



# Final implementation status of the activities and actions at the Case Studies

## Deliverable 6.4

### WP6: Case studies: Coordination and implementation activities

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## EXECUTIVE SUMMARY

ARSINOE develops the methodological framework for the combination of the System Innovation Approach (SIA) with the Climate Innovation Window (CIW) to create an ecosystem for climate change adaptation solutions. The work in ARSINOE revolves around nine Case Studies (CSs), where the implementation of the SIA takes place. The case studies represent a range of environments and collections of (local and regional) stakeholders that are the target for the implementation of the innovation package developed in ARSINOE to strengthen resilience against climate change.

This deliverable, D6.4, focuses on conclusions, lessons learned, evidence-based recommendations to the EC and other case studies, based on the collective experience of the ARSINOE partners across the Case Studies. It presents the key results from the activities in the nine CSs. This deliverable is an updated version of Deliverables 6.1, 6.2 and 6.3, which reported on the activities in WP6 during the first 36 months of the project. This Deliverable also includes the outcomes of Task 6.5 - Lessons Learned and Evidence based recommendations. As such, the deliverable reports on the main outcomes per case study as well as those from the horizontal activities in the project, including the System Innovation Approach (SIA), governance assessment, resilience assessment, innovation open calls, financing portfolios and financial instruments. It also provides a brief comparison of the solutions based on performance indicators and an overview of actions for each case study to ensure continuation of activities or embedding and operationalization of outcomes in the local and regional context. Detailed outcomes from the case studies have been included in D6.7, in separate reports for each CS.

The implementation of the ARSINOE framework across the nine case studies has demonstrated the value of systemic, cross-sectoral approaches in advancing climate resilience. It was confirmed that **early, continuous, and participatory involvement of cross sectoral** stakeholders is required to create a **common understanding**, transparency, and the basis for long-term, institutionalised solutions. The **solutions co-designed** through such a participatory process, the System Integration Approach (SIA), are more likely to be successfully implemented as it provides the necessary legitimacy with (non-scientific) stakeholders. The support of co-development processes for climate adaptation solutions with scenario-based modelling was shown to strengthen collective understanding of future risks and trade-offs, enabling more **informed, inclusive, and adaptive** planning processes. These participatory processes are now securely embedded in the regions and municipalities that took part in the case studies; their best practices have been disseminated across Europe. Furthermore, the climate adaptation innovations that have been selected through the ARSINOE open tender for innovations are now part of the Climate Innovation Window under the European Climate Resilience Innovation Platform, and ready for broader adoption across Europe

### Resilience Assessment

The results of the case study-based resilience assessments underline the importance of sharing knowledge to cope with the increasing human and natural stressors in the face of large climate uncertainties. While multi-hazards were only considered explicitly in some of the ARSINOE case studies ARSINOE demonstrated that most regions in Europe *must* cope with multiple stressors, and hence transboundary learning and sharing of technologies and insights could be of critical importance. Prompted by needs identified, knowledge sharing therefore became a key part of ARSINOE. Another general conclusion stemming from a comparison of resilience assessment outcomes across case studies relates to the importance of the social dimension. While it is the economic impacts that are usually highlighted, most of the case studies report social impacts, that may be even more significant than the economic ones. Hence, the number of people whose wellbeing and livelihoods will be affected by extremes and gradual climate changes will be a key issue to achieving climate-resilience European societies.

### **Relation to policies and governance at the regional and national level**

At national level, ARSINOE identified several areas for improvement to support more effective climate adaptation. First, there is a need to make governance more flexible and responsive by simplifying administrative procedures and allowing local actors greater room to act. This can help speed up the implementation of adaptation measures on the ground.

At the same time, strengthening local capacity - both in terms of human resources and technical expertise - is essential. This will ensure that environmental and climate-related issues are properly considered in local planning and decision-making processes.

Better environmental monitoring is also important, especially for drought-related indicators. Reliable and up-to-date data can support more informed and timely decisions, particularly in sectors that depend heavily on water availability.

Raising awareness and improving understanding of climate risks is another key step. This can help build stronger public and political support for adaptation and encourage more proactive engagement from different stakeholders.

The legal framework should be reviewed and updated where necessary, particularly to support emerging solutions such as water reuse. These innovations often require new infrastructure and clearer legal conditions to be developed and implemented effectively.

In addition, a more integrated and cross-sectoral approach is needed—especially at the intersection of water, energy, and food. Creating spaces for dialogue and joint planning across sectors can lead to more coherent and efficient adaptation strategies.

### **Wider contribution to EU Policies**

The ARSINOE results provide clear links to European policy frameworks, reinforcing the project's wider societal and environmental relevance.

Even more remarkably, ARSINOE contributes directly to the achievement of several United Nations Sustainable Development Goals (SDGs). Notably, it advances SDG 6 (Clean Water and Sanitation) through improved governance of water resources, including aquifer protection, water reuse, and sustainable allocation mechanisms. It supports SDG 13 (Climate Action) by designing and testing adaptation pathways that reduce vulnerability to extreme events. Moreover, it strengthens SDG 14 (Life Below Water) and SDG 15 (Life on Land) through the protection and restoration of aquatic and terrestrial ecosystems in regions, and it supports the importance of SDG 7 (Clean and Affordable Energy), providing advice to Nexus co-considerations.

ARSINOE embraces the One Health perspective, recognising that human health is intrinsically linked to the health of ecosystems and animals. By improving water quality, safeguarding biodiversity, and reducing pollution exposure, ARSINOE strengthens the environmental determinants of health. Furthermore, by securing water and food supplies under changing climatic conditions, the project helps to mitigate public health risks associated with scarcity, contamination, and ecosystem degradation. ARSINOE confirms that One Health must evolve into a systemic resilience paradigm: linking environmental sustainability, water resilience, public health, and socio-economic stability. Climate change impacts such as extreme heat, floods, droughts, and biodiversity loss cannot be managed in isolation. By demonstrating practical tools, governance frameworks, and innovation pathways, ARSINOE provides a blueprint for future European and global resilience initiatives.

ARSINOE methodologies, activities and actions implemented at the case studies are relevant for the Water Resilience Strategy Act. Specifically, the SIA approach adopted in the project is in line with the core

suggestions of this Act. Additionally, all the case studies are relevant for this Act, approaching the topic from varying angles, which could be used as a paradigm for future regional actions.

ARSINOE makes a tangible contribution to the objectives of the European Green Deal. The solutions co-developed with stakeholders in the living labs exemplify how the principles of climate neutrality, circular economy, biodiversity protection, and zero pollution can be operationalised at regional and local levels. The innovation packages validated in the case studies demonstrate pathways for replication and scaling, providing evidence-based strategies to accelerate Europe's transition towards resilience and sustainability.

Through its digital solutions, ARSINOE links the Green Deal with digitalisation, which is part of the Green and Digital Transition for Europe (Twin transition) ([The twin green & digital transition: How sustainable digital technologies could enable a carbon-neutral EU by 2050 - European Commission](#)).

In summary, ARSINOE has established a strong foundation for translating scientific knowledge and systemic innovation into actionable solutions. By aligning with regional, national and European policies, the SDGs, One Health, Water Resilience and the European Green Deal with Twin Transition, the project not only addresses immediate regional challenges but also contributes to the long-term vision of a sustainable, climate-resilient Europe.

Related Deliverables: Deliverable 6.6 (M45) for a detailed report on the SIA implementation in the living labs (updated from D6.5), Deliverable 6.7 (M45) on a detailed report about the activities at all the Case Studies for the implementation of SIA, D6.8 on the financial and business perspectives (M48) and Deliverable 3.5 (M30) for the climate projections and scenarios and model selection (updated from D3.4), D3.8 describing the Multi-System Dynamic Modelling Framework (M30), D4.1 on the Visualisation Dashboard for Codesigning Solutions/ Scenarios for Digital Twin (M36), D4.7 describing in full detail the Machine Learning Models for Knowledge Graph data analytics (M36). The previous versions of this deliverable are D6.1 (M4) and D6.2 (M18).

## List of Abbreviations

|         |                                                                                             |
|---------|---------------------------------------------------------------------------------------------|
| ABS     | Agent Based Simulation                                                                      |
| AHP     | Analytical Hierarchy Process                                                                |
| AMA     | Athens Metropolitan Area                                                                    |
| AQI     | Air Quality Index                                                                           |
| CAP     | Climate Action Programme                                                                    |
| CCC     | Climate City Contract                                                                       |
| CDD     | Consecutive Dry Days                                                                        |
| CHT     | Combined days of hot days and tropical nights                                               |
| CI      | Critical Infrastructure                                                                     |
| CIW     | Climate Innovation Window                                                                   |
| CLC     | CORINE Land Cover                                                                           |
| CS      | Case Study                                                                                  |
| CTM     | Chemistry Transport Model                                                                   |
| CVVA    | Climate Change Vulnerability Assessment                                                     |
| D       | Deliverable, e.g. D6.1 is ARSINOE deliverable 6.1                                           |
| DCA     | Danish Coastal Authority                                                                    |
| DES     | Discrete Event Simulation                                                                   |
| DMRM&AF | Dynamic Multi-Sectoral Resilience Modelling and Assessment Framework                        |
| ESG     | environmental, social and governance                                                        |
| EU      | European Union                                                                              |
| FAO     | United Nations Food and Agriculture Organization                                            |
| GA      | Grant Agreement                                                                             |
| GDP     | Gross Domestic Product                                                                      |
| GIS     | geographic information system                                                               |
| IWaMM   | Integrated Water Management Model                                                           |
| KPI     | Key Performance Indicator                                                                   |
| LL      | Living Lab                                                                                  |
| LST     | Land Surface Temperature                                                                    |
| M       | Month as counted in the duration of the project, M1 being the starting month of the project |
| MCDA    | Multiple-Criteria Decision Analysis                                                         |
| MS      | Milestones                                                                                  |
| NBS     | Nature based solutions                                                                      |

|        |                                                                              |
|--------|------------------------------------------------------------------------------|
| NDVI   | Normalised Difference Vegetation Index                                       |
| OTI    | open tender for innovations                                                  |
| PCA    | Principal Component Analysis                                                 |
| PESTLE | Political, Economic, Social, Technological, Legal, and Environmental factors |
| RCM    | Regional Climate Model                                                       |
| RCP    | Representative Concentration Pathways                                        |
| SD     | System Dynamics                                                              |
| SDG    | Sustainable Development Goal                                                 |
| SDM    | System Dynamics Modelling                                                    |
| SFINCS | Super Fast INundation of CoastS                                              |
| Sh     | Stakeholder                                                                  |
| SHVI   | Socio-Economic Heat Vulnerability Index                                      |
| SIA    | System Innovation Approach                                                   |
| SLR    | Sea Level Rise                                                               |
| SSP    | Shared Socioeconomic Pathways                                                |
| SVI    | Social Vulnerability Index                                                   |
| UAV    | Unmanned Aerial Vehicle                                                      |
| WEFE   | Water Energy Food Ecosystem                                                  |
| WP     | Work Package                                                                 |
| WRF    | Weather Research and Forecasting                                             |
| WS     | Workshop                                                                     |

## 1.0 INTRODUCTION

Adaptation to climate change refers to all approaches taken to adjust, prepare for, and accommodate new conditions that are created by changing climates. Adaptations may be cultural and societal, technical or financial or nature-based solutions. As climate change is complex and interconnected with other global challenges, such as food security, water scarcity, biodiversity depletion and environmental degradation, it is insufficient to use traditional approaches to innovation that focus on one aspect of the problem.

ARSINOE developed a methodological framework for the combination of the **System Innovation Approach** (SIA) with the **Climate Innovation Window** (CIW) to create an ecosystem for climate change adaptation solutions. ARSINOE created this ecosystem with a three-tier approach: (a) using SIA it integrated multi-faceted technological, digital, business, governance and environmental aspects with social innovation for the development of adaptation pathways to climate change, to meet EU Green Deal targets for specific regions; (b) it linked with CIW to form innovation packages by matching innovators with end-users for specific regions; (c) it fostered the ecosystem sustainability and growth with cross-fertilization and replication across scales, at European level and beyond, using specific business models, exploitation and outreach actions. The ARSINOE three-tier approach was show-cased in nine widely varied regions across Europe (case studies), as a proof-of-concept with regards to its applicability, replicability, potential and efficacy.

The nine Case Studies covered representative areas of the European Continent, ranging from Spain to the Black Sea and from Greece to Denmark. In terms of systems complexity, they also covered a wide range including health, energy, transport, forestry, fisheries, farmland, and wetlands, which face challenges such as biodiversity loss, floods, water scarcity, and heatwaves in escalating severity depending on the region. The main challenges and key thematic issues, related to resilience to climate change, that were addressed for each case study are shown in Figure 1.

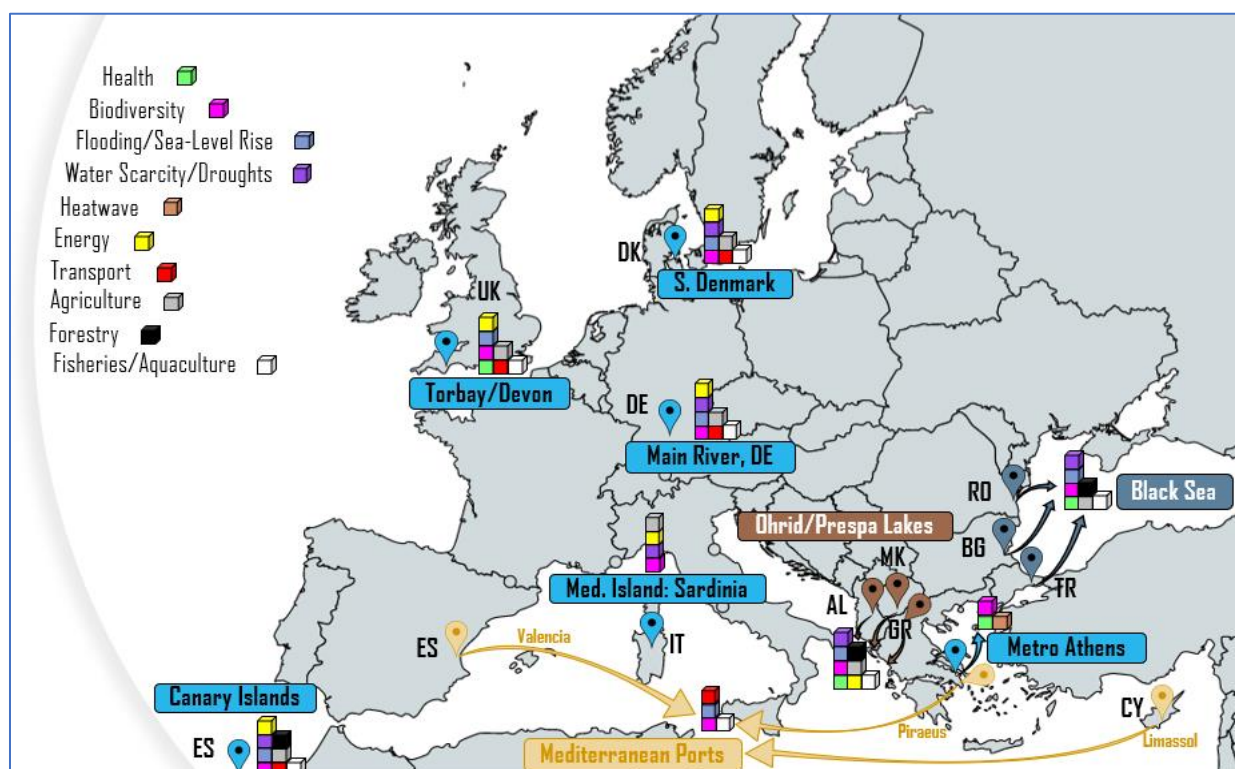


Figure 1: Location and key thematic issues/systems addressed by the CS.

## 1.1 This deliverable and its place within ARSINOE outcomes

The work in ARSINOE revolves around the nine Case Studies (CS). The methodological framework (Figure 2), including the tools and methodologies developed in the project, is put in practice in the CS. The central position of the case studies within the project is shown in Figure 3, which shows the approach and the research areas in ARSINOE.

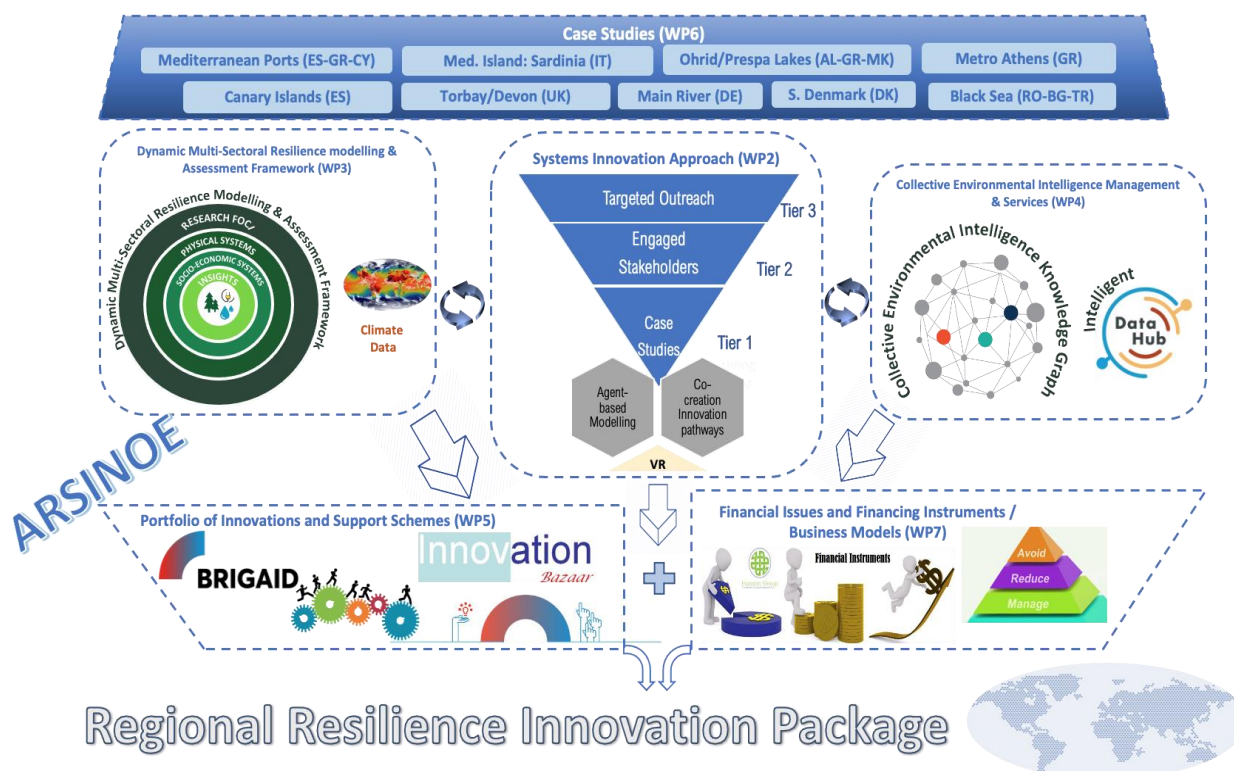


Figure 2: Methodological approach followed in the ARSINOE project for the CS.

The work in the case studies has been reported throughout the project in a number of deliverables, specifically D6.1 (Initial Roadmap and monitoring plan for the activities and actions at the Case Studies) and D6.2 and D6.3 that presented updates and status monitoring for the activities in the case studies. This deliverable, D6.4, is produced as part of this ongoing monitoring and is an updated version of D6.1, D6.2 and D6.3. The final version here includes a brief update of the activities performed in the CS. Extensive report on specific actions are included in other deliverables, particularly D6.6, which deals with the implementation of the SIA in the case studies and D6.7, which deals with the Resilience Assessment Implementation. In this Deliverable, we focus on providing a short summary of the main outcomes of the case studies, and as the final deliverable dealing with the case study activities, drawing the overall conclusions and lessons from the implementation of the methodological framework. It provides the evidence-based recommendations by synthesising the experiences from the work in the CSs. Based on this, general lessons learnt, and best practices will be identified to structure and support recommendations for implementing the ARSINOE approach in a multidisciplinary process of co-creation. The recommendations cover gaps, inconsistencies and ambiguities related to co-creation, SIA, resilience assessment and financial instruments, with regards to the GDPs. The evidence-based recommendations also include a strategy for achieving community resilience at EU level, based on the evidence-based knowledge, synergies across the Case Studies and lessons learned from them. To complete the synthesis, not only the lessons learned and recommendations from the case studies, but also from the cross-cutting work packages are included in this deliverable.

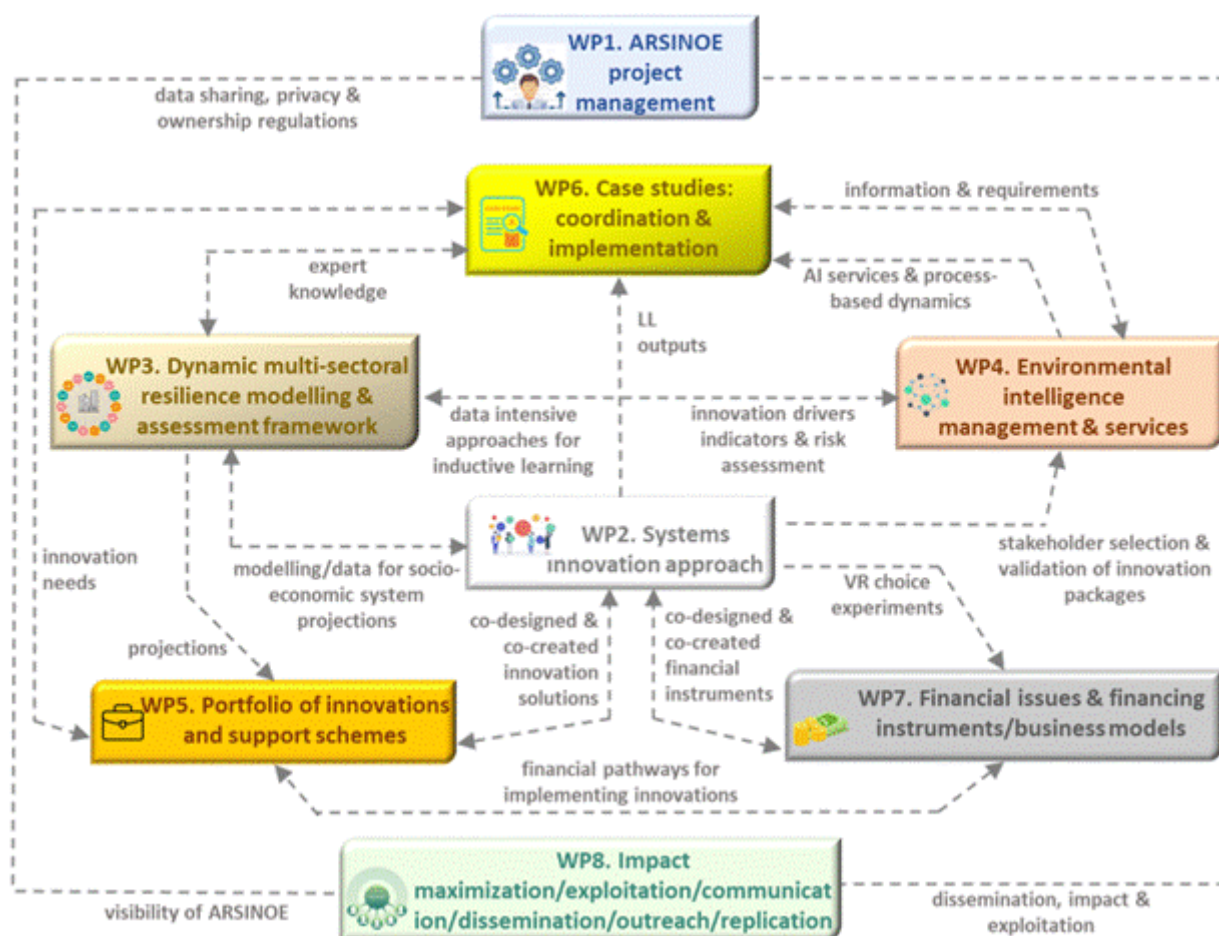


Figure 3: Schematic representation of the interlinkages between WP6 and the other WPs.

The strong connection with specific methodological building blocks in ARSINOE framework is evidenced by the structure of WP6, in which the case study activities were concentrated. Besides an overall coordination task (Task 6.1 Development and monitoring of a roadmap of actions in all the case studies), the work package was structured as follows:

#### Task 6.2 Implementation of the System Innovation Approach in each case study.

This task focussed on the implementation of the System Innovation Approach for all the CSs. This task identified stakeholders through a dynamic stakeholder mapping and implemented the stakeholder engagement activities for co-creation developed in WP2 at each CS. The outcome of this Task detailing the implementation of the SIA in each CS was reported in D6.6.

#### Task 6.3 Resilience Framework implementation in each case study.

Task 6.3 consisted of the implementation of modelling activities required in each case study for the resilience modelling framework (WP3) and the implementation of the Environmental Intelligence Services (WP4). Due to their varying natures, each CS had different modelling requirements for the implementation of the resilience framework. Consequently, modelling activities included (apart from the generic tools detailed in WP3, WP4) additional case-specific modelling activities. All these actions were reported in detail in Deliverable 6.7.

#### **Task 6.4 Innovation packages development and validation in each case study**

This task identified innovations that supported each CS in furthering their climate resilience objectives. Innovators were identified through an open call for tenders, which was organised in collaboration with WP5. The innovations packages formed for each CS, which includes the selected innovations validated by stakeholders, are reported in Deliverable 6.8.

#### **Task 6.5 Lessons learned and evidence-based recommendations**

In this task, experiences from the work in the CSs from T6.2, T6.3 and T6.4 will be synthesised and based on this, general lessons learnt, and best practices (evidence-based) will be identified to structure and support recommendations for implementing the ARSINOE approach in a multidisciplinary process of co-creation. The outcomes of Task 6.5 are reported here.

### **1.2 Structure of this document**

The deliverable is organised as follows: Chapter 2 provides a short overview of the nine case studies, presenting a short description, overview of key systems addressed and their key activities. This is followed by a summary of the main outcomes per case study, a brief comparison of the solutions based on performance indicators defined by the case studies themselves. Chapter 2 is rounded off with an overview of actions for each case study to ensure continuation of activities or embedding and operationalization of outcomes in the local and regional context, as well as an overview of evidence based best practices as identified by the case study partners. Chapter 3 then presents the most important overall findings on the horizontal methods and methodologies developed for and implemented by the case studies, including the System Innovation Approach (SIA), modelling, data, resilience assessment, innovation open calls, financing portfolios and financial instruments, policies and communication. Chapter 4 makes a synthesis of the lessons learned, while chapter 5 brings together overall recommendations from the project. Finally, Chapter 6 provides a short discussion and conclusion on the findings described in this deliverable.

## 2. CASE STUDIES

This chapter focusses on the direct outcomes from the case studies, the evidence-based recommendations from each case study and the outlook beyond the project concerning the process towards climate resilience that was supported in ARSINOE. Furthermore, an assessment of the implementation of the methodological approach followed in the ARSINOE case studies based on key performance indicators, and the impact of the solutions under various climate scenarios will be presented.

### 2.1 Overview of the CS and related activities during the project

The work in ARSINOE revolved around nine Case Studies (CS). A short description, with the key characteristics or each CS the key systems addressed in the CS and the main activities executed is provided in the following table (Table 1).

Table 1: Short updated descriptions of the nine case studies in ARSINOE.

| CS1: Greening the Athens metropolitan area                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |  | Lead Partner: UTH     |
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| <p><b>Short description:</b> Athens is the capital and largest city of Greece, within the Athens Metropolitan Area (AMA) of 40 municipalities, generating over 40% of the national GDP. Its strategic location, supported by the port of Piraeus and modern infrastructure, makes it vital for Greece and the wider Mediterranean. Attica, the wider region, is highly exposed to extreme weather events. Heavy winter rainfall frequently damages housing, infrastructure, and traffic. Recurring summer wildfires worsen flooding impacts and increase risks. These vulnerabilities affect not only Athens but also Greece as a whole. The ARSINOE project introduces systemic solutions to strengthen resilience. It supports the Athens Resilience Strategy (2017) and Climate Adaptation Plan (2022). The Municipality also finalised its Climate City Contract in 2024. Innovations include data platforms, financial tools, citizen science, and youth assemblies, focusing on environment, health, and infrastructure.</p> <p><b>Key systems addressed:</b> The key systems addressed in this case study are <b>environment, health and infrastructure</b>. In particular, the Athens municipality has a strategic focus to <b>enhance green infrastructure</b> and <b>support urban biodiversity</b>, to best shield itself from, adapt to, and build resilience to Climate Change challenges (extreme heat and flash floods). Considering that Athens faces chronic urban growth issues that amplify climate change impacts, the above key systems are addressed and are expected to deliver several benefits in terms of the resilience of the city. The case study specifically focuses to the mitigation of <b>heat waves</b> and other compound hazards, such as <b>air pollution</b> and <b>biodiversity loss</b>, in a long-term and short-term manner. The long-term manner involves urban planning options and mitigation solutions, whereas the short-term manner involves recommendations for civil protection options.</p> <p><b>Key activities performed during ARSINOE:</b> In the Athens Case Study (CS#1) several key activities were carried out to strengthen climate resilience. Citizen participation was promoted through science activities, youth assemblies simulating local Green Deal processes, and integration of climate practices into education. Stakeholder engagement and Living Labs fostered collaboration with public authorities and local actors to identify hazards and co-design adaptation pathways and solutions. Three innovative solutions were implemented to address extreme heat. High-resolution climate projections and urban climate modelling assessed future heatwave risks and the cooling potential of nature-based solutions (NBS). Urban heat island effects were mapped via satellite data, while air quality modelling and socio-economic analyses identified vulnerable groups and neighbourhoods. Ecosystem connectivity and green space accessibility were evaluated to support urban planning. A Climate Change Vulnerability Assessment framework and hotspot mapping combined environmental, social, and health risks to guide NBS prioritization. Citizen preferences were integrated through a Virtual Reality-based willingness-to-pay model. Finally, operational tools, including a Heat Event Response system, were developed to support timely decision-making during extreme heat events.</p> |  |                       |
| CS#2: Mediterranean Ports                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |  | Lead Partner: AUEB-RC |
| <p><b>Short description</b> This transboundary case study covers the ports of Piraeus (Greece), Limassol (Cyprus), and Valencia (Spain). Piraeus (partner PPA), the world's second maritime cluster, is a leading European hub for coastal</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |  |                       |

shipping, cruises, and container cargo. COSCO holds 51% ownership, and the port participates in 14 EU-funded projects to become a “green” and financially independent seaport. Limassol handles 90% of Cyprus’s trade and major passenger traffic, including cruises and ferry links with Greece, Israel, Egypt, and Lebanon. It is operated by DP World Limassol, P&O Maritime Cyprus Limited, and Eurogate. Valencia, managed by the Port Authority of Valencia (Fundacion Valenciaport), oversees three state-owned ports (Valencia, Sagunto, Gandía). It is Spain’s top Mediterranean port for commercial traffic, with extensive global connections, and participates in over 40 EU projects (partner FV), many on environmental sustainability.

ARSINOE will help these seaports and surrounding communities adapt to climate change by:

- conducting vulnerability assessments as a basis for resilience and adaptation planning,
- identifying and prioritising adaptation actions, and
- designing tailored adaptation pathways.

Findings will be translated into transformative interventions that integrate port authority tools, stakeholder engagement, and financial instruments. Adaptation pathways will be co-designed through SIA and BRIGAD mechanisms, supported by existing and proposed financing, and reinforced by policy and administrative adjustments.

**Key systems addressed** Climate change intensifies weather events that threaten seaports and waterways through sea level rise, storm waves, flooding, and coastal erosion—posing risks to infrastructure, economies, and human lives. The EU Blue Economy, worth €750 billion and employing 5 million people (2018), is vital, especially for Cyprus, Greece, and Spain, where tourism, fisheries, and shipping are key. In Greece, maritime transport is essential due to insularity, making short sea shipping critical.

Strengthening resilience and adaptation of seaports is therefore crucial. ARSINOE will address infrastructure and maritime transport by reducing cascading climate impacts on communities, while indirectly supporting fisheries, aquaculture, and nearby biodiversity. The case study will also explore nature-based solutions (NBS), including blue carbon approaches such as seagrass and salt marsh restoration, as alternatives or complements to conventional adaptation measures.

**Key activities performed during ARSINOE** Across the three Mediterranean ports (Piraeus, Valencia, and Limassol), a set of **common activities** was carried out to strengthen resilience and co-develop adaptation pathways. These included:

- **Living Labs with key stakeholders:** Each port organised three Living Labs structured around:
  - Mapping, identification, and definition of problems, threats, and relevant sectors
  - Validation of mental maps and envisioning the 2050 Mediterranean Ports Vision
  - Back casting exercises and development of innovation pathways

In addition to these shared activities, **each port carried out specific actions** reflecting their local contexts and priorities:

#### **Piraeus Port Authority (PPA SA)**

- Completed a tender for open innovation applying the **DIORAMA tool**, a multi-layered system supporting emission source attribution and air quality mitigation strategies in port areas. It focused on:
  - Vehicle-emissions correlation through AI-based detection and pollutant sensors
  - Monitoring ferry activity and associated maritime emissions
  - Cargo port pollution mapping with mobile sensors linked to meteorological data
  - Satellite data collection and analysis of air pollution in the wider Piraeus area

#### **Port of Valencia (FV)**

- Launched and managed the **CLEVER TOOL** through the ARSINOE Open Tender, linked to the Climate Change Observatory, developed with Puertos del Estado, the Port Authority of Valencia, and companies in the port community.

#### **Limassol Port**

- Beyond the common deliverables, Limassol led an **open tender process** for a climate-adaptive Early Warning System (EWS) integrating sensors, machine learning, and AI.
- The process included:
  - A pan-European call (ARSINOE Open Call 2) yielding seven submissions, four meeting TRL and scope requirements
  - A formal procurement via the Cyprus government’s **e-procurement platform**, ensuring compliance with Public Procurement Law 73(I)/2016

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| <ul style="list-style-type: none"> <li>○ Evaluation of four shortlisted companies, resulting in the selection of <b>Embio Diagnostics</b> as the winning provider, offering the most economically advantageous solution aligned with technical specifications and legal requirements</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                           |
| <b>CS#3: Main River, Germany</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <b>Lead Partner: LMU</b>  |
| <p><b>Short description:</b> The Main is the Rhines' largest right tributary. The river has a complex runoff regime. The diverse topographic and climatic conditions in the catchment have led to heterogeneous land use patterns. While Upper Franconia, due to its mountainous character and adverse climatic conditions, is characterised by forests, Middle and Lower Franconia are characterised by intense and very diverse agricultural use with specific effects on natural habitats, groundwater and alternative land use. The transition towards renewable energy production is underway along the Main and causes land use change (biomass, photovoltaic, wind). Critical infrastructure (water, wastewater, power, heat) is often managed at municipal level. The river is used for shipping from the Black Sea to the North Sea. The Rhine-Main-Danube Canal, as part of the Franconian Water Transfer System, employs a complex network of artificial reservoirs and rivers to transfer on average 150 Mm<sup>3</sup> per year from the Danube to augment low flow conditions and water quality in the Main River system.</p> <p><b>Key systems addressed:</b> The Main River basin is highly vulnerable to the effects of climate change. There is substantial conflict and competition for land and water resources caused in parts by land use change, (irrigation) agriculture and the energy transition. The river basin experiences major dependency on Danube water. Projections suggest intensified winter floods and particularly extreme summer droughts, posing a real challenge for all "areal" economies (agriculture, forestry, water resources management). In addition, the urban centres in the basin are not prepared for the expected heatwaves. ARSINOE focused on stream and groundwater quality and quantity, examining specifically the impact of anthropogenic activities such as agriculture, energy production, and waste management, on the hydrogeochemical pathways between the terrestrial and aquatic environments, on land resources competition and ecosystem services (air and water quality, habitat fragmentation, erosion), on water quality; land use change and conflicts, examining the effect of agricultural practices and competition with other economic uses.</p> <p><b>Key activities performed during ARSINOE</b> Implementation of the SIA by mapping stakeholders and establishing a living lab for the qualitative assessment of climatic risks, the co-design of transformation pathways and identification of innovation gaps. Joint development of key issues and selection criteria for the open tender for innovation with the stakeholders from the living lab. A governance analysis was carried out to assess the current state of Water Energy Food Ecosystem (WEFE)-NEXUS-governance in the region with view to identifying levers and barriers for change towards climate resilience. Implementation of a hydrological model and land-surface response tools to model the projected changes of key hazards (floods, droughts, heat) under the common baseline in the Main River basin. SIA resulted in a list of innovations. A Political, Economic, Social, Technological, Legal, and Environmental factors (PESTLE) analysis was conducted with stakeholders to assess hurdles and levers for realising the innovation pathways. In addition, two innovations were selected through the 1<sup>st</sup> ARSINOE open tender for innovators (OTI). Moreover, the need for hydroclimatic services among stakeholders in the region was assessed and a simple tool for jointly designing climate services was built.</p> |                           |
| <b>CS#4: Ohrid/Prespa lakes</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <b>Lead Partner: IECE</b> |
| <p><b>Short description:</b> Ohrid and Prespa Lakes are situated in a transboundary region of Western Balkans, and span across three countries (North Macedonia, Albania and Greece). They are within the most ecologically significant aquatic ecosystems in Europe, renowned for their exceptional biodiversity, and for a UNESCO protected cultural heritage area. The CS#4 aimed at improving climate resilience of environmental, economic and social sectors related to water use, by providing an intelligent comprehensive innovative set of long-term planning solutions, allocation and use of sufficient quantity and of adequate quality water for all users, respecting their interests and development. The following issues were considered as relevant for the project: 1) high level of exposure of the region to climate risks, 2) identified problem of depletion of surface and groundwater bodies, 3) vulnerability, of multiple sectors dependent on water, 4) need for integrated cross sectoral actions, for improvement of their climate resilience.</p> <p><b>Key systems addressed:</b> CS#4 contributed to secure a balanced use of available water resources and bridged the gap between social and economic sectors facing the climate change impacts on a transboundary water ecosystem of Ohrid and Prespa lakes (app. 3000 km<sup>2</sup> of watershed area), by addressing the flowing key systems: 1) Environment: Biodiversity &amp; ecosystems, 2) Society: citizens, households, water management utilities, policy making and 3) Economy: agriculture, fishery, tourism, Industry, hydropower sector.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                           |

**Key activities performed during ARSINOE:** The complete set of modelling tasks was supported by co-creation activities with stakeholders through national and transboundary workshops and resulted in directions for an Improved adaptiveness to water scarcity induced by climate changes in the observed region. Actions included: 1) Collection of data and specification of long-term water needs; 2) Overview and analysis of the existing studies and plans; 3) Preparation of baseline and forecast climate scenarios report and its presentation to stakeholders; 4) Complex system numerical model adjustment to the observed region needs, software modifications, preparation of databases, 5) Integration of the identified multi sectoral consumption patterns; 6) system modelling and simulation of coupled multi sectors' response in climate risks scenarios; 7) optimization of multi-sector climate adaptiveness; 8) Integrated model of climate adapted water management, development and presentation at stakeholders workshops; 9) Transboundary Communication and Collaboration Framework; 10) Evaluation of key performance Indicators; 11) Model outputs exploitation plan; 12) Developed System Dynamics Modelling (SDM) solution for the Lesser and Great Prespa Lakes and Lake Ohrid complex; 13) Biodiversity observations through citizen science (MINKA) involving local schools.

#### CS#5: Canary Islands

**Lead Partner: ULL**

**Short description:** The Canary Islands are an outermost region of the European Union belonging to Spain, located approximately 2000 km from the Iberian Peninsula. Due to their insular condition, they are characterised by limited resources and high dependence on the outside world. This archipelago must develop and implement an ecological transition on the islands, so that life on them can develop in a sustainable way in the future. This is key in a region where the population is growing annually and where a large part of the water resources come from the subsoil and from seawater desalination, all framed in a scenario of climate change.

Climate change scenarios predict an increase in temperatures as well as a variation in rainfall patterns, so that without early action, there is a risk of depleting the aquifers' reserves, putting them in a vulnerable situation. All this would lead the archipelago to increase the use of desalination, which has positioned itself as one of the largest consumers of electricity. Therefore, improving the quantitative and qualitative status of groundwater in the Canary Islands is therefore essential for sustainable development in the archipelago.

**Key systems addressed:** This case study focuses on the hydrogeological systems of two islands in the European outermost region of the Canary Islands: El Hierro and La Palma. The primary objective was to achieve a comprehensive, science-based understanding of the aquifer systems on both islands, recognising their unique geological contexts and water management challenges. Another essential component of the case study involved the evaluation of sea level rise (SLR) and its potential effects on the freshwater systems of both islands.

**Key activities performed during ARSINOE:** To do this, we developed high-resolution three-dimensional hydrogeological models, which represent a significant advance in the spatial and structural understanding of subsurface water systems. These 3D models integrate geological, hydrological, and climatic data, providing precise and actionable insights into groundwater dynamics.

Also, with climate change accelerating the rise of global sea levels, island regions are especially vulnerable to the salinization of coastal aquifers, a phenomenon that can degrade water quality, reduce availability, and compromise infrastructure near the coast. Our assessments modelled the shifting position of the baseline water table under different SLR scenarios, identifying critical risk zones and offering adaptation pathways to mitigate future impacts.

#### CS#6: Black Sea case study

**Lead Partner: AUTH**

**Short description:** The Black Sea basin is experiencing growing pressure from human activities and climate change, leading to the degradation of its marine ecosystem since the 1970s. ARSINOE adopts a source-to-sea approach through a virtual watershed that integrates four sub-case studies: Aliakmon River (GR), Ropotamo River (BG), Danube Delta (RO), and Western Black Sea coast/Marmara (TR). These represent headwater, riverine, deltaic, and coastal systems. The case study promotes climate adaptation and SDG fulfilment via improved monitoring, a digital twin, biofiltration assessments, and integrated land-sea system modelling, offering a scalable and transferable framework for regional resilience.

**Key systems addressed:** The case study targets the interconnected systems of upstream land use, riverine flows, wetlands, and coastal-marine ecosystems of the Black Sea. It addresses climate-induced pressures—floods, droughts, pollution, biodiversity loss—exacerbated by human activities. Through a virtual watershed model, ARSINOE integrates the headwaters (Aliakmon River), the biodiverse Ropotamo wetland, and the Danube Delta Biosphere Reserve, focusing on water quality, habitat resilience, and plastic/nutrient inflows. The Western Black Sea and Marmara connection further highlight marine-climate linkages. The CS leverages synergies with BRIDGE-BS, DOORS, and Black Sea CONNECT to inform adaptive solutions and policies.

