g. ripples), either natural or nature-based

Development assessment rule	Development
0%	3
Less or equal to 0.5%	2
Between 0.5 and 2.5%	1
More or equal to 2.5%	0

121 - Awareness and understanding of ecosystem services/functions (-)

Beyond just an awareness of the natural assets, is there an understanding of the functions that this natural capital provides?

Dimension	Spatial
Subdimension	-
Resilience objective	Provision of protective infrastructures and ecosystems
Criteria	Protective infrastructures and ecosystems services
Source	UNISDR Scorecard P5.1, adapted in ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Examples of functions or ecosystem services: mitigation of flooding, heat waves and land slides, provision of food, water, raw material or medicinal resources, habitat services, carbon sequestration, air regulation, pollination, aesthetic value, mental and physical health benefits and cultural services.

Development assessment rule	Development
The key stakeholders are familiar with the term ecosystem services and understand the economic value all of the functions provided by key local natural assets	3
The key stakeholders understand the majority of the functions provided by key local natural assets. These are not economically valued	2
There is an incomplete awareness and understanding of the functions delivered by the natural capital	1
Very little / no awareness of this topic	0

122 - Awareness of the role that assets providing ecosystem services play in the area's resilience (-)

Assets that provide ecosystem services are specifically identified and managed as critical assets?

Dimension	Spatial
Subdimension	-
Resilience objective	Provision of protective infrastructures and ecosystems
Criteria	Protective infrastructures and ecosystems services
Source	RESCCUE, adapted in ICARIA
Importance	Essential
Level	Tactical
Metric type	Single choice

This metric conditions the metric S23 and S24.

Development assessment rule	Development
Yes	3
Partially	1.5
No	0

124b - Effective protection of protected areas (-)

Are protected areas duly protected?

Dimension	Spatial
Subdimension	-
Resilience objective	Provision of protective infrastructures and ecosystems
Criteria	Protective infrastructures and ecosystems services
Source	ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

A scale to 3 is made.

Development assessment rule	Development
Key stakeholders understand its functions	1
The area is managed as a critical asset	1
General good condition is maintained	1
Annual monitoring is ensured by a defined set of indicators	1
None of the above	0

129 - Transboundary environmental issues (-)

Is there awareness of ecosystem services being provided to the area from natural capital beyond its administrative borders? Are agreements in place with neighbouring administrations to support the protection and management of these assets?

Dimension	Spatial
Subdimension	-
Resilience objective	Provision of protective infrastructures and ecosystems
Criteria	Dependence and autonomy regarding other services considering climate change
Source	UNISDR Scorecard P5.3, adapted in ICARIA
Importance	Comprehensive
Level	Strategic
Metric type	Single choice

-

Development assessment rule	Development
There is awareness of its importance and plans are in place	3
There is awareness of its functions and there have been some early discussions with neighbouring administrations.	2
There is some awareness of its functions, but no actions have taken place	1
Little to no awareness	0

Figure 29. Detailed informative datasheets for new metrics in the spatial dimension for Natural Areas

Functional dimension

900a - Natural areas governance (-)

Are all natural areas assigned to a specific management entity or department?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Strategic planning
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Development assessment rule	Development
Yes	3
Partially. More than one organization is responsible, but an articulation process is in place	2
Partially. More than one organization is responsible.	1
No	0

900b - Integration of natural areas in policy and development projects (-)

Are natural areas being promoted on major urban developments and infrastructure projects through policy?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Strategic planning
Source	Beceiro (2021) and ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Development assessment rule	Development
Yes	3
Partially, in concentrated areas or neighbourhoods	1.5
No	0

901a - Mitigation of perceived social detrimental effects of natural areas (-)

Identify the aspects taken into account in the planning for new natural areas:

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Strategic planning
Source	ICARIA
Importance	Essential
Level	Tactical
Metric type	Multiple choice

Please select one or more of the options provided as answers. Sum of the selected answers and a scale to 3 is made. Green/blue gentrification is the process by which the increase in green and blue areas increases local desirability, that result in higher property values and rents, leading to the original population being forced to move to other areas.

