Deliverable Phase 2 – Climate risk assessment

CLIMAAX for Aveiro Region: Planning for Future Resilience and Sustainability (CLIMAAX4CIRA)

Portugal, Comunidade Intermunicipal da Região de Aveiro

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Document Information

Deliverable Title	Phase 2 – Climate risk assessment
Brief Description	Deliverable Phase 2 marks the operational advancement of the CLIMAAX4CIRA project. Building on Phase 1, this report transitions from broad screening to a decision-oriented evidence base through high-resolution local data. It establishes a nuanced risk prioritization for the Aveiro Region, identifying critical vulnerabilities such as wildfires and coastal flooding, which serve as the strategic foundation for developing adaptation pathways in the project's final phase.
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Abbreviations and acronyms

Abbreviation / acronym	Description
AdRA	Water and Sanitation Companies
AIDA	Business Associations
APA	Portuguese Environmental Agency
ARH	Hydrographic Region Administrations
BGRI	Geographic Information Reference Database
BUPI	Portuguese national land registry
CCDRC	Regional Coordination and Development Commission
CIRA	Intermunicipal Community of the Region of Aveiro
COS	Portuguese Land Cover dataset
CRA	Climate Risk Assessment
CRM	Climate Risk Management
DAO	Department of Environment and Planning
DEM	Digital Elevation Model
DGT	Directorate-General for Transport
DRAPC	Regional Directorate for Nature Conservation and Forests
EIDT.RA 2030	Integrated Territorial Development Strategy
ENAAC	National Strategy for Adaptation to Climate Change
E-Redes	Electricity Grid
FWI	Fire Weather Index
GADM	Global Administrative Areas
GAEZ	Global Agro-Ecological Zones
GIS	Geographic Information Systems’
ICNF	Institute for Nature Conservation and Forests
INE	Statistics Portugal
IP	Portuguese Infrastructures
IPMA	Portuguese Institute for Sea and Atmosphere
JRC	Joint Research Center
KRA	Key Risk Assessment
LUISA	Land-Use-based Integrated Sustainability Assessment
NGO	Non-governmental organizations

OE	Engineering Professional Bodies
OSM	Open Street Maps
PDM	Municipal Master Plan
PMACs	Municipal Climate Action Plans
PRA Centro,	National Integrated Rural Fire Management System
SERI Index	Socio-Economic Vulnerability
TWI	Topographic Wetness Index
UA	University of Aveiro
UHI	Urban Heat Island
ULS	Local Health Unit of the Aveiro Region
WUI	Wildland-Urban Interface

Executive summary

This Deliverable presents the Phase 2 Climate Risk Assessment (CRA) for the Intermunicipal Community of the Aveiro Region (*Comunidade Intermunicipal da Região de Aveiro*, hereafter referred to as the Aveiro Region or CIRA), developed under the CLIMAAX framework. Transitioning from the European-scale screening conducted in Phase 1, Phase 2 marked a critical shift toward operationalization and localized policy relevance. Executed between September 1, 2025, and June 30, 2026, this phase sought to answer whether integrating national and municipal datasets within a highly heterogeneous territory led to more actionable and equitable climate risk outputs.

The assessment deepened the analysis of five priority risks—extreme precipitation, floods (river and coastal), heatwaves, droughts and wildfires. This phase actively addressed the limitations of Phase 1 by incorporating high-resolution, geo-referenced local data (e.g., Portuguese land use dataset (COS), and cadastral data). Crucially, the wildfire risk modelling was entirely recalibrated using multi-dimensional Pareto optimization to reflect the specific biophysical drivers, fuel loads, and socio-demographic vulnerabilities of the Portuguese landscape.

Another central pillar of Phase 2 was the integration of environmental justice principles. The analysis revealed that climate impacts in the Aveiro Region are unevenly distributed, mirroring deep socio-economic asymmetries between the densely populated, industrialized coastal areas (facing sea-level rise and flash floods) and the aging, depopulated inland municipalities (facing severe wildfire and drought risks).

Structured stakeholder engagement was instrumental in this phase, built around two key milestones: a technical municipal consultation (November 2025) to secure local data and define scenarios, and a comprehensive regional workshop (May 2026) involving civil protection, environmental agencies, health authorities, and municipalities. This engagement validated the refined risk maps, capturing vital local nuances—such as the critical danger at the wildland-urban interface (WUI) and the impacts of inadequate local drainage systems—that broad models often miss.

Ultimately, Phase 2 established a robust, transparent, and locally validated evidence base. By synthesizing these multi-criteria evaluations into a definitive Key Risk Assessment (KRA), this deliverable successfully prioritizes hazards to guide future action: Wildfire is identified as the paramount threat (Very High priority) due to structural land management deficits, followed by Coastal Floods (High priority), which are effectively modulated by existing intermunicipal protective frameworks. River Floods, Heavy Rainfall, and Drought are categorized as Moderate priority risks requiring sustained mid-term interventions, while Heatwaves are classified as Low priority, indicating that current adaptive capacities are largely sufficient.

By highlighting both the critical risk hotspots and the structural limitations in local data interoperability, this assessment provides a clear, equitable foundation for Phase 3, where the focus will shift to integrating these findings into spatial planning, with the Municipal Master Plans (PDMs) and Municipal Climate Action Plans (PMACs).

1. Introduction

1.1. Background

The Aveiro Region (NUTS III) (Região de Aveiro, 2024), located in central-north Continental Portugal, encompasses 11 municipalities and covers approximately 1,693 km². The territory is characterized by a stark geographic and demographic duality. To the west, the coastal zone is dominated by the Ria de Aveiro—a sprawling, highly dynamic coastal lagoon ecosystem of immense ecological and economic value (supporting aquaculture, tourism, and a major port). This coastal strip is densely populated and industrialized. Conversely, the inland eastern municipalities transition into steep, forested mountainous terrain, which has suffered from decades of demographic inversion, rural abandonment, and an aging population.