**Key activities performed during ARSINOE:**
**Aliakmon River – Greece**

As the Aliakmon River is the largest river in Greece and is used for energy production, water supply and irrigation, the research team focused on understanding and modelling its hydrological state to produce a digital twin to improve water management efficiency. Specifically, a HEC-HMS model was implemented to simulate rainfall-runoff processes in the basin by collecting hydro-meteorological, topographical, geological, soil and land-use data including ERA5 reanalysis, EUDEM v1.1, JRC and CORINE. In the model, measured river flow rates, reservoir stages and hydropower production data were integrated and a real-time monitoring system was designed and installed to validate results. Furthermore, extreme events were simulated (floods and droughts) to assess impacts on critical infrastructure, water supply, irrigation and hydropower, while ecological thresholds were identified. Finally, AUTH was responsible for the implementation of the three International Living Labs, which revealed the innovation pathways for a climate-resilient Black Sea.

**Danube Delta – Romania**

The description and understanding of microbial ecology are very important for optimising the biofiltration. In our research, with the aim of identifying the species that are involved in natural biofiltration process through their bioaccumulation characteristics, we have managed to isolate more than 200 strains of which several were further used for DNA extraction. From all the isolated and identified strains, several species isolated by our team stood out and were described in literature for having potential in bioaccumulation or bioremediation processes.

**Ropotamo – Bulgaria**

The ENOVA H2O innovation, deployed in 2024, introduced fixed-point sensors along the river to continuously monitor key water quality indicators (e.g. COD, TOC, BOD, pH, and blue-green algae). Two-year UAV campaigns (photogrammetric + thermal + multispectral) were performed to map habitat dynamics, combined with regional climate modelling with ALADIN 5.2 (RCP4.5 & 8.5, 2023-2050). These UAV flights provided geo-referenced imagery to support GIS-based habitat assessment. Building on this foundation, installation of ENOVA H2O solar-powered sensor station was done. The data collected by the ENOVA H2O innovation enables real-time evaluation of pollution trends, self-purification capacity, and potential risks to ecosystem integrity. In addition, three national Working-Groups were organised and PESTLE & Innovation-Pathway exercises performed to co-define a 2050 vision and milestones.

**Black Sea - Türkiye**

The METU team focused on the southwestern Black Sea and its connection with the Sea of Marmara. The work centred on marine water quality and resilience to climate change, addressing issues such as eutrophication, hypoxia and mucilage events. It developed and applied the NEMO-TURSEM coupled marine biogeochemical model, integrating nutrient dynamics phytoplankton growth, oxygen depletion, and carbon cycling under SSP3–7.0 climate scenarios. Field data from ship-based water quality monitoring and downscaled EuroCORDEX climate projections were combined to assess seasonal algal blooms, hypoxic area expansion, and primary production changes, providing critical insights for fisheries and marine ecosystem resilience planning. Furthermore, it cooperated with Polyregnum to install a Smart Monitoring System platform, a high-resolution marine and atmospheric system, which integrates modular sensors that measure temperature, pressure, salinity, pH, ORP (oxidation-reduction potential), dissolved oxygen, humidity, sea level, and CO<sub>2</sub>.

**CS#7: Southern Denmark**
**Lead Partner: DTU**

**Short description:** Southern Denmark includes Funen (Fyn), nearby small islands, and the southernmost part of Jutland bordering Germany. The region is dominated by coastal areas connecting the North Sea, Baltic Sea, and Inner Danish Waters. This case study focuses on the south-western area bordering the UNESCO-listed Wadden Sea, covering four municipalities: Esbjerg, Tønder, Varde, and Fanø (total area: 3369 km<sup>2</sup>). Esbjerg municipality, home to about half of the region's 206,000 people, is the focus, with Esbjerg city and towns like Ribe and Bramming. Esbjerg's port is a regional economic hub, supporting industry, wind energy, and oil and gas. Key sectors include fisheries, agriculture, and aquaculture. Ribe is Denmark's oldest town with significant cultural heritage.

Climate change severely impacts the area, causing flooding, sea level rise, storms, and drought, affecting many sectors. Adaptation is hindered by conflicting sectoral, institutional and economic interests, physical and knowledge limitations, and underdeveloped institutional frameworks, especially in places like the Wadden Sea area.

**Key systems addressed:** Flooding caused by extreme sea levels, sea level rise, storms, extreme rainfall and runoff events severely affects most natural and human systems in the Wadden Sea region, which is dominated by low-lying coastal areas, coastal cities and vulnerable natural resources. Due to climate change, multi-hazards and their associated risks to key societal and natural systems are expected to increase. To build sustainable resilience to both direct and cascading impacts of flooding, ARSINOE addresses co-designed systemic solutions involving different scales and socio-economic sectors that exploit intelligent water management, citizen engagement and other innovative solutions.

**Key activities performed during ARSINOE** CS#7 established a Living Lab with authorities and public/private sector representatives to co-develop climate risk assessments, design transformation pathways, and identify innovation gaps. The process also produced key issues and selection criteria for an open innovation tender, leading to three innovations tested in Esbjerg—two social and one technical. The social innovations included: 1) a new workshop concept to build local capacity by connecting authorities with citizens and businesses, held shortly after a major 2024 flood and aiding in its evaluation; 2) a web platform to boost citizen involvement and climate adaptation knowledge. The technical innovation, *Saferplaces*, is a digital twin for flood modelling used in the case study. The third innovation, *KlimaKlar* Esbjerg, is an app using augmented reality and a 3D city model to show climate change impacts like sea level rise and heavy rain.

Other key activities developed within the case study include an AI-based extreme sea level model (as part of a PhD study carried out at DTU); extreme value analyses and evaluation of the novel flood model (SFINCS) proposed by the Danish Coastal Authority for today and with SLR; a comprehensive resilience analysis comprising flood risk as well as social and economic elements using an updated version of the *DamageCost* model; and initiation of a process towards the co-design and implementation of a local infrastructure model inspired by the Cascading Effect Model from CS#8 (see below).

#### CS#8: Torbay and Devon County

**Lead Partner: UNEXE**

**Short description:** Torbay, in South Devon (UK) covers about 62 km<sup>2</sup> and has suffered from flooding from several different sources. This includes surface water run-off, highway flooding, sewer flooding, main river and ordinary watercourse flooding during intense rainfall events. Coastal flooding also occurs due to overtopping of the sea defences during high tides that coincide with easterly winds. Low-lying areas in Paignton and Brixham are particularly affected during high tidal cycles when the capacity of the surface water outfalls discharging to coastal waters is impeded. In addition to the property flooding, road closures are common. As sea level is predicted to rise by over 1 m in Torbay over the next 100 years, the frequency and impact of overtopping of the sea defences will increase, affecting more critical infrastructure and properties. The objectives of this case study are to analyse the effects of coastal, pluvial and fluvial flooding on Critical Infrastructure (CI) because of climate change over the next 100 years within both Torbay and Devon.

**Key systems addressed:** Health issues can be assessed to some degree within the case study by identifying residential properties at risk and assessing the effects of this flooding on health. Water will be assessed within the case study by looking at the effects of flooding on the water supply network. Environment, including biodiversity can be assessed as part of the study by investigating the effects of flooding on the local environment. Infrastructure including clean energy and transport will be assessed within the case study by assessing the effects of flooding on critical infrastructure including roads, railways, electric gas, water, telecommunications, etc.

**Key activities performed during ARSINOE:** To achieve the objectives, the case study: developed the Arsinoe Serious Game, created community engagement with Torbay Communities, developed the following models and tools: Cascading Effect Model, Traffic Flow Model, Resource Allocation Model, Hazard Impact Assessment tool, Infrastructure component tool, the ARISNOE Digital Twin. CS#8 also participated in the open tender for innovators, selection and implementing innovations together with the stakeholders.

#### CS#9: Mediterranean island -- Sardinia

**Lead Partner: AGRIS**

**Short description:** The southern part of Sardinia, where the case study is located, accounts for 47.7 and 32.3% of the Sardinian population and surface, respectively. The climate is typically Mediterranean with dry summers and mild winters; it is classified as semi-arid due to an annual rainfall of about 450 mm, mainly between autumn, winter and early spring. Southern Sardinia is the main agriculture area of the island; water supply comes from rainwater, surface water (e.g. rivers and dams) and groundwater. This area shows a great soil variability due to the ancient geological origin of the Island. The main extensive crops are durum wheat and other cereals such as barley and oats; legumes; and forages. Among them, durum wheat is the most extensively grown in the area and fuels local chain food production with upward (i.e. certified seeds) as well as downward (i.e. milling, pasta-and-

bread making) activities. However, durum wheat production is affected by climate change, with projected threats for food security and social stability.

**Key systems addressed:** CS#9 focuses on durum wheat by tailoring adaptation and mitigation strategies with the aim of improving staple food production to stabilise or enhance yields. In line with ARSINOE's Water-Food-Energy Nexus, this goal can be achieved through a mix of genetic improvement and conservative agriculture based on minimum tillage and/or sod seeding to enhance locally produced staple food chains (i.e. pasta and breads).

**Key activities performed during ARSINOE:** Key activities focused on tackling climate change are: 1) Preserving and restoring soil fertility, through agronomy based on agricultural techniques and innovative crop management; 2) durum wheat genetic improvement aimed at selecting and releasing new cultivars adapted to climate change conditions; 3) stabilising crop yields to ensure staple food security; 4) strengthening short supply chains to enhance local food production.

## 2.2 Summary of the Outcomes from the CS

This section provides a summary of the main outcomes for each of the case studies in ARSINOE. More details about the outcomes can be found in the WP6 associated deliverables D6.6 (Implementation of the System Innovation Approach in all the Case Studies- Final report), D6.7 (Resilience Assessment Implementation for all the Case Studies), D6.8 (Innovation packages and financial instruments for all the Case Studies) as well as deliverables following from transversal work packages including D24. (Report on pathways identification in case studies), D3.8 (ARSINOE MultiSystem Dynamic Modelling Framework), D4.3 (Two Digital Twins - Torbay case study + 1 case study) and D5.1 (Synthesis report on the results of the open calls for innovations).

### 2.2.1 CS#1

The following outcomes are considered the primary outcomes from ARSINOE by the CS#1 team. Detailed information regarding the models used in CS#1 can be found in D6.7.

#### **Continuous Risk Assessment for Heatwave Adaptation: A Participatory and Multi-Hazard Approach**

Adapting to heatwaves is best understood as a continuous risk mitigation and assessment exercise that must account for the compound nature of hazards and the complex interplay of vulnerabilities and exposures across different time horizons. Heatwaves rarely occur in isolation; they interact with air pollution, biodiversity loss, noise, violence, and landscape fragmentation to form a dense web of interdependent risks. Crucially, the construction of the risk equations underpinning this assessment has been a participatory modelling process, refined through iterations between modellers and the living lab, ensuring that scientific outputs reflect local realities and stakeholder perspectives. This means that adaptation planning cannot be static: short-term operational responses require efficient allocation of resources and strong coordination across diverse actors, while long-term strategic planning should focus on embedding Nature-Based Solutions (NBS) into urban design to reduce systemic risks and enhance resilience. At the same time, health risks—both physical and mental—must be tackled through a One Health approach that recognises the interconnections between human, animal, and ecosystem health. Finally, early and continuous stakeholder engagement is essential to capture local knowledge, secure ownership, and ensure that adaptation measures are both feasible and effective in the long run.

#### **Statistical downscaling and projections for temperature model**

In CS#1 and the Athens metropolitan area, daily gridded maximum (Figure 4) and minimum temperatures are produced following the study of Varotsos et al. (2023), for each of the ClimEx-II simulations, using global SSP climate projections (outlined in D3.5). In the mentioned methodology, a 1 km × 1 km high resolution daily gridded reference dataset is created, which is then used as a reference dataset to statistically downscale RCM simulation data from ClimEx-II, covering periods 1981–2000 and 2081–2100. Blending ground station observations with the output of the WRF meso-scale meteorological model using

various gridding techniques, ensured that the reference dataset maintains long-term statistical properties of the observed temperature variables. Comparisons of the gridded dataset against observations showed that the dataset retained the long-term statistical features for the temperature variables from 1981 to 2000. Finally, to express heatwave properties, the aforementioned datasets are post-processed to calculate the Combined days of hot days and tropical nights (CHT) climatological index. CHT is given on a 1 km x 1 km spatial resolution raster layer, which expresses the average number of combined hot days and tropical nights (days with maximum temperature exceeding 35 °C and minimum night-time temperature higher than 20 °C), Figure 5.

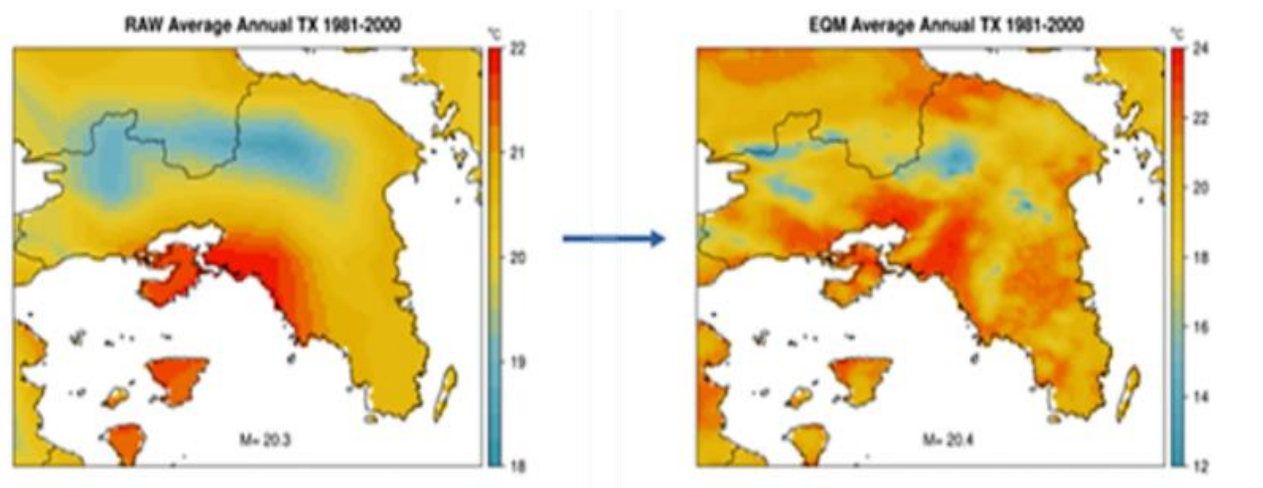


Figure 4: Indicative map depicting the average annual maximum temperature before (left) and after (right) the statistical downscaling implementation in the area of interest.

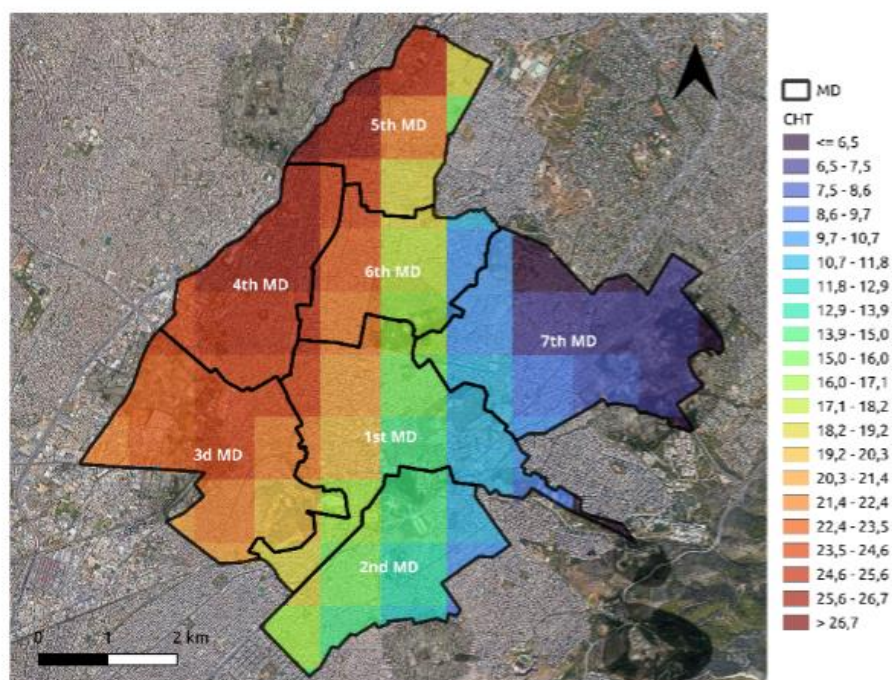


Figure 5: Calculated CHT climatic index, average number of combined hot days ( $T > 35\text{ }^{\circ}\text{C}$ ) and tropical nights ( $T > 20\text{ }^{\circ}\text{C}$ ). Black borders define the spatial extent of the 7 Municipality Districts (MD) of Athens.

### Urban heat island model

The model output provides the mean distribution of summer land surface temperatures (LST) for the months June, July and August from five years (2018-2023). The data used for the LST distribution covers the greater area of the Athens municipality and come from a Landsat satellite (several missions) with a spatial resolution of 100m. In this way, information is given about LST that also affects near surface air temperatures and helps to identify UHI hotspots, contributing to the planning of potential mitigation activities over the CS#1 study area, Figure 6.

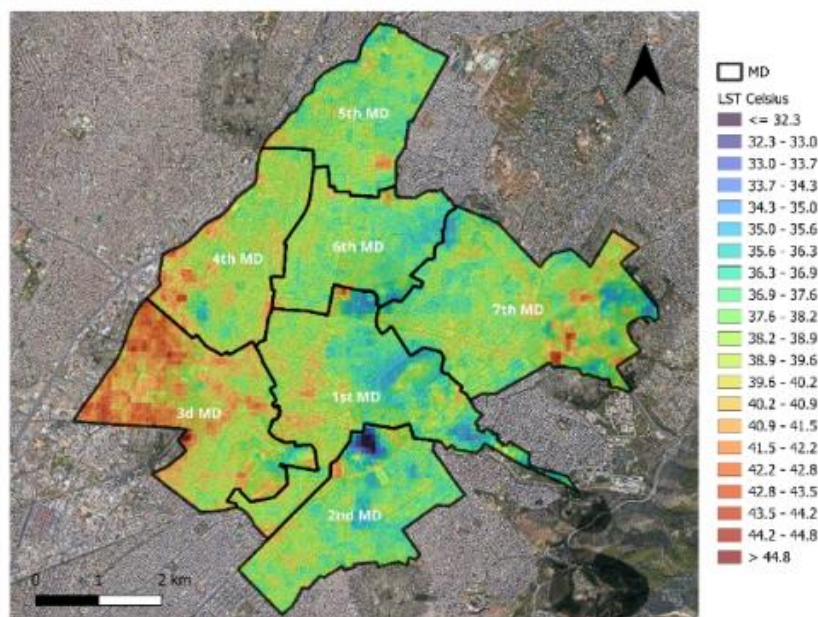


Figure 6: Satellite (Landsat) derived 3 months (June-July-August) mean land surface temperature (LST in Celsius), over 3 years (2020-2023), at a spatial resolution of 100m.

### Air Quality model

Air quality analysis utilizes output data from air quality simulations carried out with a city scale chemistry transport model (CTM), EPISODE-CityChem (Karl et al. 2019). The model provides output fields of pollutants, on a 100 by 100 m grid, evaluated with air quality monitoring data. For Athens CS#1, the month of June 2019 is selected as a representative summer month according to mean monthly values of observed  $\text{NO}_2$  and  $\text{PM}_{2.5}$  and their correlation to CTM predictions. Identification of air pollution hotspots at the urban scale is based on the European Air Quality Index (AQI) ([airindex.eea.europa.eu/AQI/index.html#](http://airindex.eea.europa.eu/AQI/index.html#)) calculated by the mixture of CTM predicted pollutants. Hourly AQI occurrences with values corresponding to air pollution conditions in the “moderate” to “hazardous” range, are used to identify specific areas of air pollution extremes, as seen in Figure 7.

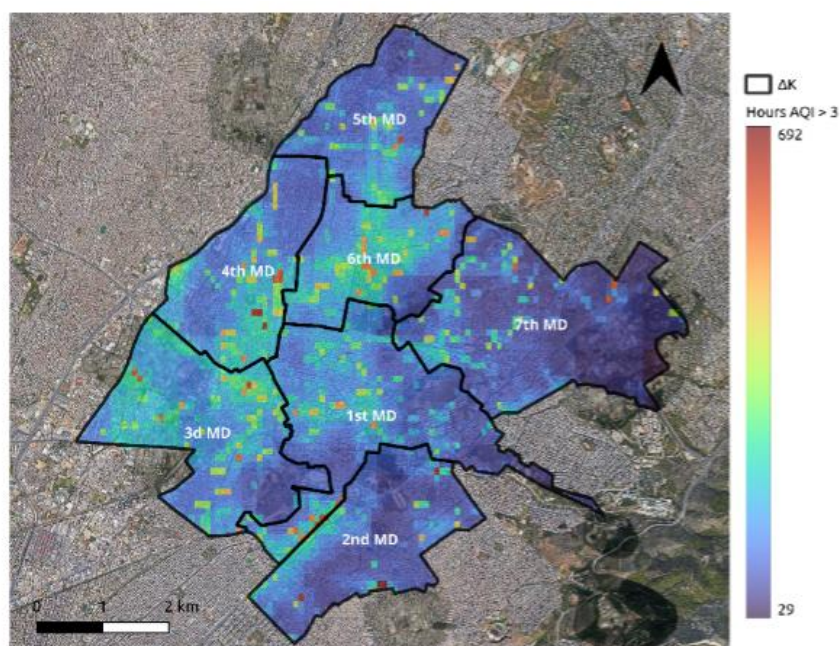


Figure 7: Number of hours when the values of European AQI reflect moderate or worse urban air quality conditions (AQI  $\geq 3$ ), for June 2019. The polygons reflect the seven districts of Athens municipality.

### Landscape Fragmentation model

The model (a GIS-based toolbox) aims at measuring the connectivity of green areas (including protected areas) and the landscape fragmentation in the Athens Metropolitan Area (AMA). The model is applied using the Morphological Spatial Pattern Analysis (MSPA) in ESRI ArcGIS. The workflow includes, 1) the definition of protected areas in AMA, by overlapping the Natura 2000 network with AMA boundaries. In this step the protected areas are geographically identified along with the most valuable species and habitats according to the 1979 Birds Directive and the 1992 Habitats Directive. Also, 2) the Normalised Difference Vegetation Index is applied to detect and map vegetation patterns in AMA. Finally, 3) a spatial pattern analysis of the green areas in AMA is performed for the estimation of isolated small green fragments, core vegetation areas and connecting pathways (green corridors) of AMA's landscape, as seen in Figure 8.

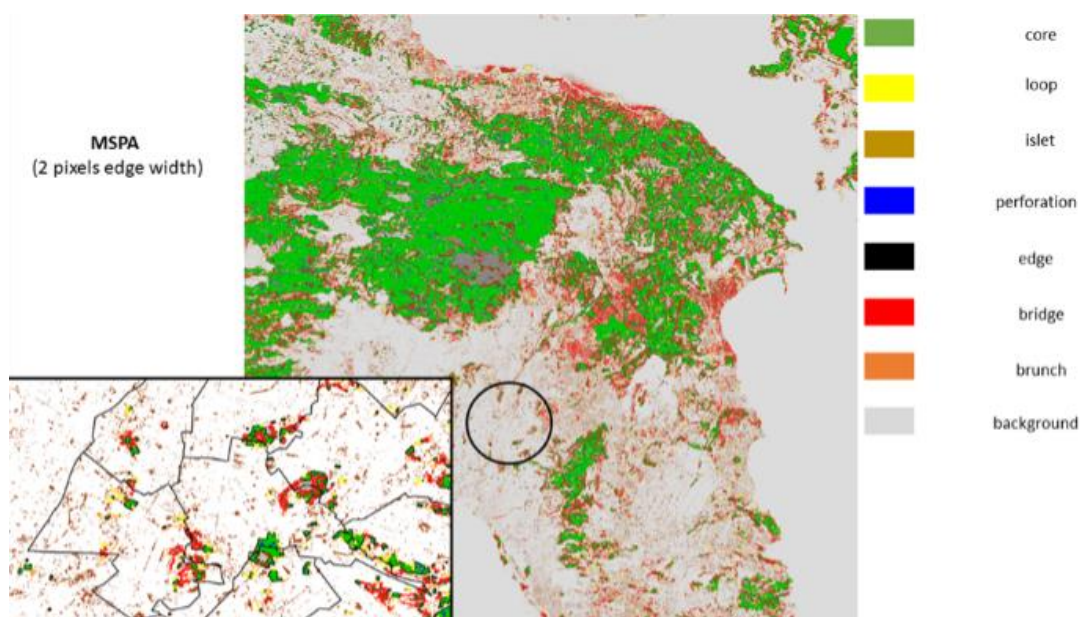


Figure 8: Connectivity map of AMA with 2 pixels edge width, focusing on the centre of Athens.

#### Accessibility of Green Urban Areas model

The model (based on the ESRI ArcGIS tool) aims at measuring how conveniently located green urban areas are for the citizens of AMA. The model calculates the surface area of green urban areas within a walking distance of 5 minutes/300 meters (following the 3+30+300 rule) and the number of citizens with access/no access to green urban areas. In this way, the proximity of green urban areas for AMA is assessed along with the percentage of people living in AMA with no accessibility to green urban areas. The workflow includes the following steps:

- definition of green urban areas in AMA: based on the highest-resolution available datasets (Copernicus Urban Atlas) the model selects public green areas, such as gardens, parks, and suburban natural areas, but also small patches of urban green;
- proximity of green urban areas: the model determines green urban areas, larger than 5 ha, within a 5-minute walking distance (approximately 300 m) performing a network analysis in ArcGIS;
- estimation of the population with accessible or not within a 5-minute walking distance green urban areas in AMA: the model estimates the total residential population of AMA at a 300 m distance from a green urban area and the population with no proximity to green urban areas, as well as other socio-economic characteristics of the residents (Figure 9).

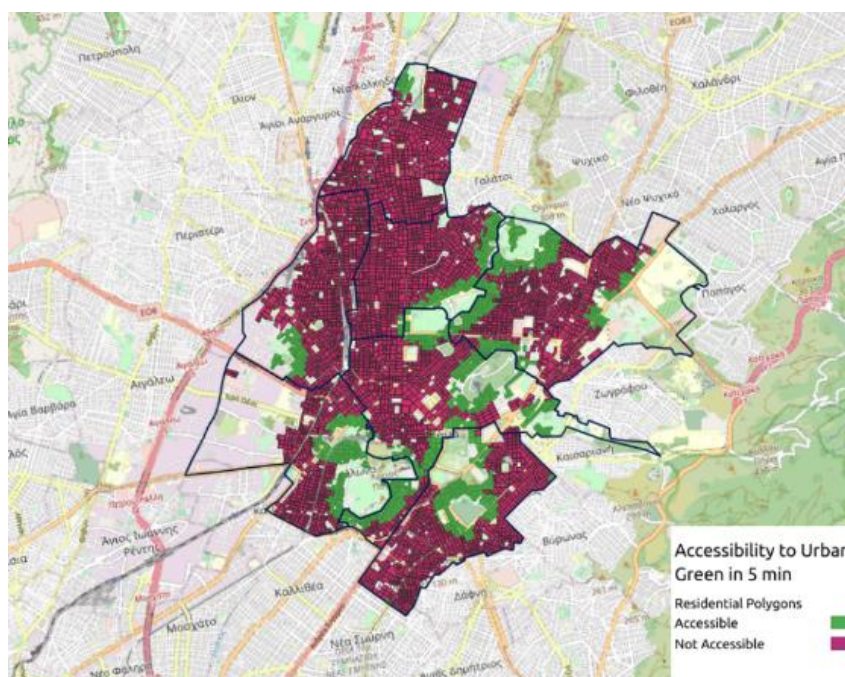


Figure 9: Accessibility of residential polygons of the city of Athens to Green Urban Areas larger than 5 ha, within a distance of 5 minutes (300m).

### Urban biodiversity model

This model combines remote-sensing technology and citizen-science data to evaluate urban biodiversity. It integrates satellite imagery with observations from residents to create a comprehensive picture of biodiversity in cityscapes. By analysing these data sources, the model identifies key areas for conservation and monitors changes over time. This approach supports the development of sustainable urban planning strategies. Ultimately, it aims to enhance biodiversity and promote healthier, more resilient urban environments. In the case study of Athens CS#1, the analysis showed that biodiversity is primarily concentrated in urban green areas, with species occurrences up to 100 times higher than in densely built-up regions. By visualising these findings on maps, the model helps identify biodiversity hotspots and areas in need of conservation.

### Citizen Science for biodiversity

Citizen science plays a central role in the ARSINOE project as a reliable, inclusive, and community-driven source of environmental data. Through the ARSINOE Educational Community ([https://minka-sdg.org/projects/arsinoe\\_educational-community](https://minka-sdg.org/projects/arsinoe_educational-community)), a network of 55 primary and secondary schools in Attica actively engages students and teachers in documenting biodiversity and urban ecosystem data using the MINKA platform (<https://minka-sdg.org/home>). These contributions support the creation of a local biodiversity observatory, enhance understanding of climate change impacts such as urban heat and biodiversity loss, and provide essential input for the design of nature-based solutions.

To date, the community has recorded 9,779 observations and identified 1,508 species with the support of 48 identifiers and 54 active observers. Verified observations are promoted to research grade and shared in global biodiversity repositories, filling critical gaps in urban monitoring and complementing official datasets with real-time, high-resolution information. Beyond data generation, the initiative fosters scientific literacy, environmental awareness, and civic engagement, transforming schools into hubs of climate action and empowering youth to contribute to more resilient and inclusive urban futures.

### Socio-economic heatwave vulnerability model

A gradient boosting machine learning model (XGBoost), trained on heatwave mortality rates, was applied to develop the Socioeconomic Heat Vulnerability Index (SHVI) in Ziliaskopoulos, K., & Laspidou, C. (2024). This index integrates mortality data with a set of socio-economic indicators to identify population groups and urban areas most at risk during heatwaves. The model consistently pointed to demographic and housing-related factors as the strongest drivers of vulnerability in Athens, with elderly and retired populations emerging as the most influential, followed by the age of buildings. These results confirm that social and built environment characteristics play a decisive role in shaping urban heatwave risk, beyond temperature exposure alone. The application of the SHVI to Athens revealed significantly elevated vulnerability levels compared to the national average (33% vs. 22.5%). The highest concentrations of risk were found in the historic centre and inner-city districts (Figure 10), where aging housing stock, high shares of elderly residents, and social isolation intersect. This spatial inequality underscores the importance of targeted adaptation strategies and highlights priority zones for intervention.

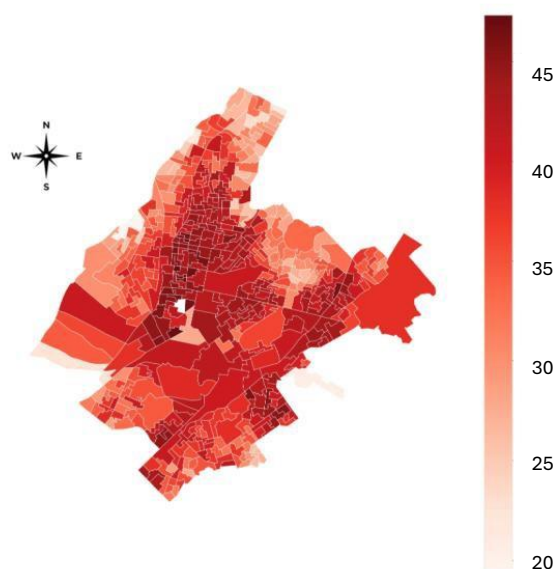


Figure 10: The SHVI values, expressed as percentage, throughout the city of Athens by census tract.

### Climate Change Vulnerability Assessment (CCVA) model

The proposed Climate Change Vulnerability Assessment (CCVA) framework (Androna et al., 2024) integrates environmental, social, economic, and political dimensions to provide a structured and scalable approach to resilience and vulnerability analysis. It is supported by the SustainGraph, which enables the collection and management of diverse indicators across spatial and temporal scales and facilitates their integration into analytical processes. The framework employs clustering techniques and Principal Component Analysis (PCA) to identify patterns of vulnerability and distinguish between high-, medium-, and low-vulnerability regions. Its design is generic and adaptable, allowing application across different territorial contexts and levels of governance.

Results from the application of the framework demonstrate clear spatial differentiation of vulnerabilities (D6.7). Urban areas are predominantly shaped by economic and environmental pressures, while rural areas present more heterogeneous vulnerability profiles due to varying socio-economic conditions and ecosystem characteristics. The clustering analysis confirms the existence of distinct categories ranging from low to very high vulnerability, while PCA highlights how different dimensions contribute unevenly to regional resilience outcomes. In the case of Athens (CS#1), the CCVA framework highlights elevated

vulnerability in the environmental dimension, linked to high levels of urbanization and limited availability of green/blue spaces. Despite overall vulnerability levels being comparable to Thessaloniki, the underlying drivers are distinct, with Athens more environmentally constrained while Thessaloniki is more economically fragile. For Athens, indicators such as built-up surface distribution, particulate matter trends, and green/blue area availability are critical in shaping vulnerability outcomes. These findings illustrate the framework's ability to disentangle complex vulnerability dynamics and provide evidence-based insights for targeted resilience planning in highly urbanised contexts.

Innovations:

- Timely implementation of the selected innovations for Athens
- Support to the implementation of the Climate Action Plan through the KAUSAL Platform
- Appreciated cooling effect of the two implemented interventions in Serafeio (Green Oasis and Singular Ribbon); good replication potential to other hot spot areas.

### **Heat Event Response model**

The Heat Event Response Model supports operational decision-making during extreme heat events in the Athens Metropolitan Area. Built on agent-based simulation (ABS) and discrete-event simulation (DES) methodologies, it provides a detailed, dynamic representation of how diverse actors respond to heat-related risks. The model integrates environmental, demographic, and infrastructural data to simulate real-time resource allocation and emergency response strategies during urban heatwaves. Simulations are run for multiple climatic scenarios—business-as-usual, SSP1, and SSP3—using data from 28 July 2019 as a reference extreme event. A key feature of the model is its ability to mobilize different resources provided by multiple players—including the Municipality of Athens, the Region of Attica, ministries, the Red Cross, and local NGOs—depending on the severity of the heatwave category. These resources are grouped into three main capacity layers: (i) information and awareness (e.g., digital alerts, public guidance, helplines), (ii) cooling and shading (e.g., air-conditioned shelters, shaded kiosks, parks, water distribution), and (iii) first aid and healthcare (e.g., mobile health units, emergency workers, street outreach teams). By assessing how various neighbourhoods respond under different risk levels and testing the effectiveness of alternative deployment strategies, the model directly informs operational readiness and ensures that limited resources are allocated where they are needed most. This makes the Heat Event Response Model a cornerstone for real-time urban heatwave resilience in Athens.

### **A Decision-Support Dashboard for Heatwave and Compound Hazard Resilience**

The Heatwave Resilience Dashboard serves as the integrative interface of the modelling framework, soft linking all subroutines that capture the multiple elements of risk. It brings together hazard simulations, vulnerability indices, and exposure data into a coherent decision-support environment aligned with the Sendai Framework for Disaster Risk Reduction. By combining hazards that are most relevant for the strategic planning horizon—such as extreme heat, air pollution, and urban fragmentation—with socio-economic vulnerabilities and demographic exposures, the dashboard enables a holistic risk perspective. Beyond risk assessment, it also offers functionality for presenting the adaptation capacity of various urban planning solutions—such as Nature-Based Solutions, cooling infrastructures, and awareness mechanisms—helping stakeholders and users understand how specific interventions can enhance resilience against heatwaves and compound hazards. This integration allows decision-makers to explore different planning horizons, compare adaptation strategies, and prioritise interventions that strengthen resilience at both local and metropolitan scales.

### **Risk hotspot and NBS selection model**

A multi-dimensional approach is opted for the hotspot mapping of the Athens Municipality, which is highly multidisciplinary and includes diverse modelling approaches regarding climatology, remote

sensing, air quality, geospatial analysis and urban vulnerability assessment. The hotspot identification method consists of the prioritization of sites with the worst conditions related to urban heat and air pollution, as well as the lack of green urban areas and socio-economic vulnerability levels. A detailed evaluation and quantification of the above parameters provide the necessary input framework to determine multi-hazard hotspots at the city-scale. In the context of CS#1, the final output (Figure 11), an integrated multiparameter hotspot map in raster format, is produced by applying a spatial overlay analysis and spatial statistics that reveal both spatial patterns and statistically significant clusters of high or low values that are hot or cold spots of environmental and socio-economic vulnerability, respectively, for the city of Athens.

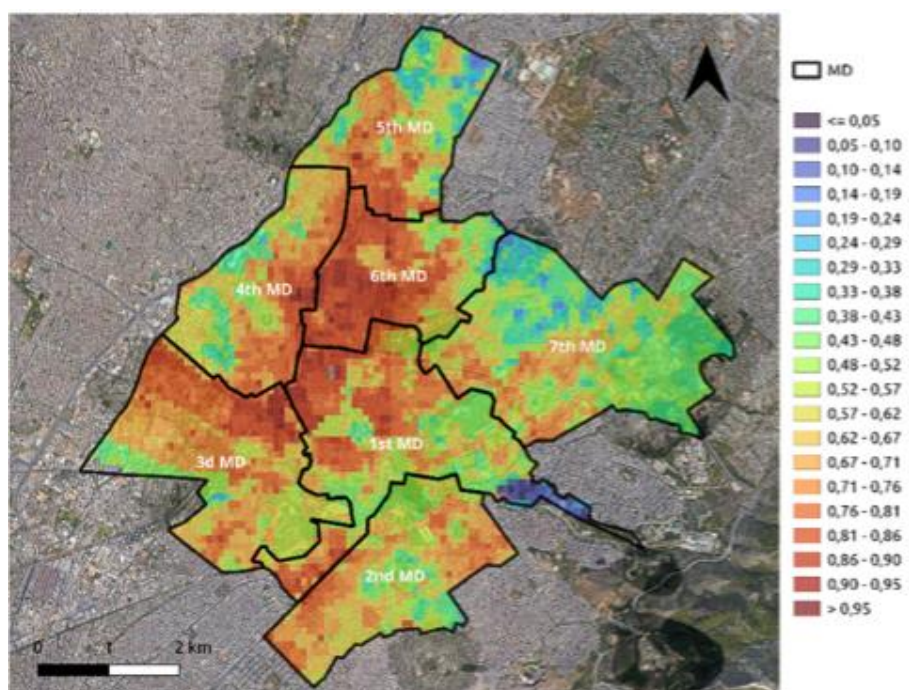


Figure 11: Normalised combined hot spot map from climatic, land surface temperature, air-quality, accessibility and vulnerability layers, for the 7 Municipal Districts of Athens. Values closer to 0 denote good environmental conditions while values closer to 1 denote a degradation of overall conditions.

Following the identification and mapping of the most prevalent environmental hazards and their combination with the vulnerability of the city, the most problematic sites of the city where NBS (also specifying the type of NBS) should be applied, are spatially defined. As a final step, an in-situ investigation of each site to determine the local characteristics is carried out and a range of possible NBS that could be performed per site according to the NBS type, are proposed.

### Urban climate model

The urban climate model (WRF regional climate model) is applied to simulate present climatic conditions of AMA by performing short term high spatial resolution (200m) runs (Figure 12, left). Next, it is used to validate the outcomes of the risk hotspot and NBS selection model that highlight sites with low percentage (or absence) of urban green, affected by extreme thermal stress, and identify the sites that can support mitigation/adaptation measures such as NBS. The impact of selected NBS on the city's microclimate is investigated by simulating different land use and urban planning scenarios, e.g., cool roofs, green roofs, urban greening. The simulated scenarios and the quantification of their cooling potential (see example in Figure 12, right) contribute towards assessing the effectiveness of NBS, thus concluding on the most suitable NBS to be implemented in each site to improve climate resilience in the municipality of Athens.

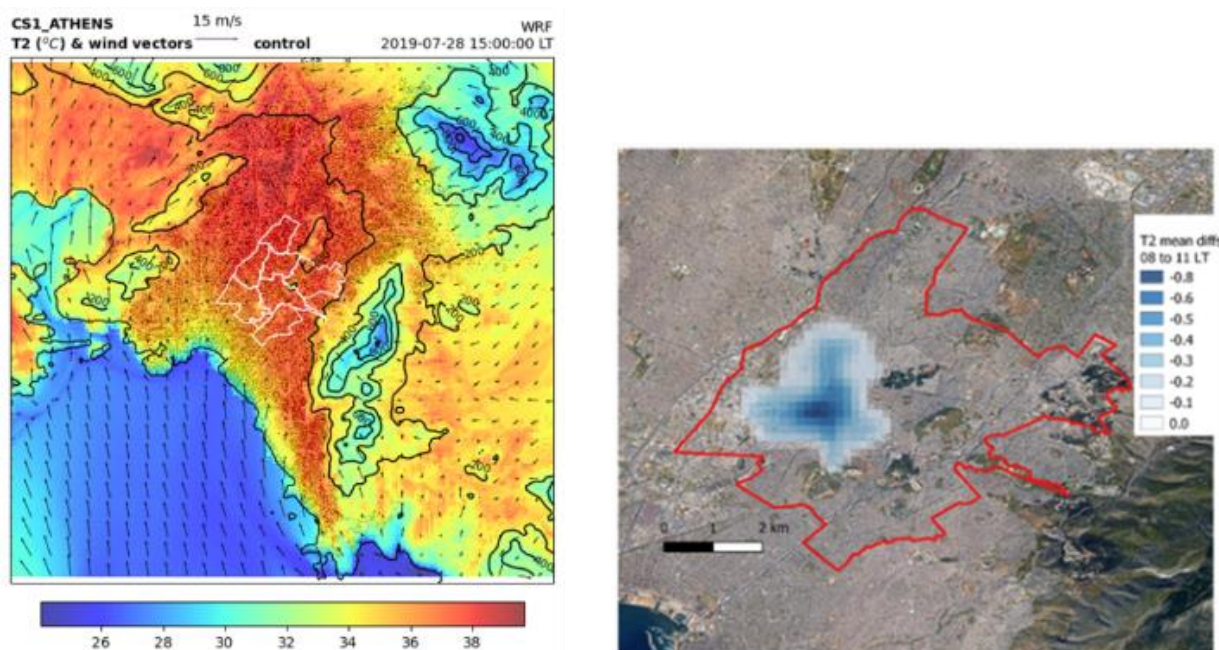


Figure 12: (left) Example of WRF model current summer climatic conditions output for temperature at 2 meters (T2) given with colour contours and wind vectors (black arrows) showing speed and direction. Black contour lines represent topographic height, and white borders indicate the location of the 7 districts that form the Athens Municipality. Scattered dark points show the spatial extent of the urban built-up area within the Athens basin. (right) Example of mean differences between scenario (implementation of green roofs & urban greening) and control microclimatic simulations of T2 temperature for the Athens municipality (red polygon).