Development assessment rule	Development
a) Green/blue gentrification aspects were taken into account and mitigated with social protection measures.	1
b) People's mobility was taken into account and mitigated so that the natural areas are not a barrier for circulation.	1
c) Security aspects were taken into account so that the natural areas are a safe space to be in.	1
d) The selected aspects were taken into account in all the area under assessment.	1
e) None of the above.	0

901b - Ecosystem services (-)

Are the existing and necessary Ecosystem Services (ES) identified, for the area under assessment?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Strategic planning
Source	Beceiro (2021) and ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Ecosystem service can be structured into four categories: provisioning services (food, raw materials, fresh water, medicinal resources), regulating services (local climate and air quaility regulation, carbon sequestrations and storage, moderation of extreme events, wastewater treatment, erosion prevention and maintenance of soil fertility, pollination, biological control), habitat or supporting services (habitat for species, maintenance of genetic diversity), and cultural services (recreation and mental and physical health, tourism, aesthetic appreciation and inspiration for culture, art and design, spiritual experience and sense of place) (Millennium Ecosystem assessment 2005; TEEB, 2011).

Development assessment rule	Development
Yes	3
Partially, most of either the existing or the necessary ES are identified	2
Partially, some of either the existing or the necessary ES are identified	1
No	0

901c - Natural areas alignment with ecosystem services (-)

Is there an alignment between the existing/planned natural areas and the main existing/necessary Ecosystem Services (ES)?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Strategic planning
Source	Beceiro (2021) and ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Development assessment rule	Development
Yes	3
There are some projects or initiatives focused in this alignment	1.5
No	0

901e - Financial support to private implementation of nature-based solutions (-)

Is there any initiative, developed by the municipality or the governing organization(s), to subsidize the implementation of NBS in households?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Strategic planning
Source	Beceiro (2021) and ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

Development assessment rule	Development
Yes, for the last and future years	3
Yes, for the last or the future years	1.5
No	0

905a - Health and well-being co-benefits (-)	
Are natural areas used as community locations for sport and recreation activities (e.g., running or yoga)?	
Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

Development assessment rule	Development
Yes, there is a significant number of events and a significant increase of NBS visitors;	3
Yes, there is a significant number of events but there is not a significant increase of NBS visitors;	2
Yes, there is some sport and recreation events;	1
No	0

905b - Biodiversity enhancement (-)	
The natural areas present living spaces for plants or animals, providing appropriate conditions (food, water, and shelter) for different species (migratory or non-migratory)?	
Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

Development assessment rule	Development
Yes, all of the natural areas	3
Yes, most of them	2
Yes, some of them	1
No	0

905c - Undesired species (-)

The natural areas present living spaces for undesired species (e.g., plants emitting allergic pollen) and plagues (e.g., mosquitos)?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
No	3
Yes, sometimes or in some of the natural areas	2
Yes, frequenly or in most of them	1
Yes, in all of them	0

905d - Aesthetical and recreational importance (-)

Are the natural areas used as community locations for cultural activities (e.g., theatre or musical events)?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Yes, all of the natural areas	3
Yes, most of them	2
Yes, some of them	1
No	0

905e - Groundwater recharge (-)

Is there a significant increase in groundwater level nearby the natural areas?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Yes, there is a significant increase in groundwater level nearby most natural areas	3
Yes, there is a significant increase in groundwater level nearby most natural areas only during the wet season	1.5
No	0

905f - Temperature reduction for local climate regulation (ºC)

Is a local temperature reduction expected due to the implementation of natural areas?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Yes, higher than or equal to 4 ˚C	3
Yes, higher than or equal to 2 ˚C and lower than 4 ˚C	2
Yes, higher than 0˚C and lower than 2 ˚C	1
No.	0

905g - Air quality improvement (kg/ha/year)

What is the estimated air quality improvement due to the implementation of natural areas (in terms of annual removal rate of air pollutants per canopy cover)?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
High improvement (removal above 90 kg/ha/year)	3
Medium improvement (removal between 10 and 90 kg/ha/year)	2
Low improvement (removal below 10 kg/ha/year)	1
No improvement	0

905h - Carbon sequestration and storage (tC/ha)

Are carbon sequestration and storage increase expected due to the implementation of natural areas?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Yes, above 30 tC/ha	3
Yes, between 20 and 30 tC/ha	2
Yes, between 10 and 20 tC/ha	1
Yes, less than 10 tC/ha	0