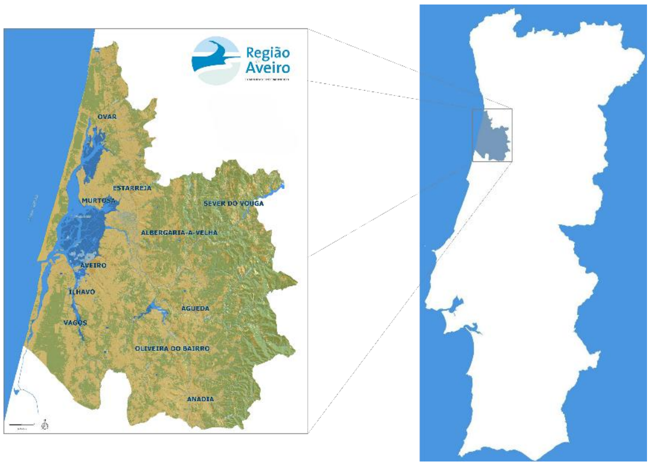

Figure 1-1 Aveiro Region location.

This spatial dichotomy creates a complex matrix of climate vulnerabilities. The region features a temperate Mediterranean climate (Csb) with mild, rainy winters and hot, dry summers. However, climate change is profoundly altering these baselines. The coastal areas are increasingly threatened by sea-level rise, coastal erosion, and extreme precipitation events that overwhelm urban drainage systems. Meanwhile, the inland areas face intensifying agricultural droughts and escalating rural wildfire risks, exacerbated by the proliferation of highly combustible, unmanaged eucalyptus plantations resulting from land abandonment and fragmented private ownership.

Compounding these physical vulnerabilities are significant structural challenges. Historically, regional planning has grappled with uneven technical and financial capacities across municipalities. Access to high-resolution, interoperable environmental data remains asymmetrical, frequently creating a "technical invisibility" for peripheral areas and hindering the implementation of equitable, data-driven adaptation strategies.

1.2. Main objectives of the project

The overarching goal of the CLIMAAX4CIRA project is to establish the enabling conditions for robust climate adaptation in the Aveiro Region by delivering a reliable, science-based Climate Risk Assessment (CRA). While Phase 1 tested the conceptual CLIMAAX workflows using European-scale data, Phase 2 shifted towards operationalization and local relevance.

The specific objectives of Phase 2 were to:

- **Refine Risk Assessments:** Downscale the Phase 1 assessment by integrating high-quality, high-resolution datasets maintained by national and municipal institutions (e.g., specific land-use maps, updated demographic censuses).
- **Promote Environmental Justice:** Democratize access to climate data, ensuring that socio-economic vulnerabilities—such as aging populations, isolated rural communities, and marginalized coastal settlements—were explicitly factored into risk modeling.
- **Support Policy Integration:** Produce spatial risk outputs that can be directly absorbed into municipal planning instruments, particularly PDMs and PMACs.
- **Enhance Multi-Level Governance:** Foster collaboration among stakeholders across various sectors (civil protection, forestry, health, and urban planning) to validate empirical findings against local lived experiences and operational constraints.

1.3. Project team

The CLIMAAX4CIRA project is a transdisciplinary collaboration between regional governance and academia, structured as follows:

- **Project Coordination (CIRA)**: Led by José Eduardo de Matos (Executive Secretary) and Patrícia Castro (Project Manager), driving stakeholder facilitation and policy alignment.
- **Technical Partners (University of Aveiro)**: Executed by the Department of Environment and Planning (DAO) and CESAM (Sílvia Coelho, Bruno Augusto, Fábio Matos, Ana Isabel Miranda, Myriam Lopes), handling climate modelling, data engineering, and risk frameworks.
- **Academic Integration (University of Aveiro)**: Expanded via master's research by Jade Alves-Gabiron (wildfire vulnerability) and bachelor's support from Ryu Yamashiro, integrating early-career researchers into applied, interdisciplinary science.

1.4. Outline of the document's structure

This document presents the Phase 2 Climate Risk Assessment for the Aveiro Region. Chapter 2 details the core CRA process according to the CLIMAAX framework: it begins with Scoping (2.1) and Risk Exploration (2.2), highlighting the specific governance context, stakeholder engagement, and scenario selection applied during this phase. Section 2.3 provides the detailed Regionalized Risk Analysis for the five priority hazards, showcasing the methodological refinements and local data integration. The analytical outputs are then synthesized in the Key Risk Assessment Findings (2.4), which evaluates severity, urgency, and adaptive capacity guided by stakeholder validation. Finally, Monitoring and Evaluation (2.5) and the Work plan for Phase 3 (2.6) outline the progress made, remaining data gaps, and the roadmap for developing targeted adaptation strategies. The document concludes with a summary of Phase 2 results (Chapter 3), an evaluation of progress to date (Chapter 4). Supporting materials and references are included at the end.

2. Climate risk assessment – phase 2

2.1. Scoping

2.1.1. Objectives

The overarching objective of this Climate Risk Assessment (CRA) was to provide a solid, localized evidence base for climate adaptation planning in the Aveiro Region. Transitioning from the conceptual screening in Phase 1, Phase 2 focused on operationalizing the CLIMAAX framework by utilizing high-resolution, municipal, and national-level datasets. The expected outcome was a set of refined, spatially explicit risk maps and indicators that support decision-making, policy development, and the prioritization of adaptation investments across the 11 municipalities.