### Willingness to Pay model (Virtual Reality application)

The Virtual Reality (VR) model developed for the Willingness to Pay assessment in ARSINOE integrates immersive choice experiments with behavioural economics and environmental valuation methodologies. The approach is grounded in established discrete choice experiment theory, estimating the economic value individuals assign to environmental attributes (e.g., air quality, biodiversity) under different climate adaptation pathways. The VR experience guides participants through a series of decision-making scenarios where they compare alternative futures for Athens. Each choice card presents three options: (a) an improved future at a certain cost, (b) the status quo, and (c) a "do nothing" option at zero cost. The immersive environments depict realistic visualizations of each alternative, including attributes like heat, noise, air pollution, traffic, and biodiversity. For example, poor biodiversity scenarios feature dead birds, wilted trees, and a hazy sky, whereas improved conditions include lush vegetation and active animal life. The user, wearing a VR helmet with a heads-up display (HUD), can scan features in the environment to gather more context (e.g., tree health, animal behaviour). People are rendered as ghost-like figures to emphasize the observational — rather than interactive — nature of the experience. This enhances engagement while preserving the consistency of experimental conditions.

The VR model was applied within a structured resilience assessment for the Athens Metropolitan Area. Participants were immersed in two divergent futures — a dystopian scenario with no interventions and a sustainable one where NBS are implemented — and were asked to simulate adaptation strategies. The underlying scenarios reflect outputs from Shared Socioeconomic Pathways (SSP1 and SSP3), visualised as environmental conditions in 2030 and 2048. In the VR experience (Figure 13), users made decisions about tree planting, green walls, mobility solutions, and cool materials, which then altered the virtual environment. The model thus served as both a valuation tool and an engagement platform, capturing

citizens' preferences in terms of willingness to invest financially in different adaptation options. These immersive experiments directly support the integration of public input into resilience policy and NBS prioritization for the city.

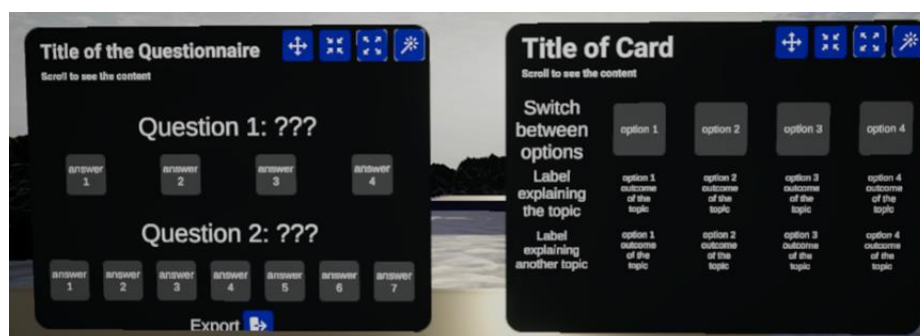


Figure 13: Representation of the choice experiment questionnaire in the VR experience.

## 2.2.2 CS#2

The following outcomes are considered the primary outcomes from ARSINOE by the CS#2 team:

### Piraeus Port – Main Outcomes

The Port of Piraeus focused on stakeholder engagement, system innovation pathways, and piloting digital tools for emission monitoring to enhance resilience and sustainability.

#### Actions implemented (tools, solutions, innovations):

- Conducted stakeholder mapping and identification of climate threats and vulnerable sectors.
- Organised Living Labs to:
  - Validate mental maps and co-develop the 2050 Mediterranean Ports Vision.
  - Apply back casting and define innovation pathways for port resilience.
- Tested the **DIORAMA tool**, a multi-layered approach to emission source attribution and mitigation strategy design, focusing on:
  - Vehicle emissions correlation via AI-based detection and pollutant sensors.
  - Monitoring ferry activity and maritime emissions.
  - Cargo-port pollution mapping using mobile air-quality sensors and meteorological data.
  - Satellite data analysis to identify emission sources in the wider Piraeus area.

#### Main findings and outcomes:

- Improved knowledge of local and regional emission sources affecting port air quality.
- Enhanced stakeholder involvement in resilience planning.
- Development of financial instruments and innovation packages to support climate adaptation.
- Contribution to EU-wide resilience assessment and evidence-based recommendations.

### Port of Valencia – Main Outcomes

The Port of Valencia emphasised participatory governance, long-term visioning, and the deployment of digital tools for adaptation planning.

#### Actions implemented (tools, solutions, innovations):

- Organised three Living Labs with stakeholders to:
  - Map threats and sectors, validate mental maps, and co-develop the 2050 MedPorts Vision.

- Apply back casting and design innovation pathways.
- Implemented the System Innovation Approach across the case study, including roadmap design and monitoring.
- Presented the **Climate Change Observatory challenge** at the 2nd ARSINOE Open Tender.
- Selected, contracted, and technically supported the development of **CLEVER TOOL**, a digital platform to support climate change adaptation.
- Contributed to ARSINOE deliverables, dissemination materials (newsletters, website, social media), and sustainability & exploitation plans.

#### Main findings and outcomes:

- Strengthened stakeholder engagement and co-creation processes in the port community.
- Identification and prioritization of climate risks and adaptation needs for long-term resilience.
- Established innovation pathways and financial options for Mediterranean ports.
- Increased visibility of the Port of Valencia as a European leader in sustainability and resilience.
- Successful adoption of **CLEVER TOOL**, enhancing decision-making capacity for adaptation planning.
- Contribution to EU-level resilience assessment and development of transferable innovation packages.

#### Limassol Port – Main Outcomes

The Port of Limassol prioritised climate-threat mapping, participatory planning, and the deployment of a novel early-warning monitoring system.

#### Actions implemented (tools, solutions, innovations):

- Conducted mapping of climate threats to port operations and infrastructure.
- Organised Living Labs for stakeholder co-creation (visioning, back casting).
- Defined the 2050 Mediterranean Ports Vision and climate risk pathways (joint vision validated with Piraeus and Valencia).
- Launched a **public tender** through the Cyprus e-procurement portal, ensuring transparency and legal compliance.
- Selected and deployed the **Marina-Breath™ Early Warning System (EWS)**, featuring:
  - 10 IoT air-climate sensors (CE-certified, real-time, predictive).
  - Mobile app and cloud dashboard for alerts and visualization.
  - AI/ML models for pollution forecasting and anomaly detection.
  - Monthly stakeholder reports and feedback mechanisms.
  - End-user training sessions for operators.

#### Main findings and outcomes:

- Successful integration of the EWS into operations by Euro gate and DP World.
- Improved responsiveness during pollution peaks.
- Enhanced data-driven decision-making for port management.
- Strong stakeholder engagement and positive reception of the system.
- Recognition of the solution's scalability to other zones within Limassol or to other EU ports.

### 2.2.3 CS#3

The following outcomes are considered the primary outcomes from ARSINOE by the CS#3 team:

#### **Hydrological modelling of the Main River Basin, land-surface-response tools**

**Outcomes:** Land-surface response tools were used to prepare regional climate model data at 12.5 km spatial resolution for use in impact modelling. This included bias adjustment (i.e., quantile delta mapping) and statistical downscaling to 500 m to resolve spatial features of interest (e.g., courses of rivers, valleys/mountains). The bias-adjusted and statistically downscaled climate data served as meteorological input to a hydrological model for the Main River catchment. Simulations were performed for a single ensemble member in the process-based water balance model WaSiM, but with two different scenarios (SSP1-2.6 and SSP3-7.0). Outcomes of the simulations were time series of 3-hourly discharge, aggregated statistical metrics and derived metrics to characterize the hydrological regime in the area. Both droughts and floods are projected to increase. The results lie within the range of previous simulations in the region with other data (global climate model, scenario, bias adjustment algorithm). However, the results also show the high uncertainty introduced by the impact modelling chain and internal climate variability (e.g., due to a single member).

#### **Stakeholder mapping**

**Outcomes:** Stakeholder mapping resulted in a list of actors impacted by climate change in the region and an understanding of key stakeholders for addressing challenges. It was the basis for concerned and relevant partners throughout the project. The stakeholder mapping demonstrated the far-reaching consequences of climate change in the region due to water linking a wide array of sectors. Federalism and the complex division of responsibilities in resource management caused the inclusion of multiple state agencies and authorities from the local regional, state and national level. The municipalities play a key role in climate adaptation because of their power of self-government, their responsibilities for different sectors of the nexus and because the local effects of climate change leads citizens to asking municipalities for climate adaptation solutions. However, the mapping also covers the private sector and civil society. Later work on hurdles and levers for climate adaptation underscored the relevance of political decision-makers in setting goals and impacting the incentive structures for pursuing an integrated water resource management.

#### **Living Lab Workshops**

**Outcomes:** The living lab is a unique platform for exchanges about climate change and its consequences in the region. Previously, this type of cross-sectoral debate did not exist in the Main River basin. Thus, one key outcome of the living lab is a new kind of debate and forum for exchange. Other outcomes are a common view of key challenges, a shared vision of a climate resilient future and innovation pathways supported by key stakeholders as well as an understanding of innovation gaps (see D6.5 & D6.6). Moreover, the living lab inspired a webinar on water retention, sponge cities and sponge landscapes for water utility companies to further exchange on how municipal supply companies could support such measures. Furthermore, the living lab triggered a survey on climate risks for public utilities and the provision of basic public services in the region which resulted in a discussion paper on how to make those services (water supply, wastewater management, energy production and supply, etc.) more resilient. ARSINOE demonstrated that the methodology of the living lab can be used to create understanding and mediate resource conflicts. Considering the likely occurrence of resource conflicts in the Main River basin in the future this outcome is especially pertinent.

### **Creation of Innovation packages**

**Outcomes:** Stakeholders identified a number of necessary innovations that should be implemented to increase climate resilience. A list can be found in the annex of D2.4. This selection of measures identified in the innovation pathways supports the view that climate resilience requires a mix of technical, social and governance innovations, including education efforts (e.g. education for sustainable development). These innovations need to occur in all sectors of the WEFE-nexus. They have to be supported politically and societally. Moreover, there is a significant need for publicly accessible and reliable information on available water resources, their development and existing water rights and permits. Moreover, the case study showed that there is a distinct backlog in implementing available solutions. Several effective measures for increasing climate resilience are known but rarely implemented into practice. Reasons for the lack of implementation were explored in the PESTLE-analysis and the governance analysis. Moreover, identified innovation gaps were the subject of the open tender for innovation.

### **Implementation of the open tender for innovation in the case study**

**Outcomes:** The open tender for innovation (OTI) resulted in four specific outcomes:

- (1) Due to a dissemination strategy for publicising the first call for innovation the OTI contributed significantly to people's awareness of ARSINOE.
- (2) The OTI resulted in the creation of the tap-friendly cycle route along the Main River. The innovation combined public education, networking and consulting services to increase the public access points to tap water, mapped them and created information materials to publicise the benefits of tap water and to support a fact-based debate about climate resilience in the region.
- (3) Additionally, the OTI led to the application of the IRRIBIGDATA tool in the region. By combining the tool for estimating water demands with data on agricultural land use and climate scenarios the project resulted in an estimate of future water demand for irrigation in different climate scenarios. Moreover, it enabled a dialogue between stakeholders from the Main River basin and irrigation experts from northern Italy.
- (4) Moreover, the open tender offered very tangible benefits to the region. The OTI was one reason why ARSINOE was considered different from other research projects on climate resilience. The OTI offered access to EU-funding to actors who may otherwise not have been able to access EU-funds due to administrative burdens. Especially, after the reference to the SME-definition was excluded from the first call the funds could be accessed by all SMEs in the region.

### **Co-creation of climate and hydro services for the region**

**Outcomes:** In response to the demand for more and publicly available information about climate change and its impact in the region workshops for the co-creation of climate and hydro services with stakeholders were set up. They focused on participants who are not researchers or climate managers employed by cities or regions as they usually reported having access to relevant information.

The workshops revealed that there is little awareness of what climate and hydro services are, what services already exist and how they can be used among stakeholders from business and civil society. Consequently, these stakeholders struggle to express their specific needs and do not have the ability to process and interpret data independently and to subsequently develop climate adaptation strategies based on that information.

ARSINOE developed education material on climate and hydro services and a simple template (Figure 14) that was used to systematically narrow down data needs and how that data should be structured and presented. Nevertheless, the project revealed a substantial need for better information about climate change, its consequences and data literacy with data analysis and processing capabilities.

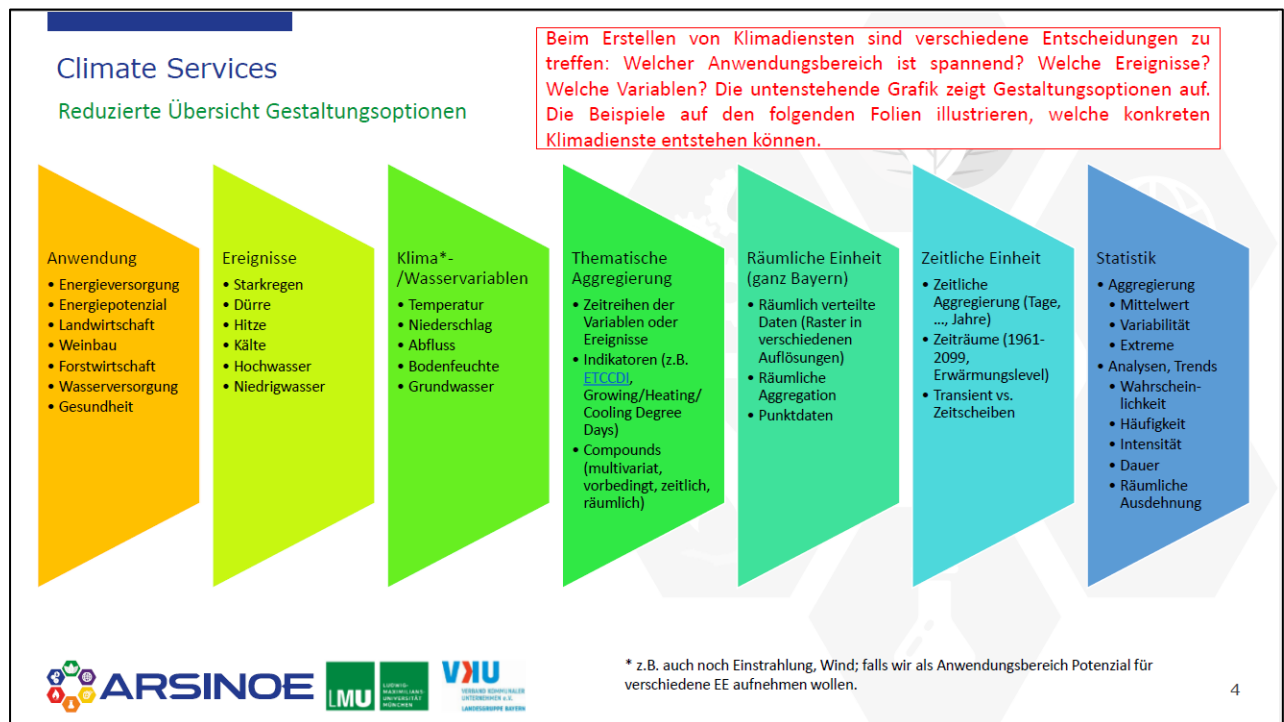


Figure 14: Template to narrow down data needs and support data structuring. (in German, for applicability in the case study).

While these activities did not result in the intended co-creation of specific climate or hydro services, it did reveal a gap between potential providers and end users of those services. A description of the gap, alongside a framework for addressing it, was presented at a conference and submitted as a paper to Advances in Science and Research.

ARSINOE results were presented to the Bavarian Environment Agency and the Federal Environment Agency. They are the state agencies responsible for creating climate services for public use and for providing some of the data necessary for municipal adaptation to climate change.

## PESTLE analysis

**Outcomes:** The case study identified political, ecological, social, technical, economic and legal factors benefitting and hindering the realisation of the innovation pathways. For details, please see D2.4.

## Governance analysis and conference

**Outcomes:** The current state of resource governance has elements that support and some that restrict more cross-sectorality between water, energy, food and ecosystems. There are extensive networks sharing and creating knowledge on water management. However, they are often restricted to single sectors. Federalism causes many different levels of state to be involved in resource management. This means that the state has many competent experts on resource governance. Not all authorities take a holistic view of the river basin but instead focus on administrative boundaries. Many are only responsible for one or few sectors meaning that conflicts between sectors need to be addressed and resolved between authorities. Water management and climate adaptation is a key issue for many influential stakeholders. However, problem perspectives and goals differ; e.g. water availability can be seen as a transportation issue or question of permitting water treatment and reuse or as a problem of resource protection and land use. Stakeholders can hold seemingly conflicting goals e. g. local economic

development and water protection. Simultaneously, there is a lack of flexibility in goals and problem perspectives which restricts the room for compromise between sectors. Strategies and instruments for climate adaptation are well known but there is a lack of cross-sectoral coordination locally and regionally. Also, there is a lack of flexibility in pursuing solutions e.g. many stakeholders plan to use the river as a water source even though the run-off is strongly impacted by water-transfer from the south which can be restricted. Furthermore, it remains unclear how much water would be taken from the river and if that could be allowed with view to ecological conditions, if all stakeholders planning to do so would realise those plans. The available resources and division of responsibilities are hindering cross sectoral water management in the region. Stakeholders would benefit from stronger political backing as that would likely result in clear strategic goals for the region, more funding, staff and projects as well as more education on the issues and public attention.

The governance conference, attended by politicians, administrators, practitioners and scientists, validated the results of the scientific governance analysis. It showcased successful adaptation initiatives and projects attempting more cross-sectorality. The stakeholders in attendance validated the results of the governance analysis. They agreed that there was a high awareness of the challenges but little agreement on the appropriate strategies. They criticised a lack of coordination between sectors as well as differing and conflicting goals. They agreed that there was a lack of resources. Especially financial resources and reliable and public knowledge about water availability and water uses was considered lacking. The event created and strengthened ties across sector boundaries and made dialogue possible. Thus, the event itself addressed some of the hurdles identified in the analysis.

### Discussion paper on financing climate resilience

**Outcome:** The debates about innovation pathways, hurdles and levers for resilience and governance resulted in a brief discussion paper about financing climate resilience. It posits the following frequently listed solutions to decreasing the financial burden of climate change and to aid efficient spending:

- Increase investment in climate protection and adaptation to decrease damages
- Select measures that contribute to various objectives e. g. soil protection and improving water quality
- Political backing for climate goals and financing creates reliable conditions for planning further investments
- Align state budgets and subsidies with climate targets (green budgeting)
- Use damage repair and reconstruction to build resilience rather than reconstructing old systems and infrastructures (building back better)
- Optimise consulting services on climate adaptation to aid effective investments in resilience in the private and public sectors
- Resolve conflicts between climate adaptation and property rights
- Enable financial support for participatory planning processes to help resolve conflicts
- Make funds for climate adaptation accessible to local public utilities

### Dissemination of results

**Outcomes:** The results of the case study were regularly communicated through newsletters, website articles, social media posts, press releases and publications. This contributed to the awareness of the ARSINOE project among stakeholders and kept important partners informed about the progress of the innovation action. Moreover, direct dialogues with members of parliament, administration officials were used to spread results. Besides adding to the awareness of ARSINOE and its results, the project increased knowledge of the European Green Deal and its objectives among stakeholders.

## 2.2.4 CS#4

The following outcomes are considered the primary outcomes from ARSINOE by the CS#4 team:

### **Innovative solutions developed, tested and implemented**

In CS#4, the Integrated Water Management Model (IWaMM), along with the suite of models described in the report D6.7, was implemented for the modelling of multi sectoral coupled systems. The model provided insight into how a balanced use of available water resources can be secured. The main outcomes from the modelling are described below.

The modelling activities were carried out in two phases.

**In the first phase** (M10-M30), downscaled regional climate model (RCM) data were used for the selected climate change indicators, for the scenarios RCP 2.6 and RCP 8.5. The main findings from the first model run, as reported in D6.3, were:

- Both Ohrid and Prespa lakes will be affected by the climate changes.
- Decrease of water level can be expected at Prespa Lake, in a more severe way for RCP8.5.
- To maintain the water level of Ohrid Lake, discharge will have to be limited, leading to a decrease of hydropower generation.
- The most affected sectors will be the environment and the agriculture and energy sectors.
- Adaptation strategies must be developed in a WEFE nexus approach, using multi – criteria analysis and decision-making approach.
- Sectoral trade-offs that must be made have been identified.
- Allocation of groundwater sources in the Prespa lake watershed area to the water supply of households and/or agriculture.
- Allocation of water in the Ohrid lake watershed to environment or energy (hydro power generated).
- No common transboundary water use or water sharing issues have been identified in the present situation.
- Likewise, the modelling shows no issues are expected in the future, under the pre-condition that the lessons from the SIA implementation are implemented: shared responsibility of all parties and sectors as well as development and implementation of a consensus based cross-sectoral long term management plan.

In the living lab workshops, part of the SIA implementation, the following groups of adaptation measures have been identified:

A1: Improved measurement and monitoring of water resources, especially of groundwater.

A2: Improved measurement and monitoring of water consumption.

A3: Improved (innovative) technologies for effective use of water in sectors.

A4: Improving capacity, awareness, knowledge and skills of stakeholders and water sector actors, for a rational and effective use of water in adapting to water scarcity.

For evaluation and ranking of the adaptation measures, a MCDA (Multiple-Criteria Decision Analysis) has been applied, implemented as a subroutine of the Water Allocation module in IWaMM. The MCDA is based on an AHP (Analytical Hierarchy Process) approach. The following summarises the ranking from the of the MCDA:

- 1st. Measures for water resources.
- 2nd. Measures leading to a more efficient and rational water consumption. These measures include use of recycled water in the tourism and industry sectors and use of advanced irrigation techniques in the agricultural sector.
- 3rd. Measures to reduce the losses during water distribution.
- 4th. Measures to raise awareness.

**In the second modelling run (M36-M48)**, data from the from the ClimEX –II climate experiment were used for the time frame of 2080-2100 and for SSP1-2.6 and SSP3-7.0. Table 2 presents a summary of the models applied and the main findings.

Table 2: Models applied and main findings of the 2<sup>nd</sup> run of modelling activities in CS#4.

| Models applied                                                                      |                    | Main conclusions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-------------------------------------------------------------------------------------|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Integrated Water Management (IWaMM),</b>                                         | <b>Water Model</b> | Under the two scenarios, SSP1, SSP3, with four simulations of climate indicators of precipitation and temperature in each of the scenarios, the model predicts declining Prespa lake water levels and surface area, causing an increase of dried out coastal area.                                                                                                                                                                                                                                           |
| <b>Integrated Water Management (IWaMM) &amp; Watershed Hydrology Model (WH)</b>     | <b>Water Model</b> | The application of the two models served to identify whether the available water sufficient for the societal needs for water in the future.<br><br>The model outputs show that: 1) availability of fresh water will decline, more strongly so under SSP3 than under SSP1; 2) the quantity of water needed for human activities exceeds availability. Without adaptation measures, a situation of water deficit will be reached.                                                                              |
| <b>Integrated Water Management (IWaMM) &amp; Energy Generation Model (EG Model)</b> | <b>Water Model</b> | The impact on hydropower was estimated based on availability (volume / yearly) of regulated water discharge from the Ohrid Lake and the contribution of this discharge to the total amount (volume/yearly) of water used for the generation of hydropower and compared to present day (baseline scenario).<br><br>The model outputs show that a reduction in the contribution of Ohrid Lake discharge to hydropower generation can be expected. This negative trend is more emphasised in the SSP3 scenario. |
| <b>Water Allocation (WA) Model</b>                                                  |                    | The impact of individual and combinations of adaptation strategies was simulated. This shows that total water consumption could be reduced by more water efficient technologies and by using recycled water. This shows a potential reduction in freshwater demand of 5-10 % by 2039 and 20% by 2050 without negative impacts on social and economic growth.                                                                                                                                                 |

**Other outcomes from CS#4 complementing and leveraging the modelling outcomes include:**

#### **Stakeholder engagement and participatory processes**

The SIA was applied in the Ohrid and Prespa lakes region. Stakeholders represented various sectors, such as administration/water management, environment, agriculture, fishery, tourism, education, forestry, engineering. Participatory design and co-creation of innovation pathways and outcomes shaped the process of selection and piloting of the nationally and regionally improved monitoring and management of waters. The outcomes are reported in detail in D6.6.

#### **Innovation implementation**

Two innovations were selected and implemented: *Water4All* (implemented in North Macedonia) and *Integrated Water Resilience System – IWRS* (implemented in Albania). These innovations are complementary and relevant to all stakeholders in all three countries involved in CS#4 as they provide real time information and open data on the status of Ohrid and Prespa lakes. The availability of this information enables informed decision making.

#### **Impact on local communities and ecosystems**

CS#4 activities raised the awareness of the importance of communities, economic sectors and public administration towards sustainable water management and their roles and responsibilities.

The results of the modelling activities were brought to the attention to the national authorities in charge of climate change mitigation in North Macedonia and have the potential to be used in the first national climate adaptation plan in the country.

### Impact on young community

Implementation of the citizen science platform MINKA had as a main outcome the engagement of teenagers (local High School in the Greek part of Prespa) in collecting biodiversity observations around the lakes. A number of 154 biodiversity observations were collected, involving local teachers and pupils and raising awareness about the connections between climate change, biodiversity and water management.

## 2.2.5 CS#5

Collaboration across ARSINOE's **work packages (WPs)** greatly enriched this case study, allowing the adoption of a systemic, interdisciplinary, and participatory approach. The main outcomes are described in this section.

### Stakeholder Engagement & Governance

Three living labs were organised using WP2's participatory methodology, bringing together local stakeholders from public institutions, civil society, and the private sector. These sessions were fundamental to identifying as the main problem the lack of reliable, high-resolution data in the Canary Islands—data needed for better-informed decision-making and forward planning. This insight guided the innovation focus of WP5.

The governance analysis revealed a paradoxical governance system: despite being geographically remote, the Canary Islands are economically tied to the EU and exposed to both environmental vulnerabilities (e.g. volcanic risks, biodiversity threats, climate change) and intense socio-economic pressures (mass tourism, overexploitation of water resources, housing tensions). Governance challenges include:

- A lack of cross-sectoral and long-term planning, especially regarding land, water, agriculture, and energy.
- Fragmented and sometimes conflicting policy instruments that do not account for WEFE (Water-Energy-Food-Ecosystems) interdependencies.
- Tensions between public and private control over water, with private water rights dominating and enabling speculation, despite high leakage rates and costly desalination.
- Structural reliance on fossil fuels, yet with pioneering examples in renewables, such as El Hierro.
- Inequitable access to key resources (like water and energy) due to economic asymmetries, and obstacles to local renewable initiatives due to national regulatory constraints.
- Weak influence of actors promoting environmental sustainability and cross-sectoral coordination, often hindered by entrenched sectoral interests.

These findings underscore the need for improved data systems, stronger coordination among sectors, and inclusive governance to enhance climate resilience and sustainable development in the Canary Islands.

### System Dynamics & Resilience Tools

These tools supported the enhancement of the modelling frameworks used in CS#5 by addressing **uncertainty analysis**, integrating **resilience indicators**, and applying methodologies like the **resilience wheel**. The modelling framework developed in WP3 followed a tiered structure in which the output of one model served as input for others, enabling a systemic analysis of infrastructure resilience. Crucially, the **Resilience Wheel** developed in WP3 was instrumental in understanding how these models interrelate. It provided a structured approach to visualising interactions between environmental, socio-

economic, and infrastructural systems, helping to identify systemic vulnerabilities and target points for intervention. This integrated approach enhances strategic planning by linking climate and socio-economic projections with infrastructure risk and resilience analysis.

The following three models were developed in CS#5:

**Water availability Modelling and Analysis** has been developed using *GeoModeller* software, which integrates surface and subsurface geological data through a geostatistical algorithm. Before modelling, key geological information was compiled from IGME geological maps, scientific publications and the IGME Water Points Database, which includes data on wells, boreholes, and galleries. The model aims to enhance aquifer management by providing accurate estimates of natural recharge for the first time. Given the influence of climate change, variations in precipitation patterns will impact groundwater infiltration, potentially reducing available water resources. This is the first time that such an integrated model for the hydrogeology of the island of El Hierro, unifying all the existing geological information and integrating it into a 3D geological model using *GeoModeller* software, was developed (Figure 15). The updated 3D hydrogeological models of La Palma and El Hierro, and the resilience assessments post-Tajogaite eruption, have been incorporated into regional hydrological planning strategies.

This is a methodology that can be exported to the rest of the Canary Islands, as it is key to have a better knowledge of the behaviour of the island aquifers. It is important to implement all this new information in future Hydrological Plans, and the models act as a fundamental tool for establishing management measures that consider climate change scenarios.

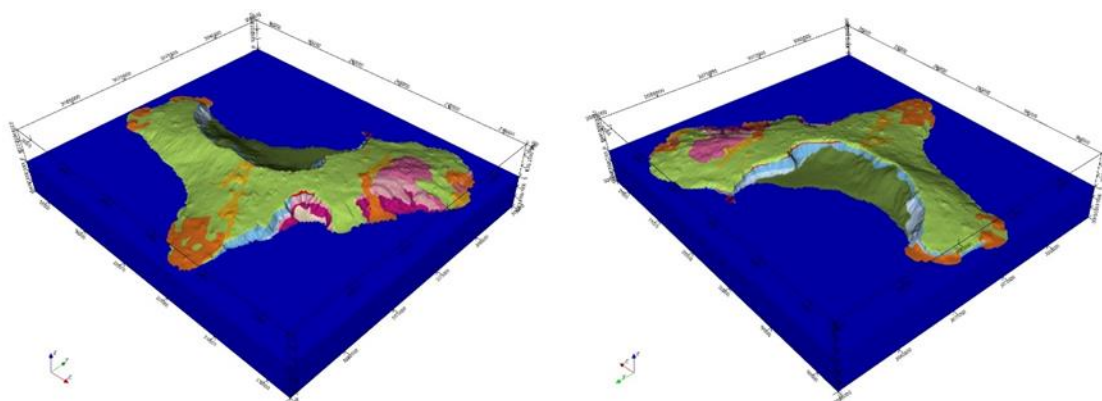


Figure 15: Obtained fully 3D geological model of El Hierro Island observed from the southeast (left) and northwest (right).

- **The Sea Level Rise Model (SLR)** provides characterization of oceanographic variables based on climate change projections for the Canary Islands, with a focus on El Hierro and La Palma islands. The key variables considered include sea level, wind velocity and direction, as well as significant wave height, direction, and frequency. The average and extreme tide regime can be used to estimate the intensity of overwash events. The MIKE21 HD model was utilised for the simulation. Dynamic time steps are employed in the model to enhance simulation speed, ensuring numerical stability with Courant-Friedrichs-Levy (CFL) and accounting for the Coriolis forces of barotropic density that vary within the domain. The HD model utilizes an unstructured mesh, featuring finer resolution near the coast, particularly in the flood zone up to approximately ~40 meters (see Figure 16 and Figure 17).

The results of this model have been implemented as input for the hydrogeological model, as the aim is to assess whether the change in the base level of the aquifer could contribute to the salinization of the aquifer and associated infrastructure, such as wells.

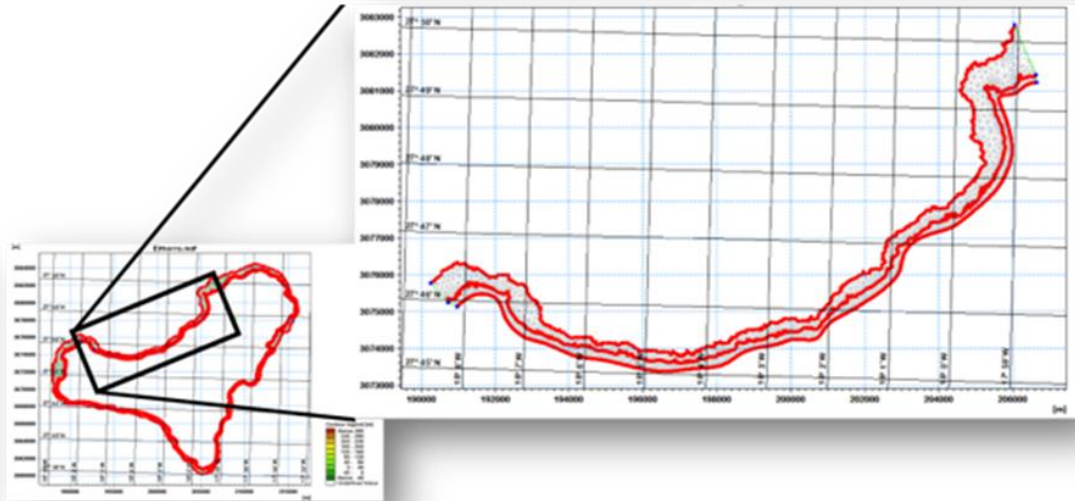


Figure 16: Grid detail of Valle del Golfo (El Hierro island).

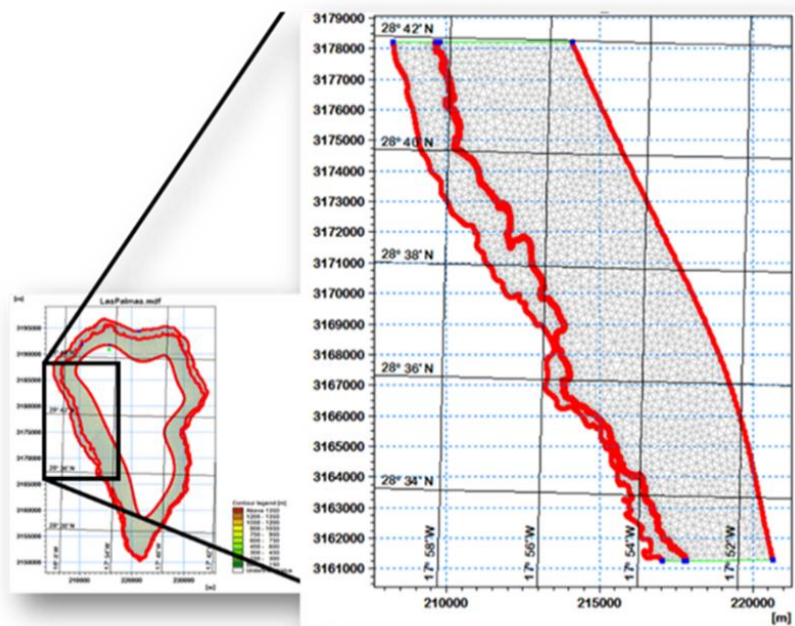


Figure 17: Grid detail of Tazacorte (La Palma Island).

- **The Cascading Failure Engine (CFE)** is a simulation engine, developed in Julia programming language, to model the cascading failure of critical infrastructure and its effect on overall service capacity. The CFE combines graph theory/network-based approach with a supply/demand area-based approach, while considering co-dependencies between population and infrastructures. The simulation engine delivers quantitative estimates useful for both strategic and emergency

planning: we can obtain an overview of the states of critical services for the whole town, but we are also able to see an estimate at the level of each local neighbourhood or “Output Area”. Disruptions to specific services can be analysed i.e. one can quantify the impact of closing potable water supplies on other critical services such as hospitals, schools, and fire rescue for example.

### Implementation of the open tender for innovation in the case study

The CS#5 team led innovation activities in collaboration with **SICMA Canarias**<sup>1</sup>, a regional expert in high-resolution climate projections. The **high-resolution climate dataset** developed with SICMA Canarias was a critical innovation. It provided 100-meter scale climate projections used in modelling, significantly enhancing the scientific basis for regional planning. This dataset was critical for projecting future hydroclimatic conditions and stress-testing our aquifer models. This tool, now being reused in other initiatives, marks a step-change in climate data usability for small island territories.

### Dissemination & Impact

Outcomes include the publication of **peer-reviewed scientific articles** and **open-access datasets**, particularly on the post-eruption hydrogeology of La Palma and the structural dynamics of El Hierro. These outputs have significantly enriched global understanding of **aquifers in volcanic island environments**.

## 2.2.6 CS#6

Case Study 6 consisted of 4 different sub-cases. The following outcomes are considered the primary outcomes from ARSINOE by the CS#6 team and are described per sub-case.

### Aliakmon River – Greece

Actions Implemented:

- Developed a Digital Twin of the Aliakmon River basin integrating:
  - Hydrological modelling using HEC-HMS.
  - Real-time monitoring through the RiverMon low-cost IoT water level sensors (Figure 18).
  - Integration of climate projections (SSP1-2.6, SSP3-7.0) for flood and drought risk.
- Established calibration and forecasting tools:
  - Genetic Algorithms for model optimization.
  - Neural network for irrigation demand estimation.
  - ARIMA-based reservoir operation forecast.
- Engaged stakeholders through participatory modelling and Living Lab activities to codevelop mitigation and adaptation pathways.

Main Findings/Outcomes:

- Created a dynamic operational tool for water quantity management under climate stress.
- Identified critical vulnerabilities for domestic supply, irrigation, and hydropower under drought scenarios.
- Provided scenario-based forecasts to support stakeholder-informed decision-making.
- Enabled replicable framework for upstream basin management in the Black Sea virtual watershed.

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<sup>1</sup> <https://canarias.sicma.red/>

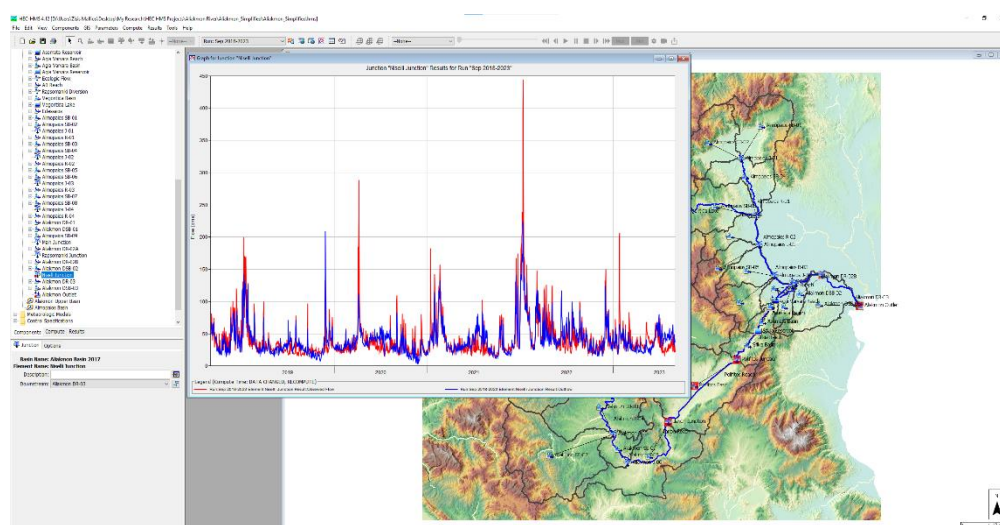


Figure 18: RiverMon low cost IoT water level sensor.

## Danube Delta – Romania

### Actions Implemented:

- Established a multi-source monitoring and modelling system for the Danube Delta including:
  - Water quality and hydrodynamics monitoring via buoy systems.
  - Land-use and watershed modelling (SWAT) for nutrient and pollutant transport (Figure 19).
  - Integration of climate and socio-economic scenarios in the ARSINOE Wheel framework.
- Implemented participatory workshops to validate environmental and socio-economic KPIs.
- Linked monitoring results with economic and ecological risk assessments for deltaic systems.
- Testing salt-tolerant plants on naturally salted soil in Danube delta for demonstrating alternative agriculture practices and the impact on the soil microbiome dynamics
- Biofiltration bacteria identification and monitoring using flow cytometry and DNA sequencing

### Main Findings/Outcomes:

- Detected sensitive zones where land use significantly affects delta water quality.
- Identified impacts on fisheries and local economic activities under low-flow and high-temperature conditions.
- Provided a baseline for source-to-sea management connecting Danube inflows to the Black Sea.

- Enhanced capacity for transboundary resilience assessment in the Black Sea basin
- Two out of 4 tested plant species have shown good adaptability on the specific soil (Safflower and Camelina). The analysis of the soil microbiome after 3 years tests showed a significant increase in diversity, including both beneficial and opportunistic bacteria.



Figure 19: Land-use and watershed modelling (SWAT) for nutrient and pollutant transport.

### Ropotamo – Bulgaria

#### Actions Implemented:

- Deployed the ENOVA H2O innovation: an autonomous real-time monitoring system in the Ropotamo River, measuring COD, BOD, DO, turbidity, pH, conductivity, and water level.
- Conducted monthly field sampling to calibrate and validate real-time measurements.
- Performed UAV-based habitat mapping using thermal, RGB, and multispectral imaging to assess land-use, vegetation stress, and erosion dynamics (Figure 20).
- Integrated monitoring outputs with downscaled ALADIN 5.2 regional climate model projections (RCP4.5 & RCP8.5) for 2023–2050.
- Applied the ARSINOE Wheel Resilience Assessment Framework with defined environmental and socio-economic KPIs.
- Built a structured GIS geodatabase for data consolidation, cross-analysis, and visualisation.
- Facilitated multi-actor engagement through three national-level Working Group meetings, Vision 2050 co-creation, and PESTLE barrier analysis.

#### Main Findings/Outcomes:

- Confirmed self-purification potential of the river system before reaching the Black Sea.
- Identified seasonal vulnerability hot spots for water quality under climate extremes.
- Delivered a real-time and spatially enabled decision-support tool for resilience planning by potential replicability of a combined ENOVA H2O + UAV + modelling system for Natura 2000 rivers and wetlands.
- Identified spatial correlations between water quality degradation and upstream land-use pressures, particularly during low-flow periods.
- Observed climate-related risks to water oxygenation and ecological buffer capacity under RCP8.5 scenario.

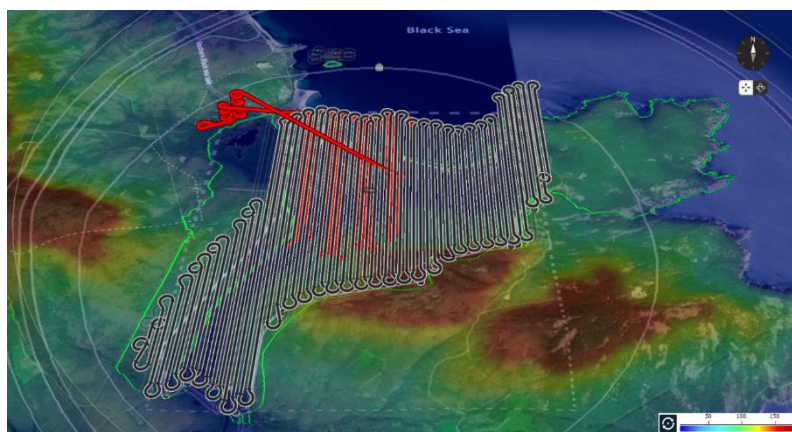


Figure 20: UAV-based habitat mapping to assess land-use, vegetation stress, and erosion dynamic.

