

Communication

Improving Climate Resilience of Critical Assets: The ICARIA Project

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Abstract: The number of climate-related disasters has progressively increased in the last two decades and this trend will drastically exacerbate in the medium- and long-term horizons according to climate change projections. In this framework, through a multi-disciplinary team and a strong background acquired in recent projects, ICARIA aims to promote the use of asset-level modeling to achieve a better understanding of climate related tangible direct and indirect impacts on critical assets due to complex, cascading, and compound disasters. Furthermore, it takes into account the related risk reduction provided by suitable, sustainable, and cost-effective adaptation solutions. ICARIA focuses on both (i) critical assets and services that were not designed for potential climate change-related impacts that can increase the unplanned outages and failures, and (ii) on housing, natural areas, and population. Cutting edge methods regarding climate scenario building, asset-level-coupled models, and multi-risk assessment approaches will be implemented and replicated in three EU regions to understand how future climate scenarios might affect critical assets and to provide decision-making support tools to private and public risk owners to assess the costs and benefits of various adaptation solutions.

Keywords: critical assets; climate resilience; asset modeling; compound events; cascading effects



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1. Introduction

In the period from 2000 to 2019, over 7000 natural hazard-related disasters have been recorded worldwide, affecting over 4 billion people and resulting in economic losses of nearly USD 3 billion. These numbers represent a sharp increase compared to the previous two decades. Much of this increment is due to a significant rise in the number of climate-related disasters (heatwaves, droughts, flooding, etc.), whose frequencies are dramatically increasing due to the current climate change crisis [1,2]. It is estimated that the world stands to lose around 10% of its total economic value due to climate change if the temperature increase stays on the current trajectory and both the Paris Agreement and 2050 net-zero emissions targets are not met [3].

According to the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC), since the 1950s, European regions have experienced a significant temperature rise leading to more frequent and severe heat waves. This trend is expected to exacerbate in the future decades [2]. Furthermore, the European Environment Agency

states that Europe is warming up faster than the global average and indicates that a particularly high warming rate is being observed over eastern Europe, Scandinavia, and the eastern part of the Iberian Peninsula [4].

Regarding flooding events, IPCC states that for both 1.5 °C and 2 °C global warming scenarios, floodings associated with intense precipitation levels will increase in terms of intensity and frequency [5]. The same report indicates the morphology of cities (sealed surfaces and small natural environments) leads to an increase in local temperatures aggravating hot extremes and heatwaves [5].

Historically, the impact and risk assessment of climate extreme events have been developed under a “one at a time” scope, analyzing each hazard individually. Nevertheless, it is presently recognized that there is a need to shift this scope to multi-hazard events, defined as the combination of multiple drivers and/or hazards that pose a risk to society, infrastructures, or the environment in a combined manner, which can pose a more severe and complex risk for its receptors [6–8].

In this context, ICARIA (Improving ClimAte Resilience of crItical Assets) aims at promoting the use of a comprehensive asset-level modeling framework to achieve a better understanding about the climate-related impacts caused by complex, compound, and cascading disasters and the possible risk reduction provided by suitable, sustainable, and cost-effective adaptation solutions. To this end, a comprehensive climate resilience and risk assessment framework, including the development and validation of cutting-edge asset-level models, will be developed. It will allow the simulation of cascading effects (caused by single and compound events) and will perform multi-hazard and multi-risk assessments for different scenarios.

Importantly, this project has been conceived with a regional scope, aiming to develop tools and methodologies that can serve European regions to improve the holistic climate resilience of their critical assets against multi-risk extreme events.

ICARIA focuses on three European regions, with profound differences regarding their geographical and population characteristics, which face distinct climatic risks: the Barcelona Metropolitan Area in Spain, the Salzburg Region in Austria, and the South Aegean Region in Greece.

The present scientific communication has the objective to highlight the methodologies, tools, and the potential outcomes related to the ongoing ICARIA project.

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2. Materials and Methods

2.1. The ICARIA Project

The ICARIA project (www.icaria-project.eu) aims at supporting European regions to improve the climatic resilience of their critical infrastructures and services against the growing threat of extreme multi-risk climate events. To this end, ICARIA will generate a whole new methodology to enable a wide range of decision makers (e.g., local and regional authorities, civil protection agencies, climate-related policymakers, urban planners, critical infrastructure operators, and transport service providers) to evaluate the current climate resilience of specific assets and evaluate the most suitable, sustainable, and cost-effective adaptation solutions. In this sense, the ICARIA project focuses on supporting the decision-making process to define mid- and long-term planification strategies to improve the assets’ climatic resilience.

This novel framework will consist of a set of risk impact models, standardized evaluation methodologies, and decision support tools that will be suitable to evaluate the impacts of different climate hazards on specific assets, with special focus on multi-risk events.

Three European Regions have been selected as case studies to develop an effective implementation and replication of ICARIA methods and results, the Barcelona Metropolitan Area (Spain), the Salzburg Region (Austria), and the South Aegean Region (Greece), as can

be seen in Figure 1. Hence, this project will contribute to strengthen their climate resilience and improve their planning capacity.