905i - Estimated infiltration enhancement (mm/h)

What is the estimated infiltration rate due to the implementation of natural areas?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Above 150 mm/h	3
Between 95 and 150 mm/h	2
Between 10 and 95 mm/h	1
Less than 10 mm/h	0

905j - Estimated water retention enhancement (%)

What is the estimated water retention enhancement due to the implementation of natural areas?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Between 80% and 100%	3
Between 50% and 80%	2
Between 20% and 50%	1
Less than 20%	0

905k - Estimated evapotranspiration improvement (mm/day)

What is the estimated evapotranspiration due to the implementation of natural areas?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Above 5 mm/day	3
Between 1 and 5 mm/day	1.5
Less than 1 mm/day	0

905l - Regeneration of abandoned areas (-)

Do NBS contribute to derelict areas and brownfield lands regeneration?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Yes, all of the natural areas	3
Yes, most of them	2
Yes, some of them	1
No	0

905m - Land slide and erosion prevention (-)

Do NBS contribute to land slide and erosion prevention?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	Beceiro (2021) and ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Yes, all of the natural areas	3
Yes, most of them	2
Yes, some of them	1
No	0

909 - Co-ordination with other services in the area (-)

Is there any coordination mechanism in place with other services/entities either at municipal, metropolitan or regional level, namely with with urban planning, security, water supply, stormwater and wastewater management, solid waste, energy, mobility, education, health and social services?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Resilience engaged service
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

-

Development assessment rule	Development
Yes, with 6 or more of the mentioned services	3
Yes, with at least 3 of the above mentioned services	2
Yes, with one of the above mentioned services	1
No	0

910b - Integration with other neighbouring natural areas (-)

Identify the integrated management processes with other natural areas in the vicinities, belonging to the same functional area (e.g. the same drainage basin, coastal line, vegetated zone):

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Strategic planning
Source	ICARIA
Importance	Essential
Level	Tactical
Metric type	Multiple choice

Please select one or more of the options provided as answers. Sum of the selected answers and a scale to 3 is made.

Development assessment rule	Development
a) At strategic level (e.g. aligning strategies, emergency response, ...)	1
b) At technical level (e.g. sharing design solutions, protective infratructure, databases...)	1
c) At operational level (e.g. surveillance, monitoring, maintenance actions)	1
e) None of the above.	0

933 - Ecosystem services improvement (-)

Will the planned natural areas contribute to the ecosystem service's (ES) functions of regulating, provisioning, habitat/supporting, and cultural objectives?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Reliable service
Source	Beceiro (2021) and ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

-

Development assessment rule	Development
Yes	3
Yes, to most ES functions	2
Yes, to some ES functions	1
No	0

934 - Water reuse (-)

Do specific plans include risk information (such as exposure and vulnerability, damage and loss quantification, etc.) related to natural areas and are regularly updated?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Flexible service
Source	Beceiro (2021) and ICARIA
Importance	Complementary
Level	Strategic
Metric type	Single choice

-

Development assessment rule	Development
Yes	**3**
Yes, in most natural areas	**2**
Yes, in some natural areas	**1**
No	**0**

935 - Water uses (-)

Do specific plans include risk information (such as exposure and vulnerability, damage and loss quantification, etc.) related to natural areas and are regularly updated?

Dimension	Functional
Subdimension	Natural areas
Resilience objective	Service planning and risk management
Criteria	Flexible service
Source	Beceiro (2021) and ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
More than or equal to 50%	**3**
More than 25% and less than 50%	**2**
More than 10% and less than or equal to 25%	**1**
Less than or equal to 10%	**0**

Figure 30. Detailed informative datasheets for new metrics in the functional dimension for Natural Areas

Physical dimension

1903a - Maintenance plan for natural areas (-)

Is there a preventive maintenance plan for natural areas, with annual interventions planned, including the necessary resources?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Safe infrastructure
Criteria	Infrastructure assets robustness
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Development assessment rule	Development
Yes	3
A maintenance plan exists but does not cover all natural areas or resources are not identified	1.5
No	0

1903 - Maintenance of natural areas (-)