### Black Sea - Türkiye

- Under the Open Tender Innovation (OTI) of WP5 of ARSINOE, the Smart Monitoring Sensors (SMS) Platform was funded and successfully deployed. This innovative system has established a new benchmark for comprehensive, real-time data collection and analysis in challenging marine environments.
  - The platform's modular design integrates 10 different sensor types, including high-precision instruments for measuring temperature, salinity, pH, Electrical Conductivity, Oxidation Reduction Potential, dissolved oxygen and atmospheric CO<sub>2</sub>. The use of AI-driven data processing not only facilitated data collection but also enabled advanced pattern recognition.
  - A particularly noteworthy achievement was the platform's performance during the monitoring season, where it is expected to be detected early signs of mucilage formation before visible manifestations appear, allowing local authorities to implement preventive measures. The corrosion mitigation system established for the Platform, combining a proprietary anti-corrosive polymer coating with an innovative bubbling mechanism (15-minute intervals at 2 bar pressure), demonstrated exceptional durability, showing only 3% performance degradation after 2 months of continuous operation in high-biofouling conditions.
  - The data transmission system proved equally robust, maintaining 98.7% uptime despite challenging marine conditions, with redundant communication pathways including GSM/GPRS, satellite backup, and local SD card storage (256GB capacity). This multi-layered approach ensured continuous data flow even during severe weather events.
- A coupled physical-biogeochemical model was used to understand how the Black Sea ecosystem will respond to climate change and human pressures in the coming decades. Their work explores future risks such as algal blooms, oxygen loss, and changes in carbon cycling under different warming scenarios. These projections help identify vulnerable areas and critical periods, supporting the development of strategies to protect marine biodiversity and sustain ecosystem services. METU's modelling approach differed from the general ARSINOE concept due to issues identified in the Black Sea forcing files used by ARSINOE partners, which could not be used. Based on WP3's recommendation, we redesigned the simulations to maintain the SSP3 scenario while applying alternative forcing files.
- Regular sea expeditions with state of art ocean sensors and samplings performed (Figure 21) in connection to the major oceanographic features of the sub-case study took place with support from ARSINOE in 2022 and 2023. The expeditions started from the Marmara end of the Bosphorus

and included observation stations throughout the strait all the way into the Black Sea end. A dense grid of stations in the southwestern Black Sea then enabled the tracking of the Bosphorus water input to the case study area. Seawater quality parameters such as temperature, pH, turbidity, nutrient concentrations and dissolved oxygen levels were measured either in situ or after laboratory analyses of samples. This approach will altogether show the fate of the waters flowing from the Marmara Sea into the Black Sea and its control on the water quality of the case study.



Figure 21: Sea expedition with state of art ocean sensors.

#### Main Findings/Outcomes:

- The SMS platform supported early detection of mucilage risk, maintaining reliable data flow in harsh conditions and demonstrating durability against corrosion and biofouling.
- The platform's CO<sub>2</sub> flux measurements contributed to Turkey's Marine Carbon Sink Inventory, influencing the nation's climate commitment revisions under the Paris Agreement.
- Coupled model simulations revealed increasing risks of algal blooms, hypoxia, and carbon cycle disruption under future warming scenarios, providing science-based guidance for ecosystem protection.
- Regular sea expeditions delivered a new dataset of water quality and nutrient dynamics across the Bosphorus–Southwestern Black Sea connection, clarifying the influence of Marmara inflows on Black Sea ecosystem resilience.
- The combination of real-time monitoring, expeditions, and modelling established a replicable framework for integrated climate adaptation and marine ecosystem management.

### 2.2.7 CS#7

The following outcomes are considered the primary outcomes from ARSINOE by the CS#7 team:

#### Stakeholder mapping and Living Lab

**Outcomes:** Ensuring the wellbeing and protection of people, assets and investments along Esbjerg coastal city and its port is a key priority for the local government. For this aim, a diverse set of stakeholders was brought together to form a Living Lab, including representatives from Esbjerg municipality, the Port of Esbjerg, the local utility company, insurance, emergency preparedness, the local policy authority, local educators, cooperative and social housing associations, an owner of rental properties, investors, NGOs, engineers, and the Danish Coastal Authority among others. These stakeholders are affected directly or indirectly by water-related climate change risks within urban areas extending from the port and coast

and deep into the city. These stakeholders were identified as being central for both climate change adaptation efforts and for improvement of emergency preparedness towards extreme events.

For one year the members of the Living Lab met four times to go through the process of creating mutual understanding of the challenges, envisioning and back casting. Stakeholders have been invited to participating in later activities, e.g. a workshop on cascading effects from flooding.

The SIA approach on how to choose the right stakeholders and how to secure balanced contributions from different stakeholders has caused new perspectives for Esbjerg Municipality and will be implemented in coming projects and processes.

### **Creation of innovation packages**

**Outcomes:** A key outcome of the Living Lab was to identify key innovations and innovation pathways towards a climate-resilient Esbjerg. These were subsequently post-processed by the local ARSINOE team and analysed in terms of the political, ecological, social, technical, legal, and economic (PESTLE) factors affecting the realization of the innovation pathways. The innovation packages and the PESTLE analysis are reported in Deliverable D2.4.

### **Implementation of the open tender for innovation**

**Outcomes:** CS#7, with Living Lab stakeholders, identified key challenges for an open innovation tender, emphasising the need for deeper engagement from commercial actors, citizens, and civil society in climate risk management. A holistic approach was seen as essential, with innovations needed in social, technical, economic, and governance areas. Education, risk awareness, digital platforms, open data, and AI were highlighted. The tender focused on: (1) engaging civil society in climate adaptation beyond usual groups, and (2) improving communication between authorities and citizens during extreme floods.

CS#7 received 14 innovation applications, shortlisted five, and funded three:

One innovation (*MAPEX*) introduced and tested a novel multi-stakeholder workshop concept where local vulnerability and capacity assessments are combined with crisis management exercises. This approach ensured the integration of the local context and the content was relevant for the involved stakeholders and citizens. Two initial workshops were carried out involving authorities, citizens and private sector stakeholders from two of the most flood-exposed areas in Esbjerg. One of these areas was subject to unprecedented flooding just weeks before the first workshop, and thus the workshop simultaneously served as dissemination of this event. The second set of workshops held 2 months later served to better characterize the roles of the different actors, potential interfaces and collaboration, and to build capacity and networks. Evaluation after the workshop revealed that public officials gained a better understanding of citizens' perspectives and their expectations of authorities. It was also recognised that inter-agency collaboration could be improved, and several reached out to colleagues after the workshops. Some gained new knowledge about the specific flood risks in the two selected areas. Among the citizens participating, some felt that the workshops did not concern enough concrete actions or decisions. However, all mentioned gaining a clearer understanding of the authorities' expectations of them as citizens. Only a few of the participants had taken immediate action after the workshops, but all reported that they gained new knowledge about flood risks, discussed preventive measures with neighbours, and had developed a better understanding of how authorities operate.

The second innovator (*GoVocal*) delivered a digital platform, which was integrated into the official website of Esbjerg municipality to support both digital and physical citizen engagement. The implemented platform was used as means to disseminate results from ARSINOE in general, and specifically to collect and disseminate experiences and data relating to the pluvial flood event that took place in Esbjerg on 27<sup>th</sup> September 2024, when a record-breaking 144,6 mm of rain fell over the main city of Esbjerg in 24 hours, causing widespread flooding. While this demonstration of the platform's potential

must be deemed a success, in general the outcomes of the platform demonstration in terms of citizens engaged were modest.

The third innovation introduced into Esbjerg municipality was *Saferplaces*, a cloud-web digital twin solution for flood risk modelling. An added value of *Saferplaces* is that this software can be tailored to the local context and easily combines existing tools and data to address flood risks in areas prone to sea-level rise, storms, and runoff events, delivering precise flood risk hazard assessments and damage predictions that are vital for informed decision-making. The tool was well received and used to demonstrate the evident potential of advanced tools such as *Saferplaces* for flood risk management in Esbjerg. Applications of *Saferplaces* in Esbjerg went far beyond demonstration; the tool played central roles for both the post-event analysis of the September 2024 rain event and the ARSINOE resilience analysis.

### **Flood risk modelling for the Wadden Sea**

**Outcomes:** SFINCS (Super Fast INundation of CoastS) is a tool for dynamic modelling of coastal flooding originally developed by Deltares. The Danish Coastal Authority is participating in the further development of the tool, which was used to benchmark other model developments in CS#7. SFINCS, unlike the static modelling tools previously used nationally, includes the time and space dimensions of a storm. This makes it possible to achieve flood mapping showing the ‘likely’ flooding rather than the largest potential flooding from a storm of indefinite duration (see the figure below). Model output includes meteorological forcing, hindcast models and future projections of mean sea level and storm surges. Additionally existing coastal protection measures, for example Wadden Sea dikes are included. To account for vertical land motion, remotely sensed observations from the European Copernicus Sentinel-1 program were supplemented by new measurements of ground motion at local “hotspots” of subsidence. For this aim, nine satellite reflectors were recently being deployed within the Danish Wadden Sea area. The reflectors are linked and related to benchmarks in the Danish height system (DVR90), to GNSS- and tide gauge stations to assess and detail absolute rates of vertical land motion locally thereby also providing more accurate data to supplement the European Ground Motion Service ([egms.land.copernicus.eu](http://egms.land.copernicus.eu)).

With SFINCS it is possible to model coastal flooding more precisely hereby creating more accurate mapping of the spread of the flooding. This is advantageous in planning and prioritising future coastal protection/adaptation measures. The development of a “FloodAdapt” tool has, in connection with the application of SFINCS, been initiated; this tool will be utilised to simulate dike breaches and consequent flooding within the Wadden Sea area by the Danish Coastal Authority.

To inform flood risk modelling in CS#7, improved extreme sea level statistics based on tide gauge data have been updated (with extended time series and a new methodology) for the Wadden Sea region. The updated statistics were used together with sea level projections and SFINCS flood modelling. The same methods tested for the Wadden Sea were recently applied nationally.

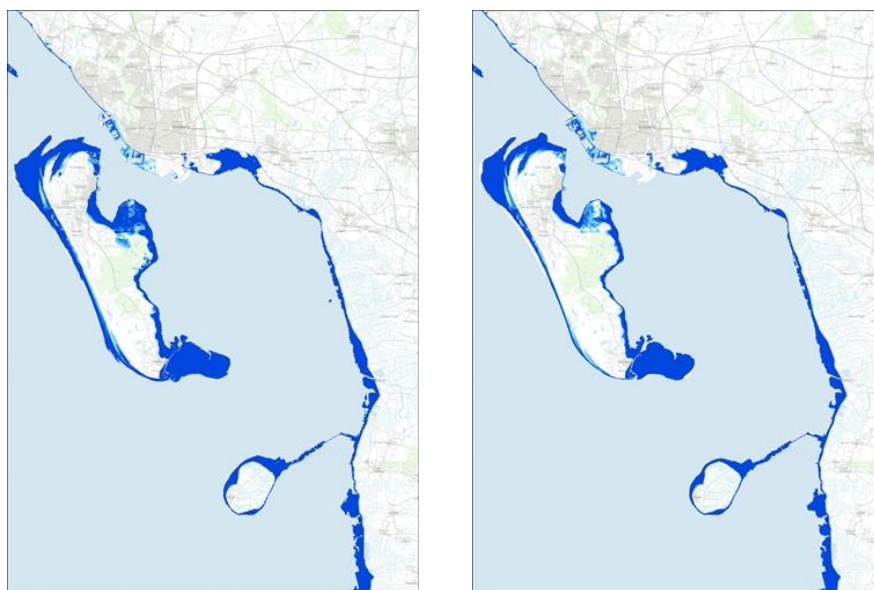


Figure 22: Flood extent using SFINCS (left) compared with a 'bathtub'-model (right) in the Danish Esbjerg and Wadden Sea area.

### Development and testing of an AI-based model for predicting extreme sea levels

**Outcomes:** As part of a PhD study co-funded by ARSINOE, a novel AI-based model for predicting extreme sea levels in Esbjerg harbour has been developed by WP3 and tested in CS#7. The AI model employs the LSTM (long-short-term-memory) machine learning method to train sea level models at specific geographic locations and then combines these using a Graph Neural Network (GNN) approach. The extreme sea level model was trained on hindcasted sea levels combined with modelled wind fields, i.e. reanalysis and sea level data provided by the Copernicus Climate Data Store and Danish Meteorological Institute. By training an AI-based model on current and future wind fields, the role of winds as well as rising mean sea levels is explicitly considered in future projections of extreme sea level statistics for improved modelling of both present and future storm surges.

### Hydrodynamic modelling of the extreme pluvial flood event in 2024

**Outcomes:** The digital platform *SaferPlaces*, which was part of the innovation window used in the Esbjerg Case Study, was implemented and tested. The platform is an AI-based Digital Twin for flood risk assessment. It combines geospatial, satellite, climate data and AI-based models into a cloud computing environment that provides insights in terms of flood risk intelligence. Scenarios for different storm surge events were set up in the software and a 2D hydrodynamic model was used to assess the extent of surge on land for different durations of the storm. The model can be run within a few minutes and can be used by the disaster response team to plan where to deploy protection measures during a storm event. The devastating event in 2024 was a rain event with a long duration and a large rain volume and this is expected to become more frequent in the future. During such rain events the drainage system plays an important role in protecting the urban area. It is not possible to implement the sewage system directly in *SaferPlaces*, so tests were carried out to try different methods simulating the drainage system. All the flood maps were compared to risk maps created using a fully hydrodynamic model coupling sewage system, surface flow and tidal levels. Tests were carried out assuming the drainage system was designed for 140 l/s/ha and applying it in the model. The sewer system was also mirrored using a river module in *SaferPlaces* and all surcharging manholes for the event in 2024 were added as river import (volume) on the surface. This method provides promising results in agreement with observed flooding. Finally, a plug and play flood tool was created for QGIS where hydrodynamic models for selected hotspots were

installed and on the fly flood maps can be created with different rain input from the user. This is a powerful tool for early warning, planning for protection or adaptation measures and the speed of the tool makes it useful for workshops as well.

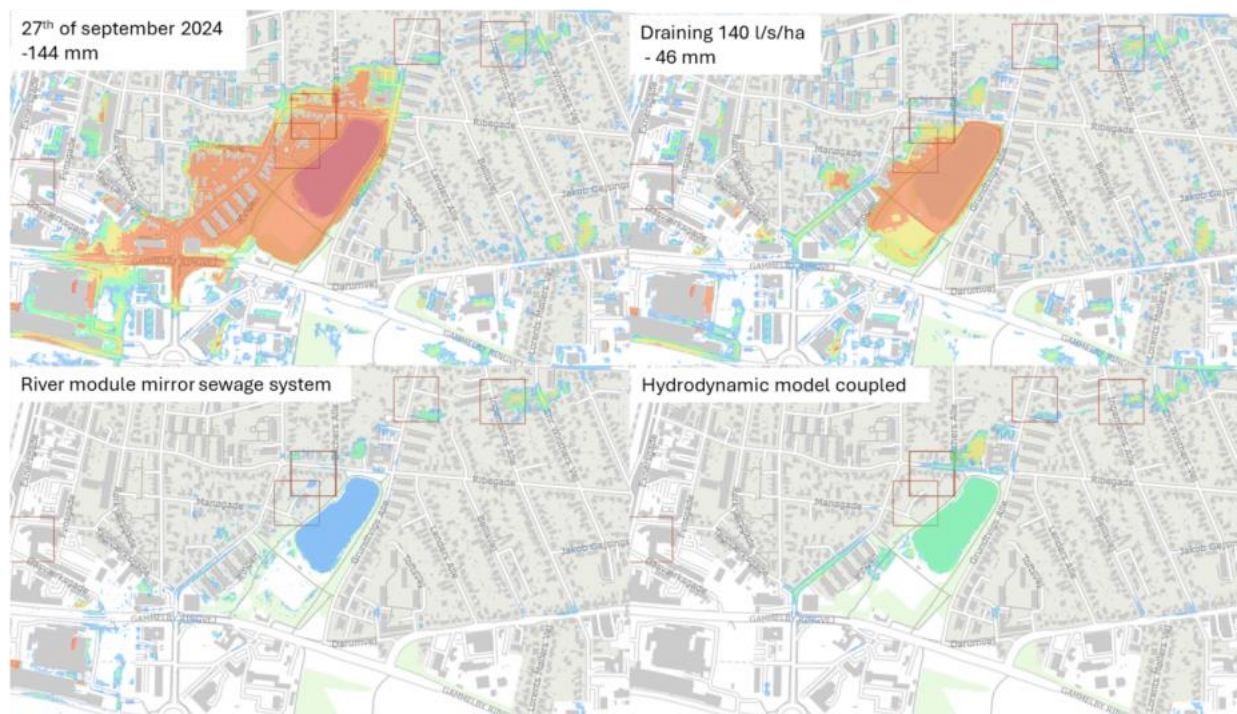


Figure 23: Flood extent using different methods in SaferPlaces. Squares show reported flooding.

### Resilience analyses based on physical, social and economic modelling

**Outcomes:** A comprehensive resilience analysis was carried out focused on the city of Esbjerg, highlighting key elements of social, economic and environmental resilience. The results of the resilience analysis are reported in Deliverable D6.7 and exemplified in the figure below (Figure 24). They were presented to and discussed with ~90 Danish stakeholders at a full-day conference in Esbjerg on 15 September 2025.

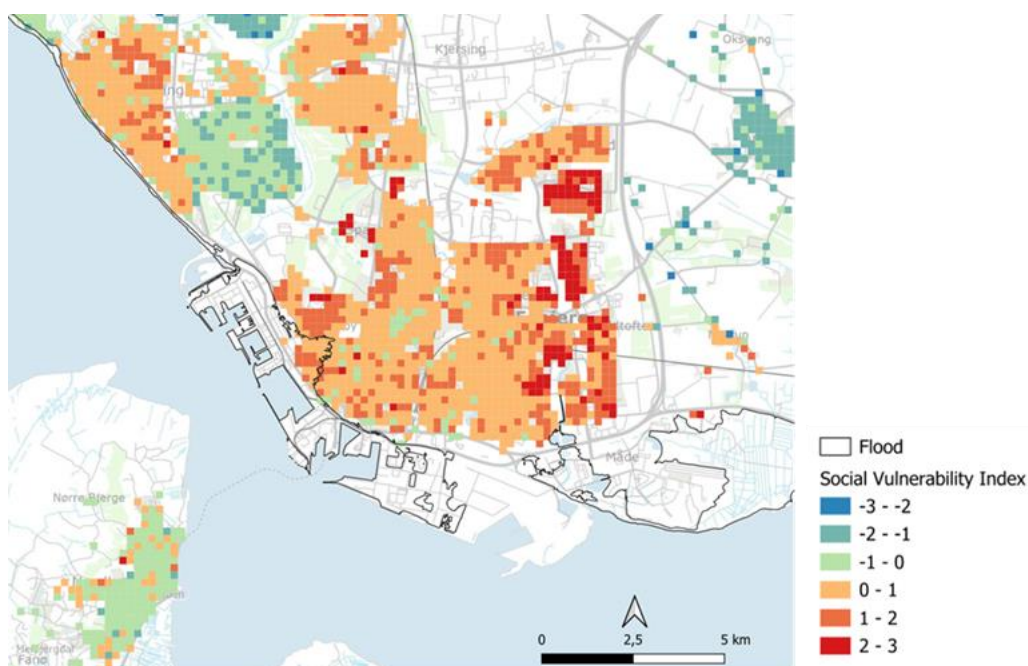


Figure 24: Excerpt from the resilience analysis for Esbjerg, i.e. the Social Vulnerability Index (SVI) developed by the Danish Coastal Authority. Blank grid cells indicated areas with too few inhabitants to ensure personal data protection. The thin black line close to the coast indicates the extent

### Social Vulnerability Model

**Outcomes:** A social vulnerability model has been developed by the Danish Coastal Authority as a tool for screening to which extent socially vulnerable people will be affected by a flood (Figure 24). The model is a national mapping of social flood vulnerability and social flood risk in a Danish context. An approach for assessing social flood exposure including both direct and indirect exposure is introduced in the model. The approach of the model is based on the recognition that different groups and individuals in a society are not equally susceptible to flooding. They do not have the same capabilities to deal with a flood situation, therefore the same flood can have potentially higher impact on some group/individuals than others, even if the flood exposure is the same. Achieving an understanding of which areas contain the most socially flood vulnerable populations, is important to make informed decisions about flood risk management to ensure effective and equitable adaptation solutions. Different solutions will most likely be needed in areas with a high concentration of socially marginalised residents compared to areas with more resilient communities. The development of the social vulnerability model has allowed for a better understanding of social vulnerability in the case area.

### 2.2.8 CS#8

**CAFlood** is a flood hazard analysis software developed by the Centre of Water Systems at University of Exeter (project partners UNEXE). The underlying simulation paradigm driving the model is Cellular Automata (CA). In the ARSINOE project, CAFlood software has been used to develop a flood hazard analysis model for the Torbay case study. The modelling results include the maximum and temporal snapshots of water depths and velocities, which can be used to further estimate the impact of flood events and evaluate the resilience of the case study.

**The Resource Allocation Model (RAM)** is a hybrid simulation model that uses three simulation methodologies, namely, discrete-event simulation, agent-based simulation and system dynamics, to model prioritisation and allocation of resources for emergency response. It is implemented in AnyLogic

multi-methodology simulation software. Four scenarios have been developed for the Torbay case. The scenarios are examined primarily to test whether the resource sharing policy, as well as the priority queuing policy can contribute to infrastructure resilience (i.e., retaining better service capacity through better resource allocation policy). The priority queuing policy means that the RAM model allocates resource according to the priority of ER requests in a queue rather than following ‘first come, first served’ principle in order to obtain better overall performance in retaining service capacity of critical infrastructures and mitigate the impacts of flooding.

**The Traffic Model (TM)** built using the open-source micro-scale traffic modelling software SUMO allows for the analysis of potential disruption to traffic flows for different flood scenarios. Based on the work conducted in the ARSINOE project, more targeted efforts can be made to mitigate flooding on key sections of transport infrastructure (hard-measures) or controlled re-routing of traffic flows under flooded conditions (soft-measures) could be trialled. The traffic model of Torbay was integrated to the four flood scenarios used by the Cascading Failure Engine

**The Cascading Failure Engine (CFE)** is a simulation engine, developed in Julia programming language, to model the cascading failure of critical infrastructure and its effect on overall service capacity. The CFE combines graph theory/network-based approach with a supply/demand area-based approach, while considering co-dependencies between population and infrastructures. Disruptions to specific services can be analysed i.e. one can quantify the impact of closing potable water supplies on other critical services such as hospitals, schools, and fire rescue for example.

**The infrastructure component criticality (ICC)** model is developed with the aim of identifying and ranking infrastructure assets according to their criticality. This enables the formulation of resilience enhancement strategies when there are resource constraints (i.e. prioritization of assets according to their criticality). The framework behind the model is very flexible and allows for the consideration of multiple criticality criteria. We employ a node-weighted directed multiplex network representation of the interdependent infrastructure system, where nodes represent the infrastructure assets, links their interactions and layers of the different types of these interactions. In this way, (1) potential cascading effects across systems, (2) different types of infrastructure interdependencies and (3) multiple dimensions of criticality can be considered.

**The Hazard Impact Assessment Tool (HIAT)** used numerical simulation to evaluate the direct and indirect damage caused by hazards. The tool was built on top of the outcome from previous CORFU project with extended functionalities. The modelled flood depths (using CAFlood) were used to estimate the impact and risk. The building layouts, obtained from the Ordnance Survey Mastermap, the Ordnance Survey point of interest, and the National Grid Network map, Office of National Statistics and OpenStreetMap datasets were used to determine the extent and use of buildings, critical infrastructure or services and socioeconomic attributes. The building use information was combined with the modelled flood depth to determine the direct damage caused by flood, using the depth-damage curves for different building uses from the Multi-Coloured Handbook. The geospatial relationships were analysed to identify the interdependencies of properties to different critical infrastructure and services, in order to evaluate indirect impact of flooding.

**The digital twin** has utilised the real-time weather observation data to drive flood simulations using CAFlood, where the modelled flood maps provide the forecast of flood propagation across the region. The information is further applied to the HIAT for analysing the spatiotemporal evolution of direct damage and indirect impacts to the areas. The outcomes enable the risk-based early warnings that highlight the vulnerable communities and critical infrastructure, which timely response and measure could be implemented to mitigate the impacts and better protect the citizens.

**Implementation of the open tender for innovation in the case study** – HYDS Innovation Work (innovator) have developed the ARGOS City tool that simultaneously addresses river, pluvial and coastal flooding covering all origins of flooding within Torbay. This tool integrates real time data from multiple sensors, including radar, model results, impact calculation algorithms, vulnerability information and real time incident information, into a single platform for the purpose of early warning and flood risk management. ARGOS is a cloud-based platform, accessible from any device with internet connection. Its modularity gives huge flexibility to include new sources of data, new models to be run in real time or adapt the information to end user needs.

**Torbay Communities Innovation work** – Ripple Effects - This innovation work involved grass roots community engagement where solutions come from people working together on shared challenges and ambitions. This work was carried out in three catchment areas of Torbay and involved workshops with local schools, businesses and residents. Educational workshops included discussions with school children around risk of flooding, the effects of climate change and natural flood management.

### 2.2.9 CS#9

Results from case study 9 are based on a multidisciplinary and participative approach developed through interconnections among the various ARSINOE WPs and through the collaboration with stakeholders.

#### Living Lab Workshops

**Outcomes:** The Living Lab workshops, bringing together stakeholders from the public and private sectors, were aimed at gathering views on combating climate change using local-scaled solutions. Concerning innovations, some main points emerged during the three workshops: importance of conservative farming practices and genetic improvement to stabilize and/or enhance crop yields in climate change conditions with a special focus on durum wheat; local agri-food chains to enhance integrated productions and foster dialogues among farmers end-use producers and consumers. Again, the durum wheat short chain was analysed and highlighted due to its economic, cultural and historical importance in the Mediterranean diets. Innovative crop management applied to traditionally rainfed crops (e.g. irrigated durum wheat). Sustainable production techniques based on the use of renewable sources and strengthening models of circular economy based on organic fertilizers and/or amendments. These topics resulted in four thematic areas:

- Digital Adaptation
- Certification Branding and Consumer Awareness
- Technological Integration
- Zero Waste

#### AQUACROP model

**Outcomes:** The AQUACROP model was developed by the FAO Land and Water Division to address food security and assess the impact of environment and management on agricultural production. This model is particularly suitable for conditions where water is a limiting factor in crop production, such as durum wheat. In the context of CS#9, the model was used to simulate durum wheat production on a regional scale and under current and future climatic conditions. The use of climate projection data and resilience wheel methodology, allowed the implementation of this model for durum wheat simulations, focused on its response to water with a special attention to defining the exact timing and water amount of irrigation based on weather forecasts, soil data and real-life agronomic performance (i.e. durum wheat crop yields, Figure 25). The primary conclusions indicate that supplemental irrigation consistently improves both yield and quality, with reduced irrigation (i.e. 50% of total crop water requirement) offering an optimal balance between achieving high yields and saving water resources. While there is no total agreement among different models and projections about the overall trend of yields in climate change scenarios, a general

increase in durum wheat productivity is projected for Sardinia, though with increased variability of the crop performance. This is mainly due to more erratic natural rainfall during the growth season, as well as increased likelihood of crop failures. Reaching maximum yields will necessitate a significantly greater water demand, specifically an increase of over 40%, whereas stabilising yields at 2 t/ha is more realistically achievable with a smaller increase in water use, less than 20%. Critical climatic factors influencing these outcomes include extreme temperatures and year-to-year precipitation variability.

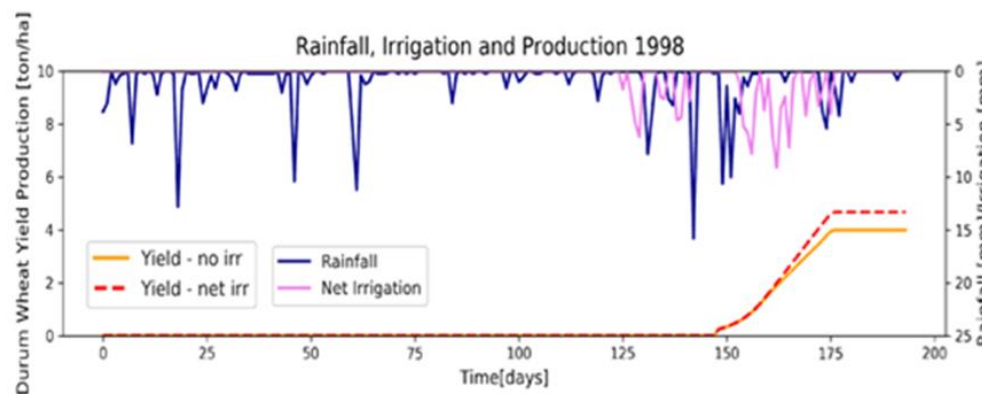


Figure 25: Example of potential increase of durum wheat production with additional irrigation simulated with Aquacrop.

### Implementation of the open tender for innovation in the case study

Four innovations were selected through the Open Tenders and implemented:

- Development and widespread use of innovative agronomic inputs from Circular Economy to guarantee sustainable crop production (e.g. organic fertilizers, amendments, etc.). Thematic area from Living Labs (LL): Zero Waste. Innovator name: Concimi Biologici srl.
- The development and integration of digital technologies tailored for farmers, such as weather forecasting tools, Decision Support Systems, and blockchain applications. Thematic area from LLs: Digital Adaptation. Innovator name: Sarda Energia.
- Incorporation of innovative sensors, water storage systems and other technologies powered by sustainable energy. Thematic area from LLs: Technological Integration. Innovator name: Lobelia.
- Implementation and promotion of certified products that emphasize quality, sustainability and origin supported by platforms and/or apps designed to enhance consumer knowledge and appreciation for sustainable and local food products. Thematic area from LLs: Certification Branding and Consumer Awareness. Innovator name: Comitato Promotore Pane Coccoi IGP.

### Selecting new genotypes adapted to climate change conditions in Sardinia.

During the project, many genetically advanced and segregating lines of Durum wheat have been selected. At the end of the project, a number of them have been short-listed to identify the best performing one to be released as a new cultivar adapted to Sardinian and possibly Mediterranean environments in climate change conditions (Figure 26). To comply with Italian and European legislation, two years of evaluation in different growing environments of Italy are needed. If the candidate cultivar proves to be better performing when compared to the control cultivars, it can be formally released and commercially exploited.



Figure 26: A candidate durum wheat advanced line to be released as a new cultivar.

### **Implementing zero-and minimum-tillage to preserve long-term soil fertility and stabilising crop production**

During ARSINOE experimental trials aimed at evaluating durum wheat performances under conservative practices (i.e. zero tillage; minimum tillage) and conventional tillage (Figure 27) were performed. The results showed an advantage of conservative practices when compared to conventional ones, both in terms of crop performances and increase of soil fertility due to higher content of organic matter. This advantage seems to increase during dry years, suggesting that conservative practices can be a winning strategy to face climate change conditions. Consequently, a dissemination activity with the goal of spreading conservative practices among farmers has been implemented and successfully enhanced also in collaboration with other EU projects (e.g. synergies with InBestSoil).



Figure 27: Comparisons between conservative and conventional tillage techniques.

### **Introducing innovative agronomic techniques (e.g., irrigating wheat to stabilize yields).**

Since from the beginning of ARSINOE project, a 3-year plot trial across two different sites (i.e. Benatzu: high fertility site; Ussana: low fertility site) has been set up (Figure 28). The performance of durum wheat was analysed under two irrigation strategies: full irrigation: I100, 100% of total plant water requirement and reduced irrigation: I50, 50% of total plant water requirement. The results from these irrigation strategies were compared to a rainfed control group. The preliminary results generally show better performance for irrigated plots vs. rainfed plots, with no significant differences between I100 and I50. These results suggest that I50 can be a trade-off solution between enhanced yields and water savings. In addition, a demonstrative activity based on pumping irrigation water with renewable sources (e.g. pumps driven by solar panels) was implemented.



Figure 28: Ubication of ARSINOE irrigation trials at Benatzu and Ussana in 2023 and 2024.

### **Implementing satellite-driven techniques from precision agriculture (e.g. NDVI-index from Sentinel 2) to monitor crop growing phases**

Data from Copernicus/Sentinel-2 Level 2° were collected for all available spectral bands during two cropping seasons to monitor wheat crop health and biomass (greenness) for the two experimental sites of Benatzu and Ussana in 2023 and 2024. The Normalised Difference Vegetation Index (NDVI) was calculated using the two spectral bands (B08, B04):  $NDVI = (B08 - B04) / (B08 + B04)$ . Furthermore, NDVI maps were collected every five days upon satellite passage and were operationally utilised when the monitored test fields were clear of cloud cover (Figure 29).

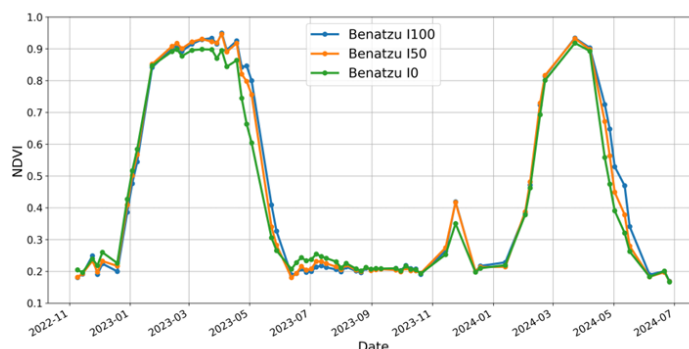


Figure 29: Time series of spatially averaged NDVI values for each irrigation treatment in Benatzu for 2023 and 2024 cropping seasons. Markers on the lines indicate the dates when NDVI images were cloud-free over the study fields.

### 2.3 Comparison across the CS based on the KPIs

Each of the nine case studies has implemented a resilience assessment based on the activities described above (Section 2.2), framed by the ARSINOE Dynamic Multi-Sectoral Resilience Modelling and Assessment Framework, i.e. the ARSINOE “Wheel”. A detailed description of these resilience assessments and the associated results can be found in Deliverable D6.7 (Resilience Assessment Implementation for all the Case Studies). As part of the individual assessments, all case studies defined a number of “key performance indicators” (KPIs) representing the themes of the case studies *in a broader context*. For CS#2 (Limassol, Piraeus, Valencia) and CS#6 (Bulgaria, Greece, Romania and Türkiye) these indicators were defined at the sub-case study level. A minimum of three KPIs were selected by each case study, referring to specific research questions and the three dimensions of sustainability that are typically defined as:

**Environmental:** This dimension relates to the preservation and protection of the natural environment, addressing issues like climate change, ecosystems and biodiversity.

**Social:** This dimension emphasises social equity, community well-being, etc.

**Economic:** This dimension involves the use of resources to ensure economic viability and growth while maintaining ecological and social balance.

The table below (Table 3) explains the rationales for selecting individual thematic case-study specific KPIs within each of the abovementioned dimensions of sustainability.

Table 3: Summary of thematic case-study specific KPIs.

| CS#  | Theme/description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CS#1 | <p><i>Urban heat stress</i>; [extreme temperature].</p> <p>The environmental indicator is the mean air temperature of the Athens Metropolitan Area. Social indicators comprise counts of the vulnerable population in Athens exposed to heat waves of increasing severity. The economic dimension is measured in terms of the aggregated number of consecutive dry days (CDDs) over a 20-year time slice and the number of resources needed to help the Athenian population cope with extreme heat waves.</p>                                 |
| CS#2 | <p><i>Port operations</i>; [wave climate]</p> <p>The environmental indicators represent the wave climate in and outside Mediterranean ports. The social indicator is the weighted health risk score (Valencia port only; see D6.7). The economic indicators are the annual mean downtime at critical berths measured in hours due to wave activity, corresponding to loss of operations.</p>                                                                                                                                                  |
| CS#3 | <p><i>Water-energy-food nexus</i>; [water resources]</p> <p>The environmental dimension of the Main River basin is a metric representing hydrological drought, i.e., the number of days with baseline mean flow that are required to compensate for discharge deficits. The social indicators represent exposure to heat and floods, respectively measured by the number of hot days/days with above average flood risk per year in the region. The economic dimension is measured by the hydropower potential.</p>                           |
| CS#4 | <p><i>Water-energy-food nexus</i>; [water resources]</p> <p>The environmental dimension is represented by the size of the natural area covered with flora and fauna in m<sup>2</sup>. The social indicator highlights human usage of water resources around the Ohrid-Prespa lakes: the availability of groundwater for household usage (in m<sup>3</sup>). The economic indicators refer to economic sectors: water availability for agriculture in m<sup>3</sup>/year and potential electricity generation from hydropower in GWh/year.</p> |
| CS#5 | <p><i>Water availability</i>; [water resources]</p> <p>The environmental indicators represent water availability, measured in mm: average annual precipitation and groundwater extraction. The social indicator measures total groundwater extraction for human usage. The economic indicator is an estimate of the net water budget (in hm<sup>3</sup>), measuring the water deficit for humans and socio-economic sectors in the Canary Islands.</p>                                                                                        |
| CS#6 | <p><i>Water quality</i>; [water resources]</p> <p>The environmental dimensions are related to good water quality. The social dimensions to the population affected by poor/varying water quality; and the economic dimension to the economic risk related to degrading water quality. The CS#6 indicators are categorical rather than numeric.</p>                                                                                                                                                                                            |
| CS#7 | <p><i>Coastal and pluvial flood risk</i>; [floods]</p> <p>The size of flooded natural areas during a 100-year coastal flood event comprises the environmental indicator. The social indicators refer to the population, the vulnerable population and the built environment in CS#7 affected by a 100-year coastal (or pluvial) flood event. The economic indicator indicates the economic cost of a 100-year flood event across selected socio-economic sectors.</p>                                                                         |

|      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CS#8 | <p><i>Coastal and pluvial flood risk; [floods]</i></p> <p>The environmental indicator corresponds to the area flooded by at least 5 cm of water (in km<sup>2</sup>) during an extreme flood event. Social indicators indicate the corresponding number of people and properties flooded by at least 5 cm of water in Torbay. The economic indicator is the number of infrastructure services affected by at least 5 cm of water.</p>                                                                                                                  |
| CS#9 | <p><i>Crop yield (durum wheat); [water resources]</i></p> <p>All indicators are related to the production of durum wheat on Sardinia. Environment is represented by climate variability, i.e. the interannual variability in durum wheat yields in t/ha. The social dimension is the average variation in durum wheat yield in t/ha, a metric of farmer's livelihoods. The economic dimensions are related to productivity: the irrigation demands (water resources) in mm for maximising production and to stabilize productivity, respectively.</p> |

As indicated above, thematically, five of the case studies (CS#3, CS#4, CS#5, CS#6 and CS#9) are related to *water resources*; whereas two of the case studies (CS#7 and CS#8) are related to *flooding*. The last two case studies are largely unrelated to the others, though CS#1 thematically shares an indicator with CS#3 (heat exposure). Each of the indicator mentioned in the table above were calculated for two different time slices: a baseline: 1979-2015 and a future time slice: 2081-2100, exploring two different future climate scenarios: SSP1-2.6 (representing a sustainable and heavily mitigated future) and SSP3-7.0 (representing a low mitigation future). A comprehensive description of the ARSINOE climate scenario baseline as implemented in the nine case studies can be found in Deliverables D3.5 and its update D3.6 ("Common climate scenario baseline").

### 2.3.1 Environmental indicators

Table 4 summarizes the environmental KPIs collected within the case studies. As expected, case studies depict increasing environmental risks due to climate change, in particular under the high warming SSP3-7.0 scenario, i.e. a significant increase (almost 5C compared to the present climate) in the urban mean air temperature of the Athens Metropolitan Area (CS#1), hydrological drought risk in the Main River area increases (CS#3), the natural areas covered by flora and fauna around the Ohrid-Prespa Lakes are highly reduced (CS#4) as is the availability of water for humans and ecosystems in the Black Sea region and on the Canary Islands (CS#5, CS#6). Meanwhile the risk of flooding increases in Northern Europe (CS#7, CS#8) with implications for properties and natural systems, whereas increased variability with respect to precipitation affects crop production in Sardinia (CS#9).

For the ports of Piraeus, Limassol and Valencia (CS#2) we see significant and non-trivial variations in the wave climate compared to the present climate associated with the location of the ports, changes in wind and sea level rise.

Table 4: Environmental indicators.

| Environment                                                                                                            | Base           | SSP1-2.6<br>2081-2100 | SSP3-7.0<br>2081-2100 |
|------------------------------------------------------------------------------------------------------------------------|----------------|-----------------------|-----------------------|
| <b>CS#1</b>                                                                                                            |                |                       |                       |
| "Mean air temperature in °C"                                                                                           | 24.49          | +1.49                 | +4.93                 |
| <b>CS#2</b>                                                                                                            |                |                       |                       |
| "Change in significant wave height rp1 (Piraeus) in %"                                                                 | 0.00           | 0.66                  | -21.77                |
| "Change in significant wave height rp1 (Limassol) in %"                                                                | 0.00           | 87.72                 | 59.65                 |
| "Change in significant wave height rp100 (Piraeus) in %"                                                               | 0.00           | -26.14                | -25.00                |
| "Change in significant wave height rp100 (Limassol) in %"                                                              | 0.00           | -16.49                | 0.54                  |
| "Change in mean wave agitation inside port basin (Piraeus) in %"                                                       | 0.00           | 21.92                 | 12.50                 |
| "Change in mean wave agitation inside port basin (Limassol) in %"                                                      | 0.00           | 16.03                 | 10.95                 |
| <b>CS#3</b>                                                                                                            |                |                       |                       |
| "Hydrological drought - number of days with baseline mean flow that are required to compensate for discharge deficits" | 1.24           | 1.40                  | 1.60                  |
| <b>CS#4</b>                                                                                                            |                |                       |                       |
| "Natural area covered with flora and fauna in m <sup>2</sup> "                                                         | 222.74         | 127.94                | 5.00                  |
| <b>CS#5</b>                                                                                                            |                |                       |                       |
| "Groundwater extraction in mm"                                                                                         | 822.83         | 827.03                | 630.15                |
| "Average annual precipitation in mm"                                                                                   | 750.64         | 650.14                | 567.94                |
| <b>CS#6</b>                                                                                                            |                |                       |                       |
| "Water self-purification potential (Bulgaria)"                                                                         | Medium to high | Medium                | Low                   |
| "Capacity to retain good ecological water status (Greece)"                                                             | Medium-high    | Medium                | Low                   |
| "Water quality (Romania)"                                                                                              | High           | Medium                | Low                   |
| <b>CS#7</b>                                                                                                            |                |                       |                       |
| "Natural area flooded by sea water rp100 in km <sup>2</sup> "                                                          | 13.00          | 13.70                 | 14.00                 |
| <b>CS#8</b>                                                                                                            |                |                       |                       |
| "Area flooded by min 5 cm sea water in km <sup>2</sup> "                                                               | 1.07           | 3.15                  | 3.20                  |
| <b>CS#9</b>                                                                                                            |                |                       |                       |
| "Year-to-year variability in durum wheat yield in t/ha"                                                                | 0.58           | 0.62                  | 1.23                  |

### 2.3.2 Social indicators

Social indicators generally represent the impacts of climate-induced stressors (see Section 2.3.2) on social systems. Table 5 summarizes the social KPIs within each of the case studies. All indicators show significant increases in the severity of social impacts from around 20% to more than 1000% (right-most column) when comparing the baseline climate with a SSP3-7.0 future; with most indicators projecting a change of more than 100%. In absolute terms the highest changes (e.g., total number people and properties affected) are related to floods (CS#7, CS#8), reflecting the role of sea level rise for coastal flood risk in low-lying areas. Conversely, some of the most catastrophic impacts are related to drought. In the area of the Ohrid-Prespa Lakes (CS#4) the ground water available for households is practically gone by the end of this century under SSP3-7.0, which is likely to have disastrous consequences for the region. In Sardinia, the average variation in yields increases by nearly 50% under the same assumptions due to water scarcity, which will stress in particular small-scale farmers and total Mediterranean durum production in general (CS#9). In the Black Sea region (CS#6) - and probably the Mediterranean in general - water quality issues are likely to compound issues of water scarcity further.