Figure 1. Location of the case study regions of the ICARIA project.

Specifically, ICARIA will focus on a large set of critical services and public and private infrastructures related to water, transport, energy, waste, and tourism. Moreover, population, housing, and natural areas will be considered as potential assets/risk receptors affected by extreme events. The strong background acquired by ICARIA partners in previous projects, such as RESCCUE [9], EU-CIRCLE [10], CLARITY [11], and SNOWBALL [12], establish the knowledge base to achieve the research expectations.

In order to optimize the project resources (ICARIA is a mid-size EU project with a budget of around EUR 2.3 M and a short duration of 3 years) and to ensure and maximize the replicability of the scientific and technological output implementations, a two-step approach will be followed to develop the multi-risk assessment of climate hazards in the case study regions. Therefore, the same case studies will act as demonstrators and sites for the replication depending on the local expertise and data availability.

In a first assessment cycle, the so-called trials, risk assessments for specific climate hazards will be conducted to achieve the highest possible quality of predictions, so that the results can be used “as is” for operative decision making. In a second phase, the so-called mini trials, other hazards will be assessed following the methods and tools implemented in other regions during the trials phase. This will serve to assess the methods’ replicability and to evaluate the possibility of achieving similar results in other contexts with potential considerable differences in terms of data availability and resources. Figure 2 presents the different climatic hazards, risk receptors, and tangible impacts that will be considered in each case study region of the project.

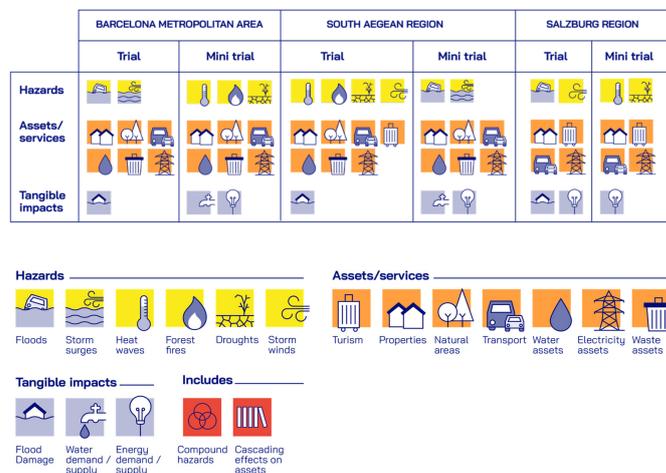


Figure 2. Summary of the trials and mini trials of each case study in the ICARIA project.

2.2. A Novel Methodological Framework for a Comprehensive Risk Assessment

The complex socio-ecological–technological nature of urban and territorial systems requires that potential impacts from natural hazards aggravated by climate change are analyzed in a holistic way. This involves considering both the effect of single hazards (e.g., floods, heat waves) on specific assets and the fact that individual hazards can increase the probability of compound events occurrence, aggravating the impact scenario with potential cumulative damages and cascading failures of interconnected networks and systems. The possible interactions between natural hazards have been only partially investigated to date, while in recent years the increasing levels of temperature and precipitation extremes has often been associated with multi-hazard events (e.g., pluvial floods associated with landslides and debris flows, or forest fires fueled by persistent drought and heatwave conditions) [6–8,12,13]. The risk assessment of this kind of events requires a careful evaluation of hazard interdependencies and vulnerability of exposed assets to inform the development of resilience measures and contingency plans. The IPCC AR5 reaffirmed the centrality of hazard, exposure, and vulnerability as key variables of a robust risk/impact assessment framework (see Figure 3) [14]. Extending this framework to support multi-risk analyses requires, in particular, the evaluation of the vulnerability of assets and services at risk towards the diverse potential hazards affecting the area. Additionally, the time variable has to be taken into account within such a space-dependent exposure analysis to determine whether critical assets are likely to suffer cumulative damage from multi-hazard events or cascading effects.

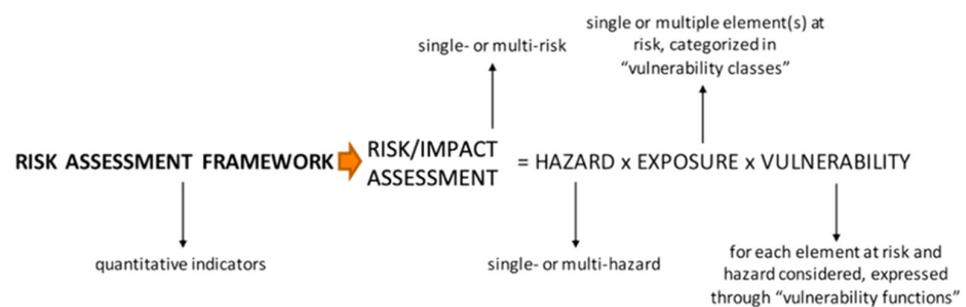


Figure 3. Consolidated approach for disaster risk assessment in the field of geophysical hazards (UNDRO [15], updated by the UNDRR 2017 Terminology [16]), harmonized in the context of climate change (IPCC-AR5, 2014 [14]).