Are natural areas maintained on a regular basis (according to the plan), resources for corrective maintenance are assured and all maintenance information is continuously registered?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Safe infrastructure
Criteria	Infrastructure assets robustness
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Development assessment rule	Development
Yes.	3
Just in some cases or registration is not fully assured.	2
Preventive maintenance is not in place or corrective maintenance is not effective and efficient.	1
Maintenance is not in place.	0

1903b - Monitoring program for natural areas (-)

Is there a monitoring program for natural areas and is it being implemented?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Safe infrastructure
Criteria	Infrastructure assets robustness
Source	ICARIA
Importance	Essential
Level	Strategic
Metric type	Single choice

Development assessment rule	Development
Yes	3
A monitoring program exists but does not cover all natural areas or it is not fully mplemented	1.5
No	0

1903c - Monitoring of ecosystem services in natural areas (-)

Are the ecosystem services of the natural areas being monitored, as well as its change in time?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Safe infrastructure
Criteria	Infrastructure assets robustness
Source	ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

The aspects to be monitored to assess the provision of ecosystem services (e.g. biodiversity or air quality enhancement, health and wellbeing, creation of green jobs) depend on the type of natural areas. For example, those with the aim to reduce the heat island effect ought to have temperature monitoring in place. Please identify in the Comments box the relevant aspects for the area under assessment.

Development assessment rule	Development
At least the ecosystem services of the critical natural areas are monitored annually	3
The majority (more than 2/3) of the ecosystem services of all the natural areas is monitored annually	2
At least half of the ecossystem services are monitored every 3 years	1
Monitoring is incipient or nonexistent	0

1903d - Monitoring of natural areas' condition (-)

Is the condition of the natural areas being monitored, as well as its change in time?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Safe infrastructure
Criteria	Infrastructure assets robustness
Source	ICARIA
Importance	Complementary
Level	Strategic
Metric type	Single choice

The aspects to be monitored to assess the condition of the natural areas depend on the type of natural areas. For example, those designed to support stormwater management might be monitored for water quantity and water quality variables. Green areas ought to have the health of the various specimens monitored. Please identify in the Comments box the relevant aspects for the area under assessment.

Development assessment rule	Development
The condition of at least the critical natural areas is monitored annually	**3**
The condition of the majority (2/3) of the natural areas is monitored annually	**2**
The condition of at least half of the natural areas is monitored every 3 years	**1**
Monitoring is incipient or nonexistent	**0**

1903e - Monitoring targets for natural areas (-)

Have targets (for the provision of ecosystem services and for the natural areas' condition) been defined, to support the evaluation of the monitoring results?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Safe infrastructure
Criteria	Infrastructure assets robustness
Source	ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

The targets depend of the ecosystem services (ES) to be provided and of the natural areas under assessment. For example, regarding ES, there might be an annual target of 10 green jobs to be created, of 5 community events to be organized and of 10 kg/ha/year of air pollutants removal rate per canopy cover. For example, regarding the condition of the natural areas, there might be a target of 50% peak flow reduction in a stormwater detention basin, a reduction to 1 day out of service per year of a lake due to low water height, a 15% increase in crown condition (amount, condition, and distribution of foliage, branches, and growing tips of trees) or a 20% increase in the survey of down woody materials (which estimates the amount and condition of dead and downed wood) in a park. Please identify in the Comments box the targets that were defined.

Development assessment rule	Development
Yes	**3**
Targets have been defined but not for all ecosystem services or all natural areas	**1.5**
No	**0**

1904 - Natural areas out of service last year (-)

Natural areas out of service for longer than a day, due to problems in the natural assets, last year

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Safe infrastructure
Criteria	Infrastructure assets robustness
Source	ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

Being out of service depends on the hazard and on the assets of the natural area under assessment. For example, it might be restrictions to circulate in a park due to fallen branches, a fireevent or flooding, or restrictions to use stored stormwater due to water quality problems.