Table 5: Social indicators.

| Social                                                            | Base   | SSP1-2.6<br>2081-2100 | SSP3-7.0<br>2081-2100 | From Base to<br>SSP3-7.0 |
|-------------------------------------------------------------------|--------|-----------------------|-----------------------|--------------------------|
| <b>CS#1</b>                                                       |        |                       |                       |                          |
| "Vulnerable population exposed to a category 2 heatwave or above" | 139298 | 170630                | 170630                | 22%                      |
| "Vulnerable population exposed to a category 3 heatwave or above" | 0      | 0                     | 170630                | -                        |
| "Total population exposed to a category 2 heatwave or above"      | 464658 | 655279                | 655279                | 41%                      |
| <b>CS#2</b>                                                       |        |                       |                       |                          |
| "Weighted Health Risk Score (Valencia)"                           | 6      | 9                     | 30                    | -                        |
| <b>CS#3</b>                                                       |        |                       |                       |                          |
| "Heat exposure - number of hot days per year in the region"       | 5.30   | 7.10                  | 15.80                 | 200%                     |
| "Flood exposure - number of days per year above baseline"         | 0.15   | 0.12                  | 0.52                  | 247%                     |
| <b>CS#4</b>                                                       |        |                       |                       |                          |
| "Ground water available for households supply in m3"              | 10.53  | 5.72                  | 0.05                  | -100%                    |
| <b>CS#5</b>                                                       |        |                       |                       |                          |
| "Total groundwater extraction in mm"                              | 854.88 | 840.25                | 843.56                | -1.3%                    |
| <b>CS#6</b>                                                       |        |                       |                       |                          |
| "Population affected by degraded water quality (Bulgaria)"        | 7.88   | 9.83                  | 15.33                 | 95%                      |
| "Population affected by shifts in water quality in % (Greece)"    | 7.00   | 11.00                 | 16.00                 | 129%                     |
| <b>CS#7</b>                                                       |        |                       |                       |                          |

| Social                                                            | Base | SSP1-2.6<br>2081-2100 | SSP3-7.0<br>2081-2100 | From Base to<br>SSP3-7.0 |
|-------------------------------------------------------------------|------|-----------------------|-----------------------|--------------------------|
| "Buildings flooded by rp100 coastal event"                        | 637  | 1532                  | 1721                  | 170%                     |
| "Buildings flooded by rp100 pluvial event"                        | 1583 | 1801                  | 2607                  | 65%                      |
| "Total people flooded by rp100 coastal event"                     | 175  | 1933                  | 2502                  | 1330%                    |
| "Vulnerable people flooded by rp100 coastal event - economic"     | 0    | 1706                  | 2018                  | -                        |
| "Vulnerable people flooded by rp100 coastal event - SVI"          | 0    | 1730                  | 2105                  | -                        |
| <b>CS#8</b>                                                       |      |                       |                       |                          |
| "Properties flooded by min 5 cm water"                            | 984  | 12128                 | 12471                 | 1167%                    |
| "Population and vulnerable communities flooded by min 5 cm water" | 1736 | 10091                 | 10376                 | 498%                     |
| <b>CS#9</b>                                                       |      |                       |                       |                          |
| "Average variation in durum wheat yield in t/ha"                  | 2,83 | 3.49                  | 4.13                  | 46%                      |

### 2.3.3 Economic indicators

Economic indicators generally represent the socio-economic impacts of climate-induced stressors (see Section 2.3.2). Table 6 summarizes the economic KPIs within each of the case studies. Unlike the results discussed in the previous section, indicators depict a more varied picture with respect to the economic impacts of climate change, which in relative terms are moderate compared to the social impacts (cf. Table 5). Here, changes are typically < 100% when comparing economic indicators under SSP3-7.0 with the current climate. While these indicators cannot be compared directly this seems to confirm the general importance of considering not only the economic consequences but also the associated social perspectives of climate resilience.

Results for CS#1 and CS#8 illustrate the increasing need to focus on infrastructure and enhanced disaster risk response in the face of increasingly severe climatic extremes both from the perspectives of heat and floods. Similarly, economic indicators for CS#7 and CS#8 confirm increased impacts of floods also derived for the social dimension.

Interestingly, results for the hydropower potential in CS#3 and CS#4 show opposite trends. While there are increased risks of drought and water scarcity in both cases, CS#3 (Main River) depict an increasing hydropower potential, whereas water availability for agriculture is dramatically reduced, and the hydropower potential halved in CS#4 (Ohrid and Prespa Lakes). Conflicting trends are also observed for CS#5, CS#6 and CS#9. Whereas the Canary Islands generally exhibit a negative net water budget, climate projections suggest improvements for both SSP1-2.6 and SSP3-7.0 compared to the current situation. Meanwhile, CS#6 projects a high risk of economic losses from water scarcity in the Greek part of the Black Sea region. Finally, CS#9 indicates a slightly decrease in the irrigation demand, related to the changing soil moisture conditions (see next section).

Table 6: Economic indicators.

| Economic indicators                                            | Base   | SSP1<br>2081-2100 | SSP3<br>2081-2100 | From Base<br>to SSP3-7.0 |
|----------------------------------------------------------------|--------|-------------------|-------------------|--------------------------|
| <b>CS#1</b>                                                    |        |                   |                   |                          |
| "Consecutive dry days (CDD)"                                   | 689    | 857               | 1311              | 90%                      |
| "Resource allocation capacity requirement"                     | 21441  | 24253             | 32300             | 51%                      |
| <b>CS#2</b>                                                    |        |                   |                   |                          |
| "Change in mean annual downtime at critical berths (Limassol)" | 0      | 149               | 13                | -                        |
| "Change in mean annual downtime at critical berths (Piraeus)"  | 0      | 5                 | 3                 | -                        |
| "Change in mean annual downtime at critical berths (Valencia)" | 0      | 22                | 53                | -                        |
| <b>CS#3</b>                                                    |        |                   |                   |                          |
| "Hydropower potential - mean flow in m <sup>3</sup> /s"        | 190    | 182               | 255               | 34%                      |
| <b>CS#4</b>                                                    |        |                   |                   |                          |
| "Water availability for agriculture in m <sup>3</sup> /year"   | 28.08  | 18.08             | 0.18              | -99%                     |
| "Electricity generation from hydropower in GWh/year"           | 351.57 | 327.63            | 168.24            | -52%                     |
| <b>CS#5</b>                                                    |        |                   |                   |                          |
| "Net water budget in hm <sup>3</sup> "                         | -3.49  | -2.05             | -2.50             | 28%                      |
| <b>CS#6</b>                                                    |        |                   |                   |                          |
| "Economic risk due to degraded water quality (Bulgaria)"       | Low    | Moderate          | High              | -                        |
| "Economic losses across sectors from water scarcity (Greece)"  | Low    | Moderate          | High              | -                        |
| <b>CS#7</b>                                                    |        |                   |                   |                          |
| "Buildings flooded during rp100 coastal event - cost in MDKK"  | 835    | 1764              | 1966              | 135%                     |
| "Buildings flooded during rp100 pluvial event - cost in MDKK"  | 328    | 376               | 552               | 68%                      |
| <b>CS#8</b>                                                    |        |                   |                   |                          |
| "Infrastructure services affected by min 5cm water"            | 454    | 1903              | 1940              | 327%                     |
| <b>CS#9</b>                                                    |        |                   |                   |                          |
| "Irrigation demand in mm to max production"                    | 158.07 | 145.35            | 150.17            | -5%                      |
| "Irrigation demand in mm to stabilize productivity"            | 28.51  | 15.13             | 26.22             | -8%                      |

### 2.3.4 Discussion

The individual resilience assessments and the associated KPIs for the nine ARSINOE case studies clearly illustrate the regional differences between locations in Europe and Europe's Outer Regions (Canary Islands) in terms of climate change pressures, the need for local, tailored solutions but also the potential for knowledge transfer.

As already mentioned, some case studies depict conflicting trends with respect to the net water budget (Section 2.3.3). A climatological water balance is generally defined as the difference between precipitation and potential evapotranspiration, where the latter accounts for changes in both precipitation and temperature. Thus, the net water budget can be used as an indicator to describe the seasonal water availability and soil moisture conditions. Figure 30 shows the net summer water budget at European level for the present climate and for the two future scenarios SSP1-2.6 and SSP3-7.0 explored by the case studies (a detailed description of the simulations shown in this section can be found in Deliverable D3.6). The location of the case studies is indicated in the maps by CS#1 ... CS#9. Most of the case studies in Southern Europe are located in areas that have a slight negative water budgets in the summer today (Figure 30, top panel), whereas CS#3, CS#7 and CS#8 show slightly positive water budgets (the water budget during winter is generally positive in all instances; results are shown in D3.6). For all the case studies, numbers are close to zero, implying that we need to consider the uncertainty related to climate variability when interpreting these results. Under future climate conditions the net water budget is expected to change positively in most of the case study regions and in particular around the Mediterranean though opposing signs of relative change can be found in close proximity to one another. This is reflected by several of the KPIs and across locations. Thus, for CS#4 multiple KPIs suggest massive challenges related to water resources, whereas in CS#9 there is a positive development with respect to crop yields due to improved soil moisture conditions.

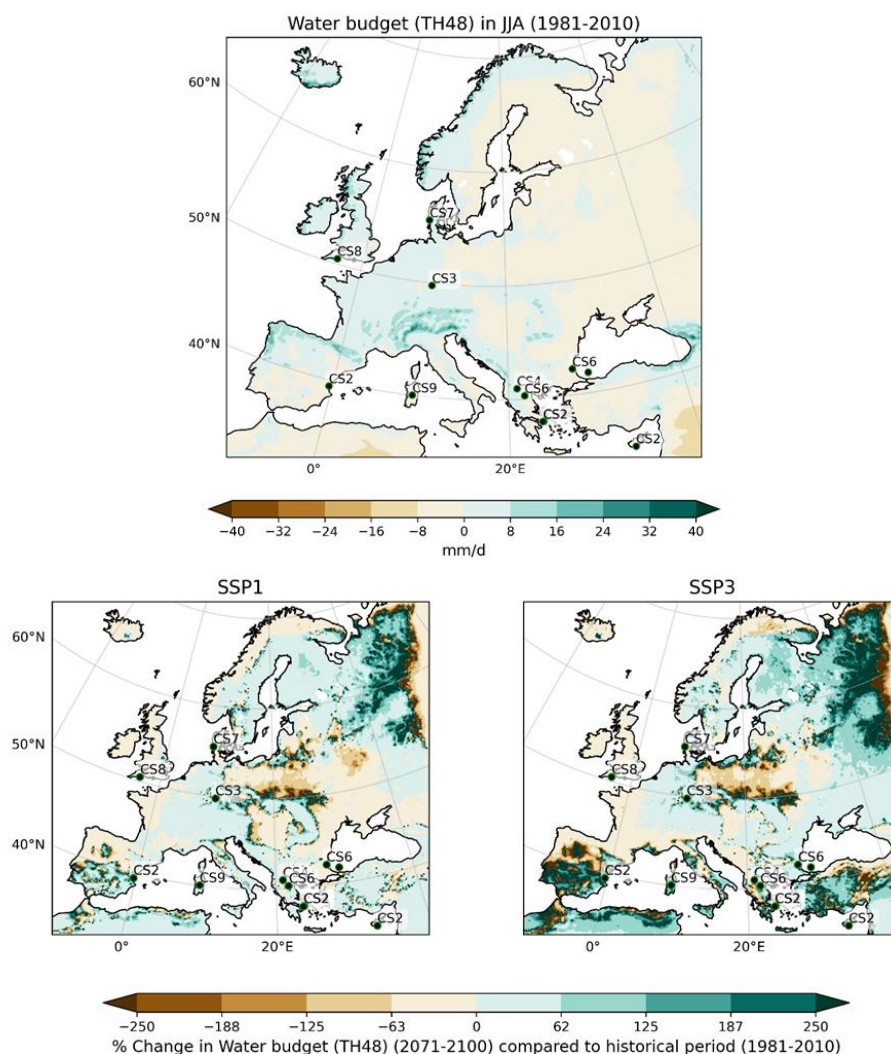


Figure 30: Water budget during the summer months (JJA) under current (top panel) and future conditions (lower panels). See also Deliverable D3.6.

CS#1 explores the consequences of heat-related extremes and possible measures to enhance the resilience of the Athens Metropolitan Area. One of the thematic indicators defined in this regard is the “consecutive dry days” (CDD, Section 2.3.3). Figure 31 expands the results of CS#1 to the European scale., clearly suggesting that findings from CS#1 will be applicable not only to other ARSINOE case studies (who did not consider them in this project) but to a wide European region, spanning both Southern and part of central Europe.

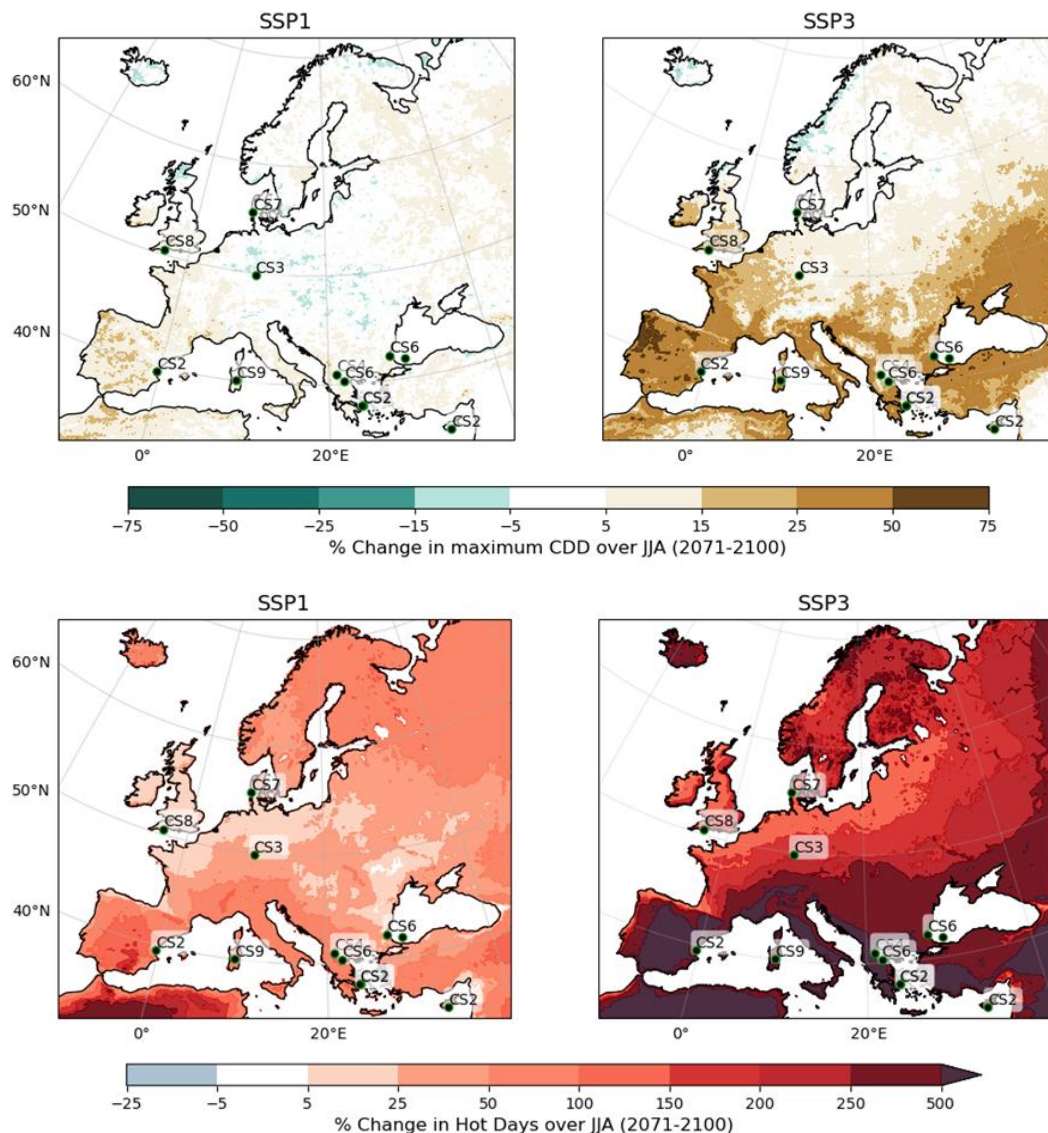


Figure 31: Change in consecutive dry days (top panel) and hot days (bottom panel) under the SSP1 and SSP3 scenarios. See also Deliverable D3.6.

Within ARSINOE, flooding was mainly considered by the northernmost case studies: CS#3, CS#7 and CS#8, where the former primarily explored pluvial flooding, whereas the last two case studies focused on pluvial and coastal flooding. Figure 32 provides a metric of future pluvial flood risk in Europe under SSP1-2.6 and SSP3-7.0, respectively, at the end of the current century (2081-2100). The maps emphasise the role of the three abovementioned case studies as potential archetypes for adaptation to future climate stressors. Interestingly, they also highlight the challenge faced by the case studies and more generally in Southern Europe. While unprecedented rainfall is already a major problem under the current climate as evidenced by Storm Daniel in September 2023, which particularly affected the area around Thessaly, Greece (close to CS#6), and by the extreme flooding west of Valencia in September 2024 (close to CS#2), future climate trends in these regions are clearly uncertain (Figure 32), which may hinder the implementation of effective adaptation solutions.

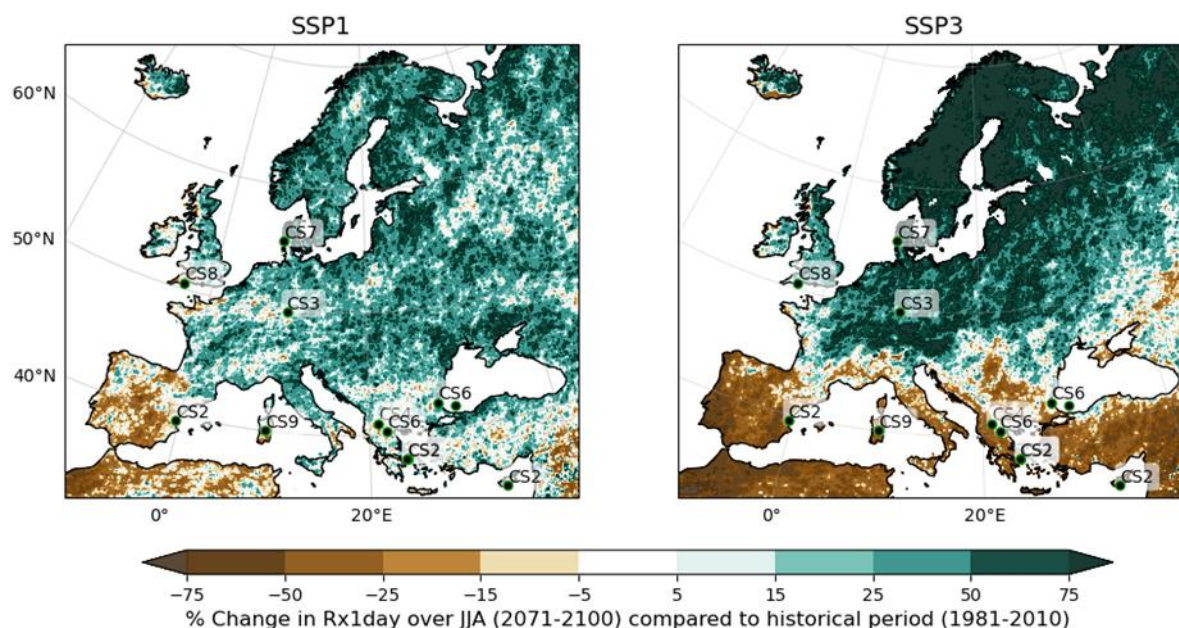


Figure 32: Percentage change in the number of days exceeding the historically “wettest day” (Rx1day) during the summer months (JJA) in the SSP1-2.6 and SSP3-7.0 scenarios (2071 – 2100). See also Deliverable D3.6.

The results of the case study-based resilience assessments underline the importance of sharing knowledge to cope with the increasing human and natural stressors in the face of large climate uncertainties (e.g. Deliverable D3.10). While multi-hazards are only considered explicitly in some of the ARSINOE case studies, Figure 30 - Figure 32 demonstrate that most regions in Europe *have to* cope with multiple stressors, and hence transboundary learning and sharing of technologies and insights could be of critical importance. Prompted by needs identified, e.g. through the Living Labs and local resilience assessments, knowledge sharing therefore became a key part of ARSINOE too (see also the following Section 2.4). One example of this includes CS#5 and CS#7 adopting the perspectives of infrastructure resilience, which in the main focus of CS#8 (and represented by their “economic KPI”). Another general conclusion stemming from a comparison across case studies relates to the importance of the social dimension. While it is the economic impacts that are usually highlighted (e.g. Section 2.3.3), most of our case studies report social impacts, that may be even more significant than the economic ones, relatively speaking (e.g. Section 2.3.2). Hence, the number of people whose wellbeing and livelihoods will be affected by extremes and gradual climate changes will be a key issue to achieving climate-resilience European societies.

## 2.4 Further actions- continuation of activities beyond the project

The work on climate resilience does not end with ARSINOE. In this section, the case studies describe the specific follow-up actions to further the implementation of ARSINOE outcomes in the case studies and beyond.

### 2.4.1 CS#1

To continue and build on the successes of ARSINOE several measures should be taken:

- **Virtual Living Labs:** Within CS#1, a strong ecosystem of stakeholders was established and remained active throughout the duration of the project. To ensure that this network continues to be engaged and collaborative beyond the project’s conclusion, the concept of a Virtual Living

Lab was introduced. The Virtual Living Lab is envisioned as a dynamic, interactive space where stakeholders can exchange knowledge, co-develop solutions, and maintain long-term cooperation. The Virtual Living Lab is hosted on the ENRICH GLOBAL community platform (<https://egcp.enrich-global.eu/>), under the thematic group ‘*Climate Change and Sustainability*,’ led by Professor Chrysi Laspidou. The platform functions as an interactive virtual space that enables the stakeholders to collaborate effectively, share knowledge, and exchange resources. It offers dedicated features for uploading files and news, organising events, and facilitating continuous dialogue. In this way, the Virtual Living Lab not only extends the impact of the project but also fosters an international community of practice committed to advancing climate resilience and sustainability.

- **UNSDSN Global Classroom – Ages Of Globalization Course:** Through the participation of ATHENA RC and the United Nations Sustainable Development Solutions Network in Greece (UN SDSN-Greece) within the ARSINOE project, collaboration was established with UNSDSN Global, Columbia University, the SDG Academy, Harvard University, and UNESCO to develop a training course complementary to the educational and youth engagement activities undertaken in the Athens case study area. The *Ages of Globalization* course is an innovative, free, and interactive multidisciplinary program that takes learners and educators on an engaging journey, blending world history, science, geography, and technology into an immersive educational experience designed to prepare participants for the world’s sustainable development challenges.

Delivered over 28 virtual classes, the course uniquely integrates storytelling and visits to UNESCO World Heritage Sites, using a historical lens to explore sustainable development. By understanding our shared past, participants are equipped to address the pressing challenges of the present and future. The curriculum combines world history, science, geography, and technology with interactive maps, hands-on learning activities, and monthly live dialogues with Professor Jeffrey D. Sachs and distinguished global leaders.

The course also incorporates outputs from the ARSINOE project, including case studies (such as the Athens Case Study), climate challenges, and potential solutions and approaches to address these challenges. In addition, a dedicated *Greek Community* has been established within the Global Classroom to support Greek-speaking learners and educators. This space is being developed and enriched with knowledge and learning resources generated by the ARSINOE project, such as video clips, tools like MINKA, handbooks, and guidelines created by project partners to advance climate change and sustainable development education across different levels. Importantly, this platform will remain accessible beyond the conclusion of the project, ensuring its long-term educational value and impact

- **Report “Building Resilience to Heat in the City of Athens”:** An important initiative developed by R-Cities is the report “Building Resilience to Heat in the City of Athens.” This report addresses a critical knowledge gap: although Athens has gained global recognition as a pioneer in heat resilience, its concrete strategies and on-the-ground actions have remained dispersed across technical papers, municipal memoranda, and project briefs. The report consolidates this evidence into a coherent, practice-oriented narrative designed for practitioners, policymakers, and funders seeking actionable guidance on extreme-heat adaptation. The added value of the report is threefold:
  - **Synthesis:** It integrates climate data, governance analysis, and community perspectives into a single storyline structured around awareness, preparedness, and redesign.
  - **Transferability:** Each chapter distils lessons and decision-making tools that other cities can adapt, complemented by maps, diagrams, and case examples.

- **Systems Lens:** By emphasising ARSINOE’s Systems Innovation Approach, the report illustrates how technological solutions, institutional reforms, and citizen co-creation can reinforce one another.

Athens demonstrates that extreme heat is not an unavoidable tragedy but rather a governance challenge that cities can—and must—address. By combining scientific rigor, inclusive design, and sustained investment within its urban fabric, the city is advancing toward cooler, healthier neighbourhoods.

The lessons captured in CS#1 encourage municipalities, funders, and civil society partners worldwide to accelerate action, align mandates with resources, and shape a future where people and nature can thrive together.

- Adoption of the ARSINOE open and modular knowledge management framework to support data management and analysis processes. The framework consists of a set of open and modular tools (Data Hub, SustainGraph, Digital Twins, Dashboard and Visualization Kit) that will be maintained and extended in the future, aiming to support the development of climate adaptation solutions for smart cities. Data collection, qualitative assessment and semantic alignment will be continued taking advantage of the developed data population pipelines. Furthermore, the developed services for Climate Change Vulnerability Assessment will be offered for the upcoming years following the inclusion of fresh data. Generative AI technologies will be further explored and - where applicable- adopted and used by the various tools to assist the interaction with end users.
- The next steps focus on ensuring the long-term uptake, usability, and sustainability of the modelling tools developed. First, clear governance and maintenance structures must be established, defining responsibilities for updating datasets, refining models, and ensuring interoperability with existing urban planning and emergency management systems. Second, capacity-building activities—including training workshops, user manuals, and continuous support—are essential to enable municipalities, regional authorities, ministries, NGOs, and civil protection agencies to effectively use the tools in both strategic and operational contexts. Third, mechanisms for continuous stakeholder engagement should be institutionalised, ensuring that knowledge from diverse actors is fed back into the models and that the outputs remain relevant for evolving socio-economic and climatic conditions. Finally, integration into formal planning frameworks, decision-support systems, and cross-sectoral collaboration platforms will be crucial for embedding the tools into everyday practice. By addressing maintenance, governance, and inclusiveness, the modelling tools can evolve into a living system that actively supports resilience-building and coordinated action against heatwaves and compound hazards.

Further follow-up activities concerning the CS#1 outcomes include:

- Continuation of the KAUSAL Platform (innovation implemented in CS#1) and expansion to integrate additional plans of the city.
- Maintenance of the established Green Oasis and Singural Ribbon (innovations implemented in CS#1) by Serafeio personnel.
- Exploration of replication potential of appreciated cooling effect to other hot spot areas, in collaboration with the City of Athens.

## 2.4.2 CS#2

To continue and build on the successes of ARSINOE several measures should be taken:

### Piraeus Port – Next Steps

The Port of Piraeus aims to build on ARSINOE results by consolidating technical outputs (e.g., DIORAMA tool), embedding them into strategic planning, and strengthening its resilience framework against climate change impacts.

#### Next steps based on ARSINOE work:

- Review port needs, challenges, and opportunities considering ARSINOE for technical studies and models.
- Support the development and integration of port adaptation plans, reinforcing links between scientific outputs and decision-making.
- Maintain and expand the established transboundary stakeholder network with CS#2 partners.
- Extend and upgrade the **DIORAMA tool** into an applied operational instrument for air quality management and emission mitigation.
- Explore opportunities for implementing further innovative solutions to enhance port climate resilience.
- Integrate key findings and project outputs into the port's strategic operational plan to ensure safe, smooth operations and protect passengers and employees.
- Pursue internal valorisation (not commercialization) of project results to guide future infrastructure investments and safeguard port resilience.

### Port of Valencia – Next Steps

Fundación Valencia port (FV) will build on ARSINOE by advancing and scaling the **Clevertool**, ensuring its institutional uptake and replication in other ports and sectors, while aligning with broader climate adaptation policies.

#### Next steps based on ARSINOE work:

- Consolidate and upscale the **Clevertool**, ensuring continued deployment in Valencia, Sagunto, and Gandía, as well as its replicability in other ports.
- Strengthen engagement with port authorities, local stakeholders, and international networks to foster adoption.
- Enhance interoperability with diverse data sources and integrate AI-based predictive models to expand forecasting capacity.
- Incorporate operational limits into the tool, enabling real-time safety margin assessments and alerts after extreme events.
- Use tool outputs to program adaptation plans, schedule implementation of measures, and support periodic reviews of vulnerabilities.
- Align Clevertool with national and local climate policies to facilitate institutional uptake and long-term sustainability.
- Actively disseminate outcomes in international forums (e.g., Greenport Congress, European Maritime Day) and port networks.
- Seek financing through EU and international programmes and public–private partnerships for scaling and long-term operation.
- Position **Clevertool** as a European reference solution for adaptive climate resilience in ports, supporting replication across the wider sector.

## Limassol Port – Next Steps

Limassol Port seeks to extend the monitoring system piloted under ARSINOE, ensure institutional uptake, and position it for replication in other Mediterranean ports.

### Next steps based on ARSINOE work:

- Extend the monitoring system to additional port sections, particularly high-risk and emission-intensive areas.
- Promote institutional uptake by embedding the system in official port operations (logistics planning, environmental monitoring, emergency procedures).
- Integrate the system into **Cyprus's national climate adaptation strategy**, enabling access to public sector support and structural funds.
- Pursue EU-level funding (e.g., Horizon, CEF) to replicate the solution in other climate-exposed Mediterranean ports.
- Maintain active stakeholder engagement (Eurogate, DP World, logistics companies) to embed the system in daily workflows.
- Publicly report results (e.g., improvements in air quality, accuracy of alerts) to build trust and stimulate interest from other ports and cities.
- Ensure sustainability by assigning clear ownership (a dedicated unit/person within the port or municipality) responsible for system maintenance, expansion, and integration.

## 2.4.3 CS#3

To continue and build on the successes of ARSINOE several measures should be taken:

(1) The **innovation pathways** should be implemented. This requires overcoming the hurdles identified in the PESTLE and governance analysis and the long-term political commitment to building climate resilience. Activities in the areas of education and dissemination should be further expanded, for example by making innovation packages available to specific stakeholder groups. Ideally, the measures should be incorporated into existing programs and initiatives, such as those at higher education institutions or universities.

(2) The **stakeholder network** created by ARSINOE should be maintained through continuous information sharing and cooperation. These efforts could be supported by creating online communities e. g. on the platform “KommunalDigital”. Groups about water management and water availability could be set up. Here, the various interested parties could post information, but above all, they could find out about the current and future climatic and hydrological situation and exchange ideas on possible adaptation strategies.

(3) Building on the success of the living lab in the Main River basin, **living labs** centering around integrated water management should become more widespread. They should be created in all river basins to support the implementation of the water framework directive. Alternatively, they could be created with a focus on the geographical areas of responsibility of the water management authorities. The living lab in the Main River basin should be considered as proof-of-concept showing how the methodology can support integrated water resource management.

(4) The **co-creation of user-friendly climate and hydro services** should be continued. ARSINOE has laid the groundwork and developed a toolkit that could be utilised to provide data directly to stakeholders who could use it for their adaptation strategies. In order to make climate services useful, usable and used for a specific problem, stakeholders should be included in their development from the beginning. Moreover, the dialogue with other providers of climate and hydro services should be continued. A platform for providers of climates services (universities, climate and hydrological projects and state agencies) and potential end-users could avoid the redundant development of similar tools and aid the

efficient use of available resources while ensuring that the landscape of available services remains easy to navigate for prospective end-users. To this end, it is necessary to provide additional and long-term financial and human resources, to consolidate the newly established partnerships and work together on the tasks described.

(5) **Integrated resource management** and a WEFEE-nexus perspective should become the norm in political decision making and administrative thinking. Since water availability is likely to be the biggest problem in the region in the future, this kind of thinking should be expanded further. A cultural shift in how we think about water management should be achieved. Education is key to achieving this end.

(6) **Financing** is crucial for building on the results of ARSINOE and implementing the projects' recommendations. The discussion paper on financing climate resilience drafted in the case study sets out several priorities for efficient spending.

(7) There are numerous **research and innovation projects** about climate resilience and water in Bavaria and Germany. To increase their impact and to ensure efficient use of funds, those projects should be linked in clusters. By bringing researchers into contact with one another and by enabling the exchange on results of projects, new research and innovation ideas could be created.

(8) ARSINOE demonstrated the benefits of **international cooperation** and exchange on climate resilience. Continuously inviting international exchange on questions of water management and inviting outside perspectives to contribute to local and regional questions of water management may be beneficial for the further implementation of the innovation pathways.

(9) ARSINOE results have been **disseminated** successfully among different stakeholders with a special focus on public utilities, policymakers and administration. They have found entry into the publications, events and webinars of the association of local public utilities and will continue to impact the thinking of the key association for organisations in charge of providing basic public services. The survey on climate resilience of basic public services, first carried out by VKU in ARSINOE, could be continued and built on in coming years. The results need to be further integrated into the organisational knowledge at practice partners such as VKU and into teaching at education and research institutions involved in ARSINOE.

## 2.4.4 CS#4

Activities carried out in CS#4, in line with the ARSINOE Resilience Framework and System Innovation Approach, were designed to lead to informed decisions for development of strategy for optimal climate adapted water resource use and management in the region, considering different climate scenarios.

This was reached by the complete set of modelling activities and was found in compliance with the methodology recommended in the document issued by the EC: River basin management in a Changing Climate.

The results of the modelling activities, at several milestones and crucial points of delivery, were presented and discussed with the stakeholders, through the SIA sessions (national and transboundary). This enabled the establishment of multi stakeholder transboundary engagement for deployment and application of the adaptation strategy.

In further steps towards the application of the adaptation strategy, the CS#4 team remains committed to achieving long term impacts in the interest and benefit of all stakeholders that have participated in co – designing and implementation of the project activities. These future activities will be directed towards the strengthening of an integrated water resource management across sectors, in the transboundary environment, and will include:

(1) Extension and upgrade of the applied models by i) integration real time measurement data provided by the innovations implemented during ARSINOE, ii) receiving continuous water resources monitoring

feedback, iii) observing social and demographic changes and their impact on water consumption, towards identification of the most vulnerable water users and iv) updating the prioritisation of the water using sectors by integrating information on their resilience.

(2) Providing assistance in the development and integration of sectoral adaptation plans, reinforcing the linkages between scientific outputs and decision-making.

(3) Maintaining the established transboundary network of stakeholders, through communication and dissemination activities, as well as training sessions for capacity building

(4) Continuation of Citizen Science activities through i) continued use of MINKA, which will remain active and managed by the local High School in Prespes (Greece) and supported by ARSINOE partner NECCA, ii) starting similar citizen science projects with other organisations that have been members of the ARSINOE Living Labs.

(5) Exploring further opportunities for implementation of innovative solutions that enable climate resilient water management and use.

### 2.4.5 CS#5

Following the completion of ARSINOE, the Canary Islands case study is actively pursuing the continuation and upscaling of its most impactful adaptation actions, grounded in the evidence and methodologies developed during the project:

#### **Institutional Integration**

Key project outcomes, such as the updated 3D hydrogeological models of La Palma and El Hierro, and the resilience assessments post-Tajogaite eruption, have been incorporated into regional hydrological planning strategies. The case study team maintains close collaboration with the regional government and water authorities, who are now integrating ARSINOE-derived models and climate data into their ongoing water management and land-use planning processes. The governance analysis piloted through the living labs are being maintained as tools for ongoing community engagement and consultation in infrastructure planning and climate adaptation.

#### **External Financing and Project Continuity**

Building on the synergies established during ARSINOE, several funding pathways are being pursued:

- **EU-level:** The case study partners are participating in new Horizon Europe proposals and are actively contributing to the NATALIE project, which continues to apply ARSINOE tools, particularly the SICMA Canarias climate data, in operational settings across other Canary Islands like Tenerife.
- **Private and blended financing:** Based on the innovation procurement processes initiated in WP5, there is interest from local SMEs and innovation hubs in co-developing technological solutions for groundwater monitoring and early-warning systems related to volcanic impacts.

### 2.4.6 CS#6

#### **Aliakmon River – Greece**

Building on the ARSINOE achievements, firstly the team will focus on the continuous operation, maintenance, and enhancement of the Digital Twin of the Aliakmon River basin. This includes ensuring that the hydrological model, integrated with real-time data from the RiverMon water level sensors, remains fully operational and updated with the latest climate projections and hydrological inputs. Regular data assimilation and model recalibration will enable the system to continue providing accurate short- and medium-term forecasts for water availability. This operational continuity is critical to sustain decision-support role of the Digital Twin beyond the project's lifetime. It is noted that the methodology

can be replicated to other tributaries enhancing the “source-to-sea” approach for monitoring and adapting to climate change.

Furthermore, the developed Digital Twin and its supporting monitoring infrastructure should be officially embedded into the operational procedures of regional and national water management authorities, including irrigation consortia, hydropower operators and civil protection units. As a result, the system could directly support the implementation of the Water Framework Directive through the Water Management Plans and the regional Climate Adaptation Plans. To ensure sustainability, blended financing mechanisms should be explored, including EU Cohesion Funds, LIFE and Interreg programmes.

The model could be enhanced via combining hydrological and climate modelling with socio-economic and ecological indicators, enabling a multi-hazard risk management framework. Through these activities, the Basing could act as a living laboratory for adaptive water governance, demonstrating best practices that can be used in other regions facing similar climate pressures.

### **Danube Delta – Romania**

Based on the ARSINOE findings on the biofiltration bacteria, INCDSB, will continue a targeted monitoring of bacteria involved in heavy metals bioaccumulation processes within the research activities made within the framework of DANUBIUS-RI, an ESFRI research infrastructure of which INCDSB is part.

As for the conclusions issued in soil bioremediation work, the balance of plant-beneficial and opportunistic bacteria can serve as an indicator of the plant's overall health and its ability to cope with different stress. This will be further extended by INCDSB to other soil issues and evolved in applied plant-based technologies for new research project applications.

INCDSB is also committing to continue collaboration with the innovator for long-term data monitoring of water quality parameters and promoting the metaverse platform to ARSINOE stakeholders in close relationship with the local authorities, and for potential future projects.

BSUN is extending the activities related to the development of Digital Twins for other aquatic ecosystems from the South-East region of Romania. In this respect, it has been established the National Competence Centre for adaptation to Climate Change, which is aiming the development of a National Digital Twin on Adaptation to Climate Change. The achievements in the ARSINOE Project shall be further replicated and scaled up under the frame of this Centre.

### **Ropotamo – Bulgaria**

Building on the integrated monitoring and stakeholder engagement activities implemented under ARSINOE, the next steps should focus on maintaining access to the data and tools developed for the Ropotamo sub-case and exploring their relevance for future applications.

CTBG plans a long-term data preservation solution to ensure that the results from the ENOVA H2O system, UAV mapping, and GIS integration remain available for further analysis, replication, or uptake. This will enable the continued use of the data for stakeholder engagement, scientific work, and potential future projects.

Based on interest expressed during national level Working Group activities, the combined ENOVA H2O + UAV approach may be presented as a replicable example for monitoring river/wetland systems within the Natura 2000 and Ramsar networks in Bulgaria. CTBG intends to explore such dialogue further with public authorities and environmental bodies, including the Ministry of Environment and Water and regional environmental inspectorates.

The engagement methodology and resilience indicators developed under ARSINOE can also inform future regional or EU-funded proposals in the areas of climate adaptation, river basin governance, or digital

environmental monitoring. Where relevant, CTBG will seek to integrate the Ropotamo experience into such proposals, building on the technical and stakeholder groundwork already laid.

Dissemination and further analysis of the results will continue through scientific publications, participation in relevant events, and CTBG's broader innovation and policy networks, including the Clean & Circle Centre of Competence and the MENA Maritime Accelerator.

### **Black Sea - Türkiye**

Under the Open Tender Innovation (OTI) of WP5 of ARSINOE, the Smart Monitoring Sensors (SMS) Platform was funded and successfully deployed with support from ARSINOE. Building upon the project's demonstrated success, a comprehensive five-year roadmap has been developed to maximize long-term impact. The expected expansion phase will focus on deploying 12 additional SMS platforms along the southwestern Black Sea coast, creating a dense monitoring network with 25 km spacing between units. This deployment strategy was optimised through hydrodynamic modelling to ensure complete coverage of major current systems and pollution pathways.

METU and Polyregnum's Policy integration efforts are now focusing on the development of a new Marine Environmental Monitoring Directive in collaboration with the Turkish Ministry of Environment and EU DG-ENV. This legislative framework will institutionalize SMS data into national environmental reporting requirements and establish standardised protocols for mucilage early warning systems.