The ICARIA project will build upon existing single-hazard methodologies (provided by projects, such as RESCCUE [9], EU-CIRCLE [10], and CLARITY [11]) to develop a fully quantitative multi-hazard modeling framework. The former project, SNOWBALL [12] provides the theoretical background for such a development (see Figure 4). This approach will evolve from a classical single-hazard perspective to a holistic multi-hazard vision (including compound and cascading effects). Furthermore, it will incorporate the capacity to evaluate alternative climate-resilient development pathways through tools for cost–benefit and multi-criteria analyses.

The output of the ICARIA risk assessment framework will be impact information represented through risk distribution maps and fully quantitative datasets specific for each critical asset or service considered. These outputs will support holistic resilience assessment approaches in the definition of the best cost–benefit adaptation measures. In particular, the methodology will ensure that the definition of local hazard conditions and expected impacts on assets are “responsive” to the implementations of adaptation measures. The responsiveness of impact modeling to the effect of potential adaptation measures is essential to support climate-resilient and sustainable planning and design of critical assets and services (see Figure 5).

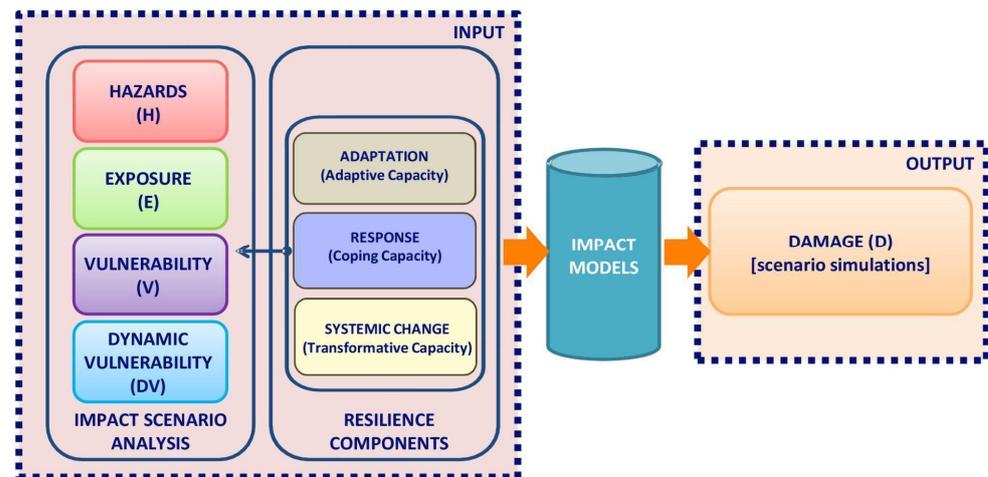


Figure 4. Conceptual model for holistic multi-risk and cascading impact assessment of extreme weather events on critical assets.



Figure 5. Risk Governance Framework to support the full disaster risk management cycle and sustainable and resilient development pathways (elaborated from diverse sources).

Following this framework, holistic resilience assessments will be performed in relation to the selected hazard/impact scenarios. These scenarios will introduce the effects of adaptation strategies (adaptive capacity), emergency response (coping capacity), and systemic changes (transformative capacity) in reducing the impacts on exposed assets. Following the most recent EU guidelines [17,18], the objective is to allow the integration of such measures in a given scenario and perform an “alternate run” of hazard/impact models to evaluate their effects on reducing impacts.

2.3. Asset-Level Modeling in the Context of Complex and Compound Events

Multi-hazard events may occur in various combinations of hazard types, dynamics between hazards, spatial and temporal scales, etc. Therefore, their assessment requires comprehensive knowledge and modeling tools to simulate the involved processes. Most existing studies and projects, such as RESCCUE [9] and EU-CIRCLE [10], consider an asset-based approach to assess the resilience of selected cities to climate-driven events under current and future climate change scenarios. However, the projects to date include only a one-directional perspective (influence of one by another and ignore the feedback). In this sense, ICARIA will bring multidisciplinary expertise together to establish a novel integrated modeling approach to quantify the joint probability of multi-hazard events occurrence based on their spatiotemporal interactions and the triggering mechanisms that are established between the single hazards involved. The climate resilience of critical assets and the impact of climate-related hazards on their serviceability will be analyzed to quantify the likelihoods of failures or malfunctioning, which consequently lead to service disruption cascading effects. More importantly, the assessment framework will be an interactive procedure that will fully reflect the mutual influences between different hazards. Therefore, the interdependencies among critical infrastructures, such as those relating to water supply, electricity, wastewater, solid waste, transportation, buildings, and natural areas will be assessed. Other project innovations in terms of multi-hazard modeling will be provided by the establishment of thresholds to identify extreme events and hazard variables, as

well as their probability distribution functions (PDFs) for one hazard triggering others under specific environmental conditions. This will be achieved according to physically based theories and the influence of natural processes. The historical records of multi-hazard events were collected and used to calibrate and validate compound hazard models; therefore, ICARIA will not only compare the modeling results of individual hazards but also investigate the interrelations among disasters and the parameters derived that can be verified to ensure that the framework properly captures hazard interactions.