Development assessment rule	Development
No natural areas affected	3
No critical natural areas affected	2
Less than half of the natural areas affected	1
More than half of the natural areas affected	0

1905a - Ecosystem services provided last year (-)

Were the ecosystem services provided last year according to the expected targets?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Safe infrastructure
Criteria	Infrastructure assets robustness
Source	ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

Development assessment rule	Development
Yes, in the critical natural areas	3
Yes, for the majority (more than 2/3) of the ecosystem services	2
Yes, for at least half of the ecossystem services	1
No	0

1905b - Natural areas' condition last year (-)

Was the condition of the natural areas last year according to the expected targets?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Safe infrastructure
Criteria	Infrastructure assets robustness
Source	Beceiro (2021) and ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Yes, in the critical natural areas	3
Yes, for the majority (more than 2/3) of the natural areas	2
Yes, for at least half of the natural areas	1
No	0

1918 - Water self sufficiency (%)

Percentage of water consumption coming from self water sources (abstraction, storage or reuse)

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Autonomous and flexible infrastructure
Criteria	Infrastructure assets autonomy
Source	ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
More than or equal to 30%	3
More than or equal to 15% and less than 30%	2
More than or equal to 5% and less than 15%	1
Less than 5%	0

1920 - Redundancy and easy access to natural areas (-)

Are natural areas scattered in the area under assessment?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Autonomous and flexible infrastructure
Criteria	Infrastructure assets redundancy
Source	Beceiro (2021) and ICARIA
Importance	Essential
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Yes, natural areas are scattered	3
Yes, they are partially scattered and no natural area has more than 50% of the total natural area	1.5
No, natural areas are concentrated (a single one has more than 50% of the total area)	0

1920b - Connection of natural areas (-)

Are natural areas connected?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Autonomous and flexible infrastructure
Criteria	Infrastructure assets redundancy
Source	ICARIA
Importance	Essential
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Yes, natural areas are easily connected by pathways, road or public transport	3
Yes, natural areas are easily connected by road or public transport	1.5
No	0

1928 - Implemented design solutions to address climate change mitigation and adaptation (-)

What type of solutions were implemented in natural areas' design to address climate change mitigation and adaptation?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Infrastructure preparedness
Criteria	Preparedness for climate change
Source	ICARIA
Importance	Essential
Level	Tactical
Metric type	Multiple choice

Please select one or more of the options provided as answers. Sum of the selected answers and a scale to 3 is made.

Development assessment rule	Development
a) Creation of clearings where all flammables are removed	1
b) Promote urban-rural interactions in the peri-urban areas, as open areas at the urban fringe may favour species richness	1
c) Promote the use of available space in peri-urban areas under development to implement larger scale NBS	1
d) Wellconnected network of natural areas, which form ventilation channels, facilitates the circulation of fresher and cleaner air	1
e) Creation of green corridors that reduce traffic emissions, mitigate noise and provide a cooling effect.	1
f) Associate green and blue natural areas to promote interactions	1
g) Diversify the use of NBS for the same ES to enhance the overall effect	1
h) Use of adequate vegetation species to reduce maintenance, water consumption, and promote biodiversity and shadowing	1
i) other	1
j) none	0

1928b -Planned design solutions to address climate change mitigation and adaptation (-)

Are carbon sequestration and storage increase expected due to the implementation of natural areas?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Infrastructure preparedness
Criteria	Preparedness for climate change
Source	ICARIA
Importance	Essential
Level	Tactical
Metric type	Multiple choice

Please select one or more of the options provided as answers. Sum of the selected answers and a scale to 3 is made.

Development assessment rule	Development
a) Creation of clearings where all flammables are removed	1
b) Promote urban-rural interactions in the peri-urban areas, as open areas at the urban fringe may favour species richness	1
c) Promote the use of available space in peri-urban areas under development to implement larger scale NBS	1
d) Wellconnected network of natural areas, which form ventilation channels, facilitates the circulation of fresher and cleaner air	1
e) Creation of green corridors that reduce traffic emissions, mitigate noise and provide a cooling effect	1
f) Associate green and blue natural areas to promote interactions	1
g) Diversify the use of NBS for the same ES to enhance the overall effect	1
h) Use of adequate vegetation species to reduce maintenance, water consumption, and promote biodiversity and shadowing	1
i) other	1
j) none	0

1929a - Natural areas out of service in the last relevant event (-)

Natural areas out of service for longer than a day, due to problems in the natural assets, in the last climate related event, with similar or harsher climate variables than the most probable scenario

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Infrastructure preparedness
Criteria	Preparedness for recovery and buildback
Source	ICARIA
Importance	Complementary
Level	Tactical
Metric type	Single choice

Being out of service depends on the hazard and on the assets of the natural area under assessment. For example, it might be restrictions to circulate in a park due to fallen branches, a fireevent or flooding, or restrictions to use stored stormwater due to water quality problems.