Limitations and Boundaries: While Phase 2 significantly improved the quality of the assessment, several limitations materialized during its execution, primarily related to data availability and institutional fragmentation. Gathering local data revealed profound disparities in "informational health" among municipalities. Even when data existed, the heterogeneity of the Geographic Information Systems' (GIS) formats, different spatial reference systems, and the absence of metadata posed major hurdles to interoperability and regional harmonization. Consequently, integrating data into a cohesive regional analysis required intensive manual harmonization, which limited the speed and depth of some overlay analyses.

2.1.2. Context

The Aveiro Region is deeply sensitive to climate variability. Historically, the territory has dealt with alternating extremes: severe coastal and pluvial flooding in the low-lying lagoon areas (*Baixo Vouga*), and devastating rural wildfires in the inland mountainous and forested municipalities.

As in other Portuguese NUTS III regions, the structural vulnerabilities of the territory amplify these climate hazards. Inland areas face rural depopulation, the abandonment of agricultural lands, and an aging population, which together with fragmented private land ownership and the proliferation of highly combustible eucalyptus plantations, create an explosive environment for wildfires. Meanwhile, the coastal and central urban areas suffer from dense soil sealing and inadequate drainage infrastructure, compounding the risks of extreme precipitation and urban heat islands.

The governance context for climate risk assessment is framed by the National Strategy for Adaptation to Climate Change (ENAAC) (Agência Portuguesa do Ambiente, 2015) and the ongoing development of Municipal Climate Action Plans (PMACs) (Almeida and Nunes, 2024; Barroso et al., 2025; Cardoso and Nunes, 2021, 2024; Carlos et al., 2016; Costa and Nunes, 2024; Laranjeira and Nunes, 2023; Medina et al., 2024). However, translating these national guidelines into local implementation remains challenging. Similar to other regions in Portugal, there is a structural gap in technical and financial capacity at the local level, making the provision of actionable, regionalized climate data through the CLIMAAX project a critical tool for empowering these municipalities.

2.1.3. Participation and risk ownership

The stakeholder involvement process in Phase 2 was continuous, integrating institutional and territorial knowledge throughout the project's development. Following an initial online consultation that aligned the CIRA coordination team, the University of Aveiro experts, and municipal environmental technicians, a comprehensive mapping of relevant stakeholders was conducted. This process identified key entities whose roles are critical for climate risk management in the region. The table below categorizes these stakeholders by their primary area of action:

Table 2-1 Stakeholders mapping.

Entity/Category	Stakeholders
Municipalities	Águeda; Albergaria-a-Velha; Anadia; Aveiro; Estarreja; Ílhavo; Murtosa Oliveira do Bairro; Ovar; Sever do Vouga, Vagos
Civil Protection	Sub-Regional Emergency and Civil Protection Command (*Comando Sub-Regional de Emergência e Proteção Civil*)
National/Regional Authorities	Portuguese Environmental Agency (APA)
Utilities & Services	Hydrographic Region Administrations (ARH)
Health	Institute for Nature Conservation and Forests (ICNF)
Academia	Regional Coordination and Development Commission (CCDRC)
NGOs & Socio-Economic	Environmental NGOs (*Ria Viva*) Tourism Board (*Turismo do Centro*) Business Associations (AIDA) Engineering Professional Bodies (OE) Insurance Associations

This diverse group represents the full spectrum of governance, technical and scientific expertise, and sectoral interests, ranging from governmental infrastructure management to community-based advocacy. Their contributions were instrumental in validating the relevance of the selected risks, grounding technical models in territorial reality, and identifying critical data gaps that needed to be addressed.

The governance of these risks in the Aveiro Region follows a collaborative model where risk ownership is shared across administrative mandates, and the stakeholders identified above were selected precisely to ensure that this entire cycle—from strategic planning to operational mitigation—is fully represented. While national and regional authorities provide strategic framework and foundational data, the actual identification, assessment, and mitigation of risks are operationalized through municipal technical services. These local departments hold the primary responsibility for land-use planning and the deployment of preventive measures, operating in constant coordination with emergency response structures. Within this framework, vulnerable groups, such as the elderly and isolated populations, are supported through the intersection of municipal social services, regional health authorities, and the community-based advocacy of NGOs. Risk tolerance is not explicitly codified; instead, the region operates under an implicit threshold defined by established Civil Protection protocols, hydrological alert systems, and meteorological warning triggers, which serve as the operational basis for current decision-making and risk management in the region.

2.1.4. Application of principles

The methodological approach of this study systematically operationalizes the core pillars of the CLIMAAX framework. By anchoring the technical workflow in local realities, the assessment transitions from a theoretical data exercise into a practical tool for equitable climate resilience.

The CLIMAAX framework principles were systematically applied, heavily guided by an Environmental Justice perspective:

- **Social justice, equity, inclusivity:** The assessment recognized three dimensions of environmental justice: *distributive justice* (mapping where hazards intersect with vulnerable populations, such as the elderly or isolated rural communities), *procedural justice* (democratizing access to high-resolution climate data so all municipalities, regardless of their resources, could plan effectively), and *recognition justice* (acknowledging local contexts, such as the specific dynamics of the wildland-urban interface).
- **Quality, rigour, transparency:** The workflow moved from generalized European datasets to detailed national and local data. Transparently addressing the challenges of data interoperability and explicitly presenting modelling uncertainties to stakeholders ensured scientific rigor.
- **Precautionary approach:** Recognizing the severe consequences of under-preparing for climate impacts, the assessment incorporated worst-case scenarios (RCP8.5) and long-term horizons for specific analyses, particularly for infrastructure stress-testing, following direct requests from municipalities.

By interlocking the technical rigor of the CLIMAAX framework with an explicit Environmental Justice lens, this workflow evolves climate risk assessment from a passive data-exercise into an active tool for equitable governance. It shifts the paradigm from broad-scale exposure mapping to targeted, community-level vulnerability validation, empowering local authorities to safeguard both critical infrastructure and marginalized populations with equal precision.