2.4. From Detailed Impact Models to a Holistic Analysis to Assess and Improve Climate Resilience

The outputs of the detailed modeling tools, such as the results of exposure and vulnerability functions, and the knock-on effects due to cascading events, will be used to perform an assessment of tangible impacts [19]. In ICARIA, methodologies to estimate the tangible impacts, both direct and indirect, will be developed, validated, and replicated.

In this context, it is useful to remark on the importance of properly assessing indirect damage to achieve a comprehensive estimation of the impacts produced by climate related hazards. Indirect damage can be considered as the impacts induced by direct ones and that may occur—in space or time—outside the hazard event and are caused by disruptions to linkages within the economy (i.e., business disruptions, relocations expenses, supply chain interruption, loss of industrial production, traffic disruption, emergency costs, temporary housing of evacuees, etc.). Furthermore, indirect losses of an infrastructure network can be divided into two categories: those associated with the temporal prolongation of time and those associated with a loss of connectivity [20,21].

In the literature, three techniques appear more frequently to estimate indirect damage: simple empirical methods (derived from post-event surveys), input–output modeling, and Computable General Equilibrium (CGE) models. Recent studies tried to estimate the indirect damages to critical assets and services produced by natural hazards (climate and geophysical) through econometric models, achieving Input (direct losses)/Output (indirect losses) tables [22–24] or more simplified constant relations between the direct and indirect tangible damage validated through historic data [20].

Finally, according to Forcellini [25], since indirect losses affect communities that are served by the infrastructure, it is essential to take into account the source of damage and, in case of natural events, it is realistic to consider the possibility that not only single infrastructures can be affected by the loss of functionality.

In this framework, the ICARIA project proposes the estimation of these losses through the evaluation of the costs produced by infrastructures and services failures through detailed asset-level modeling considering important issues as infrastructure redundancy and the joint probability of compound events.

On the other hand, historical public insurance data for extreme events and sectoral economic data, such as economic impacts on utilities and other affected assets, will be used alongside hazard modeling results. Methods for cost estimation will be based on vulnerability functions, including reconstruction costs (direct costs) and the cost of not providing the intended service (indirect costs). Outputs will be expressed in monetary terms to compare the impacts of “doing nothing” (business as usual) against the total costs to recover the affected assets, the costs of service interruptions, the knock-on effects on other services, in addition to the investment needed for adaptation scenarios. Furthermore, the expression of impacts in monetary terms will facilitate the comparison between adaptation measures to identify the most suitable and cost-effective solutions.

A comprehensive resilience assessment of critical and strategic assets and services, will complement the assessment of the tangible impacts. Increased resilience to disruptive events aims at reducing the related risks and damages as well as at the ability to bounce back rapidly to a stable state [9]. The resilience assessment considers that assets and services with different functions coexist in time and space, as complex interdependent networks. The performance of these assets and services is interlinked in their everyday lives and while enduring disruptive events [26]. This is particularly relevant for services based on linear

assets, such as transport, energy, or water services, with interconnected infrastructures, crossing urban and adjacent areas. These assets and services contribute to or hinder city or regional resilience; therefore, a holistic approach is required. For such, the results of the detailed modeling tools, along with the data on governance, socio-economic aspects, spatial planning, and service management, will contribute to a holistic and critical infrastructure resilience assessment. The ICARIA holistic resilience assessment tool will build on existing frameworks (from the RESCCUE project RAF and RAF App [27], to the EU-CIRCLE and the RAT tool [28]) and will be complemented with a regional scope and complementary assets (e.g., housing or natural areas).

A portfolio of adaptation solutions, regarding ICARIA assets, hazards, and geographic scale will be developed, with a focus on Nature Based Solutions (NBS). Risk prevention and reduction through structural and non-structural measures are essential to enhance the economic, social, health, and cultural resilience of people, communities, and their assets, as well as the environment. Additionally, such measures are instrumental in saving lives, preventing and reducing losses, and ensuring effective recovery and rehabilitation [29]. This portfolio will be based on a literature review and other existing portfolios, such as the RESCCUE web-based Adaptation Platform, the RECONNECT NBS portfolio, and the CLARITY Catalogue of adaptation options.

All ICARIA models, tools, and methods will feed a decision support system (DSS) for climate resilience planning on strategic assets. The DSS aims to facilitate and systematize the comparison between adaptation measures to identify the most adequate, sustainable, and cost-effective solution for each case. The DSS will be designed as a toolbox, ensuring data transferability between other EU services, such as C3S and Climate-ADAPT. A common syntax will allow the outputs of the modeling tools to serve as inputs for the assessment tools. A user-friendly web-based platform and interface, including a GIS surface displaying risk maps, will allow visualization of the impacts from single and compound hazards and the results of implementing specific adaptation solutions. Assessing current and future resilience scenarios is the basis for asset managers to know where they stand; to support the decisions on strategies, on climate planning in the long, medium, and short terms; to develop resilience action plans; and to assess progress through KPIs [30,31].