Development assessment rule	Development
No natural areas affected	3
No critical natural areas affected	2
Less than half of the natural areas affected	1
More than half of the natural areas affected	0

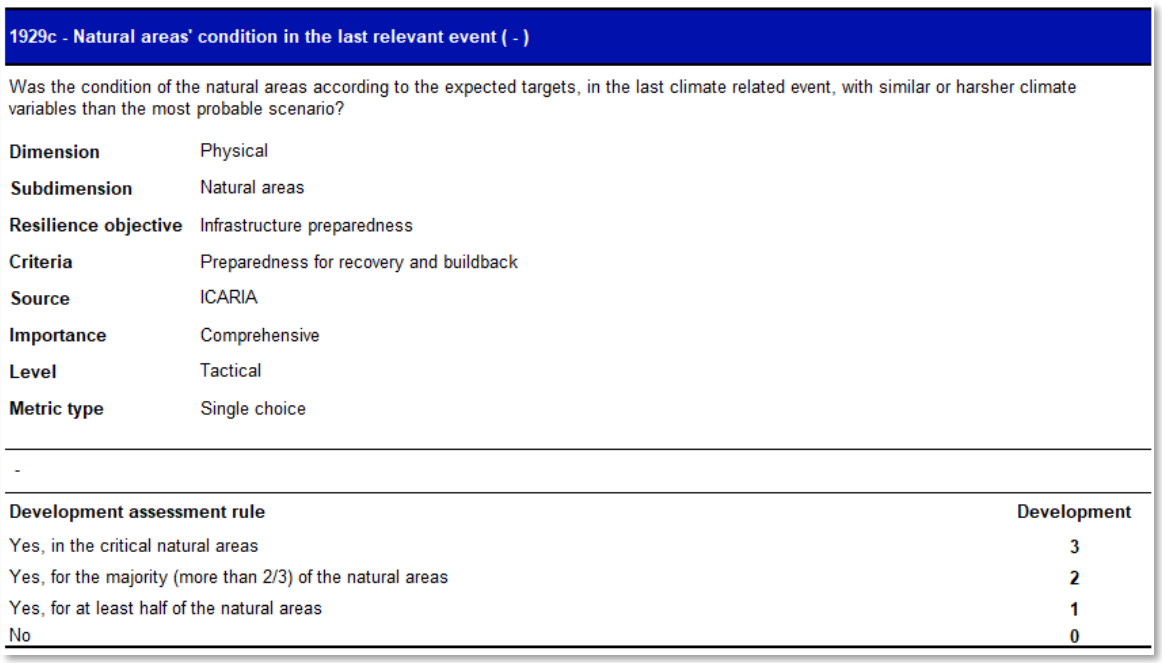
1929b - Ecosystem services provided in the last relevant event (-)

Were the ecosystem services provided according to the expected targets, in the last climate related event, with similar or harsher climate variables than the most probable scenario?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Infrastructure preparedness
Criteria	Preparedness for recovery and buildback
Source	ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	Development
Yes, in the critical natural areas	3
Yes, for the majority (more than 2/3) of the ecosystem services	2
Yes, for at least half of the ecossystem services	1
No	0



1929c - Natural areas' condition in the last relevant event (-)

Was the condition of the natural areas according to the expected targets, in the last climate related event, with similar or harsher climate variables than the most probable scenario?