2.1.5. Stakeholder engagement

The stakeholder engagement process for the CLIMAAX4CIRA project was structured as a continuous and iterative cycle, building upon the initial partnerships established during Phase 1. This momentum was sustained through an online technical consultation in November 2025, which reunited environmental technicians from all 11 municipalities, the CIRA coordination team, and researchers from the University of Aveiro. This session served to align methodological priorities, secure updated local data, and confirm the specific hazards and climate scenarios relevant to each municipal context, ensuring that the project's technical baseline remained grounded in territorial reality.

Throughout Phase 2, this formal momentum was supported by constant bilateral interactions. The CIRA coordination team and the University of Aveiro maintained an active dialogue with specific stakeholders as needed, ensuring that technical clarifications and data requests were addressed through direct, focused collaboration. This ongoing bridge between the project team and individual entities culminated in the regional in-person workshop held on May 28, 2026. This milestone gathered a wider group of regional actors—including civil protection authorities, infrastructure managers, tourism representatives, and environmental Non-governmental organizations (NGO)—to collectively validate the refined risk maps (Figure 2-1). During this workshop, project goals and intermediate results were presented, facilitating a direct dialogue that allowed attendees to cross-reference technical outputs with their territorial experience. Participants validated the identified risk hotspots as consistent with their empirical knowledge and identified significant potential for future integration into municipal workflows, such as the revision of Municipal Master Plans (PDMs) and the prioritization of physical interventions like forest fuel management and drainage infrastructure. Furthermore, discussions during this workshop highlighted critical themes for the region's long-term resilience, such as the economic impacts of climate risks on tourism and the combined effects of extreme precipitation, spring tides, and coastal erosion within the Ria de Aveiro system.

Figure 2-1 Regional in-person workshop (28 May 2026).

While this structured engagement proved highly productive, maintaining the continuous presence of all target entities required significant logistical effort. The synchronization of diverse professional schedules was a recurring challenge, as securing the participation of key representatives in pre-scheduled formal sessions demanded constant coordination. Nevertheless, the project team actively worked to broaden the engagement beyond these dedicated milestones; for instance, in February 2026, the project was presented at an Environmental Justice Conference held in Aveiro. Although the conference took place within a scientific framework, it served as a bridge to a wider audience, fostering an inclusive debate that brought together not only the academic community, but also various public and private stakeholders committed to addressing regional climate challenges.

2.2. Risk Exploration

2.2.1. Screen risks (selection of main hazards)

Following Phase 1 screening and robust stakeholder validation in Phase 2, the assessment retained its focus on five primary hazards: floods (river and coastal), extreme precipitation, heatwaves, droughts and wildfires.

The relevance of these hazards was overwhelmingly confirmed by the municipalities during the data request phase, with clear spatial divisions reflecting the territory's duality (e.g., floods dominating coastal concerns, wildfires dominating inland concerns). While stakeholders mentioned other emerging threats—such as strong winds, coastal erosion, and the combined effect of storm surges with spring tides—these were not fully modeled in the current workflows but were documented as critical cascading risks for future spatial planning and adaptation iterations.

The main development in this step is the systematic transition from regional hazard indices to high-resolution, asset-level exposure maps. The project currently possesses robust, localized datasets for these primary threats, including 50m downscaled flood-depth rasters and localized land-cover matrices. However, critical knowledge gaps remain regarding the vulnerability curves of specific critical infrastructure and socio-economic data at a higher resolution, which will provide significant information for the adaptation measures that will be the focus of phase 3.

2.2.2. Choose Scenario

The selection of future climate conditions was directly driven by municipal feedback, aiming to balance probabilistic planning with the need to protect long-term infrastructural investments:

- **Future Climate Scenarios:** The assessment considered both the RCP4.5 (intermediate emissions) scenario, which represents a stabilization pathway useful for medium-term societal adaptation, and the RCP8.5 (high emissions) scenario. The inclusion of RCP8.5 was explicitly requested by municipalities (such as Ovar and Albergaria-a-Velha) as a precautionary stress-test for infrastructure, since under-dimensioning protective works (like drainage systems) carries a far higher socio-economic cost than over-dimensioning.
- **Time Horizons:** The analysis spanned short-term (up to 2040) and medium-term (2041-2070) horizons, aligning with current municipal planning cycles. Furthermore, a long-term horizon (2071-2100) was adopted for specific hazards (such as extreme precipitation and sea-level rise) to evaluate the end-of-life resilience of major built assets and urban layouts. Socio-economic baselines (e.g., population distribution) were kept static based on the most recent census data to isolate and evaluate the pure climate signal on the territory.

2.3. Regionalized Risk Analysis

The transition from Phase 1 to Phase 2 was marked by a significant shift from European/national-scale datasets to localized, high-resolution inputs. This regionalization effort was largely supported by data provided directly by the 11 municipalities following the initial stakeholder consultation.

A key advancement in this assessment is the incorporation of high-resolution local parameters to capture fine-scale exposure dynamics. This was achieved by leveraging the Portuguese Land Cover dataset (COS) alongside a localized Digital Elevation Model (DEM) (Direção Geral do Território, 2026):

- **Spatial Exposure & Asset Characterization (COS):** Rather than treating the territory uniformly, the vector attributes of the COS dataset were used to categorize and isolate vulnerable land-use types. This allows the model to differentiate risk profiles across urban fabrics, industrial hubs, transport networks, and natural ecosystems.
- **Topographical & Terrain Context (DEM):** The DEM supplies the underlying elevation, slope, and aspect matrix. This terrain context is vital for validating the physical routing of hazards, such as constraining fluvial and coastal flood depths or determining fire-propagation vectors in the wildland-urban interface.

Integrating these parameters ensures that the final risk metrics are directly calibrated to the unique physical geography and socioeconomic layout of the municipalities.