2.5. Implementation and Replication following the DRIVER+ Trial Guidance Methodology

The ICARIA project is built around three case studies representing 3 different regions of Europe: the Metropolitan Area of Barcelona, the Salzburg region and the South Aegean Region archipelago. As presented in Section 2.1, for each region, a two-stage risk assessment cycle will be conducted. These two steps correspond to the “trial” and the “mini trial” phases.

The execution of both assessment cycles will be done following the DRIVER+ Trial Guidance Methodology (TGM). It represents a systematic approach for planning, conducting, and evaluating crisis management trials that have been successfully deployed in multiple EU Projects to evaluate the effectiveness of novel crisis management solutions [32]. Despite being specifically designed for a different purpose, the TGM has already been successfully applied to project RESILOC, which, similarly to ICARIA, was focused on climate change resilience methodology [33].

The three main phases of the TGM trials (preparation, execution, and evaluation) are designed to be executed sequentially, while each phase is designed as an iterative process and thus compatible with the best practices and methods of design thinking (preparation) and agile development (execution). In ICARIA, trials (implementation phase) will be followed by mini trials (replication phase) and by the exploitation phase where the final results will be presented to other European regions beyond the consortium (exploitation phase) (see Figure 6 below).

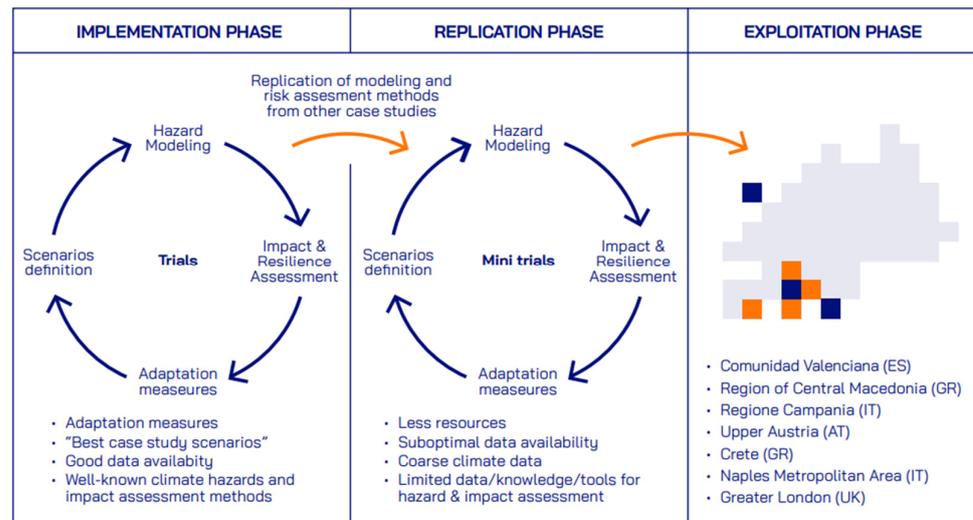


Figure 6. ICARIA testing and validation methodology.

The trial preparation phase starts with the so-called “step zero” where the operative gaps (or “needs”) that should be addressed in the trial (trial gaps) and the main conditions and parameters of the trial (trial context) are defined. In this step, the core trial team is also formed, consisting of the trial owner, technical coordinator, evaluation coordinator, and the practitioner coordinator. The evaluation coordinator ensures that the objective assessment of the trial findings is built in the trial design and that relevant data are duly collected and assessed in the final trial phase, whereas the practitioner coordinator ensures the participation of extended trial team members in all phases of the trial. In ICARIA, the practitioner coordinator is a link between the core trial team and the regional Communities of Practice (see Section 2.6).

In the ICARIA context, the gaps to address are: (1) inadequate asset-level models for impacts of climate hazards and adaptation options; (2) inadequate decision support for holistic multi-hazard/multi-asset resilience assessments and planning; and (3) a need to optimize the interactions between climate change, climate adaptation, and society.

Following “step zero”, in the preparation phase, six key elements are co-defined by the trial team in an iterative process in order to define a rigorous and systematic process for evaluating the performance and impact of the solution and differentiate them from the demonstrators. These six elements are: (1) trial objectives, (2) research questions, (3) data collection plan, (4) evaluation approaches, (5) scenarios, and (6) solutions to be trialed.

In the trial execution phase, the TGM second phase, the trials are developed. It starts with an initial “trial integration meeting” and ends with the “trial run”—a final event where the final results of the trial are assessed by the extended trial team. TGM also foresees two “dry run” meetings as milestones where progress towards the organization of the trial run is discussed and corrective measures are decided upon, as needed.