Dimension	Physical
Subdimension	Natural areas
Resilience objective	Infrastructure preparedness
Criteria	Preparedness for recovery and buildback
Source	ICARIA
Importance	Comprehensive
Level	Tactical
Metric type	Single choice

-

Development assessment rule	**Development**
Yes, in the critical natural areas	**3**
Yes, for the majority (more than 2/3) of the natural areas	**2**
Yes, for at least half of the natural areas	**1**
No	**0**

Figure 31. Detailed informative datasheets for new metrics in the physical dimension for Natural Areas

Annex D: ICARIA RAF subsets of metrics in the new filters

M - Data from modelling

CI - Related to critical infrastructure

SSH - Related to social sciences and humanities

Sc - Associated with scenarios

DSS - Relevant for the decision support system

Table 19. Identification of ICARIA RAF subsets of metrics included in the new filters

Metric ref.									FILTER				
Dimension		subdimension (services)							M	CI	SSH	Sc	DSS
		Water supply	Wastewater	Stormwater	Solid waste	Energy	Mobility	Natural areas					
Organizacional	1										x		
	2										x		
	3										x		
	4										x		
	5										x		
	6										x		
	7										x		
	8										x		
	9										x		
	10										x	x	
	12										x		
	13										x		
	15												x
	17a										x		x
	17b										x		
	17c										x		
	20								x				x
	21								x				x
	23a												x
	23b											x	x

Metric ref.									FILTER				
Dimension		subdimension (services)							M	CI	SSH	Sc	DSS
		Water supply	Wastewater	Stormwater	Solid waste	Energy	Mobility	Natural areas					
	23d										x		
	24										x		
	26								x			x	x
	27										x		
	28										x		
	30b										x		
	31								x			x	
	32										x		
	33										x		x
	34										x		
	37											x	
	40												x
	41												x
	43a										x		
	43b										x		
	45											x	
	49												x
	50												x
	97											x	
Spatial	101								x	x			
	102											x	
	103								x			x	
	104								x			x	x
	105								x			x	x
	105b								x			x	x
	106								x			x	x
	107a											x	
	109												x
	109b												x
	114								x			x	
	115								x			x	
	116											x	
	117											x	

Metric ref.									FILTER				
Dimension	subdimension (services)								M	CI	SSH	Sc	DSS
	Water supply	Wastewater	Stormwater	Solid waste	Energy	Mobility	Natural areas						
	118									x			x
	119									x			
	120									x			
	123												x
	125												x
	127									x		x	
	128											x	
Functional								901a			x		
								903b			x		
								905a			x		
								905d			x		
								905e	x				
								905f	x				
								905g	x				
								905h	x				
								905i	x				
								905j	x				
								905k	x				
	306	406	506	606	706	806	906						x
	307	407	507	607	707	807	907						x
	313	413	513	613	713	813	913		x			x	x
	314	414		614		814			x			x	x
	315	415	515	615	715		915		x	x		x	
	316	416							x	x		x	
	317	417	517	617	717		917		x			x	
	318								x			x	
	319	419	519	619	719	819	919		x			x	
	320					820			x			x	
	321	421	521	621	721	821			x			x	
	322	422		622					x			x	
	323	423	523	623	723	823	923		x				
	324	424		624		824			x				
	325	425	525	625	725		925		x	x			

Metric ref.									FILTER				
Dimension		subdimension (services)							M	CI	SSH	Sc	DSS
		Water supply	Wastewater	Stormwater	Solid waste	Energy	Mobility	Natural areas					
		326	426						x	x			
		327	427	527	627	727		927	x				
		328	428		628				x				
		329	429	529	629	729	829	929	x				
		330					830		x				
		333	433	533		733		933	x				x
		334	434	534	634	734		934					x
		335	435	535	635	735		935					x
		338	438	538	638	738	838						x
		340	440	540	640	740	840	940			x		
								942		x		x	
		342	442	542	642	742	842					x	x
		343	443	543	643	743	843	943				x	x
		349	449	549	649	749	849	949				x	
		350	450	550	650	750		950	x	x			
		352	452	552	652	752	852	952			x		x
		353	453	553	653	753	853	953			x		
		356	456	556	656	756					x		
		359	459	559	659	759	859	959	x				
		360	460		660		860		x				
		361	461	561	661	761		961	x				
		362	462						x				
		363	463	563	663	763		963	x				
		364	464		664				x				
		365	465	565	665	765	865	965	x				
		366					866		x				
Physical		1300	1400	1500	1600	1700	1800	1900		x			
		1300b	1400b	1500b	1600b	1700b	1800b	1900b		x			
		1300c	1400c	1500c	1600c	1700c	1800c	1900c		x			
		1300d	1400d	1500d	1600d	1700d				x			
		1301	1401	1501	1601	1701	1801	1901		x			x
								1905a					
								1905b					