2.3.1. Floods – finetuning to local context

2.3.1.1. River Floods

Grounded in the standard CLIMAAX River Flood framework, the hazard analysis utilized high-resolution hazard maps provided by the Joint Research Center (JRC). The spatial fidelity of the baseline workflow was significantly improved by incorporating COS 2025 vector layers to represent localized land-use distributions, while the Global Administrative Areas (GADM) layers were implemented to define municipal administrative boundaries across the study area.

Table 2-2 Data overview for river floods workflow.

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Joint Research Center (JRC) flood map dataset	Geographic Information Reference Database (BGRI21) (Instituto Nacional de Estatística, 2021)	Portuguese Land use Dataset 2025 (COS 2025) (Direção Geral do Território, 2026)	Spatial distribution analysis of projected river flood economic damage (Millions of €/cell) comparing RCP4.5 and RCP8.5 emissions scenarios for 2030, 2050, and 2080
	Directorate-General for Transport (DGT) - Road Network (Direção Geral do Território, 2026)	Global Administrative Areas (GADM) (GADM, 2026)	
	Buildings	LUISA Basemap 2018	

2.3.1.1.1. Risk assessment

Following the hazard assessment — which leveraged COS and GADM datasets to refine the spatial representation of the study area—exposure and risk maps were developed as a core component of the risk assessment. In this phase, localized population statistics (BGRI), road networks, and building footprints were integrated to quantify asset and community exposure to river flooding. These layers directly informed the calculation of the Damage Magnitude (Figure 2-2) across RCP4.5 and RCP8.5 pathways for the 2030, 2050, and 2080 time horizons. This methodology yielded an integrated asset exposure dataset that was subsequently synthesized into a Composite Climate Risk Score, successfully isolating high-risk areas concentrated around the Aveiro Lagoon.

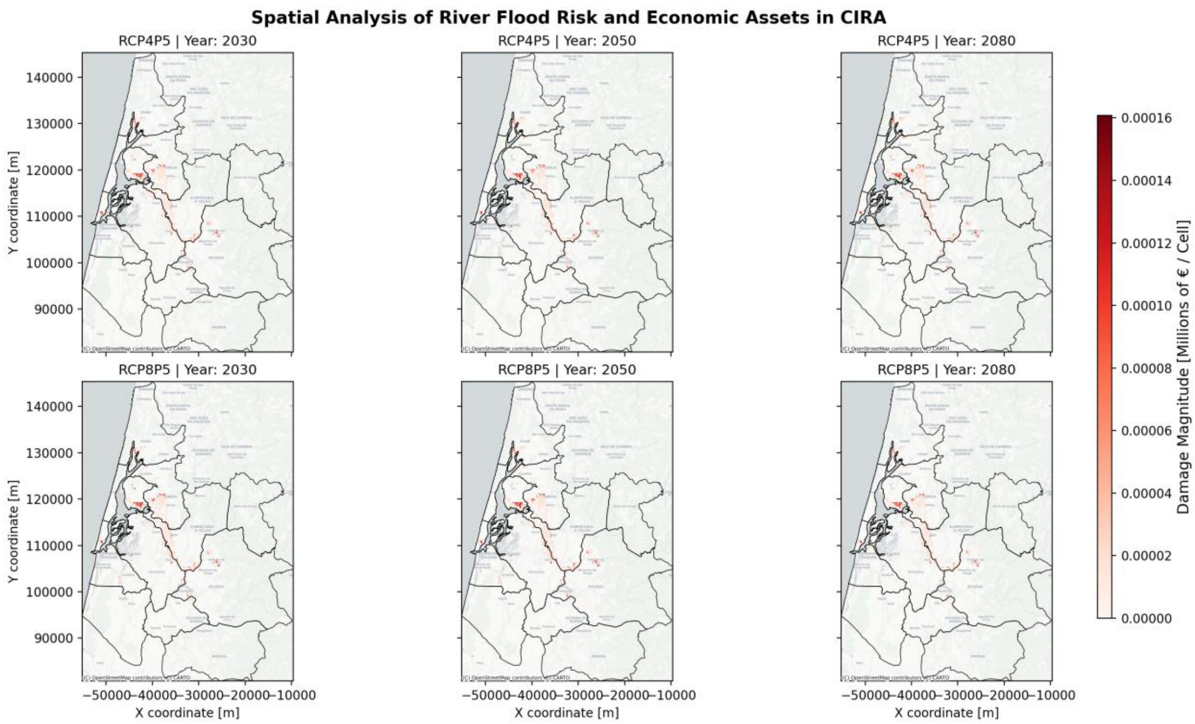

Figure 2-2 Spatial distribution analysis of projected river flood economic damage (Millions of €/cell) comparing RCP4.5 and RCP8.5 emissions scenarios for 2030, 2050, and 2080.

2.3.1.2. Coastal Floods

Following the same methodological approach, the coastal flood hazard analysis adapted the standard CLIMAAX framework using high-resolution JRC mapping data. This workflow mirrored the river flood enhancements by integrating COS 2025 vector layers and GADM administrative datasets, ensuring that localized land-use patterns and municipal boundaries were captured with identical spatial fidelity.

Table 2-3 Data overview for coastal floods workflow

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Global Flood Maps dataset	Digital Elevation Model (MERIT-DEM) (Direção Geral do Território, 2026)	Portuguese Land use Dataset 2025 (COS 2025) (Direção Geral do Território, 2026)	Coastal flood damages for extreme sea water level scenarios
		LUISA Basemap 2018	Coastal flood impact and context for year 2050
		Global Administrative Areas (GADM) (GADM, 2026)	

2.3.1.2.1. Risk assessment

The risk assessment framework maintained its alignment with the standard CLIMAAX workflow, but was significantly enhanced by integrating updated Maximum Economic Exposure Values for Portugal, derived from Statistics Portugal (INE) (Instituto Nacional de Estatística, 2023). By combining these baseline economic metrics with COS 2025 and GADM layers, the spatial representation of vulnerable assets was highly refined. The resulting output, exemplified in Figure 2-3, illustrates the projected localized impacts of coastal flooding for the 2050 time horizon.