Finally, the trial evaluation phase (the third and last TGM phase) consists of checking the quality of the data gathered at the trial run and continues with a data analysis and data synthesis, where the overall results of the trial are assessed and the lessons learnt are defined. In the last step, TGM explicitly foresees the dissemination of the trial’s findings to the relevant stakeholders.

Once the fully fledged trials have been executed and evaluated, the most promising parts thereof will be repeated in different ICARIA case study areas. Resulting “mini trials” will still largely follow the TGM methodology; however, the mini trial’s preparation and execution will be shortened by re-using the knowledge gained in the initial trials. Most notably, the objectives and related research questions examined in mini trials will differ from those in the initial trials and concentrate on replicability and societal impacts. Finally, the exploitation phase will be mainly informed about the most successful parts of trial/mini

trial executions, with an intent to disseminate the lessons learnt and to validate the project results by external stakeholders.

2.6. ICARIA Case Studies and the Role of Local Communities of Practices

The overall approach of ICARIA stands on a close cooperation between technical and social sciences. The project fosters stakeholder engagement through the creation and management of local Communities of Practices (CoPs).

Based on the successful past experiences gained from projects, such as BINGO [34], CoPs will be created in each case study region involving scientific experts; problem owners; other relevant local; regional, and national stakeholders; and citizens. Within these CoPs, collaboration and communication channels in local languages will be established to facilitate the dialogue and cooperation and improve governance, coordination, and knowledge transfer related to the multi-risk management and long-term resilience planning of infrastructures. Participatory processes will be fostered to identify the gaps and needs and to achieve a better understanding of the risk awareness of local stakeholders and to ensure their involvement in the strategic decisions about the project's outcomes and tools as representatives of their potential end users. The CoPs workshops for each case study region will be thematized to address the important issues concerning the project developments and its evolving needs.

In the field of citizen science, ICARIA will promote the involvement of citizens in collecting data, contributing to fill data gaps, and participating in the models and DSS conceptualization. With the broader vision of the involvement of the public in the co-generation of scientific knowledge and the associated opportunities for learning and collaboration, ICARIA CoPs will foster the three first levels of citizens engagement of the Haklay pyramid [35] addressing their participation as data collectors (crowdsourcing, level 1), interpreters of data (distributed intelligence, level 2), and also as active actors for problem definition and solutions (participatory science, level 3) (see Figure 7 below).

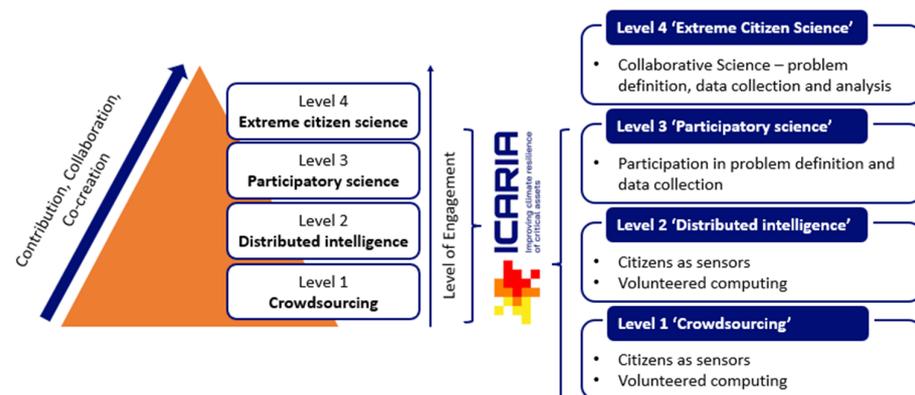


Figure 7. Citizen science classification by levels of engagement, according to Haklay [35].

3. ICARIA Case Studies

3.1. Context and Climate Challenges for the Case Study of the Barcelona Metropolitan Area (Spain)

The Barcelona Metropolitan Area (AMB, for its acronym in Catalan) is the largest conurbation of Catalonia (Spain). Encompassing 36 municipalities, it covers 636 km², has over 3.3 million inhabitants and is responsible for half of the region of Catalonia's GDP. In 2016, as a result of the Paris Agreement, the AMB authority elaborated The Climate and Energy Plan 2030 [36] to take decisive action against climate change. According to this plan, throughout the 21st century the main climate-related threats for the region will be higher temperatures, lower levels of annual average rainfall, and more extreme weather events (storm surges and heavy rain), increasing its related impacts (heat island and heatwave effects, floods, etc.). Similar results were achieved by project RESCCUE [22],

which also analyzed the cascading effects on the main services of Barcelona for current and future scenarios.

Although the occurrence and impacts of such hazards have been widely addressed, few studies have considered their combined impact on the region, which would result in further damage, as shown by storm Gloria in 2020, with high economic and environmental impacts and human losses [37]. Within this context, ICARIA will analyze the occurrence and characteristics of compound extreme events along the AMB as a paradigm of the northwest Mediterranean coastal zone.