The commercialization strategy involves establishing a spin-off company under Istanbul University's technology transfer office, Polyregnum Corporation. Technological advancements will focus on three key areas: (1) functional sensor packages for offshore deployment, (2) integration of microplastic detection capabilities using hyperspectral imaging, and (3) development of data authentication to enhance credibility for carbon credit verification. The R&D roadmap includes 18-month cycles for iterative improvements, with the next generation prototype scheduled for the near future.

In terms of the Living Labs, METU will ensure the uptake of Living Lab results in relation to the BRIDGE-BS Research and Innovation Action (2021 – 2025) which held joint activities with ARSINOE. METU is the coordinator of the BRIDGE-BS and Black Sea CONNECT CSA (2019-2023) which also focused on the research and innovation in the Black Sea at national and regional scale. Black Sea CONNECT has established an Operational Network of Funders in the region which consists of representatives of ministries and funding agencies of the Black Sea countries. BRIDGE-BS continues to engage this network and facilitates regional dialogue for joint calls and funding for solutions such as SMS and Living Lab outputs.

METU is also involved in the Mission Ocean Mediterranean Lighthouse and established Türkiye's national hub under the Lighthouse with a strong focus on innovation. The outputs, best-practices and lessons learnt of sub-case study works will also be fed into the activities there, paving the way for replication.

### **2.4.7 CS#7**

To continue and build on the successes of ARSINOE several measures should be taken:

1. Building on the work carried out in the Living Lab, Esbjerg aims to move forward towards climate resilience and sustainable urban development, informed by the findings and innovation pathways outlined within ARSINOE. In the short term, the planned flood wall will be constructed to protect the city of Esbjerg against storm surges, corresponding to a 100-year extreme sea level event in the middle of the century. The wall will be partly financed by the state funding and – for the main part - by the municipality.
2. The municipality will move forward in terms of planning and financing of an even more comprehensive multi-function green and grey storm surge barrier, which will eventually replace

the flood wall. To implement this solution, urban development and relocation of business activities and residential buildings along the coastline will be needed, requiring broad acceptance and investments from citizens and the private sector.

3. ARSINOE has identified the need for improved communication and citizen engagement both in terms of climate change adaptation and disaster risk management as a main challenge; this was emphasised by consecutive pluvial flood events in 2024 and 2025. Improving communication and citizen engagement will remain a high priority for Esbjerg municipality and pursued in different ways beyond the project.
4. Further modelling and monitoring (SFINCS, FloodAdapt, land motion) will take place. This will include continuous detailing of efforts including dike breach and flood modelling and land motion monitoring to inform and qualify climate adaptation and risk reduction efforts and operationalization of these into contingency planning. Continue to share learning and solutions in a mainly national context.
5. The AI-based extreme sea level model developed within ARSINOE has been extended also to Kattegat and the Baltic Sea and will be further developed for applications within both disaster risk management and climate change adaptation. For disaster risk management and sea level forecasting, the model has attracted great interest from both the Danish and Polish Meteorological Services, and it is planned to implement and test it operationally for these purposes beyond the end of ARSINOE.
6. Research on the social aspects of flooding, and how these aspects are including in “traditional” flood risk management and in national risk assessments under the European Floods Directive will continue both in the context of the Danish Coastal Authority and DTU. A new project focused on cultural heritage was recently initiated by the Danish Coastal Authority, whereas complementary research on the social impacts of flooding is already taking place at DTU in the context of other Horizon EU projects like CARMINE and CROSSEU.
7. In the context of improved damage cost assessment due to flooding, including climate-induced damages to infrastructure (and its associated cascading and compounding effects), the Danish Ministry of the Environment funded a new project in 2025 that partly continue activities developed in ARSINOE with DTU as a lead partner. The Danish Coastal Authority is also involved. Additional funding is being sought for further continuation of this work in 2026 and onwards.

Ultimately, achieving the intended impacts of ARSINOE will require different financing pathways. Currently, the cost of coastal protection is carried by landowners and municipalities but may partly be funded by state funds upon application to the Coastal Protection Pool, managed by the Danish Coastal Authority. Conversely, flood-related challenges related to rain and rising groundwater levels may be funded by water tariffs and implemented by local utilities, provided socio-economic benefits to society may be demonstrated. Achievements within ARSINOE can serve to further funding sources, including in terms of attracting further funding for research and development through national and international research councils and programs. At the time, Esbjerg Municipality is pursuing dialogue and investigations on how to motivate private companies to contribute with investments on reducing climate risk in the area.

## 2.4.8 CS#8

The approaches used in ARSINOE have been presented to stakeholders by the University of Exeter and Torbay council including Environment Agency and Devon County Council, with further discussions planned beyond the project to apply the methodologies more widely and expand their use. The Flood Warning System, which is a combination of work from CAFlood, HIAT, and HYDS, is continuing to be

developed through the Devon Resilience Innovation Project (DRIP) of Devon County Council. Information will also be disseminated to the council to help them understand the risks and consider plans to protect communities, while outputs from the traffic model will be shown to the Highways Agency, First Responders and Emergency Planning team in Torbay Council. All outcomes and findings could potentially be used to update the major incident plan for the area.

In considering the longevity of the Living Lab group, proposals are being made for its continued involvement in future EU projects by the University of Exeter and KWR.

Finally, the Ripple Effect works will continue beyond ARSINOE, especially with the school engagement works, as Torbay Communities have successfully secured further funding from the Department of Education to carry out Sustainable urban Drainage Systems (SuDS) school projects in schools work as a direct result of their ARSINOE work.

### 2.4.9 CS#9

Some of the outcomes from CS#9 can be further developed after ARSINOE. Innovations selected through the open tender are relevant for upscaling and replication activities.

#### **EU certification branding for traditional Sardinian bread Coccoi IGP**

Concerning this social innovation, an acceptance is required from Brussels at the end of a formal EU procedure. If the submission of certification branding has been accepted, the following steps must be developed: communication actions among producers (e.g. farmers and end-use producers) and consumers (e.g. citizens) implying: information meetings among supply chain actors, policy makers and citizens; organised communication through media and social media (e.g. newspapers, TVs, Facebook, Instagram); dissemination events.

#### **Solar pumps driven by solar panels**

Field demonstrations at farm level with stakeholders (e.g. farmers, salesmen, extension service, water consortia, institutional public bodies, decision makers) to show the functioning of pumps driven by solar panels for irrigation of durum wheat and other crops and create trust and willingness to implement.

#### **Organic fertilizers and amendments from innovative processing**

Field demonstrations at farm level with stakeholders (e.g. farmers, salesmen, fertilizer producers, extension service, institutional public bodies, decision makers) to show the beneficial effect of organic fertilizer from circular economy in comparison with mineral fertilizer.

#### **Other activities**

- Technical meetings with institutions (i.e. decision makers, agricultural extension services, politicians, institutional public bodies such as regional ministries and municipality) and private sector (i.e. farmers, water consortia, professional orders such as agronomist and engineers, citizens associations such as environmental associations).
- Field meetings with farmers, end-use producers (i.e. millers, bread- and pasta- makers) to show and exploit experiences, experimental results and achievements based on ARSINOE-related technical activities, with a special focus on selection and release of new durum wheat cultivars adapted to climate change conditions and on new crop management practices based on conservative agriculture and smart irrigation.

## 2.5 Evidence-based best practices from the CS

This section briefly describes what the case studies learned about how to achieve the goals set out for ARSINOE and what recommendations follow from the work in ARSINOE for other communities and European Regions working to increase their climate resilience. The best practices reported here are evidence based – this means that they follow from the (scientific) work in the project. The best practices are reported in aggregated form, i.e. not per case study, but as overall outcomes from the project.

### 2.5.1 Co-design solutions with stakeholders

During the ARSINOE project, the case studies established a strong stakeholder ecosystem by applying the System Innovation Approach through Living Labs, bilateral meetings, and continuous exchange and collaboration. The vision and pathways of the case studies were co-created, while innovations were co-designed with key stakeholders from diverse disciplines, ensuring smooth implementation and acceptance by the local community. Throughout the process, stakeholders validated the models at different stages, contributing to the development of practical and effective tools.

As the living lab connected multidisciplinary stakeholders with strongly diverging views on water and resource management; it was crucial to allow for the creation of social acceptance and trust. This was achieved by allowing sufficient time, approaching stakeholders who were considered open to constructive dialogue and by implementing Chatham House rules for the initial meetings. Moreover, the living lab benefitted from a clearly defined geographic and thematic scope and well-prepared moderation.

This approach highlighted the critical importance of involving key stakeholders, such as local authorities, from the very beginning of the project to secure relevance, ownership, and long-term impact. By fostering inclusiveness, the methodology not only ensured smoother implementation but also enhanced the potential for scaling and replicating the solutions across other urban contexts facing similar challenges.

Specific benefits from this approach include:

- Acceptance of the solutions offered by ARSINOE
- Increased potential for uptake
- Empowered communities to develop their own solutions
- Better-informed policy and resource management decisions
- Including underrepresented groups in the process
- Results are fit for purpose

### 2.5.2 Implementation of the Open Tender for Innovations / Working with innovators

The work with innovators in the project brought significant advantages. They brought a new and unique set of skills, perspectives, and creativity that enhanced the development and impacts of services and methods in the case studies. Moreover, the OTI attracted a wide array of solutions to choose from that may not have been identified otherwise, it allowed for the implementation of projects that may not have been funded and realised without ARSINOE. The innovators' ability to approach problems from different angles and their expertise added to the value created by the ARSINOE partners.

The innovation call launched through WP5 closed the loop on stakeholder engagement. It empowered local actors to propose and implement solutions, reinforcing their role as co-creators of innovation and not just end-users. This participatory mechanism significantly strengthened the social impact of the project and anchored its results in regions where the innovations were implemented.

### 2.5.3 Use of a suite of complementary computational models in combination with the SIA approach

Integration of a suite of computational models, consisting of analytical, simulation and planning (optimization) components across environment, social and economy sectors with the SIA approach to co-design climate adaptation measures proved effective, both in regional, national and transboundary contexts. Through the integration of a combination of climate risks and strategic and technical response measures under various social, economic, and climate scenarios, and analysing competitive interests of different sectors sharing a limited and scarce resource was facilitated. The integrated modelling in combination with the participatory design approach was applied as a method to describe and communicate measures for coping in long term with impacts of climate change in a complex environment, creating insights and understanding with all stakeholders and is supportive of future application of resilience measures.

### 2.5.4 Agreements on data source sharing

Data gathering was a key prerequisite for the work in ARISNOE for the modelling and scenario development activities. This has made clear the importance of gathering data from all relevant sources, and to proactively address issues related to data sharing. For example, it is recommended to put in place data sharing agreements early on in the process to reduce delays. It is also crucial to recognise dependencies, such as the inability to adjust algorithms without developer involvement and/or consent.

### 2.5.5 Involving end-users early in development of digital tools

Engaging in user experience work with end users is essential, alongside designing clear end-to-end goals. Creating synthetic data can help test entire workflows, while scaling complexity should be balanced with time-to-results. Both development and operations environments should be considered early on.

### 2.5.6 Developing a small proof-of-concept to demonstrate and validate the approach with stakeholders

An approach that was validated in ARSINOE was the development of a small proof-of-concept to demonstrate and validate the approach with stakeholders, before full scale implementation. Introspection capabilities should be provided within the model to reveal cause-and-effect relationships, which are essential for communication with stakeholders and building trust in the model outcomes.

### 2.5.7 ARSINOE Serious Game

From developing the ARSINOE Serious Game it was learned that a practical and efficient approach is to favour low-tech solutions over full-scale digital game development, keeping ambitions deliberately small to allow proof of concept. This allows for functionality to be developed incrementally, guided by iterative playtesting, while project goals and content are periodically reviewed throughout development to ensure they remain aligned with stakeholder requirements.

### 2.5.8 Digital Twin integration

Integrating a hydrological Digital Twin with real-time monitoring data proved to be a highly effective method for forecasting water availability and assessing drought/flood risks.

### 2.5.9 Combine data sources

The Combination of HEC-HMS modelling, real-time sensors and automated calibration with Genetic Algorithms and ARIMA forecasting enabled dynamic decision support for irrigation and hydropower operations.

### 2.5.10 Use on-the-ground monitoring to complement remote sensor datasets.

Low-cost stations monitoring system were demonstrated and proved that affordable, scalable IoT solutions can provide continuous data streams for model calibration and early warning applications. By using solar-powered sensors one can create cost-efficient monitoring networks, especially in basins where official hydrometric stations are sparse.

### 2.5.11 Design modular systems

The sensor platform developed in CS#6 has a modular philosophy and emerged as a game-changer in marine monitoring technology. By developing standardised interfaces for all sensor modules, the team achieved unprecedented flexibility in system configuration. This approach allowed for rapid field replacement of malfunctioning units and enabled cost-effective customization for different monitoring priorities. The financial analysis revealed 40% lower lifecycle costs compared to integrated systems, primarily due to reduced maintenance expenses and the ability to upgrade individual components rather than entire systems.

### 2.5.12 Work next to protected areas

The protected status of the Ropotamo Reserve and Natura 2000 designation required careful coordination for monitoring activities. Sensor deployment outside strictly protected zones allowed for flexible monitoring while respecting conservation constraints.

### 2.5.13 Youth assemblies

Within ARSINOE two structured methods were developed and tested: (a) the Youth Assemblies on Climate Change (YACCs), engaging secondary and tertiary education students as a form of citizen science in the policy domain; and (b) the Training for Trainers (T4T) seminar methodology on “Climate change and simulation techniques for experiential learning in secondary education”, which strengthens climate and experiential education literacy among secondary education teachers. Together, these results foster wider integration of participatory methods in education and maximise students’ awareness and engagement with climate-related issues.

The YACCs proved particularly effective in translating complex climate policy challenges into experiential learning activities, combining citizen science with participatory governance. Framing the assemblies as simulations of real policy dilemmas helped students grasp both the physical challenges of climate change and the institutional/political constraints of mitigation and adaptation action, across governance levels (local/regional, national, EU, international). Additional elements that enhanced learning outcomes included: a study guide with easy-to-understand background information; a two-month preparation period for research; and a balanced mix of structured and open deliberation during the YACCs. Furthermore, mobilising teachers who had already attended the T4T seminars maximised uptake, since they were better equipped to guide their students.

Recommendations for organisers of participatory educational formats on climate change:

- Anchor activities to real-life policy problems and processes
- Provide accessible learning material
- Allow adequate preparation time

- Combine structured and open dialogue
- Invest in capacity-building of educators to maximise impact

### 3. FINDINGS

This chapter presents the collated findings from ARSINOE related to the methodologies and tools employed horizontally across the case studies, and includes also **gaps, inconsistencies, ambiguities** that have been identified.

#### 3.1 Findings related to the SIA approach

The SIA approach within ARSINOE began with the establishment of a Living Lab in each case study. Following this, a minimum of three workshops were organised to define the system, identify the issues to be addressed during the ARSINOE project, envisage a desirable future, and design innovation pathways using various tools and exercises (e.g. mental mapping, storytelling, back casting).

The analysis of the workshops highlighted that the effectiveness of the Living Lab workshops was strongly influenced by the number and diversity of stakeholders. While small groups risked representation gaps and biases, very large groups created coordination challenges, especially during the envisioning phase often requiring division into smaller subgroups during exercises.

Close coordination with WP2 leaders, both before and after each workshop, proved crucial for proper preparation, timely feedback, and the planning of next steps, although it demanded significant time and organizational effort. A central element of the process was the co-creation of a shared vision for the future, complemented by back casting exercises that helped design innovation pathways and identify key milestones for climate adaptation aligned with the Sustainable Development Goals (SDGs).

The three LL workshops, *Mapping*, *Envisioning*, and *Back casting*, were interconnected, but maintaining stakeholder engagement and validating outputs between sessions required ongoing communication and preparation. Reporting and documentation also played a vital role, with detailed workshop reports being essential for capturing outcomes and guiding next actions, despite the time and effort required to ensure their quality.

Finally, continuous support from WP2 leaders, including tools such as roadmaps, surveys, and reports, was essential for successful implementation, enabling flexible adaptation to different contexts, languages, and working styles, and ultimately strengthening collaboration across case studies.

##### 3.1.1 Evaluation of the SIA process

To evaluate the System Innovation Approach (SIA) within ARSINOE, ongoing self-assessments and stakeholder feedback were collected throughout the project. A dedicated survey launched in Month 40 gathered insights from the most engaged stakeholders across all case studies since LLs' workshops, providing valuable data to assess satisfaction and measure key performance indicators (KPIs).

The survey aimed to collect information on several aspects of the project: impact rating; participation and engagement levels in workshops; satisfaction with the workshops, the innovations developed, and the overall project; and the benefits (based on a predefined list of seven benefits).

This survey was completed by **119 participants of LLs' workshops of the 9 CSs**, enabling the extraction of new KPIs, which are partly presented in the following section. For more detailed information, please refer to Deliverable 6.6.

## KPIs of impact of ARSINOE

The analysis of the project's impact rates collected as part of the survey showed that a third of respondents gave a positive (4/5 star) review (Figure 33).

**One-third of respondents reported a significant rate-impact of ARSINOE.** According to the results obtained, 76% of participants gave a high score (4 or 5), while 6% gave a low score (1 or 2). Meanwhile, 16% of participants gave an average score (3).

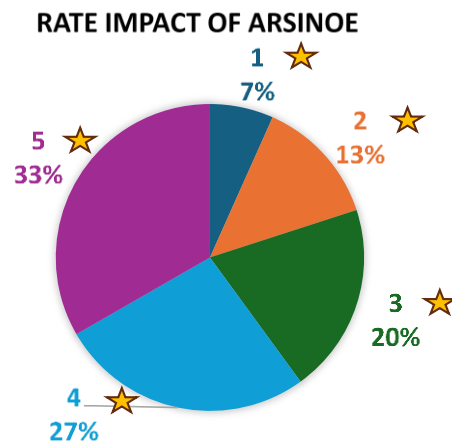


Figure 33: Distribution of the rate impact mentioned in the survey amongst participants in the Living Lab workshops.

## Satisfaction of ARSINOE

The project has an overall satisfaction rate of **89%**, indicating that the majority of participants are satisfied or very satisfied with ARSINOE (

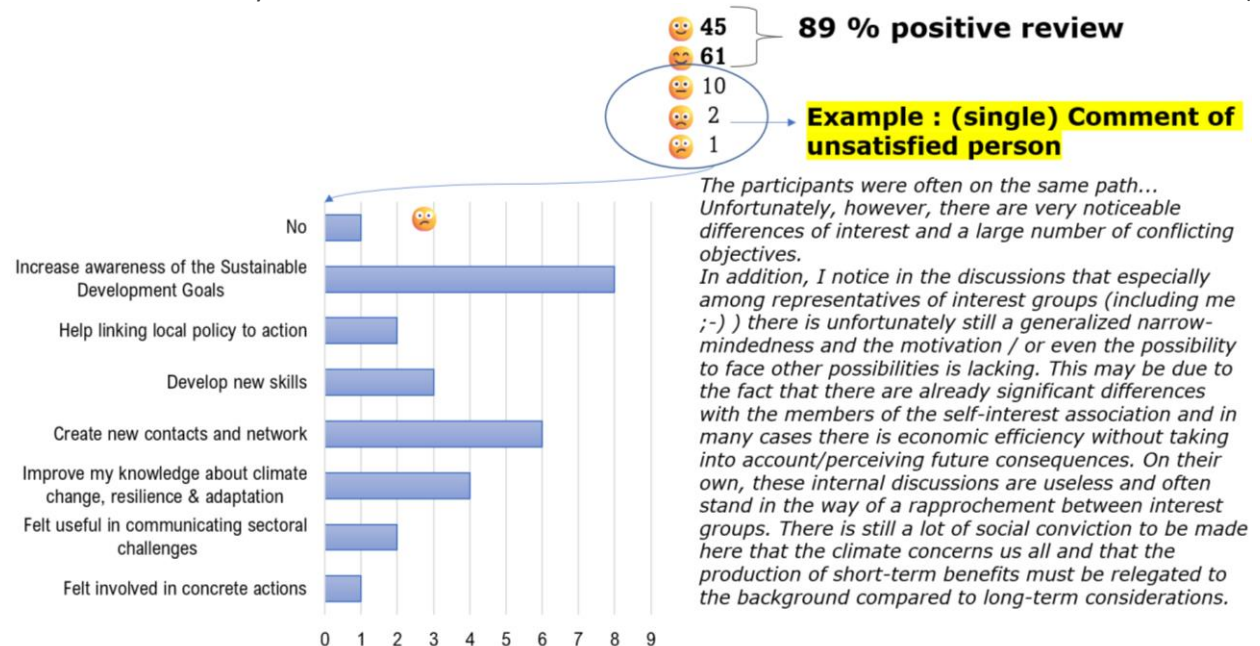


Figure 34), which is an excellent result. The most impact is the creation of new contacts and networks (Table 7). 69 stakeholders mentioned also their improvement of their knowledge about climate change, resilience and adaptation.



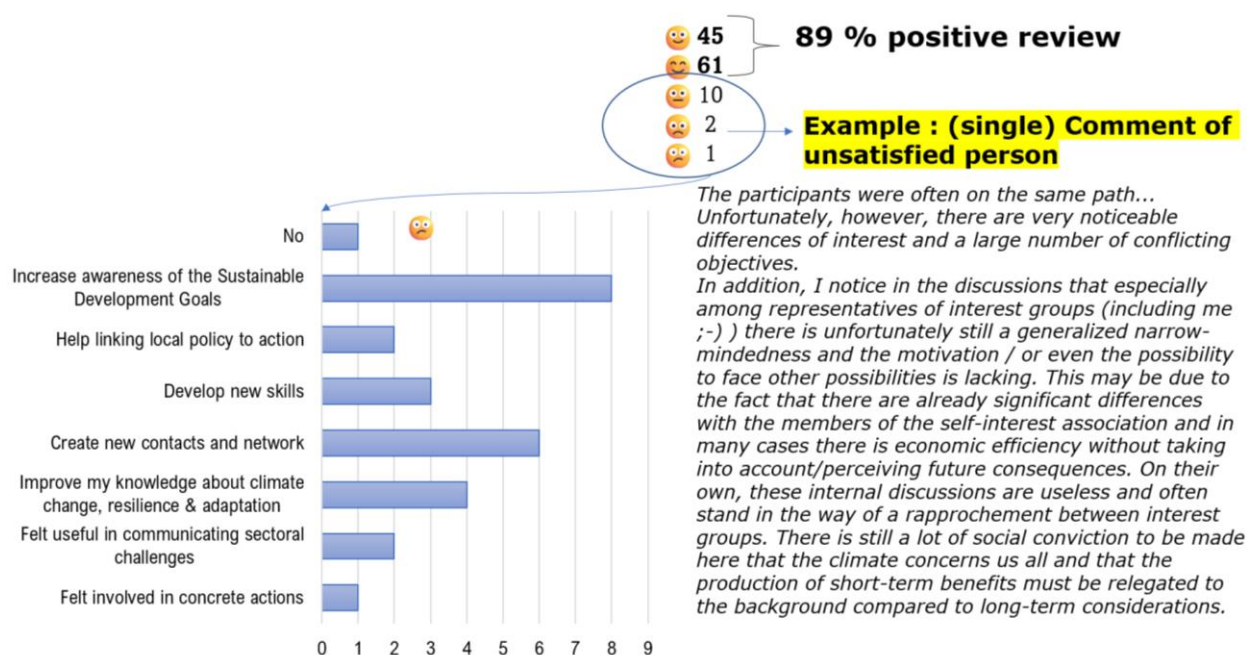


Figure 34: The very positive review of ARSINOE by stakeholders who participated to the SIA process.

Table 7: Benefits of ARSINOE (119 respondents)

| Benefits                                                             | Number of respondents who selected the benefit | Number of respondents who selected the benefit (%) |
|----------------------------------------------------------------------|------------------------------------------------|----------------------------------------------------|
| Create new contacts and network                                      | 80                                             | 67%                                                |
| Develop new skills                                                   | 38                                             | 32%                                                |
| Felt involved in concrete actions                                    | 49                                             | 41%                                                |
| Felt useful in communicating sectoral challenges                     | 36                                             | 30%                                                |
| Help linking local policy to action                                  | 39                                             | 33%                                                |
| Improve my knowledge about climate change, resilience and adaptation | 64                                             | 54%                                                |
| Increase awareness of the Sustainable Development Goals              | 41                                             | 34%                                                |
| No                                                                   | 3                                              | 3%                                                 |

#### Co-occurrence with the benefits of ARSINOE

The following figure presents a co-occurrence matrix showing how many respondents simultaneously mentioned two benefits of the ARSINOE project (Figure 35).

The results allow us to identify relevant patterns: creating new contacts and networks was the most frequently reported benefit (80 participants). This benefit co-occurred significantly with: Improved knowledge about climate change, resilience, and adaptation (49 participants mentioned both), and feeling involved in concrete actions (39 participants). This can be explained by the impact of interactions between stakeholders and scientists during the ARSINOE LLs, which were designed to promote knowledge transfer, particularly with regard to updated information on climate change, resilience, and

adaptation strategies and solutions in line with the principles of the SDGs. The first objective was therefore to maintain contact with stakeholders to facilitate interaction and the transfer of knowledge through the establishment of trust. This is what provides all the necessary conditions for realising the full range of benefits.

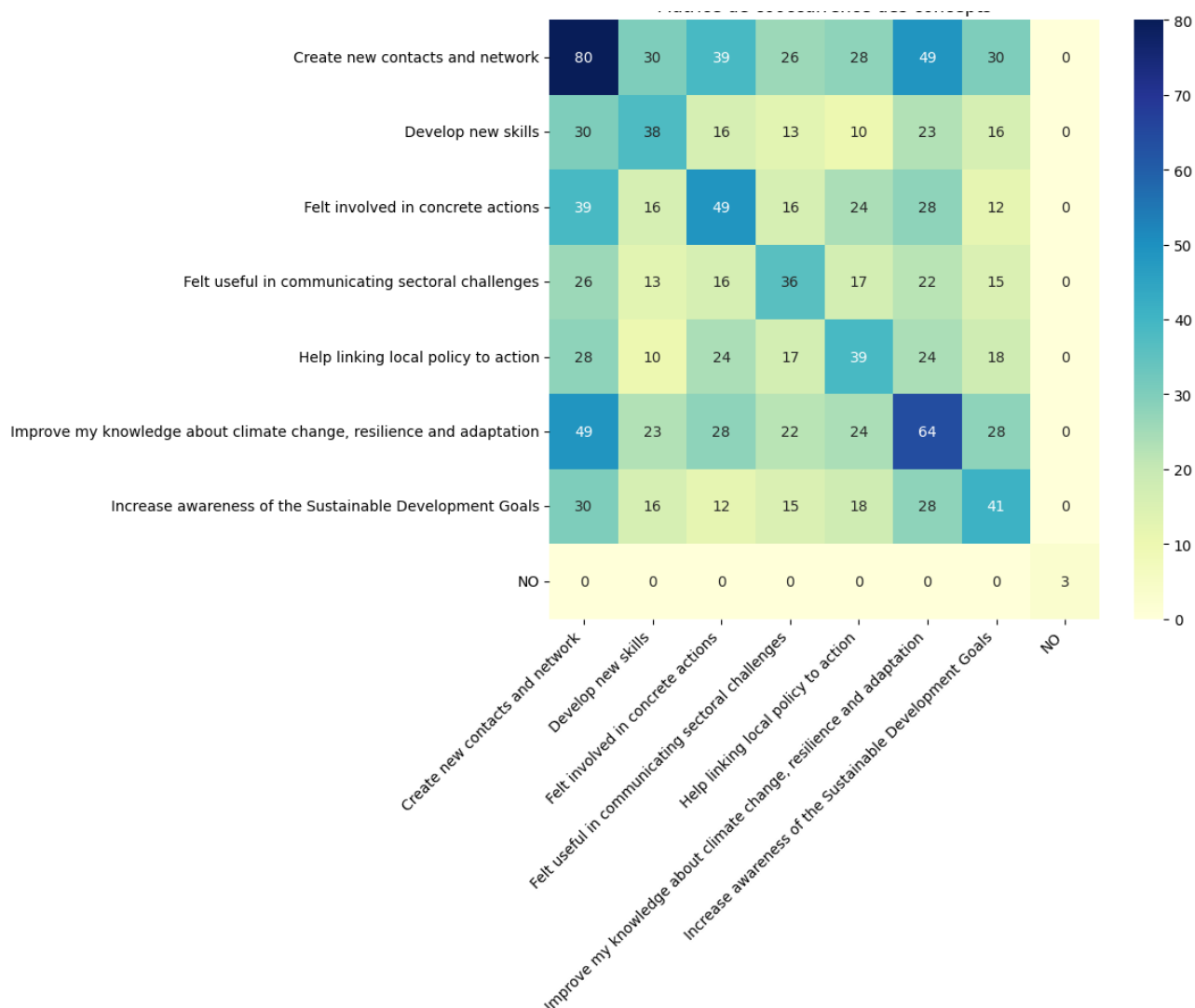


Figure 35: Co-occurrence of ARSINOE benefits (each cell indicates the number of respondents who selected both options, while the main diagonal indicates the total number of respondents who mentioned each benefit. The darker colours represent higher levels of agreement).

## 3.2 Findings related to Modelling

Uncertainties in observational data and climate records emerged as a major modelling challenge. Time series are often too short, spatially sparse, or inconsistent due to instrument changes and biases, making it difficult to capture extremes and compound events. These gaps affect calibration, validation, and bias-correction procedures, introducing inconsistencies into downstream modelling chains. Even with reanalysis data, uncertainties persist because such products inherit systematic errors from models, leaving critical ambiguities when assessing rare extremes across case studies.

A second category of challenges lies in the formulation and assumptions of process-based models. Hydrological and hydraulic models depend on parameterizations (e.g., roughness coefficients, DEM

treatment of buildings, uniform rainfall assumptions) that can oversimplify complex realities. These assumptions introduce structural uncertainties, particularly when boundary conditions, land-use characteristics, or socio-technical factors are simplified. Such gaps in representation are amplified when models are nested (e.g., regional climate models inheriting biases from global drivers), leading to propagating uncertainties across scales.

Another persistent issue identified is the bias-adjustment of climate model outputs. Although ARSINOE employed established correction procedures, the project noted that assuming constant bias-correction factors over time is a weak point, especially under changing climatic conditions. This represents both an epistemic uncertainty (limited knowledge about future system behaviour) and a methodological inconsistency, since model-driven projections might not hold when extrapolated beyond historical calibration periods. The project classified such assumptions as high-risk, underlining the fragility of water-related decision-making when based on adjusted but uncertain climate signals.

Finally, ARSINOE revealed ambiguities linked to stakeholder engagement and model co-creation. While Living Labs enhanced transparency and helped contextualize models, gaps remained where certain key sectors (e.g., tourism, fisheries, energy) did not participate. This absence skewed visions, risk maps, and adaptation options, often producing incomplete or biased model assumptions. Moreover, the ability of stakeholders to articulate precise requirements or robust adaptation scenarios was limited by knowledge gaps and the inherent uncertainties of long-term climate projections. These ambiguities highlighted the need for iterative co-creation and complementary training to improve the modelling framework's reliability and societal relevance.

The hazard modelling in ARSINOE has helped the understanding of possible consequences under various plausible future climate scenarios. Combining with damage and indirect impact analysis and the cascading impact of critical infrastructure or service failures, the outcomes have allowed stakeholders to evaluate the situations and codevelop climate adaptation strategies. However, not all information required for modelling is available or accessible such that certain assumptions must be made based on expert judgement to carry out the analysis. Thus, the accuracy of modelling outcome could be affected if the assumptions do not correctly reflect the real-world environment.

### 3.3 Findings related to Data

#### 3.3.1 Data sources

ARSINOE is a data-driven project, and one of the most persistent challenges is securing the required datasets to support the wide range of modelling activities across case studies. Over the course of the project, it became clear that the maturity of case studies in terms of data availability is uneven, resulting in solutions of varying depth and robustness. Access to local datasets is particularly critical, as local-scale information greatly influences the accuracy and credibility of model outputs and applications. To this end, the project valorised multiple types of data sources:

- **Existing databases:** widely used repositories provided essential baselines. For instance, the Copernicus Climate Data Store and ERA5 reanalysis products supported climate modelling in the Athens and Main River case studies, while the CORINE Land Cover (CLC) dataset informed surface boundary conditions in urban heat island modelling.
- **Ground-based sensors and monitoring networks:** high-frequency observational data helped calibrate and validate models. The tide gauge in Southern Denmark provided storm surge records critical for local sea-level rise modelling, while hydrological monitoring networks in the Main River basin supported calibration of the WaSiM hydrological model.
- **Remote sensing and satellite imagery:** spatially explicit information was crucial where ground data were sparse. In Athens, Landsat-derived land surface temperature (LST) maps and Sentinel-

2 NDVI indices were employed to analyse heatwaves and biodiversity impacts. In the Canary Islands, satellite-based bathymetric and topographic data complemented limited local surveys for aquifer recharge and sea-level rise models.

- **Unmanned Aerial Vehicles (UAVs):** drones provided very high-resolution local imagery in areas with ecological importance. In the Black Sea Ropotamo reserve (Bulgaria), UAV missions produced detailed orthophotos and habitat maps, enriching the integrated spatial database of protected areas. These datasets filled gaps between coarse satellite data and limited in-situ observations.
- **Citizen science contributions:** participatory data collection expanded coverage in domains where institutional monitoring was limited. The MINKA platform in Athens provided urban biodiversity observations, which, after validation, were integrated into the modelling framework.
- **Administrative and statistical datasets:** socio-economic data were indispensable for modelling vulnerabilities and adaptation options. The 2011 Greek Census formed the basis for constructing the socio-economic heat vulnerability index (SHVI) in Athens, while GDP and demographic projections for municipalities around the Ohrid/Prespa Lakes fed into the integrated water management models.
- **Specialised local datasets:** in several cases, municipal or sectoral datasets improved resolution and relevance. The Municipality of Athens fountain locations were included in accessibility models for blue infrastructure, while in the Canary Islands, locally digitised coastline maps replaced less precise national data to improve coastal flooding simulations.

By integrating these diverse sources—ranging from global reanalyses to UAV-derived orthophotos and citizen-science observations—the ARSINOE case studies demonstrated the importance of combining multi-scale data. Nonetheless, the gaps and uneven availability across regions underline the urgent need for harmonised local datasets to ensure comparability and consistent robustness of results

### CS#1

The CS#1 heatwave modelling valorised a diverse set of data sources to construct an integrated and spatially explicit risk framework for Athens. High-resolution environmental data were generated through the Weather Research and Forecasting (WRF) regional model, providing microclimatic variables such as air temperature, humidity, and wind patterns at neighbourhood scale. Air quality inputs were obtained from the EPISODE-CityChem chemistry transport model, producing fine-grained pollutant concentrations subsequently transformed into an Air Quality Index (AQI). Socio-economic vulnerabilities were represented by the Socioeconomic Heat Vulnerability Index (SHVI), which integrates demographic indicators such as age, housing conditions, and employment status, while population density data further enabled the quantification of exposure across 494 postal code areas of the Athens metropolitan region. Importantly, these scientific and demographic datasets were complemented and validated through citizen science activities, which provided ground-level insights into local vulnerabilities, exposure conditions, and adaptation behaviours. All inputs were soft-linked into a composite risk index that evolves temporally and spatially, serving as the basis for agent-based simulations of resource allocation and response strategies. By valorising both advanced modelling outputs and citizen-driven evidence, CS#1 ensures a comprehensive and participatory representation of the compound risks shaping heatwave impacts in Athens.

Regarding the hazard-dependent socio-economic heatwave vulnerability assessment, the model has been trained utilising socio-economic vulnerability indicators/variables for all the NUTS 3 regions of Greece and further applied at the postal code level within the Attica region. Eight socioeconomic indicators were selected based on data availability and their known relevance to heat vulnerability, as presented below:

- % elderly residents (65+)

- % retired individuals
- % people living in buildings built before 1980
- % living alone
- % renters
- % in small housing (<60 m<sup>2</sup>)
- % unemployed
- % immigrants from developing countries

These indicators (variables) used in the hazard-dependent vulnerability assessment were imported in the ARSINOE SustainGraph to align semantically with the stored cross-sectoral indicators. Data for the indicators is retrieved from the open SustainGraph API and transformed through data processing procedures to define the independent and dependent variables of the model's training process. The indicators data was aggregated where needed and normalised to the percentage relative to the population per NUTS 3 region. In addition, the Socio-economic Heat Vulnerability Index (SHVI), presented in Figure 10, along with the socioeconomic variables on the postal codes are used to calculate the vulnerability for 266 postal code regions in Attica and imported into the SustainGraph.

The dependent variable is the “daily average mortality rate during heat wave events per 100k population.” To construct this variable, the country is partitioned into ten climatic zones that are meteorologically similar and are expected to record concurrent temperature extremes, based on the information published by the Greek Ministry of Environment and Energy. The heatwave events within each zone, which is comprised of several NUTS 3 regions, are identified using temperature data, according to. Then, mortality weekly time-series data is collected for each NUTS 3 region in Greece and linearly interpolated to a daily timestep, to match the temperature time series to calculate the rate.

<https://catalogue.arsinoe-project.eu/dataset/?organization=cs1-greening-the-athens-metropolitan-area>

## CS#2

CS#2 Mediterranean Ports used various datasets for the modelling activities and the analysis for WP3, 4,6 and 7.

- ClimEx-II regional climate ensemble (MPI-ESM downscaling) — used as climate baseline/projection input for KPI calculations and model forcing
- Copernicus Climate Data Store (C3S) ocean surface wave time series (1976–2100) — used in wave modelling for offshore forcing and downtime KPIs
- NASA IPCC AR6 Sea Level Projection Tool — used in wave modelling to shift still-water levels and compute port downtime KPIs under SLR
- Marine survey data (Piraeus) + nautical charts — used in harbour bathymetry setup for wave modelling
- Marine survey data (Limassol) + nautical charts — used in harbour bathymetry setup for wave modelling
- Data extraction points for Piraeus (WGS84 37°53'59.9"N 23°36'00.8"E) — location for Copernicus offshore forcing data in wave modelling
- Data extraction points for Limassol (WGS84 34°37'26.6"N 33°03'49.3"E) — location for Copernicus offshore forcing data in wave modelling
- Derived historical and future sea-state frequency tables (wave height × direction, 1976–2005 and RCP4.5/8.5) — used in port agitation analysis and downtime KPIs
- Operational thresholds for port berths (e.g., Hs 0.50 m for container berths, 0.70 m for passenger berths) — applied in wave modelling to estimate berth downtime KPIs

- Valencia buoy wave/swell regime observations — used in vulnerability analysis to characterise extreme events and navigation risks
- ECCLIPSE project climate datasets (GCMs: CNRM-CM5, HadGEM2-CC, HadGEM2-ES, MIROC-ESM-CHEM, MPI-ESM-MR) — used in statistical downscaling for precipitation, Tmax, Tmin inputs to risk/vulnerability assessment KPIs
- EURO-CORDEX RCMs (ALADIN63, RCA4, HIRHAM5) — used in dynamical downscaling for sub-daily weather/climate drivers in risk/vulnerability assessment
- Stakeholder interviews and surveys (Valencia Living Lab) — used in risk matrix KPIs (likelihood, sensitivity, thresholds for heatwaves, wind, rainfall, fog, surge)
- Valenciaport traffic evolution series — used in contextual KPIs for port performance and exposure
- Mean sea-level rise in the Mediterranean — used in hazard framing KPIs (sea-level exposure)
- Secondary ESG/financial KPI datasets at port level (Valencia): emissions, air pollution, logistics indicators — used in the Hybrid Financial Reporting Model (HFRM)
- Thomson Reuters Refinitiv data (listed peers) — used in the HFRM as benchmarking dataset
- EUROSTAT datasets (public entities) — used in the HFRM as benchmarking dataset
- Eurostat and CLIA guidance — used in the HFRM for passenger traffic and social KPI targets
- ILO and European Commission guidelines — used in the HFRM for gender balance, safety, and labour KPIs

### CS#3

- One of the innovators (ANBI – CER) required data on irrigation in the Main River catchment for the implementation of their innovation. However, no systematic and openly available inventory on irrigation exists in Bavaria. It was therefore agreed to frame guiding questions in the implementation of the innovation differently and focus on the potential for irrigation, rather than absolute irrigation.
- Observational data for discharge at specific gauges in the Main River catchment was downloaded from the Bavarian water science service (“Gewässerkundlicher Dienst Bayern”). The data served as reference to assess modelling quality.
- Prior to ARSINOE there was no comprehensive review of the climate resilience of local public utilities and how they perceive climate risks. As part of the resilience assessment this was remedied. ARSINOE surveyed Bavarian local public utilities in charge of water supply, wastewater management, power supply and telecommunications or one or several of these fields of activity. The survey resulted in a rudimentary qualitative assessment of climate resilience and attitudes towards climate risk.

### CS#4

The modelling team carried out consolidation and completion of series of hydrological and meteorological data (filling of gaps of measured data) where needed, using correlation coefficients and alignment methods. Regular contact was maintained with different authorities at national/regional/local level, since data is scattered and the situation regarding its availability is not always clear. Data was gathered and compiled in tables through examining various reports and management plans. The datasets compiled are described in Table 8.

Table 8: Datasets compiled in CS#4.

| Data set                                                                                 | Sources used                                                                                                                                                                                                         | Resolution                                                                                       |
|------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Hydrological data (River flows in the wider watershed area, seven streams)               | Meteorological stations in North Macedonia (Bureau for Hydrological and Meteorological measurements in North Macedonia) and in Albania, Ministry of Environment and Energy & NECCA (local management unit) in Greece | Mean monthly river flows, 1980 – 2020                                                            |
| Meteorological data (precipitation, temperature)                                         | Bureau for Hydrological and Meteorological measurements in North Macedonia and in Albania (two in Ohrid and two in Prespa watershed area); National Observatory of Athens in Greece (Prespa region)                  | Mean monthly sum of precipitations, 1980 – 2020<br><br>Mean monthly air temperature, 1980 - 2020 |
| Discharge of Crn Drin River from the Ohrid Lake, at the town of Struga.                  | Power plants of North Macedonia, HPP Crn Drim                                                                                                                                                                        | Mean monthly water amounts [m3]                                                                  |
| Ohrid lake water levels                                                                  | Power plants of North Macedonia, HPP Crn Drim                                                                                                                                                                        | Mean monthly lake water levels                                                                   |
| Water consumption data, for households and economy sectors (industry, tourism, services) | Water supply utilities in the six municipalities in the three countries, Ministry of Environment and Energy in Greece                                                                                                | Annual consumption in cubic meters. per sectors, for 2020                                        |
| Water consumption data, for irrigation                                                   | Six municipalities in the three countries, Ministry of Environment and Energy in Greece                                                                                                                              | Annual consumption in cubic meters., for 2020                                                    |
| Population number, GDP, for 2010 - 2020                                                  | Public statistical data for the region considered, Hellenic Statistical Authority                                                                                                                                    | Yearly data                                                                                      |

## CS#5

Most of the data from the Canary Islands is open and accessible through various platforms. For example, GRAFCAN is responsible for producing, managing, and distributing geographic and territorial information about the Canary Islands. Similarly, ISTAC, the Canary Islands Institute of Statistics, offers a wide range of statistical data.