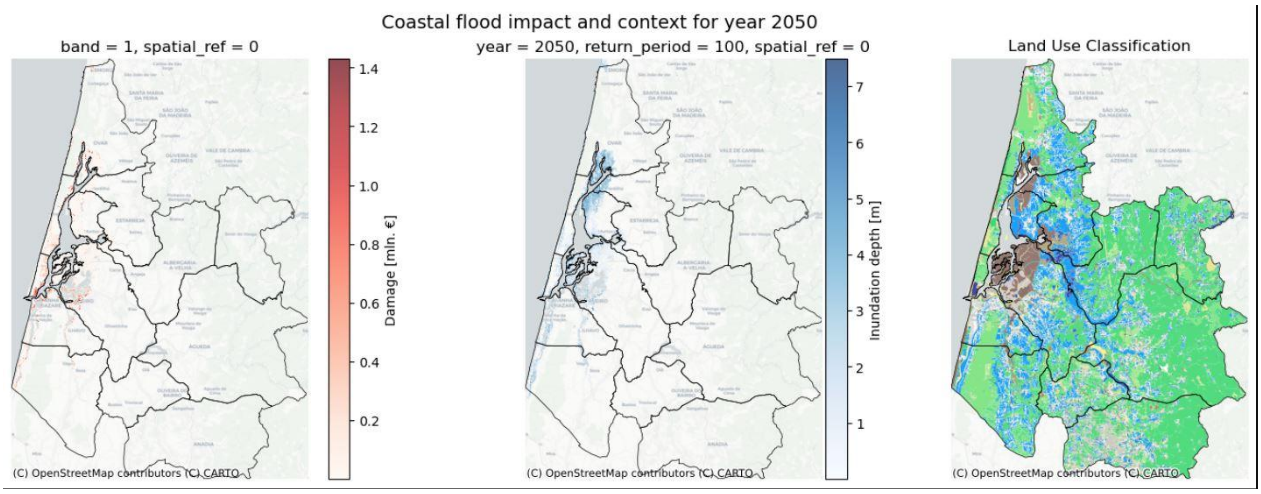

Figure 2-3 Composite panel displaying coastal flood damage, inundation depth, and associated land use classification for a 1-in-100-year return period event in the year 2050.

2.3.1.3. Flood Building Damage and Population Exposed

Similarly, the hazard analyses for Flood Building Damage and Population Exposed adapted the standard CLIMAAX framework using high-resolution JRC mapping data. This workflow mirrored the river flood enhancements by integrating COS 2025 vector layers and GADM administrative datasets, ensuring that localized land-use patterns, structural assets, and municipal boundaries were captured with identical spatial fidelity.

Table 2-4 Data overview for flood building damage and population exposed workflow.

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Joint Research Centre (JRC) CEMS-EFAS Flood Hazard dataset	Population Demographics, Geographic Information Reference Database 2021 (BGRI 2021)	Portuguese Land use Dataset 2025 (COS 2025) (Direção Geral do Território, 2026)	River Flood Maps for 10-50-100-500 year return periods;
	Open Street Maps (OSM) Building data (OSM, 2023)	Global Administrative Areas (GADM) (GADM, 2026)	Economic Damage to Buildings based on Mean Flood Depths
			Critical Infrastructure Exposure to River Floods
			Expected annual population exposed; Expected annual population displaced

2.3.1.3.1. Risk assessment

The risk assessment for this workflow underwent the most significant adaptations from the original foundation, which was initially restricted to a small, isolated pilot site. In this expanded iteration, the entire region of Aveiro was analyzed by scaling up the regional datasets for population, building footprints, and road networks using a processing pipeline similar to the baseline methodology.

However, expanding the geographical scale introduced a distinct analytical challenge: while the original small-scale workflow made it easy to isolate damage dynamics down to individual structures, these granular details are naturally lost when visualizing an entire region at once. To bridge this gap, a new spatial zooming function was implemented directly into the codebase. This tool allows users to input specific coordinates to instantly magnify a desired micro-location. As a result, the updated workflow successfully processes macro-regional data across the Aveiro district without sacrificing the ability to conduct high-fidelity, building-level impact analyses (Figure 2-4). The new improvements also increased the number of building classifications, allowing space in the code for more user input.

(a) (b)