3.2. Context and Climate Challenges for the Case Study of the South Aegean Region (Greece)

The Region of the South Aegean is an archipelago at the south-eastern edge of Greece that administratively includes the island clusters of the Cyclades and the Dodecanese. Its unique geographical location and geology/geomorphology, can cause severe problems to the local population's basic needs (water, food supplies, electricity, healthcare, etc.). Moreover, the seasonal changes in the island's population, due to tourism, can stress the use of resources, infrastructures, and assets. Water resources in the islands are supplied either by water tanker vessels or the use of local desalination facilities (for some Cyclades islands, up to 70% of the water consumed in summer). Additionally, the islands are supplied by ship, with most of the food supplies, fuel, consumer goods, etc., making ports a critical asset for social functioning. Regarding electricity, each island has its own power plant (fuel oil), with some smaller neighboring islands interconnected with underwater cables to a larger island. Out of the 52 inhabited islands, there are only 5 major hospitals, with the rest of the islands hosting small clinics. This provincial healthcare system is based on an operational protocol that dictates that patients, based on their condition, should be transported, if needed, by air or sea to the nearest major hospital or to mainland Greece.

In comparison with continental Greece and Europe, the effect of climate change is even more pronounced on such a region. The historical data indicate the increase in extreme weather events (heavy rain, floods, fires, etc.) in combination with higher average temperatures and heatwaves, yearly increases in their duration, and higher annual average rainfall levels. It therefore plays a significant role in developing solutions and implementing measures to combat climate change.

3.3. Context and Climate Challenges for the Case Study of the Salzburg Region (Austria)

The Salzburg region, situated in the Eastern Alps region of Austria, is home to 562,704 inhabitants and represents one of the major tourist areas in the country. Furthermore, it plays an important role in the energy production of Austria as it incorporates various hydropower plants. Since 1880, an approximately 2 °C increase in the average air temperature in Austria has been recorded [38], which is significantly higher than the global average. The mountainous regions are already suffering from the effects of global warming and Salzburg has recognised the risks the whole region is facing. Since the energy production in the region highly depends on hydro power plants, changes in the precipitation patterns towards extreme values poses a twofold risk: on the one hand, on the hydro plant itself due to the increased infiltration of trees, rocks, etc.; on the other hand, on road infrastructures with specific focus on the roads that need to be used in the case of damage repair needing to be performed on hydropower plants. Furthermore, the high-voltage energy power grid transporting electricity from the power plants to households is vulnerable to the potential damage caused by the increased occurrence of storms and landslides. The importance of renewable energy (already 77% due to hydropower) was emphasized even more in 2018, when Austria released its climate and energy strategy, “#mission2030”, for reaching the 2030 targets and advancing the long-term vision of a carbon-free energy sector by 2050. The vision addressed all energy sectors, mobility, and urban sprawl in one strategy and formed the basis of Austria's National Energy and Climate Plan (NECP) [39]. Apart from the energy infrastructure, the increasingly occurring hazards, such as storms, high

precipitation levels, and related landslides, also poses a threat to the road infrastructure and housing.

Contrary to extreme precipitation levels, water scarcity increasingly challenges the region, again affecting energy production due to water shortages, but also the prevailing ecosystems and tourism, thereby causing considerable economic damage. The region of Salzburg based a risk assessment on the existing 1 km data for Austria and mapped the expected climate risks, which were depicted for the energy and tourism sectors.

4. Project Outcomes and Dissemination

According to the overall objective of ICARIA to foster the systemic climate resilience of critical assets, the project's outcomes target all sectors of society and the economy, and, in particular, project target groups are the authorities at the local and regional levels as risk owners and are mainly responsible for planning and future investments, but also public and private companies managing strategic assets and services, universities, technology centers, and citizens. Table 1 summarizes the main expected outcomes of the project.

Table 1. Summary of the short-term pathway's expected outcomes.

Short-Term Pathway's Expected Outcomes	
Scientific Results (RES-SCI)	Technical Results (RES-TEC)
RES-SCI1. Project framework for climate multi-hazard holistic assessment at a regional level	RES-TEC1. Climate multi-hazard modeling tools
RES-SCI2. Regional climate projections for the long term considering the local socio-economic dimension	RES-TEC2. Holistic climate resilience assessment tool
RES-SCI3. Methods for mending the data gaps and uncertainty analysis for the risk and impact models	RES-TEC3. Portfolio of adaptation solutions
RES-SCI4. Climate-related multi-risk tangible impact assessment method	RES-TEC4. DSS for adaptation to extreme and compound events with cost-effective measures
RES-SCI5. Multi-risk and resilience assessment for the 3 case studies	
RES-SCI6. Replication, sustainability, and exploration of ICARIA results	

In the mid-term pathway, ICARIA will contribute to the Horizon Europe HORIZON-MISS-2021-CLIMA-02-03 topic by providing asset-level models beyond the state of the art for critical infrastructures to allow public authorities to better assess the adaptation measures. Additionally, ICARIA will contribute to the analysis of the gaps in the European datasets regarding the assessment of the direct and indirect economic consequences of damages to critical infrastructures.