However, for water-related data, collaboration with the island water councils was essential. These councils hold private data on different water sources, such as galleries and wells. Although most hydrological data are officially included in the hydrological plans, the councils often have the most up-to-date and detailed information needed for specific work.

Overall, data accessibility was generally good. Nevertheless, a significant challenge remains: the data often comes with low spatial resolution, which is a major limitation when working in the Canary Islands.

**CS#6****Aliakmon River – Greece**

The team relied on a combination of local and European data sets to support hydrological modelling and real-time resilience assessment. Local datasets were obtained from ELGO-DEMETER/SWRI for historical and real-time river discharge at the Niseli station, the Independent Power Transmission Operator (IPTO) for reservoir filling levels and hydropower production, and the Thessaloniki-Lagadas irrigation authorities for diversion volumes. European and open-access datasets included Copernicus EU-DEM v1.1 for topography and sub-basin delineation, CORINE Land Cover 2018 with high-resolution vegetation and imperviousness layers, and ERA5-Land combined with OpenSkiron for historical and forecasted meteorological data. Data gaps, including missing inflows and partial discharge records, were resolved using daily reservoir water balances, model-based estimations, and calibration with ARIMA and HEC-HMS simulations. In addition, new RiverMon IoT-based water level sensors deployed in ARSINOE provided real-time monitoring to validate and complement existing records.

**Danube Delta – Romania**

The CS team relied on local field monitoring, remote sensing, and hydrological modelling to assess environmental and socio-economic resilience. Local datasets were collected via floating buoy systems equipped with water quality sensors measuring DO, pH, conductivity, turbidity, and temperature, supported by periodic manual sampling. Land use, soil, and hydrographic layers were obtained from Romanian national agencies and integrated into a SWAT model to estimate nutrient and pollutant transport from upstream catchments. Meteorological and hydrological reference data were complemented by ERA5-Land and regional Copernicus datasets to fill temporal gaps. Where local time series were incomplete, model-based estimations and scenario simulations were applied to interpolate missing inputs for inflows, sediment, and nutrient dynamics.

**Ropotamo – Bulgaria**

The CS team combined local ecological and hydrological monitoring with remote sensing and regional climate data to assess resilience under ARSINOE. Local datasets included UAV-based photogrammetry, thermal, and multispectral surveys for habitat mapping and hotspot identification, as well as real-time water quality measurements from the ENOVA H2O sensor system deployed at three points along the Ropotamo River. These sensors provided COD, BOD, DO, turbidity, pH, conductivity, and water level data, validated through monthly field sampling and laboratory analysis. Land use and hydrographic data were sourced from the Bulgarian Ministry of Environment and Water and CORINE layers, while climate projections were derived from the ALADIN regional climate model under RCP4.5 and RCP8.5. In cases of unavailable historical time series, UAV observations and static sensor readings were interpolated and consolidated into a structured GIS geodatabase to support spatial-temporal analysis and resilience assessment.

Engagement with national authorities (e.g. MoEW, RIEW-Burgas) during the project demonstrated openness to innovative monitoring approaches, especially where these complement existing obligations under the Water Framework Directive, Natura 2000, or Ramsar Convention. Sustained dialogue and resource mobilisation will be important for future uptake.

**Black Sea - Türkiye**

For the coupled physical–biogeochemical model, input parameters include wind, radiation, temperature, humidity, precipitation, and snowfall data from ERA5, initial temperature and salinity from the METU IMS database, river inputs from the PERSEUS Project, and bathymetry from the General Bathymetric Chart of the Oceans (GEBCO). Model outputs were validated against data collected during dedicated expeditions, which provided in situ measurements of key hydrographic and biogeochemical variables.

Within the scope of SMS project under CS#6 sub-case study for Türkiye, The SMS project established a robust data acquisition framework combining multiple sources. Primary data came from the SMS platform's onboard sensors. The team implemented a novel data validation protocol comparing platform measurements with: (1) monthly water samples analysed by TUBITAK (The Scientific and Technological Research Council of Türkiye) (2) hourly meteorological data from the Turkish State Meteorological Service's coastal stations. Other work of the CS focused on regular expeditions and regular sea expeditions to study this crucial oceanographic connection 'in situ', with state of art ocean sensors and samplings performed in connection to the major oceanographic features of the sub-case study,

### **CS#7**

Most of the data used in CS#7 was restricted to some extent, e.g. available upon request or limited under the Data Protection Act and was collected by ARSINOE partners or from stakeholders. A limited part of the data was open.

- Socio-economic data for Esbjerg municipality and other locations from the Danish Neighbourhood Atlas - [www.nabolagsatlas.dk](http://www.nabolagsatlas.dk) - were provided upon request by Elise Stenholt Lange and Aalborg University (Denmark): Lange, E. S. (Creator), Thestrup, S. M. (Creator), Lindberg, M. R. (Creator), Bøje-Kovács, B. J. (Contributor). This resource collects a wide range of socio-economic variables collected from Statistics Denmark and presented in a form compliant with the Danish Data Protection Act.
- Traffic data were provided by Esbjerg municipality for the purpose of the project.
- Data and maps on water and wastewater systems in Esbjerg municipality were provided by the local utility company (Din Forsyning) for the purpose of the project.
- Data and maps of the electricity system in Esbjerg municipality were provided by the local power company (N1) for the purpose of the project.
- The national high-resolution digital elevation model and building layers are open for download from the Danish Climate Data Authority.
- Official climate projections for Denmark, including sea level rise, temperature and precipitation projections, were downloaded from the Danish Climate Atlas, maintained by the Danish Meteorological Institute.
- ClimEx-II data, i.e. precipitation scenarios for SSP1-2.6 and SSP3.7.0 were made available by LMU through their Globus data system (see Deliverable 3.5 and 3.6).
- Time series of precipitation from rain gauges owned by the Water Pollution Committee of the Danish Society of Engineers were provided free of charge for academic purposes as per the agreement with DTU.
- Data from ocean modelling (hindcasts) was provided for the Danish Seas by the Danish Meteorological Institute for the purpose of the project.

In addition, various data sets were retrieved from the Copernicus Climate Data Store.

### **CS#8**

Data was collected from various sources, including the topography data from Ordnance Survey Mastermap, the digital terrain model from the Environment Agency, the rainfall intensity-duration-frequency analysis from the UK Centre for Ecology and Hydrology for rainfall patterns, the future climate projections from the WP3 and the Environment Agency's climate allowances for future rainfall and sea level rise, the rain gauge observations from Torbay Council and the Environment Agency for real-time digital twin, the Point of Interest data from Ordnance Survey and OpenStreetMap, the electricity substation data from the National Grid Network, property flood depth and damage relationships from the Multi-Coloured-Handbook, the socio-economic statistics information from Office of National Statistics. The Met Office rainfall radar observation data with 1 km resolution are available from the Centre for

Environmental Data Analysis (CEDA) Nimrod Archive with a 2-day delayed availability such that they can only be used for post-event analysis. The near real-time 500m rainfall radar data were obtained via paid service through the Devon Resilience Innovation Project in order to support digital twin applications.

Confidential data was used from South West Water, a data sharing agreement was arranged between Torbay Council and South West Water. This agreement took time to prepare and agree and had restrictions on it. The agreement allowed the University of Exeter to use the data for the ARSINOE project but were not allowed to publish without further permission being granted by South West Water.

For the Serious Game, there was a miscommunication between the developer and the data owner. The data owner wanted the game to be generic so it can be used in different locations and shouldn't be specific to a location.

### CS#9

The main dataset for CS#9 comes from climate scenario data provided by LMU (D3.5) for the entire island of Sardinia, with a resolution of about 10 km and on a daily basis. For specific use in field-scale studies and for the necessary de-bias, data from two weather stations managed by AGRIS in Ussana and Benatzu were used. Additional local-scale data were obtained from the public domain: Sentinel II satellite data from the Copernicus platform, probabilistic weather forecast data from the ensemble of GFS models, and ERA5 and ERA5-land meteorological reanalysis data. As for availability, the weather station data was uploaded to the project's shared data server, while the other types of data mentioned are in the public domain and can be found at the source. There are IT procedures in place to download the data directly from the source, when needed.

## 3.3.2 Data hub

The ARSINOE project is fundamentally driven by data originating from its various Case Studies. These data are essential for supporting core project activities, including modelling, the development of Digital Twins and specialised tools, and the construction of the project's Knowledge Graph. Recognising the inherent diversity of these datasets in terms of format, schema, and licensing, the project has designed and implemented a central Data Hub. The hub serves a dual purpose: first, it provides a robust platform for Case Studies to store, manage, and make their data accessible; and second, it facilitates the dissemination of the project's findings and data assets to the broader research community and relevant stakeholders. To ensure the discoverability and explorability of this diverse data landscape, a common metadata schema is being applied to each dataset. Complementarily, the development of an interoperable service enables seamless data exchange between disparate repositories through machine-to-machine interaction. Both these aspects are integral to the Data Hub platform, which is designed to promote FAIR data principles – Findability, Accessibility, Interoperability, and Re-usability – in accordance with the Open Data best practices.

## 3.3.3 Knowledge Graph (SustainGraph)

Knowledge graphs (KGs) are gaining prominence as they are considered suitable for addressing the challenges of modern data management practices. The ARSINOE project aims to develop systemic solutions and innovations in nine case studies, which rely on robust data for socio-ecological modelling and analysis. The primary challenge lies in transitioning from a data-centric to a knowledge-centric approach, integrating participatory modelling. The ARSINOE knowledge graph, called SustainGraph, plays a pivotal role in this transformation by structuring diverse data sources into a unified, semantically rich framework, enabling more effective integration and decision-making to advance environmental sustainability and integrated development. SustainGraph integrates case study datasets stored in the Data Hub, along with external data from open repositories into a well-defined representation. Both tools enable interoperability by offering easy access to their data, allowing seamless consumption and analysis.

SustainGraph is a KG centered around the information related to the progress outlined in the Sustainable Development Goals (SDGs) on both national and regional geographical scales. Time-series and spatial data among environmental, economic and cross-sectoral indicators coming from the SDGs, third party sources or the ARSINOE case studies are hosted in SustainGraph. In addition, it integrates semi-structured and unstructured data, i.e. national policy documents and strategic recommendations coming from the European Green Deal or the Country Specific Recommendations linked with the SDGs through machine learning techniques. The different types of data in the SustainGraph are connected with the ARSINOE case studies, where their relevant information regarding the hazards they want to tackle and the innovations coming from the Climate Innovation Window (CIW) is also integrated into the KG. The ARSINOE KG is detailed more in D4.7.

Cross-sectoral indicators from international and European authorities are rigorously pre-processed, harmonised, and ingested into SustainGraph. The KG thus links spatial, temporal and semantic information to support discoverability, interoperability and trustworthy reuse. This unified representation in the SustainGraph provides a single, provenance-aware repository that standardizes formats, enforces metadata and quality metrics, and exposes data through the SustainGraph API so the ARSINOE digital tools can read interoperable. It also enables interdisciplinary scientists to conduct vulnerability assessments, spatial and temporal modelling, predictive and explainable analytics, as detailed in D3.3. Table 9 shows the multiple open authoritative data sources for the different data types hosted in the SustainGraph. In more detail, the structured and semi-structured data primarily consist of spatial and time-series datasets, spanning multiple geographical scales—from granular levels such as cities and functional urban areas to broader aggregates, including countries and regions.

Table 9: Open authoritative data sources for the different data types hosted in the SustainGraph.<sup>2</sup>

| Data Type                               | Data Source | SustainGraph Entity                                                    | Data Type                |
|-----------------------------------------|-------------|------------------------------------------------------------------------|--------------------------|
| <b>Structured</b>                       | World Bank  | Development and Economic Indicators                                    | Tabular/CSV              |
| <b>Structured</b>                       | Hazards     | Tabular                                                                | Tabular/CSV              |
| <b>Structured</b>                       | OECD        | Socio-Economic and Environmental Indicators                            | Tabular/CSV              |
| <b>Structured</b>                       | Eurostat    | SDG Indicators, Socio-Economic, Environmental and political Indicators | Tabular                  |
| <b>Structured</b>                       | Copernicus  | Land Cover and Climate Indicators                                      | Tabular/Raster           |
| <b>Structured</b>                       | EEA         | Air quality Indicators                                                 | Tabular/CSV              |
| <b>Structured</b>                       | GHS         | Demographic Indicators                                                 | Raster                   |
| <b>Structured</b>                       | WGI         | Governance and political Indicators                                    | Tabular/CSV              |
| <b>Structured</b>                       | UNDRR       | Hazards                                                                | Tabular                  |
| <b>Semi-structured</b>                  | UNSD        | SDG Goals, Targets, Indicators, GeoArea                                | OpenAPI, JSON            |
| <b>Semi-Structured and Unstructured</b> | EE          | Country Specific Recommendations and European Green Deal Documents     | Semi Structured Text/PDF |
| <b>Semi-Structured</b>                  | CIW         | Innovations                                                            | API                      |
| <b>Semi-Structured</b>                  | ARSINOE     | Case Studies                                                           | Semi-structured          |

### 3.4 Findings related to Resilience assessment (WP3/WP6)

The ARSINOE Dynamic Multi-Sectoral Resilience Modelling and Assessment Framework (DMRM&AF), also referred to as the ARSINOE Wheel, provided a framework for the implementation of the ARSINOE framework by the nine ARSINOE case studies. The modelling artefacts that are implemented are mostly computational (simulation) models used for resilience assessment, although the modelling methods could be extended as well. The ARSINOE framework consisted of five tiers, namely, Tier-1 SSP scenarios, Tier-2 climate and socio-economic projections, Tier-3 environmental and biophysical systems, Tier-4 human and operational systems model, and Tier-5 strategic decision-making models.

During the co-development of the ARSINOE framework, it was agreed that modelling methods under Tiers 3-5 were extendable, and new resilience assessment methods, including those that were not computer simulations, could be incorporated into the overarching framework to cater for the specific requirements of the case studies. For example, the Willingness to Pay (WtP) model implemented by CS#1 Athens Case Study in Tier-5 (refer to D6.7). The objective of the model was to assess WtP and it integrated

<sup>2</sup> UNSD: United Nations Statistics Division, UNDP: United Nations Development Programme, OECD: Organisation for Economic Co-operation and Development, EEA: European Environment Agency, UNDRR: United Nations Office for Disaster Risk Management, GHS: Global Human Settlement, WGI: Worldwide Governance Indicators, QoG: Quality of Government

immersive VR choice experiments with behavioural economics and environmental valuation methodologies. Similarly, CS#2 Mediterranean Ports Case Study developed the hybrid financial reporting model for Tier-4 (refer to D6.7) that was built on the methodology of the UN SDGs and used material assessments to identify key sustainable issues. These models demonstrate the extensibility of the ARSINOE framework, and which, through its design as an extensible framework of modelling methods, circumvented some of the case-study specific challenges pertaining to resilience assessment by allowing new methods in existing tiers.

A particular challenge was faced by case studies that required multiple simulation models to be soft-linked for resilience assessment experiments. In soft-linking, the output from one model is used as input for a subsequent model. For example, in CS#8 (Torbay Case Study), the CAFlood Model in Tier-3 (refer to D6. to D6.7) provided data for several other models in Tier-4, for example, the Resource Allocation Model, the Cascading Failure Model, the Traffic Model, etc. Yet another example is the hybrid Heat Event Response Model in Tier-4 of the CS#1 Athens Case Study (refer to D6.7) and which needed data from several other models, including Tier-3 air quality and urban heat island models.

### 3.5 Findings related to Innovations-open calls (WP5)

The Open Tender for Innovations (OTI) mechanism under WP5 represented a novel approach to bringing external innovators into ARSINOE case studies and directly testing solutions in real-world contexts. It was designed to bridge the gap between problem owners (cities, regions, utilities) and solution providers (SMEs, start-ups, research spin-offs), while complementing the project's Living Labs. The implementation of the OTIs revealed several important findings.

#### **Procurement as a major challenge**

The procurement of innovation contracts under Horizon Europe proved more complex than anticipated. For the first OTI, several case studies experienced delays due to double-tendering requirements and alignment issues between Horizon Europe eligibility rules and internal institutional procedures. To address this, preparations for the second OTI began much earlier, with support from BRIGAD Connect (BRC) and bilateral consultations involving case study partners, legal departments, and finance units. Adjustments were introduced, in some cases such as lowering the ceiling of individual contracts, which made the procurement feasible and aligned with internal rules, which varied strongly between ARSINOE partner institutions.

#### **Strong market interest and participation**

The OTIs generated very high interest from the innovation community. More than 100 applications were received across the two calls, with consistently strong quality proposals. Each information session attracted 60–70 participants, demonstrating active engagement and demand. Innovators valued the opportunity to test and validate solutions with real problem owners, while case studies benefitted from a broad pool of candidates, including many from outside their national context.

#### **Added value of Living Labs and case study co-definition**

The Living Labs (LLs) played a crucial role in shaping the OTIs by identifying the specific challenges and needs of the case studies. This ensured that the selected innovations responded directly to locally defined priorities and adaptation pathways. The close involvement of case study partners in the evaluation and selection processes helped create ownership and facilitated smoother integration of the solutions.

#### **Role of support and communication**

Continuous support during the entire OTI process proved essential. WP5, in collaboration with WP8, provided guidance on eligibility, contracting, and reporting, as well as communication with applicants. During implementation, innovators and case studies received assistance in monitoring progress and

reporting impacts. This support helped overcome capacity gaps at local level and reduced risks for both innovators and problem owners.

### **Trust, visibility, and long-term references for innovators**

For innovators, participation in ARSINOE's OTIs provided both validation and reference value. Implemented solutions were labelled as "*Tested in ARSINOE*" within the Climate Innovation Window (CIW), while all received applications were published with the tag "*ARSINOE Network*". This increased visibility and credibility for innovators, giving them a trusted reference for scaling to other regions and projects. Such trust-building mechanisms are crucial to support innovators in entering risk-averse markets such as municipalities.

### **Satisfaction of case studies and replication potential**

Feedback collected through interviews and workshops confirmed high satisfaction with the selected solutions. In several cases, case study partners reported that the implemented innovations exceeded expectations and expressed interest in future collaborations with the innovators. Some innovators were subsequently invited to join new Horizon Europe projects as full partners. The cross-border nature of the OTIs—where case studies selected innovators from other countries—was especially valuable, helping both sides to overcome local barriers and opening pathways for replication in other regions.

## **3.6 Findings related to Financing portfolios and financial instruments (related to GDPs)**

### **3.6.1 CS#1 – Athens Metropolitan Area**

Athens faces acute challenges in mobilising climate finance for water reuse, green infrastructure, and urban resilience. Stakeholders highlighted governance fragmentation, insufficient municipal capacity to prepare bankable projects, and the need for more diverse financing instruments. D7.5 stressed the importance of blended finance models combining public subsidies with private capital, while D7.2 underlined technical assistance and capacity building as preconditions for access to funds.

- Financing gaps remain large for non-revenue generating adaptation measures (e.g., water reuse, NBS).
- EU cohesion funds and national recovery funds identified as primary public finance sources.
- Private capital engagement is possible through PPPs for infrastructure upgrades.
- Green bonds are earmarked as long-term financing opportunities for large-scale projects.
- Blended finance suggested to de-risk private investments.
- Barriers include fragmented governance and lack standardised assessment tools.
- Capacity building and pipeline development needed for municipalities.
- Proposal to integrate ESG and SDG metrics in project design to increase investor confidence.

### **3.6.2 CS#2 – Mediterranean Ports**

Mediterranean ports require financing to strengthen maritime infrastructure, decarbonize operations, and scale blue carbon initiatives. Workshops revealed limited cross-port coordination and insufficient investment platforms. D7.5 emphasised PPPs and blended finance, while D7.2 pointed to technical assistance and innovation grants as enablers.

- Ports need financing for climate-proof infrastructure and digital upgrades.
- EU Connecting Europe Facility (CEF) and Horizon Europe are seen as major sources.
- Potential revenue from green shipping levies and port fees earmarked for adaptation.
- PPPs highlighted as key vehicles for leveraging private equity in long-term projects.
- Innovation grants suitable for pilot NBS and decarbonization projects.

- Barriers include a lack of coordinated cross-port investment platforms.
- Joint development schemes suggested for multi-country projects.
- Stronger ESG integration is needed to attract institutional investors to maritime adaptation.

### 3.6.3 CS#3 – Main River Basin

The Main River Basin demonstrates advanced governance but struggles with mobilising sufficient private capital for climate adaptation. Key financing needs include flood protection, water-energy nexus measures, and ecological restoration. D7.2 underscored the importance of multi-stakeholder coordination, while D7.5 identified insurance pools and municipal bonds as promising instruments.

- High reliance on public budgets for infrastructure, leading to competition with other priorities.
- Municipal green bonds identified as scalable, bankable solutions.
- Flood risk insurance pools are seen as vital for managing disaster risk.
- EU LIFE and cohesion funds remain key public sources.
- PPPs encouraged integrating innovative technologies into flood defences.
- Barriers: limited municipal fiscal space, risk aversion in private sector.
- Hybrid financial reporting could enhance transparency and accountability.
- Opportunities to mobilize institutional investors via ESG-linked instruments.

### 3.6.4 CS#4 – Ohrid & Prespa Lakes

This transboundary case emphasizes biodiversity protection, sustainable tourism, and water governance. Financing challenges are acute, with weak local fiscal capacity and fragmented governance across borders. D7.2 highlighted barriers to accessing finance due to poor creditworthiness, while D7.5 recommended debt-for-nature swaps, PES, and international climate funds as realistic pathways.

- High reliance on international donors and NGOs to finance conservation.
- Debt-for-nature swaps proposed as innovative instruments.
- PES schemes suggested to reward local communities for stewardship.
- EU IPA funds and Green Climate Fund identified as major external sources.
- Barriers: weak creditworthiness of municipalities and cross-border coordination challenges.
- Capacity building is essential to produce bankable ecotourism and biodiversity projects.
- Blended finance platforms could pool resources from governments and NGOs.
- Governance improvements necessary to meet eligibility criteria for international finance.

### 3.6.5 CS#5 – Canary Islands, Spain

The Canary Islands depend on fragile aquifers, agriculture, and fisheries, requiring sustainable water and resource management. Financing pathways emphasize EU funds and local revenue mobilization, while barriers include dependency on central transfers and revenue volatility due to tourism cycles. D7.5 proposed collaborative investment platforms and service fees, while D7.2 stressed the need for microfinance and grants to empower local stakeholders.

- EU cohesion and recovery funds are seen as primary public sources.
- Tourism-related environmental fees recommended to finance NBS.
- Microfinance targeted at smallholders and fishers for climate-smart practices.
- Innovation grants could accelerate uptake of water-saving technologies.
- Barriers: dependency on central funding and revenue seasonality.
- Collaborative investment platforms suggested pooling resources across sectors.
- PES schemes could reward sustainable land and water management.

- Insurance products proposed to address aquifer over-extraction risks.

### 3.6.6 CS#6 – Black Sea Region

The Black Sea case requires cross-border financing for watershed management and marine ecosystem protection. Political fragmentation and weak coordination limit access to international funds. D7.2 highlighted the need for regional platforms, while D7.5 stressed the importance of leveraging multilateral climate funds and cooperative PPPs.

- GEF, Green Climate Fund, and EU neighbourhood instruments flagged as critical.
- Regional PPPs recommended for watershed and coastal projects.
- Cooperative investment platforms are needed to bridge institutional fragmentation.
- Barriers: geopolitical risks and lack of trust between national authorities.
- Technical assistance for cross-border project preparation required.
- PES schemes could incentivize sustainable land use in upstream areas.
- Insurance pools suggested for fisheries and aquaculture resilience.
- Transparent monitoring frameworks are vital to unlock donor trust.

### 3.6.7 CS#7 – Southern Denmark

Southern Denmark faces multi-hazard flood risks and is challenged by regulation and a division of responsibility with respect to water management. Adaptation actions are anchored at the local (municipal) level, which restricts the financial capacity for implementation of adaptation solutions. The government is rarely engaged in local adaptation decisions and financing, except through the Coastal Protection Pool, which is managed by the Danish Coastal Authority. This pool is renewed more or less year-to-year and can only provide limited support to a few Danish coastal municipalities every year. Key needs include improved uptake of cost-effective and NBS for flood protection while safeguarding cultural and natural heritage. D7.2 noted barriers around aligning private incentives with public goods.

- Municipal green bonds suitable for flood defence projects.
- Insurance schemes to manage residual flood risks.
- PPPs could support large-scale NBS along coastal zones.
- Betterment charges are proposed to capture value from protected properties.
- Barriers: aligning long-term resilience with short-term incentives.
- Potential for replicating governance models across other EU coastal regions.
- Realistic schemes for consideration of a managed retreat from highly flood-prone areas are missing.

### 3.6.8 CS#8 – Torbay and Devon County

Torbay faces high climate vulnerability from coastal and inland flooding, with significant risks to infrastructure. Financing challenges are amplified by local fiscal constraints and post-Brexit uncertainty. D7.2 recommended blended finance with guarantees, while D7.5 emphasised green bonds, catastrophe insurance, and community-based mechanisms.

- UK green bonds are seen as critical for financing large flood protection projects.
- Catastrophe bonds and insurance schemes suitable for risk pooling.
- Local councils constrained by limited borrowing capacity.
- Crowdfunding and local lotteries considered for smaller community projects.
- Barriers: fiscal austerity and uncertainty over access to EU funding.
- Blended finance solutions with national guarantees recommended.
- Community-based PES could fund small-scale NBS interventions.

- Institutional investors are likely to require government-backed guarantees.

### 3.6.9 CS#9 – Southern Sardinia

Sardinia's adaptation priorities focus on agriculture, soil conservation, and circular economy initiatives. Financing gaps are significant due to fragmented smallholder structures and limited access to credit. D7.2 emphasised cooperative models and guarantees, while D7.5 recommended CAP funds, venture capital, and PES.

- CAP and EU cohesion funds identified as major public finance sources.
- Venture capital opportunities for Agri-Tech and bio-based fertilizers.
- PES schemes could reward sustainable agricultural practices.
- Barriers: smallholder fragmentation and weak access to bank credit.
- Cooperative financing models (farmer associations) recommended.
- Guarantees and risk-sharing instruments proposed to lower borrowing costs.
- Innovation grants could scale climate-smart agriculture.
- Hybrid reporting frameworks to demonstrate environmental co-benefits to investors.

## 3.7 Findings related to policies

The following experiences from the case studies with local, regional, national and European policies affected the implementation or are expected to affect implementation of the solutions and innovations in ARSINOE and scaling-up beyond ARSINOE. As can be seen from this overview, depending on the case study and the sectors and hazards targeted by the climate resilience measures, but productive and counter-productive effects of the existing policy landscape were observed.

Table 10: Local, regional, national and European policies affecting implementation of climate resilience measures demonstrated and implemented in ARSINOE (green – positive/supportive, yellow – negative/counteracting, grey – contradictory).

| Experience                                                                                                                                                                                                                                                                                                                                                       | Affected CS                                                             | Impact |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|--------|
| <b>National climate laws</b> , e.g. the <b>National Climate Law (4396/2022) in Greece</b> , set the national framework for climate adaptation and mitigation and are supported by Regional Plans for Adaptation (13, one per Region in Greece). Their implementation is facilitated by the LIFE-IP AdaptInGR project (2019-2026).                                | 1                                                                       |        |
| <b>Complete sets of relevant policies are in force (transboundary)</b> , in all the involved countries. They have been harmonised with the relevant EU Directives in the fields of water and environment. There are also good transboundary communication procedures established as well as exchange of information and data among state institutions in charge. | 4<br>(transboundary case study with member and candidate member states) |        |
| <b>Financial support for rural development</b> for example through the <b>EU the European Agricultural Fund for Rural Development (EAFRD)</b> provides access to financing, locally implemented through the RDC (Rural Development Complement).                                                                                                                  | 9                                                                       |        |
| <b>Fragmented and sometimes conflicting policy instruments</b> that do not account for WEFE (Water-Energy-Food-Ecosystems) interdependencies.                                                                                                                                                                                                                    | 5                                                                       |        |

| Experience                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Affected CS | Impact |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|--------|
| <p><b>A lack of cross-sectoral and long-term planning, and insufficient enforcement mechanisms</b> delay climate adaptation and compliance.</p> <p>A suitable policy to support climate adaptation suggested comprises of early adoption of <b>climate adaptation action plans</b> and <b>climate observatories, backed by mandatory standards and compliance measures</b> under the EU Climate Adaptation Strategy (2021), TEN-T Regulation for resilient transport, and European Climate Law (Regulation (EU) 2021/1119).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 2, 5        |        |
| <p>For Mediterranean Ports, the policy pathways are structured around progressive milestones that chart the transition toward resilience and sustainability. By <b>2030</b>, ports are expected to achieve crucial infrastructure upgrades, ensure 80% of the logistics chain is climate-resilient, extend cruise facilities, cut emissions by 30%, and generate 50% of their energy demand from renewable sources. By <b>2040</b>, the ambition rises to full climate resilience across logistics, a 50% emissions reduction, full reliance on renewable energy, and the implementation of marine waste recycling and circular economy practices. By <b>2050</b>, ports are envisioned as fully adapted and net-zero, achieving complete energy self-sufficiency, leveraging private capital effectively, and mainstreaming tested climate adaptation strategies. To reach these milestones, targeted policies and governance interventions are introduced: early <b>infrastructure action plans</b> and <b>improved port authority coordination</b> underpin the 2030 goals; adoption of <b>ISO emission standards</b> (using ISO 14064 and calculate carbon footprints to reduce emissions by 30%), <b>Fit-for-55</b> integration, and incentives for renewable bunkering infrastructure support the 2040 trajectory; and <b>innovative finance instruments</b> (green/adaptation bonds, PPPs, tax incentives) combined with capacity building, mandatory standards, and vocational training ensure the 2050 vision of resilient, sustainable, and decarbonised ports.</p> | 2           |        |
| <p><b>Political inaction hindering climate resilience:</b> While ARSINOE was ongoing the German federal government coalition (2021-2025) had set out to regulate the financing of climate adaptation after passing a national law on climate adaptation and reworking the national strategy on climate resilience. Similarly, the Bavarian government announced in 2021 that it would introduce a water extraction fee for some water users and reinvest the revenue in water security. These ongoing debates on potential policies impacted the discussions of financing the implementation of climate resilience in the Main River basin. Because political decision-making continued for most of the project's duration, local and regional stakeholders were hesitant to spend their own funds as they were waiting for new funding mechanisms to be created. Lack of clarity and political guidelines delayed spending related to climate resilience significantly. Debates about reforming the European Green Deal or adjusting national</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 3           |        |

| Experience                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Affected CS | Impact |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|--------|
| and regional climate targets and placing less importance on climate targets and sustainability had similar effects.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |             |        |
| <b>European definition of SMEs as set out in Commission Recommendation 2003/361/EC28 exclude relevant organisation from funding:</b> In order to make funds distributed through the OTI accessible to stakeholders that are crucial for climate resilience, the European definition of SMEs as set out in Commission Recommendation 2003/361/EC28 has to be reconsidered. By referencing the European definition of SMEs local public utilities, which are crucial for building climate resilience, were excluded from benefitting from the OTI. This is because of Article 3 (4) of the Annex, which states that “an enterprise cannot be considered an SME if 25 % or more of the capital or voting rights are directly or indirectly controlled, jointly or individually, by one or more public bodies”. This excludes local public utilities from the SME status, regardless of their size in terms of turnover, balance sheet total or staff headcount. ARSINOE managed to avoid excluding crucial stakeholders from the OTI by referencing the European definition of SMEs as set out in Commission Recommendation 2003/361/EC28 but explicitly excluding Article 3 (4) of the Annex. Other innovation actions including open tenders for innovation could also follow this practice to ensure that all types of SMEs can access the funding option offered by open tenders. | 3           |        |
| <p><b>The lack of harmonization in data and methodologies</b> between stakeholders, in particular between different countries, hinder data sharing. This was further affected by licenses on certain datasets, restricting the conditions allowed for the research.</p> <p>This was observed, even where <b>a framework for standardisation exists</b>. For example, the EU Water Framework Directive (2000/60) provides a standard, to which methodologies can be harmonised.</p> <p>A policy to encourage data sharing and standardised protocols that eliminates the barriers for accessing data and streamlines the data integration process would be welcomed. It would help wider adoptions of the proposed ARSINOE framework to support authorities at different levels review the existing capacities, understand potential hazards and risks, and develop strategies and interventions for strengthening climate resilience.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                          | 4, 8        |        |
| <b>Gaps in national regulations related</b> to monitoring of efficient and rational use and permissions for withdrawal of water from individual aquifers. The gap can be bridged by improving / amending the related regulations for granting water use permissions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 4           |        |
| In transboundary cases <b>differences in institutional organisation, regulations and governance in the countries</b> were observed. Also, there is a lack of awareness of their roles and responsibilities in improving sustainable water management.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 4           |        |

| Experience                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Affected CS | Impact |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|--------|
| <b>Existing committee and NGOs were helpful in bringing stakeholders</b> (from different countries) <b>together</b> and identifying innovations, as they had already established contacts and worked on issues of water management. Examples include the Transboundary Prespa Park Committee.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 4           |        |
| <b>EU certification for regional products</b> involves applying for protection under one of three schemes: Protected Designation of Origin (PDO), Protected Geographical Indication (PGI), and Traditional Speciality Guaranteed (TSG), which protect against imitation and misuse. To gain protection, producers must submit a product specification detailing the product's origin, production method, and geographical link to the European Commission, a process that can take 2-3 years. Successful applicants will have their products listed in the eAmbrosia register and can use the official EU symbols on their packaging to signal authenticity to consumers.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 9           |        |
| The current structure of <b>River Basin Management Plans</b> (RBMPs) and related monitoring procedures is largely based on manual sampling and laboratory analysis. <b>Autonomous systems</b> such as ENOVA H2O, while offering real-time data and new insights, <b>are not yet explicitly integrated into regulatory monitoring frameworks</b> . This may limit direct application of such data in formal assessments but opens opportunities for future alignment through pilot integration and regulatory updates.<br><br>For example, creation of innovation zones where regulatory requirements are adapted to accelerate environmental technology testing should be considered. Early discussions suggest this concept could be incorporated into the upcoming EU <b>Marine Strategy Framework Directive revision</b> .                                                                                                                                                                                                                                                                                                                                             | 6           |        |
| National, Transboundary and EU level nature, ecosystem, climate and biodiversity legislation supports implementation of climate resilience measures. Examples in the context of ARSINOE: The <b>Black Sea Basin Strategy 2025</b> incorporated SMS-derived data as an official input for environmental status assessments. This policy creates a sustained demand for the monitoring platform and its data beyond the project timeframe.<br><br><b>The EU level Nature Restoration Law</b> (adopted in 2024 –2025), stipulates quantitative and ecosystem – specific targets, also for urban ecosystems requiring increasing trends in urban green areas/tree canopy and a ‘no net-loss’ requirement (by 2030).<br><br>This supported work in ARSINOE in CS#1 as follows: <ul style="list-style-type: none"> <li>- Addressing urban heat, public health, nature-based –solution, all being priority areas targeted by the National and Regional Adaptation Plans</li> <li>- Highlighting the importance of urban ecosystems and the impact of green areas in climate change adaptation, also in quantitative in terms, in line with the Nature Restoration Law</li> </ul> | 1, 6        |        |

| Experience                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Affected CS    | Impact |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|--------|
| <ul style="list-style-type: none"> <li>- Providing data to facilitate the identification of most vulnerable areas, and measures for addressing the challenges relevant to extreme heat, in line with the National Climate Las and the derived regional plans</li> <li>- Contributed to resilience, heat and social equity, being national adaptation goals, validating that heat and urban density affect vulnerable populations disproportionately, identifying the relevant urban areas and stimulating solutions.</li> <li>- Worked on Governance Capacity through a relevant Governance analysis conducted and several workshops with the City's staff</li> </ul>                                                 |                |        |
| ARSINOE findings suggest that One Health should be formally embedded in <b>climate adaptation and resilience planning</b> . EU and national strategies currently focus narrowly on zoonoses, but ARSINOE shows the need to expand scope to include urban health (heat, air quality), water security, and biodiversity services. Policymakers should adopt integrated governance models that connect ministries of health, environment, and urban planning, ensuring shared indicators and co-benefits.                                                                                                                                                                                                                | 1, 3, 4, 7, 8, |        |
| <p>In 2025 Athens became part of the <b>EU Mission Cities</b> with the endorsement of the <b>Climate City Contract (CCC)</b>. The CCC functions as a quasi-binding framework that aligns city-level actions with EU and national funding and policy rules. Through ARSINOE, the city is facilitated in the heat-adaptation domain for the identification of action areas for greening, cooling, enabling access to EU and national funding.</p> <p>The CCC builds upon the <b>CAP (Climate Action Plan) of Athens</b>, accelerating its implementation for climate neutrality by 2030. The CAP is the city's detailed roadmap of sectoral policies and actions for both climate change mitigation and adaptation.</p> | 1              |        |
| Limited integration of emission monitoring and management in port operations risks failure to meet EU climate targets. The <b>adoption of ISO 14064 carbon accounting and alignment with the EU Fit-for-55 package</b> , including ETS extension to maritime transport and supporting measures under the European Green Deal, would support meeting climate targets.                                                                                                                                                                                                                                                                                                                                                  | 2              |        |
| Insufficient infrastructure for renewable bunkering, energy transition, and circular economy in port operations creates dependency on fossil fuels. The <b>Alternative Fuels Infrastructure Regulation (AFIR), Renewable Energy Directive (RED III), and Circular Economy Action Plan</b> should be used to guide and accelerate the deployment of renewable energy and bunkering infrastructure.                                                                                                                                                                                                                                                                                                                     | 2              |        |
| Fragmented financial models and limited workforce capacity restrict adaptation investments and digital transition. Mobilisation of <b>blended finance (green/adaptation bonds, PPPs, InvestEU, CEF)</b> combined with capacity building and vocational training under the <b>EU Skills Agenda and ESF+</b> are required to mobilise the necessary investments for climate resilience adaptation.                                                                                                                                                                                                                                                                                                                      | 2              |        |

### 3.8 Lessons learned from case studies on governance gaps

The results of our analysis on governance barriers and possible enablers and levers across the nine case studies of ARSINOE suggest that governance frameworks for climate adaptation remain in an evolving phase. Several areas require further development to support coordinated and thus more effective responses. This is particularly the case around water management, institutional coordination, and the implementation of cross-sectoral strategies. These insights point to areas where efforts could be reinforced, while also reflecting promising practices already emerging at the local level.

#### **Administrative and institutional constraints**

Across multiple case studies, stakeholders have underlined how bureaucratic complexity and administrative procedures can act as a barrier to action. Project initiation and implementation are often slowed down by rigid requirements or lengthy approval processes, which reduce flexibility and responsiveness. These procedural constraints, though not unique to climate adaptation, can limit the capacity of local actors to experiment or respond to urgent challenges.

In parallel, a lack of human and technical capacity at local level, especially within environmental services, makes it difficult to give sufficient weight to adaptation priorities. Even where climate strategies exist, they are not always accompanied by the resources or mechanisms required for effective implementation.

#### **Data monitoring gaps**

Reliable data remains a critical enabler of effective governance. However, several stakeholders pointed to limited monitoring of key environmental indicators, particularly concerning water withdrawals during drought periods. The absence of systematic data collection hinders both the assessment of current pressures and the design of appropriate adaptation measures. While some regions use hydrological balances to evaluate usage, a more consistent and transparent monitoring framework would be beneficial.

#### **Perception of climate risks**

Drought is systematically identified as a major risk, but its long-term implications under climate change scenarios are often underestimated, particularly in relation to water availability and its impact on socio-economic development. The disconnect between perceived and actual risk may delay necessary investment in adaptation or limit political momentum for change.

#### **Legal and infrastructure gaps for emerging solutions**

Water reuse is increasingly seen as a viable solution to tackle growing pressure on water resources, especially in the context of hydrometeorological extremes. However, the development of reuse systems often depends on updates to national and European legislation, as well as on investments in new infrastructure. The governance framework for enabling such innovations is not yet fully in place in many ARSINOE case studies.

#### **Limited cross-sectoral governance**

While the urgency of climate change and the energy transition have pushed action in certain areas, integrated approaches linking water, energy, and food systems remain underdeveloped. Adaptation efforts often remain within sectoral silos, which limits the identification of co-benefits and may result in competing and not coherent priorities.

### Emerging local initiatives and the need for knowledge transfer

Encouragingly, many pilot projects and locally driven initiatives are emerging. These benefit from growing collaborative networks of stakeholders, bridging public and private actors and fostering innovation. However, the capitalisation and dissemination of these experiences—both successful and unsuccessful—remains a gap. Without mechanisms for learning across territories, valuable insights risk being lost or repeated in isolation.

To conclude, while adaptation strategies are gaining ground, their effective implementation still faces structural and institutional barriers. Strengthening governance frameworks—through coordination, capacity building, and policy integration—will be essential to ensure that promising initiatives can scale and endure in the face of a changing climate.

## 3.9 Findings related to communication / dissemination / exploitation

Throughout the ARSINOE project, to implement the communication and dissemination (C&D) activities, WP8 partners faced several challenges stemming from the complexity and scale of the consortium, the nature of the content to be communicated, and overlapping responsibilities across tasks. WP8 partners faced the following challenges and implemented the following mitigation measures: **Communicating complex and scientific concepts to a broader audience**

Many aspects of the project involved technical and scientific content, which posed challenges in making the material accessible and engaging for non-expert audiences.

Mitigation measures:

- We created a series of factsheets that translated complex scientific concepts into plain language, using a story telling approach to enhance relatability and understanding.
- Visual tools such as explainer videos were produced to complement the factsheets, providing accessible, engaging formats to communicate project goals, methodologies, and impacts.

### Diversity and fragmented ownership of results

The project generated a wide spectrum of exploitable results, ranging from high-TRL commercial products to low-TRL scientific tools and policy frameworks. This heterogeneity complicated the definition of uniform pathways and responsibilities. Some results were jointly developed by multiple partners, creating fragmented ownership and unclear exploitation responsibilities.

*Mitigation:* WP8 established a unified profiling methodology (D8.15), clustering results into commercial, scientific, and policy innovations. Exploitable result profiles were co-developed with owners, while responsibilities and IPR were clarified through targeted questionnaires and deadlines.