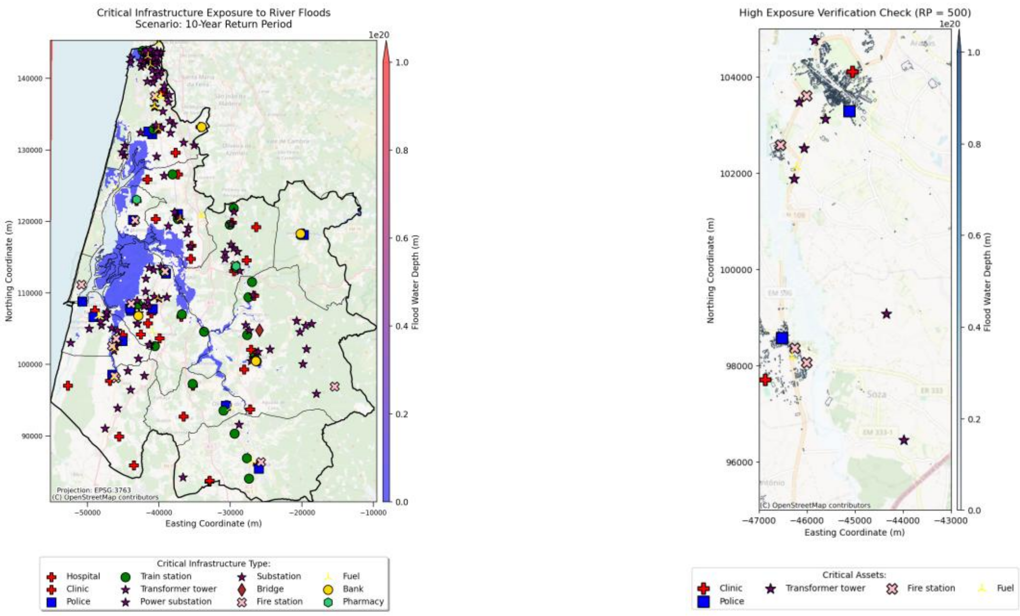

Figure 2-4 Critical infrastructure exposure map showing specific asset vulnerabilities (hospitals, schools, power stations, etc.) overlaid on a 10-year return period river flood hazard zone (a); High-exposure validation inset map checking specific vulnerable critical cluster locations for a 500-year return period flood scenario (b).

2.3.2. Heavy Rainfall – finetuning to local context

The Extreme Precipitation workflow underwent the most significant structural adaptations due to severe localized data constraints. Because it had the least amount of available data of all the workflows, its technical execution required an exploratory approach that departed substantially from both the other hazard modules and the default datasets provided in the original framework baseline.

Table 2-5 Data overview for heavy rainfall workflow.

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
CHELSA (Karger et al., 2017)	Digital Elevation Model (DEM) (Direção Geral do Território, 2026)	Portuguese Land use Dataset 2025 (COS 2025) (Direção Geral do Território, 2026)	Baseline Return Period for 70mm/24h Storms. Pure 1km Matrix — (1981-2011); Future Return Period for 70mm/24h

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
			Storms. Pure 1km Matrix — (2071-2100);
	DGT - Road Network (Direção Geral do Território, 2026)	Global Administrative Areas (GADM) (GADM, 2026)	Terrain Analysis Matrix; Surface Imperviousness; Topographic Wetness Index; Population Exposure and Socio-Economic Hotspots; Building Structural Vulnerability; Natural Water Retention Capacity; Critical Road Network Infrastructure Exposure
	Population Demographics, Geographic Information Reference Database 2021 (BGRI 2021)		Composite Vulnerability Index; Multi-Dimensional Pareto Analysis highlighting peak vulnerability areas.
	Open Street Maps (OSM) Building data (OSM, 2023)		

2.3.2.1. Risk assessment

This workflow utilized the CHELSA dataset as its foundational climate input. Daily precipitation data was analyzed for the historical baseline period (1981–2011), while monthly projections were implemented for the future horizon (2071–2100) using the MPI-ESM1-2-HR earth system model under the high-emission SSP5-8.5 scenario (Riahi et al., 2017). These datasets were leveraged to calculate the baseline return period for a 70mm/24h storm event — a threshold specifically calibrated to the climatological regime of the Aveiro Region. Because the variance between the historical and future precipitation frequencies was negligible (less than 5%) (Figure 2-5), the subsequent phases of the workflow were processed exclusively using the future climate projection dataset.

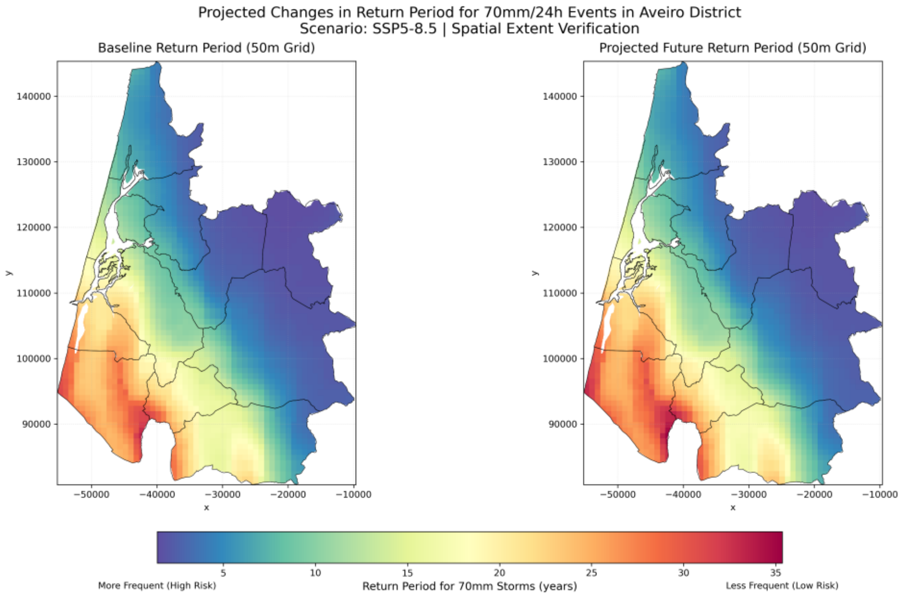

Figure 2-5 Side-by-side comparison of baseline vs. projected return periods (2071-2100) for intense 70mm/24h extreme precipitation events under the SSP5-8.5 climate scenario.

The remaining layers of the framework developed an integrated, six-dimensional vulnerability modeling pipeline. This network incorporated spatial indicators for Surface Imperviousness, the Topographic Wetness Index (TWI), Socio-Economic Vulnerability (SERI Index) derived from local population demographics and building census records, Structural Asset Exposure, Natural Retention Capacity, and Critical Road Infrastructure Exposure. Once normalized, these six diagnostic layers were synthesized using two distinct analytical methods to evaluate localized risk: i) a weighted linear combination (pondered aggregation) of the parameters, and ii) a multi-criteria Pareto frontier analysis (Figure 2-6).