Regarding the long-term impacts, ICARIA will provide general support to European regions to improve their climate resilience while mobilizing the relevant actors, such as regional and local authorities, research institutes, investors, and citizens, to create real and lasting impacts.

ICARIA will place significant emphasis on dissemination efforts throughout the project's lifespan. The initiative aims to allow both general and specialized audiences to access information about the project's progress and outcomes. It also aims to raise awareness among various audiences about the need for long-term planning to improve climate resilience. Furthermore, to encourage the widest possible application of its methods and tools beyond the project's lifetime, ICARIA will encourage communication between key stakeholders from different sectors and the exchange of knowledge with similar projects, ensuring a lasting impact on climate resilience measures in other regions.

A strategic communication and dissemination plan will be developed to achieve an efficient project communication action. This plan will include the development of an ICARIA brand, specific communication actions, and a strategy to reach target audiences.

The website of the ICARIA project (www.icaria-project.eu) will serve to provide easy access to the project's outcomes and tools, and update the climate adaptation research community about the project's activity and events.

5. Discussion

The multi-hazard risk assessment methodology that will be developed and implemented in project ICARIA (see Figure 4) will combine a top-down S-P-R-C (source, pathway, receptor, consequence) approach with a previous bottom-up evaluation of the interdependencies, interactions, and potential cascading effects among the assets and services affected by a multi-hazard event. Such an assessment will provide to the methodology a nonlinear perspective, as it will consider the impacts of the propagation of a hazard event on one asset over the entire matrix of interconnected systems and services of the risk assessment scope. Furthermore, it will include the possibility to introduce the potential adaptation measures of the assets and services considered as risk receptors. As a result, the ICARIA risk assessment methodology will shift from a classical linear impact evaluation approach to a more holistic framework that understands that the risk receptor (critical assets and services) can be considered as a subsystem of a larger system. Similar approaches, such as the DPSIR (drivers, pressures, states, impacts, responses) framework, have been previously applied with success in the field of risk assessment and disaster risk reduction [40].

Previous projects, where a similar methodology has been applied indicate non-linear relationships between the increase in hazard event intensities and impacts caused on the receptor. For instance, project RESCCUE concluded that, in the Barcelona, an increase in rainfall intensity of 12 to 16% in the future decades could lead to an increase of 42% of economic losses (considering both direct and indirect damage, including cascading effects on several services) and a 30% increase in intangible damage (e.g., area of the city classified as “high risk of flooding”) [22]. The reason behind this nonlinear growth is the existence of interconnections and knock-on effects due to cascading events among services that expand the consequences of the impact across the network of services and infrastructures.

6. Conclusions

The ICARIA project proposes a novel approach concerning asset-level modeling considering them in hazard, vulnerability, and impact models based on a strong background acquired from previous projects.

A high number of hazards (flooding, storm surges, heatwaves, droughts, forest fires, and wind storms) and assets in the sectors of water (water networks and wastewater treatment plants), transport (roads, ports, and metro), electricity (substation and distribution centers), waste (waste treatment plants), housing, and natural areas will be considered as potential risk receptors.

ICARIA is currently in its initial stage and this manuscript is proposed as a communication to describe the project’s main purpose, the methodologies that will be conducted, the assessment approaches to be followed, and the main scientific and technological outcomes expected to be achieved.

One of the first outcomes will be the achievement of climate-related hazard scenarios for three European regions using statistical and dynamical downscaling approaches allowing for tailored comparisons and uncertainty analyses.

Another novel point of the project will be the analysis of multi-hazards potentially exacerbated by climate change effects, including compound events (simultaneous and independent events), identifying trigger mechanisms and evaluating their joint probabilities.

On the other hand, a comprehensive multi-risk assessment, based on the previous and detailed sectoral vulnerability analysis, will address the tangible direct and indirect impacts, including cascading effects from specific assets/services to others.

The full risk assessment process will focus on three different trials with a high availability of resources (data, models, and tools) and will be replicated in three other mini trials with a poor level of available resources following a robust and consolidated methodology (DRIVER+ Trial Guidance Methodology).

The ICARIA Decision Support System (ICARIA DSS) will help local regional administrations and risk owners to improve their climate planning policies to face climate change in different contexts and according to tailored adaptation scenarios.

ICARIA solutions and tools will be proposed to seven other follower regions across Europe to ensure, from the very beginning, good project outreach and sustainability of its outcomes.

Stakeholder engagement will be ensured through the creation and management of local Communities of Practices formed by project coordinators, scientific experts, problem owners, technologies providers, and other relevant local, regional, and national stakeholders addressing a key aspect of the European climate policy: systemic adaptation. In this context, a participatory process will be followed during the entire duration of the project using engagement tools and exercises to identify the gaps and needs, to achieve a better understanding of risk awareness, and to ensure the co-creation of adaptation solutions.

ICARIA goes beyond the classical top-down risk assessment approach by including asset and service interdependencies to consider the propagation of impacts among the considered systems.

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