### Uneven exploitation capacity across partners

While SMEs and applied research actors often had a clear vision for commercial pathways, academic teams tended to frame their outputs mainly as scientific contributions, underestimating potential for market uptake. Many struggled with formulating value propositions, building business models, or identifying customers beyond scientific and policy circles.

*Mitigation:* WP8 organised dedicated exploitation workshops (D8.9), bilateral coaching sessions, and one-to-one validation meetings. For high-TRL innovations, business models and value proposition canvases were developed jointly with owners, providing templates and step-by-step support.

### Barriers to market access and uptake

Several recurring challenges were identified across innovations:

- Limited access to end-users, especially municipalities, unless they were already engaged in case studies.
- Perceived financial barriers, despite the existence of EU/national programmes (Horizon Europe, CAP, EMFAF, regional OPs). What was missing was the capacity to leverage these opportunities strategically.
- Regulatory and certification hurdles, particularly for agricultural and environmental products.
- Trust and awareness gaps, with innovators underestimating the effort needed for campaigns, demonstrations, and stakeholder dialogues.

*Mitigation:* External exploitation workshops brought together innovators with cities, utilities, and SMEs. These events helped reframe “lack of funds” as a challenge of awareness, trust, and alliances. WP8 also documented customer-journey insights to guide CIW services (matchmaking, funding watch).

### **Awareness, trust-building, and communication**

Many innovations had potential applications for wider user groups (SMEs, farmers, schools, communities), yet developers did not always recognise the importance of awareness campaigns and trust-building. Workshops and external events showed that adoption requires not only technical readiness but also legitimacy, visibility, and narratives that connect with non-technical audiences.

*Mitigation:* The Climate Innovation Window (CIW) was relaunched with a dedicated awareness and promotion plan by BRIGAD Connect, including newsletters, social media campaigns, and showcasing innovators at EU-level events. WP8 also promoted cross-project clustering to amplify messages.

### **Support structures and tools for exploitation**

WP8 provided a structured methodology, including exploitable result profiles, value proposition canvases, business models, and preliminary market entry strategies. The CIW was relaunched as a marketplace, complemented by the ENRICH Global e-CoP to sustain brokerage and knowledge exchange. These structures helped clarify pathways, though medium-TRL innovations still need post-project support to reach full market readiness.

*Mitigation:* Exploitation tools were standardised and made available to all partners, ensuring transparency and comparability. Tailored support was prioritised for high-TRL innovations to reach short-term market entry, while lower-TRL solutions were guided towards scientific or policy exploitation.

### **Scalability and replication potential**

Despite barriers, most innovations demonstrated significant potential for replication thanks to modular designs, policy alignment (EU Missions, Green Deal, CAP eco-schemes), and adaptability to different geographies. The key enabler was meaningful involvement of local actors, while the main constraint remained weak institutional anchoring in cases without municipal or regional partners.

*Mitigation:* Replication was linked with WP5 activities, ensuring alignment with replication pathways and sister projects. CIW and e-CoP provided a platform to showcase solutions for wider uptake beyond case studies.

## 4. LESSONS LEARNED

The outcomes from the case studies lead to various lessons learned. These can be summarised on various levels. This chapter provides a short synthesis of these lessons learned, focussing first on overarching lessons learned from the horizontal work packages. This is then followed by an overview of lessons learned as provided by the CS in different categories, such as climate hazards, economic sectors, scales etc.

### 4.1 Synthesis of the lessons by the horizontal work packages

#### 4.1.1 Data management and open-source software

Various challenges are identified for data management. A major challenge regards the lack of qualitative datasets that are consistently produced based on a standardised methodology that can be applicable in different geographical scales. A plethora of data exists, however provided ad-hoc by different data providers and in many cases lacking a reporting consistency, both in terms of structure and frequency. This is mostly evident when moving from a national scale to regional, city and neighbourhood level. Furthermore, data is mostly provided as data silos without a semantic alignment of the represented terms and concepts, hindering their interlinkage and interoperability. In ARSINOE, lot of effort is allocated towards the development of tools to provide consistent data collection mechanisms in the Data Hub and the SustainGraph, semantic alignment of data in the SustainGraph and standardised interfaces to support interoperability with socio-ecological models and analysis processes. This has led to the development of a set of services for the case studies, made available through the Dashboard and the Visualization Kit and operating based on qualitative data.

Another challenge regards the openness of both data and software. Various data analysis services are developed across research projects and initiatives, however, lacking openness and clarity in terms of the applied methodologies and the developed software. This introduces a barrier for their adoption, extension and usage in comparative studies. In ARSINOE we have followed an open-source strategy for the development of the knowledge management framework, building an infrastructure that can be more easily maintained and extended in the future. For instance, technological trends related to Generative AI and Large Language Models (LLMs) can be exploited and used to develop tools to assist the adoption, usage and explainability of the provided mechanisms. Regarding the ARSINOE tools, they are made available as open source, enabling their extensibility and replicability in the future.

#### 4.1.2 Open Tender for Innovations

The OTI mechanism within ARSINOE has proven to be an effective but demanding instrument for connecting problem owners with external solution providers. Several lessons can be drawn from its design and implementation:

##### 1. Procurement must be anticipated and streamlined

Innovation procurement under Horizon Europe requires alignment with institutional rules, which can be slow and complex. The first OTI demonstrated that starting preparations too late created delays. By contrast, for the second OTI, early bilateral work with legal and financial departments simplified processes, adjusted contract sizes, and avoided bottlenecks. Future projects should involve contracting units from the outset and develop standardised templates or framework agreements to accelerate procurement.

##### 2. Direct contracting as a systemic enabler

A crucial feature of the ARSINOE OTI scheme was that contracts were signed directly between innovators and the contracting institutions (e.g. municipalities, universities, research centres), rather than a single

project partner acting as intermediary. This was essential to overcome procurement bottlenecks, as it provided institutions with practical experience in working with innovators, exposed gaps in their internal procurement policies, and stimulated organisational learning. Such direct schemes can act as catalysts for longer-term changes in how cities, councils, and universities engage with climate innovation.

### **3. Continuous support is essential for both sides**

Cities and regional partners often lack experience in contracting and managing innovation pilots, while innovators may not be familiar with Horizon Europe requirements. Dedicated guidance, templates, and regular communication proved crucial to keeping all parties engaged and compliant. Future initiatives should allocate sufficient resources for a facilitation role—supporting innovators and case studies throughout selection, contracting, implementation, and reporting.

### **4. Living Labs are key enablers of relevance and legitimacy**

The co-definition of challenges through Living Labs ensured that OTIs targeted real adaptation needs and built legitimacy for the selected solutions. This participatory framing increased buy-in from local actors and raised the likelihood of adoption. Embedding OTIs in Living Lab structures is therefore essential for bridging innovation and local demand.

### **5. Validation and visibility matter as much as funding**

While the grants provided financial support, innovators consistently highlighted that the main added value was validation, references, and visibility. Being showcased on the Climate Innovation Window (with tags such as “*ARSINOE Network*” and “*Tested in ARSINOE*”) helped innovators build trust with other municipalities and funders. This underlines the importance of coupling financial support with visibility, branding, and brokerage services.

### **6. Cross-border collaborations strengthen scalability**

Several case studies selected innovators from other countries, which benefitted both sides: problem owners gained access to solutions unavailable locally, while innovators tested their products in new contexts. This approach supports replication and scale-up but requires strong facilitation to overcome language, regulatory, and cultural barriers.

### **7. High demand shows untapped potential**

The very high number of strong applications (over 100) and active participation in information sessions confirmed that there is a large pool of climate innovators seeking opportunities to test solutions. Open calls such as OTIs respond to a real market need by providing safe entry points and trusted partnerships. Future projects should build on this momentum by scaling up the mechanism, increasing grant sizes, and linking selected innovators to further investment opportunities.

## **4.1.3 Financial instruments**

**1. Importance of blended finance:** Across all case studies, combining public, private, and voluntary funds was essential to overcome barriers, especially in regions with limited fiscal space (e.g., CS#4 Ohrid/Prespa, CS#9 Sardinia).

**2. Capacity and governance matter more than instruments:** Access to finance was often blocked not by a lack of instruments, but by local capacity to design bankable projects and fragmented governance (e.g., CS#1 Athens, CS#6 Black Sea).

**3. Tailored instruments by sector and geography:** Each CS required context-specific mixes — ports relied on PPPs and green bonds (CS#2, CS#7), river basins on insurance pools (CS#3), and islands on microfinance/tourism fees (CS#5).

**4. Trust-building in cross-border contexts:** Transboundary cases (CS#4, CS#6) showed that political fragmentation and weak trust are major barriers; cooperative investment platforms and transparent monitoring frameworks are prerequisites before finance flows.

#### 4.1.4 Communication and Dissemination

The exploitation activities in ARSINOE provided valuable insights into both the opportunities and the challenges of transforming research-driven outputs into widely adopted climate adaptation solutions. Several lessons stand out:

##### 1. Advancing TRL and SRL through real-world testing

A major achievement of ARSINOE was its contribution to advancing the Technical and Social Readiness Levels of many innovations. High-TRL solutions were further validated through pilots in case studies, while lower-TRL concepts benefited from visibility and stakeholder feedback. This process not only demonstrated technical feasibility but also strengthened societal acceptance—helping innovators understand that broad uptake requires more than scientific excellence alone.

##### 2. Broad exploitation beyond academic communities

For many research partners, the project was an eye-opener in showing that innovations cannot remain confined to academic circles. ARSINOE highlighted the need to exploit results more broadly to generate long-term impact, behavioural change, and uptake by diverse user groups such as municipalities, SMEs, and farmers. This shifted the mindset from producing research outputs to developing solutions that must be embedded in real contexts.

##### 3. Importance of socio-economic perspectives

Exploitation exercises underscored that climate innovations must integrate socio-economic approaches, not only technical ones. Understanding user behaviour, decision-making drivers, and the economic viability of solutions proved crucial for shaping value propositions. This recognition helped partners see the need to go beyond scientific framing and engage with demand-side factors.

##### 4. Collaboration with market stakeholders is essential

Engagement with real market actors—local authorities, cooperatives, industry clusters—was shown to be a decisive enabler of uptake. Where these stakeholders were actively involved in co-creation, solutions demonstrated clearer replication and scaling potential. Conversely, innovations developed without such alliances struggled to move beyond the conceptual stage.

##### 5. Exploitation plans as guidance for continuity

By co-developing exploitation profiles, business models, and market entry strategies, ARSINOE provided concrete roadmaps that partners can continue to use beyond the project. These documents serve as a reference point for securing IPR, building partnerships, seeking funding, and planning next steps towards higher TRL/SRL levels. They gave structure and direction, reducing uncertainty for innovation teams.

##### 6. The need for trust-building and awareness campaigns

A recurring lesson was that adoption depends not only on technical soundness but also on trust and visibility. End-users and consumers need repeated engagement, demonstration, and targeted campaigns to feel confident in adopting new solutions. Many developers underestimated this, but exploitation workshops made it clear that awareness-raising and storytelling are as critical as technical performance.

## 4.2 Hazards

### 4.2.1 Flooding

The resilience framework was adopted to investigate the potential flood risks under present and future climate change scenarios. The assessment included not only hazard conditions but also the direct damage and indirect impacts to better understand how e.g. the Torbay community (CS#8), Southern Denmark (CS#7) and the Main River basin (CS#3) will be affected by flooding.

This clearly showed that the changing climate is likely to increase the frequency and exacerbate the scale of flooding in the area. Strong climate change heightens the danger of exceeding currently observed floods by large margins. Current adaptation measures are not enough to mitigate these hazards.

The results showed that some regions will experience disruptions of critical services even though the locations are not flooded, which has been exemplified in CS#7 and 8. The consequences may affect the vulnerable groups who require assistance to ensure their health and safety during the crises. The analysis from the ARSINOE resilience framework allowed the local authority not only to review their flood emergency plans to safeguard the communities from the impacts of flooding for the short term, but also to revise the strategies and investment to strengthening the long-term climate resilience.

### 4.2.2 Drought

Impact of droughts was evaluated in CS#3, CS#4 and CS#9. This shows that the affected regions will experience increased dryness and periods of drought. Specifically, the following lessons were learned:

- Water scarcity escalating by long and frequent droughts is becoming a raising trend in many regions globally.
- Environmental, social and economic sectors have been jeopardised thereby, in their survival, operation and development.
- Droughts may sometimes trigger cascading hazards, such as intensive rains (storms) and wildfires.
- Climate change pressures, along with demographic trends and economic growth, induce impacts on water consumption patterns, leading to competing demands that require complex management decisions.
- Water resources long-term planning and sustainable management needs to respond to these challenges

Specifically in the context of CS#9 it is remarked that this will result in increased agricultural vulnerability particularly affecting rainfed extensive crops such as durum wheat. Given the primary role of this crop in the mediterranean diets, even staple food security in this area may be affected in the long term.

### 4.2.3 Sea Level Rise

Sea level rise poses a direct threat to coastal aquifers through potential salinization, particularly in low-lying island zones (CS#5).

### 4.2.4 Extreme Weather

Strong winds, gusts, and heavy rain are the most disruptive weather events for port operations. Wave analysis indicates increasing significant wave height, though without notable internal agitation. Ports are increasingly troubled by weather-induced disruptions (e.g., wind, heat, fog), which impact worker health, cargo handling, and infrastructure longevity (CS#2).

### 4.2.5 Heat

Heatwaves are expected to last longer (more days), be more intense (higher temperatures), and occur more frequently. Beyond direct thermal stress, they also showcase and exacerbate compound hazards such as deteriorating air quality, water scarcity, biodiversity loss, urban noise, and even increased risks of violence and social unrest. These cascading effects multiply vulnerabilities across sectors, intensifying the overall risk landscape. The impacts are already visible in Athens (CS#1), where prolonged exposure severely affects citizen health—both physical and mental—while in coastal regions such as Limassol (CS#2), extreme heat interferes with economic activities, undermining worker safety and productivity and disrupting port operations critical to regional trade.

### 4.2.6 Volcanic Eruptions

Volcanic activity can dramatically reshape groundwater systems in island contexts, requiring updated models and monitoring strategies post-event (CS#5).

## 4.3 Economic Sectors

### 4.3.1 Water

#### **Water availability will play an increasingly important role**

Sustainable water management is becoming increasingly important. Without targeted water management, it will not be possible to satisfy all stakeholder groups. This applies to both agriculture (in the region, especially winegrowers (CS#3) and wheat production (CS#9) and municipal water suppliers (CS#3).

#### Agriculture

Focusing on water savings to face water scarcity is a crucial lesson learnt during ARSINOE. In this context, water for agricultural uses was a major topic (e.g. in CS#9) and resulted in a smart irrigation trial set up in AGRIS experimental farm to investigate different levels of water supply in comparison with rain feed cultivation. In this perspective, staple crop irrigation could be an essential tool to stabilize or enhance crop yields in durum wheat drought-prone growing areas of Sardinia and the Mediterranean.

#### Public Water Supply

Public water supply is facing pressure due to shifts in water availability and quality caused by climate change and measures to fight climate change impacts (e.g., increased use of fertilizers or pesticides). Public water demand experiences shifting patterns. Peak demands are recorded during heatwaves and can only met if sufficient water is available or can be transported to the region. Water pipes connecting supplied areas are built but may prove insufficient in case of widespread water scarcity.

Climate adaptation in the water sector necessitates intensive investment in existing infrastructures and other solutions. Financial instruments and business models need to be developed further to account for this fact. Moreover, public spending and especially state support programs could be reviewed.

The ARSINOE results confirm that early implementation of targeted adaptation measures — such as improved irrigation efficiency, water reuse, and demand management — can significantly reduce pressure on water resources across sectors, particularly in high-risk scenarios like RCP8.5.

The most effective way of response is to deploy comprehensive and integrated analytical approaches that exhibit a correct identification and setting of water issues, enable decision making under deep uncertainty and include all affected sectors in creation of consensual adaptation solutions

This is particularly of importance in case of water deficit and scarcity, under conditions of transboundary share of the same water resources.

Adaptation strategies should be based on WEFE Nexus approach, to allow fair distribution of sufficient quantity and adequate quality of water for all users (sectors).

### 4.3.2 Energy

Energy and food production systems are especially sensitive to seasonal water availability, underscoring the need for coordinated planning between sectors to avoid cascading impacts during peak demand periods (CS#3, CS#4). Rivers and lakes in CS#3 (Main) and CS#4 (Ohrid and Prespa lakes) river are used for hydropower generation and for cooling thermal power plants (CS#3). Moreover, water availability affects biomass production in the region. These forms of energy production and storage would be affected by shifting water availability. Moreover, climate change may affect demand patterns (more cooling vs. less heating).

### 4.3.3 Food

Agriculture (primarily specialised cultures) and viticulture are and will continue to be strongly affected by climate change.

#### CS#3

The agricultural sector considers a wide variety of adaptation strategies and views on which ones should be used differ within the sector. They include irrigation, crop changes, different modes of agriculture (e.g. agroforestry) and possibly abandoning agriculture and using land for other purposes e. g. Solar power generation. These decisions are strongly impacted by local feasibility of solutions, social pressures, cultural considerations and financial incentives.

#### CS#9

Concerning the importance of local agri-food supply chains, it was observed that locally produced food can be a tool for: (1) reduce the dependence from long-distance transports thereby reducing GHGs emissions (environmental health); (2) using fresh raw materials with more genuine, none-chemically treated products (individual health); (3) strengthening territories both economically and socially because all the actors involved in agri-food supply chains have the opportunity to have an access to a fair profit and a safe diet.

### 4.3.4 Health

Health-related vulnerabilities are expected to rise indirectly, especially under water-scarce conditions, due to reduced access to clean water, food insecurity, and increased ecosystem degradation—highlighting the importance of including health in Nexus-based resilience planning; ARSINOE demonstrated that climate change impacts on water systems, biodiversity, and health are deeply interlinked. This validates the importance of a One Health approach. Case studies revealed that human health cannot be safeguarded without also protecting ecosystems, water quality, and social infrastructure. Thus, One Health emerges not as a siloed framework for zoonoses or antimicrobial resistance, but as an integrative principle for regional climate adaptation strategies.

**Findings on Climate–Health Links:** Evidence across nine case studies highlighted that urban heat, flooding, and water scarcity directly translate into public health risks—mortality, morbidity, and mental health burdens. For example, Athens’ vulnerability mapping showed how social inequalities (e.g., elderly populations, poor housing) compound heat-related mortality. Similarly, biodiversity loss and degradation of wetlands in Prespa–Ohrid and the Black Sea regions were linked to impaired ecosystem services essential for water safety, agriculture, and disease regulation. These results emphasize that environmental degradation undermines both ecological and human resilience simultaneously.

ARSINOE findings suggest that One Health should be formally embedded in **climate adaptation and resilience planning**. EU and national strategies currently focus narrowly on zoonoses, but ARSINOE shows the need to expand scope to include urban health (heat, air quality), water security, and biodiversity services. Policymakers should adopt integrated governance models that connect ministries of health, environment, and urban planning, ensuring shared indicators and co-benefits. Moreover, One Health considerations should feed into **EU Green Deal targets**, disaster preparedness, and health equity frameworks, as well as the **twin transition** (green and digital).

### 4.3.5 Ecosystems

Besides climate change, competing interests and conflicts on land use (e.g. with regards to protected areas) and changing priorities (e.g., shortened funding for protection programs and incentives for ecological practices) put ecosystem services continuously under pressure.

### 4.3.6 Water Energy Food Ecosystem (WEFE) Nexus

As climate change continues and extreme events are becoming more frequent an integrated resource management considering the interlinkages between different sectors is becoming increasingly important to prevent the region from being pushed beyond its resilience threshold. In all sectors adaptation strategies are being developed. However, these are often disconnected from one another and there is a risk of conflicting strategies.

The systemic approach implemented in ARSINOE can support the shift to an integrated resource management, e.g., affect the of thinking about problems (e.g., in an integrated manner).

### 4.3.7 Transportation

Operational delays, e.g. in cargo ports (CS#2) can significantly affect local, regional, and transnational economies. Extreme weather events can disrupt port operations and affect passenger and vehicle transportation. Business operations benefit most when real-time climate information is integrated into management dashboards, but terminal operators require tailored alerts and specialised tools instead of generic environmental platforms.

## 4.4 Scale

### 4.4.1 Regional

- There are already some promising approaches at the regional level to make municipalities and cities more climate resilient. However, there is often a lack of operational implementation. The main reasons for this are a lack of personnel and financial resources.
- In order to implement sustainable solutions, it is also necessary to gain the acceptance and support of the population. This requires educational measures and/or informational events.
- The exchange within communities about obstacles to implementing measures, but also about successful strategies, helps to implement good examples - the board (or in other communities) an active network of stakeholders, such as the one created in ARSINOE through the various workshops, is therefore an important factor in achieving adaptation strategies.
- Across the region it is necessary to shift from a strongly localised view of resource management and adopt a regional perspective considering the river basin.
- Close collaboration with local authorities and stakeholders ensures that project outputs are aligned with regional priorities and can be embedded in long-term planning strategies.

### 4.4.2 National

- Existing climate resilience approaches are in place in many member states and only need better implementation.
- It is of great importance to improve regulations on water resources monitoring and to enlarge the network of measuring instruments.
- High-profile participation (e.g., Ecoislas and COP29) demonstrates how regional case studies can influence national-level conversations around resilience and sustainability.
- Regional/National: Coordination between regional and national authorities is necessary to align adaptation measures and policies.

### 4.4.3 Biogeographical

- Standardised approaches enable replication and transfer of tools and methodologies across regions.

### 4.4.4 European

- CE-marked hardware, ISO compatibility, and AI-readiness support replicability under EU adaptation initiatives, including the Green Deal.

## 4.5 Other

### 4.5.1 Data

#### Availability

- A major challenge regards the lack of qualitative datasets that are consistently produced based on a standardised methodology that can be applicable on different geographical scales. A plethora of data exists, however provided ad-hoc by different data providers and in many cases lacking a reporting consistency, both in terms of structure and frequency. This is mostly evident when moving from a national scale to regional, city and neighbourhood level. Furthermore, data is mostly provided as data silos without a semantic alignment of the represented terms and concepts, hindering their interlinkage and interoperability.
- The ARSINOE methodologies and tools were developed for generic applications, which were successfully demonstrated in CS#8 as a proof of concept. The data availability and quality did affect the outcomes of the analysis, nevertheless, the CS#8 applications have shown the feasibility of the ARSINOE approach, which can be replicated in other case studies. The analysis can be repeated and will be improved when better data is available.
- Among stakeholders, trust in data can easily be shattered by a single counter example. It is crucial to communicate uncertainties in a prudent and sensible manner.
- Historical time series: Historical data were often stored offline or required lengthy administrative procedures—highlighting the need for digitalised, real-time monitoring systems to support responsive decision-making.
- Another challenge regards the openness of both data and software. Various data analysis services are developed across research projects and initiatives, however, lacking openness and clarity in terms of the applied methodologies and the developed software.
- Real-time sensors filled a critical gap due to limited pre-existing environmental data.

#### Quality

- The data were not always complete and gaps in measurement needed to be filled in by the project team, using conventional interpolation methods

- Metadata and documentation: The lack of info regarding measurement methods, update frequency, or equipment calibration reduced the confidence in some datasets, underscoring the need for better data governance and traceability.
- The 100-meter resolution climate data developed within the project represents a qualitative leap in environmental modelling capacity for small island contexts.

### Standardisation

- To ascertain interoperability / exchange of data with partners, clear communication of the formats that can be processed is necessary (e.g., transforming data formats commonly used in scientific contexts to data formats that can be used by non-scientists). Enough time for exchange and explanations should be taken into consideration for planning purposes.
- Open API design enabled easy integration with port systems; interoperability with national weather and maritime systems is the next step.
- Cross-border data sharing: Data sharing remains limited and fragmented, creating challenges for integrated modelling and joint water management. Establishing formal mechanisms for transboundary data exchange would enhance coordination and transparency.

### 4.5.2 Transferability

- The major results of the governance analysis are transferable to other regions.
- Outcomes from the discussions in the Living Labs and Climate Services could be applicable to regions with a similar mix of hazards and comparably intersectoral interlinkages in Germany and Europe.
- The hydrological modelling is in principle transferable to other regions in Europe, if the necessary geophysical variables (e.g., soil properties, land use, (hydro-)geology, catchment boundaries) are provided and observed discharge data for reference is available. If so, the model has to be calibrated to the new region. Bias adjustment and statistical downscaling also require observational / reference data for the region under consideration and sufficient computational resources (i.e., CPU, storage).
- The developed virtual watershed concept, conceptually connecting best practices and results from similarly not geographically connected areas, can be replicated in other transboundary basins facing climate-induced pressures and complex land-sea interactions to enhance sustainable water resources management.
- Locally and regionally, the methodologies used and developed (e.g. real-time water quality monitoring, UAV-based habitat mapping) can be adapted for other Mediterranean or European basins with similar topography, land use, or climate profiles. Tools developed for the Danube Delta are especially applicable in other deltaic or wetland ecosystems affected by nutrient overloads or salinization, while the SMS platform in Türkiye, can be adapted across multiple dimensions in other marine environments.
- Internationally, the use of open-source tools, modular sensor systems and participatory modelling methods ensure that the innovations applied are science-based, but also economically feasible and socially acceptable, which are key conditions for successful replication.
- The development of the Digital Twin model developed for Aliakmon River can be upscaled and developed for other river basins due to its modular, data-driven and low-cost design. It integrates hydrological and meteorological simulations, remote sensing inputs, real-time monitoring from in-house sensor systems and forecasting. The use of low-cost, Arduino-based sensors and open-source hydrological modelling allows for adoption even in resource-constrained settings.

## 5. RECOMMENDATIONS

At national level, ARSINOE identified several areas for improvement to support more effective climate adaptation. First, there is a need to make governance more flexible and responsive by simplifying administrative procedures and allowing local actors greater room to act. This can help speed up the implementation of adaptation measures on the ground.

At the same time, strengthening local capacity—both in terms of human resources and technical expertise—is essential. This will ensure that environmental and climate-related issues are properly taken into account in local planning and decision-making processes.

Better environmental monitoring is also important, especially for drought-related indicators. Reliable and up-to-date data can support more informed and timely decisions, particularly in sectors that depend heavily on water availability.

Raising awareness and improving understanding of climate risks is another key step. This can help build stronger public and political support for adaptation and encourage more proactive engagement from different stakeholders.

The legal framework could also be reviewed and updated where necessary, particularly to support emerging solutions such as water reuse. These innovations often require new infrastructure and clearer legal conditions to be developed and implemented effectively.

In addition, a more integrated and cross-sectoral approach is needed—especially at the intersection of water, energy, and food. Creating spaces for dialogue and joint planning across sectors can lead to more coherent and efficient adaptation strategies.

Concerning the methodologies applied in ARSINOE, a number of more specific recommendations have also been formulated.

On the implementation of the ARSINOE approach (SIA), ARSINOE recommends:

- ARSINOE started with a prescriptive methodology to map stakeholders and invite them into a living lab. This step was particularly important as this made it possible to bring all case study sites to a shared understanding of the work to be carried out with stakeholders, right from the beginning of the project. It was important to create systems that allow for the sharing of experiences and lessons learned by exchanging on the implementation of a common methodology, in particular in a consortium with scientists. Many innovative projects are taking place at the local level, and putting in place mechanisms to gather and share this knowledge helped to be more efficient by spreading good practices and support continuous learning across case studies.

Specific recommendations concerning the participatory process are:

- **Strengthening local capacity**—both in terms of human resources and technical expertise—is essential. This ensures environmental and climate-related issues are properly integrated in local planning and decision-making processes.
- Successful **replication requires building long-term partnerships** and alliances across science, policy, and market actors. Municipal involvement emerged as especially critical. The project showed that alliances are not simply instrumental but central to unlocking scaling, financing, and policy support.
- The **language** used in academia is not easily understood by the audiences. This needs alignment, in particular when non-scientist stakeholders, including citizens, are included.

On the financial methodologies, ARSINOE recommends:

- **Mainstream climate finance in national/regional strategies:** Ports, municipalities, and regional authorities should integrate adaptation finance into development plans to secure predictable long-term resources.
- **Develop standardised project assessment tools:** A common EU-aligned framework for designing bankable adaptation projects would reduce transaction costs and accelerate access to funding.
- **Expand collaborative investment platforms:** multi-actor platforms (public, private, community, donors) should be institutionalised in each CS to pool resources and share risks.
- **Promote innovative financing pilots:** Case studies should pilot emerging instruments (e.g., adaptation bonds, debt-for-nature swaps, PES) and document best practices for replication.
- **Align the time-perspective of decision making to the requirements of climate resilience.** The long-term horizon required for climate adaptation investments do not match with current private and public investments, which are focussed on short-term gains. Stability of policy and regulations are also required, whereas currently they change for political reasons each legislative period.
- **Strengthen capacity building and technical assistance:** Dedicated programs for municipalities, SMEs, and community actors are needed to unlock and manage adaptation finance effectively.
- Convince insurance companies that climate adaptation requires not only CO<sub>2</sub> reduction, but also mitigation of climate risks and dealing with the consequences of climate events that can no longer be mitigated. **Insurance** and financing tools to deal with **climate change consequences and damages**, as well as adaptation measures, are essential.
- **Embedded monitoring and ESG reporting:** Transparent reporting linked to SDGs/ESGs should be a requirement in financing pathways to attract private and institutional investors.
- **Ensure continuity beyond ARSINOE:** Follow-up initiatives should focus on operationalising the identified financial instruments and pathways, moving from design to real-world implementation.

On the inclusion of innovators in climate adaptation projects ARSINOE recommends:

- **Integrate procurement expertise from the outset**  
Future projects should involve legal, financial, and procurement departments of contracting parties during proposal preparation and in the early months of implementation. Developing *pre-approved contract templates, eligibility criteria, and guidance notes* will help streamline OTIs and reduce delays.
- **Institutionalise direct contracting with innovators**  
The ARSINOE model of signing contracts directly between innovators and local institutions should be continued and scaled up. This not only accelerates procurement but also fosters long-term organisational change by familiarising municipalities, universities, and councils with innovation procurement practices.
- **Provide continuous facilitation and capacity building**  
Dedicated facilitation roles (e.g. WP leaders, innovation brokers) are necessary to guide both innovators and case studies through contracting, reporting, and impact assessment. Training modules for cities and innovators on procurement, Horizon Europe rules, and IPR would further strengthen capacities.
- **Strengthen visibility and market access for innovators**  
All innovations funded through OTIs should be systematically showcased via European marketplaces such as the *Climate Innovation Window* and EU Mission platforms. Labelling schemes ("*ARSINOE Network*", "*Tested in ARSINOE*") should be maintained to provide innovators with trusted references.

- **Link OTIs to scaling and investment pathways**  
Beyond the initial 30k grants, projects should design pathways for innovators to access *follow-up investment* (e.g. through structural funds, blended finance, or venture capital). This ensures that OTI-funded pilots can evolve into commercial rollouts rather than remain isolated demonstrations.
- **Promote cross-border innovation uptake**  
OTIs should explicitly encourage the selection of innovators from other EU regions to foster cross-border learning and replication. Mechanisms such as translation support, knowledge brokerage, and alignment with regional policies will be needed to overcome adoption barriers.
- **Embed OTIs in Living Lab and replication strategies**  
Open calls must remain closely tied to Living Lab processes to ensure relevance and legitimacy. At the same time, OTI outcomes should feed into *replication and upscaling activities* across case studies, so that pilots do not remain site-specific but contribute to broader climate adaptation pathways.
- **Scale up the OTI mechanism**  
Given the very high interest from innovators (100+ applications), future projects should expand the scope of OTIs by increasing the number of grants, raising ceilings where feasible, and aligning them with EU Missions and regional Operational Programmes to maximise systemic impact.

On communication and dissemination, ARSINOE recommends:

- **Invest in translating scientific content into accessible formats:** research projects involve highly technical or scientific material, which can be a barrier for broader public understanding and engagement. Therefore, resources should be allocated from the beginning to translate complex concepts into simplified content using plain language. Moreover, using storytelling techniques and practical examples made the content relatable and the production of visual formats such as factsheets and short videos made key messages easy to understand for non-expert audiences.
- **Be active and consistent on social media:** social media is a critical tool for broad outreach, engagement, and visibility throughout the lifecycle of the project. Therefore, EU funded projects partners should maintain a regular posting schedule across key platforms to share updates, events, results and partner activities using visuals to improve engagement and reach. All partners should also be active with regard to the posts generated by the project's account **to** widen the posts' outreach. Finally, actively engaging with other EU projects, institutions and stakeholders by tagging, sharing, and commenting increased visibility and build connections.
- **Adapt communication tools to local needs in case studies:** local relevance is important when communicating at the regional or case study level, particularly in diverse linguistic and cultural contexts. Therefore, partners should translate key materials into local languages to ensure accessibility and understanding, tailor content to address the specific concerns, context and stakeholders of each case study region, involve local partners in the co-creation of communication tools and be flexible in the creation of adaptable communication tools upon needs (flyer, poster, banner, etc.) and be attentive to case study leaders' needs.
- **Maintain communication and engagement at the local level:** sustained local engagement is important for fostering trust, ensuring participation and enhancing long-term impact of project results. Therefore, project partners should develop local communication and engagement strategies aligned with the broader project goals but tailored to the case study dynamics as well as maintain ongoing dialogue with local actors through regular workshops, newsletters and other participatory formats.

Based on the findings and lessons from ARSINOE, several recommendations can be formulated for future projects and for partners seeking to maximise the exploitation of their innovations:

- **Integrate exploitation from the start**  
Future projects should embed exploitation considerations early, including mapping of potential end-users, market studies, and IPR strategies in the first project year. This reduces delays later and ensures that exploitation runs in parallel with technical development.
- **Provide structured business support to research partners**  
Academic and technical partners often lack commercialisation skills. Dedicated training, coaching on value proposition design, and access to business mentors should be systematically included in large consortia. This will help translate scientific outputs into solutions with real uptake potential.
- **Strengthen awareness and trust-building campaigns**  
Innovations require visibility and credibility to be adopted. Future projects should allocate resources for awareness campaigns, pilot demonstrations, and storytelling activities targeted at municipalities, SMEs, farmers, and communities—not just at policymakers and researchers.
- **Ensure active involvement of end-users and multipliers**  
Municipalities, cooperatives, utilities, and industry clusters are decisive enablers of replication. Projects should make their participation mandatory in piloting and co-creation activities. This increases trust and accelerates adoption beyond the project boundaries.
- **Align exploitation pathways with funding and policy instruments**  
Developers frequently perceive financial barriers, yet opportunities exist through Horizon Europe, CAP eco-schemes, regional OPs, or blue economy funds. Future projects should provide clearer guidance on how to connect innovations with these instruments and embed them into policy frameworks such as the EU Missions and the Green Deal.
- **Promote cross-case study learning**  
Replication is often hindered by fragmented experiences. Cross-case study exchanges, joint demonstration events, and shared exploitation workshops should be strengthened to allow lessons from one context to inform others, preventing duplication of effort.
- **Sustain innovation platforms beyond project life**  
Platforms like the Climate Innovation Window (CIW) are essential to ensure long-term visibility and matchmaking. Future projects should plan early for governance, ownership, and financing of such platforms, ideally through alliances with established networks.
- **Foster multi-disciplinary exploitation teams**  
Commercial uptake requires expertise beyond technical R&D. Teams should combine technical experts, social scientists, communication specialists, and business developers to jointly craft pathways that are realistic, socially robust, and market ready.
- Make **governance more flexible and responsive** by simplifying administrative procedures and allowing local actors greater room to act.
- **One Health** provides a framework also at the practical level for authorities and municipalities encouraging them to implement **nature-based solutions** that simultaneously address climate adaptation, biodiversity, and health—such as urban greening, wetland restoration, and coastal protection. Tools like the **resilience wheel** used in ARSINOE provide actionable methods for identifying hotspots and prioritising interventions. Citizen science and participatory tools (e.g., the MINKA app, biodiversity observatories) are critical for data collection, awareness, and behavioural change, reinforcing social resilience alongside technical measures.

## 6. CONCLUSIONS

The implementation of the ARSINOE framework across the nine case studies has demonstrated the value of systemic, cross-sectoral approaches in advancing climate resilience. ARSINOE shows a surprisingly uniform message from the nine case studies about adaptation to climate change. This message is that **early, continuous, and participatory involvement** of **cross sectoral** stakeholders is required to create a **common understanding**, transparency, and the basis for long-term, institutionalised solutions. The **solutions co-designed** through this participatory process, the System Integration Approach (SIA), are more likely to be successfully implemented, accepted and supported as the process provides **legitimacy with non-technical audiences**. In designing climate adaptation solutions and strategies, scenario-based modelling, when **co-developed** with stakeholders, strengthens collective understanding of future risks and trade-offs, enabling more **informed, inclusive, and adaptive** planning processes. Furthermore, as climate adaptation and understanding of the consequences and risks of climate change is dynamic, **iterative processes, requiring continuous learning**, flexible tools, and sustained stakeholder engagement, are essential to ensure effective adaptation, also in the long term.

The legacy of ARSINOE is that these participatory processes are now securely embedded in the regions and municipalities that took part in the case studies, and that their best practices have been disseminated across Europe. Within the context of the case studies, the approach and tools will continue to be used, and their application will continue to be promoted. Successful **replication requires building long-term partnerships** and alliances across science, policy, and market actors. Municipal involvement emerged as especially critical. The project showed that alliances are not simply instrumental but central to unlocking scaling, financing, and policy support.

Besides the SIA, another key outcome from ARSINOE is a suite of climate adaptation innovations that have been selected through the open tender for innovations and successfully deployed in the case studies. These innovations, now part of the Climate Innovation Window, part of the European Climate Resilience Innovation Platform, and ready for broader adoption across Europe

The ARSINOE results provide clear links to global and European policy frameworks, reinforcing the project's wider societal and environmental relevance.

First, ARSINOE contributes directly to the achievement of several United Nations Sustainable Development Goals (SDGs). Notably, it advances SDG 6 (Clean Water and Sanitation) through improved governance of water resources, including aquifer protection, water reuse, and sustainable allocation mechanisms. It supports SDG 13 (Climate Action) by designing and testing adaptation pathways that reduce vulnerability to extreme events. Moreover, it strengthens SDG 14 (Life Below Water) and SDG 15 (Life on Land) through the protection and restoration of aquatic and terrestrial ecosystems in regions such as the Black Sea, Ohrid/Prespa lakes, and Mediterranean coastal zones. In addition, synergies with SDG 7 (Affordable and Clean Energy) and SDG 12 (Responsible Consumption and Production) are evident in the nexus-oriented solutions addressing the interdependencies of water, energy, food, and land resources.

Second, the project embraces the One Health perspective, recognising that human health is intrinsically linked to the health of ecosystems and animals. By improving water quality, safeguarding biodiversity, and reducing pollution exposure, ARSINOE strengthens the environmental determinants of health. Furthermore, by securing water and food supplies under changing climatic conditions, the project helps to mitigate public health risks associated with scarcity, contamination, and ecosystem degradation. ARSINOE confirms that **One Health must evolve into a systemic resilience paradigm**: linking environmental sustainability, water resilience, public health, and socio-economic stability. Climate change impacts such as extreme heat, floods, droughts, and biodiversity loss cannot be managed in isolation. By demonstrating practical tools, governance frameworks, and innovation pathways, ARSINOE

provides a blueprint for future European and global resilience initiatives. The key recommendation is to mainstream One Health in adaptation policies and ensure that health benefits—physical, mental, and social—become explicit targets in resilience planning.

Third, the project methodologies, activities and actions implemented at the case studies are relevant for the Water Resilience Strategy Act ([https://environment.ec.europa.eu/publications/european-water-resilience-strategy\\_en](https://environment.ec.europa.eu/publications/european-water-resilience-strategy_en)) which was adopted by the EC towards the end of the project (June 2025). Although ARSINOE had started much earlier (in 2021), before the Water Resilience Strategy was suggested, it is worthwhile pointing out that the project outcomes and recommendations are relevant for this Act. Specifically, the SIA approach adopted in the project is in line with the core suggestions of this Act. Additionally, all the case studies are relevant for this Act, approaching the topic from varying angles, which could be used as a paradigm for future regional actions.

Finally, ARSINOE makes a tangible contribution to the objectives of the European Green Deal. The solutions co-developed with stakeholders in the living labs exemplify how the principles of climate neutrality, circular economy, biodiversity protection, and zero pollution can be operationalised at regional and local levels. The innovation packages validated in the case studies demonstrate pathways for replication and scaling, providing evidence-based strategies to accelerate Europe's transition towards resilience and sustainability. Moreover through its digital solutions, ARSINOE links the Green Deal with digitalisation, which is part of the Green and Digital Transition for Europe (Twin transition) ([https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/twin-green-digital-transition-how-sustainable-digital-technologies-could-enable-carbon-neutral-eu-2022-06-29\\_en](https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/twin-green-digital-transition-how-sustainable-digital-technologies-could-enable-carbon-neutral-eu-2022-06-29_en))

In summary, ARSINOE has established a strong foundation for translating scientific knowledge and systemic innovation into actionable solutions. By aligning with the SDGs, One Health, Water Resilience and the European Green Deal with Twin Transition, the project not only addresses immediate regional challenges but also contributes to the long-term vision of a sustainable, climate-resilient Europe.

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Systems Innovation Approach (SIA) addresses the growing complexity, interdependencies and interconnectedness of modern societies and economies, focusing on the functions of the cross-sectoral system? as a whole? and on the variety of actors. The Climate Innovation Window (CIW) is the EU reference innovations marketplace for climate adaptation technologies. ARSINOE shapes the pathways to resilience by bringing together SIA and CIW, to build an ecosystem for climate change adaptation solutions. Within the ARSINOE ecosystem, pathways to solutions are co-created and co-designed by stakeholders, who can then select either existing CIW technologies, or technologies by new providers (or a combination) to form an innovation package. This package may be designed for implementation to a specific region, but its building blocks are transferable and re-usable; they can be re-adapted and updated. In this way, the user (region) gets an innovation package consisting of validated technologies (expanding the market for CIW); new technologies implemented in the specific local innovation package get the opportunity to be validated and become CIW members, while the society (citizens, stakeholders) benefits as a whole. ARSINOE applies a three-tier, approach: (a) using SIA it integrates multi-faceted technological, digital, business, governance and environmental aspects with social innovation for the development of adaptation pathways to climate change for specific regions; (b) it links with CIW to form innovation packages by matching innovators with end-users/regions; (c) it fosters the ecosystem sustainability and growth with cross-fertilization and replication across regions and scales, at European level and beyond, using specific business models, exploitation and outreach actions. The ARSINOE approach is show-cased in nine widely varied demonstrators, as a proof-of-concept with regards to its applicability, replicability, potential and efficacy.



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