Metric ref.									FILTER				
Dimension		subdimension (services)							M	CI	SSH	Sc	DSS
		Water supply	Wastewater	Stormwater	Solid waste	Energy	Mobility	Natural areas					
		1305	1405	1505	1605	1705				x			
		1308	1408	1508					x				
		1309	1409	1509					x				
		1320	1420	1520	1620	1720	1820			x			
		1320b	1420b	1520b	1620b	1720b	1820b			x			
		1320c	1420c		1620c	1720c				x			
		1321	1421	1521	1621	1721	1821	1921					x
		1323	1423	1523	1623	1723	1823						x
		1324	1424	1524	1624	1724	1824	1924			x		x
		1325	1425	1525	1625	1725	1825	1925	x	x		x	x
		1326	1426	1526	1626	1726	1826	1926				x	
		1327	1427	1527	1627	1727	1827	1927	x			x	
		1328	1428	1528	1628	1728	1828	1928					x
		1330	1430	1530	1630	1730	1830			x			

Annex E: ICARIA RAF new or revised metrics to enlarge to ICARIA's scope

r – revised metric
new – new metric

Table 20. Identification of ICARIA RAF new or revised metrics to include enlargement of ICARIA's scope

Metric ref.			purpose of addition /revision				
Dimension		subdimension (services)					
		Water supply / Wastewater / Stormwater / Solid waste / Energy / Mobility / Natural areas	geographical scope	additional hazards	compound events	housing	tourism
Organizacional	1		r				
	2		r				
	4		r				
	5		r				
	9		r				
	10		r				
	13		r				
	14		r				
	16		r				
	17a		r				
	17b		r				
	17c		r				
	18		r				
	19		r				
	21					r	r
	23a		r				
	23d		r				
	24		r				
	26		r		r		
	27		r				
	28		r				
	30a		r				
	30b		r				
	31		r				
	32		r				

Metric ref.			purpose of addition /revision				
Dimension	subdimension (services)		geographical scope	additional hazards	compound events	housing	tourism
	Water supply, Wastewater, Stormwater, Solid waste, Energy, Mobility, Natural areas	35	r				
		36	r				
		41	r				
		44a	r				
		45	r				
		97	r				
		98	r				
		99	r				
		50	r				
		52	r				
		53a	r				
		54	r				
		55a	r				
		55b	r				
		56a	r				
		57	r				
		58	r				
		60	r				
		61	r				
		70	new				
		71	new				
		72	new				
		73	new				
Spatial		101	r	r			
		101b			new		
		107c	r				
		108b	new		new	new	
		109	r				
		109b				new	
		109c				new	
		110	r				
		118	r				

Metric ref.									purpose of addition /revision				
Dimension	subdimension (services)								geographical scope	additional hazards	compound events	housing	tourism
	Water supply	Wastewater	Stormwater	Solid waste	Energy	Mobility	Natural areas						
	119								r				
	121								r				
	121								r				
	125								r				
	129								r				
							801						
	301	401	501	601	701	801							
	303	403	503	603	703	803							
	305	405	505	605	705								
	306	406	506	606	706	806							
	309	409	509	609	709	809							
	311	411	511	611	711	811							
	313	413	513	613	713	813							
	314	414		614									
						822							
	323	423	523	623	723	823							
	324	424		624		824							
						825							
	328	428		628									
						832							
						833							
	335	435	535	635	735	835							
						836							
						837							
	338	438	538	638	738	838							
						839							
						841							
	344	444	544	644	744								
	346	446	546	646	746								
	349	449	549	649	749								
	352	452	552	652	752								
	353	453	553	653	753								

Metric ref.									purpose of addition /revision				
Dimension		subdimension (services)							geographical scope	additional hazards	compound events	housing	tourism
		Water supply	Wastewater	Stormwater	Solid waste	Energy	Mobility	Natural areas					
		359	459	559	659	759	859						
		360	460		660								
Physical		1300d	1400d	1500d	1600d	1700d	1800d		r				
		1301	1401	1501	1601	1701			r				
		1321	1421	1521	1621	1721	1821		r	r			
		1324	1424	1524	1624	1724	1824		r				

ICARIA
Improving climate resilience of critical assets

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

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