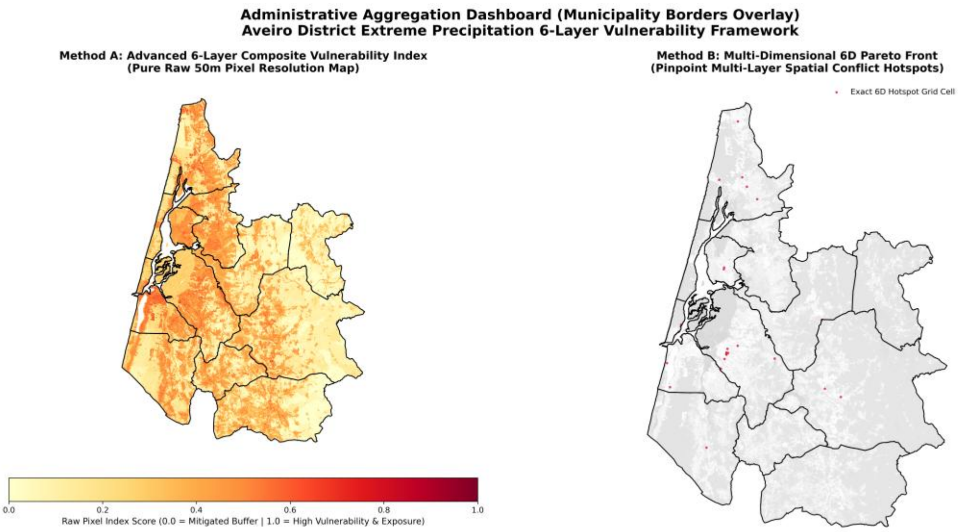

Figure 2-6 Comparison of climate risk assessment aggregation methods, showing an Advanced Composite Vulnerability Index map (Method A) alongside a multi-dimensional Pareto Front hotspot map (Method B).

2.3.3. Heatwaves – finetuning to local context

Building on the Phase 1 preliminary screening, the heatwave risk assessment for Phase 2 has been significantly refined through a transition to a high-resolution spatial framework. The approach shifted from the municipality-level analysis used in Phase 1 to a spatially explicit 50m grid analysis, enabling the identification of localized urban heat island (UHI) effects and precise vulnerability hotspots.

The EuroHEAT methodology was applied using downscaled temperature projections from EURO-CORDEX under RCP4.5 and RCP8.5 (Jacob et al., 2014). Crucially, the exposure and vulnerability layers were recalibrated by integrating the COS 2025, which significantly alters the risk profile compared to the coarse, aggregated data used in the previous phase.

Table 2-6 Data overview for heatwaves workflow.

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Health-related dataset from EuroHEAT: European and national heat spells (1986–2085, RCP4.5 and RCP8.5)	Geographic Information Reference Database (BGRI21) (Instituto Nacional de Estatística, 2021)	Portuguese Land use Dataset 2025 (COS 2025) (Direção Geral do Território, 2026)	Magnitude of the potential projected increase of the heatwave occurrence
EURO-CORDEX temperature projections (short and mid-term; RCP4.5 and RCP8.5)			Classified regions by vulnerable population density
			Potential projected increase of the heatwave risk to vulnerable population groups

2.3.3.1. Risk assessment

The high-resolution 50m grid permits the pinpointing of exact neighborhoods and industrial zones where the combination of thermal stress and limited adaptive capacity (e.g., lack of green corridors, dense soil sealing) creates the highest risk. The assessment confirms that while coastal areas benefit from maritime thermal regulation, the inland municipalities - specifically Águeda, Anadia, and Sever do Vouga - exhibit severe localized hotspots. The integration of COS data revealed that areas previously classified as "moderate risk" in Phase 1 are, in fact, highly vulnerable due to their specific surface coverage and lack of shading infrastructure, highlighting the necessity for targeted urban greening interventions in these specific 50m cells (Figure 2-7, Figure 2-8, and Figure 2-9).

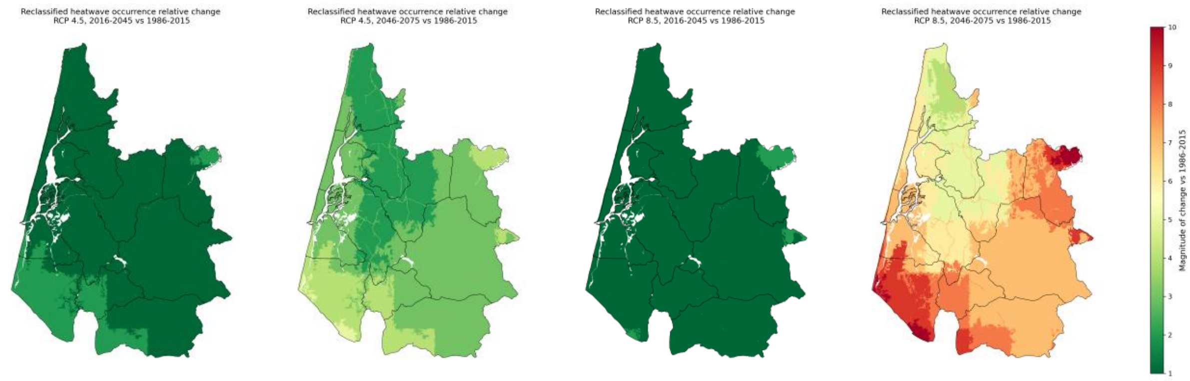

Figure 2-7 Magnitude of the potential projected increase of the heatwave occurrence, from 1 to 10 (1-very low change, 10-very high change), for the short- (2016-2045) and mid-term (2046-2075) future, under RCP4.5 and RCP8.5.

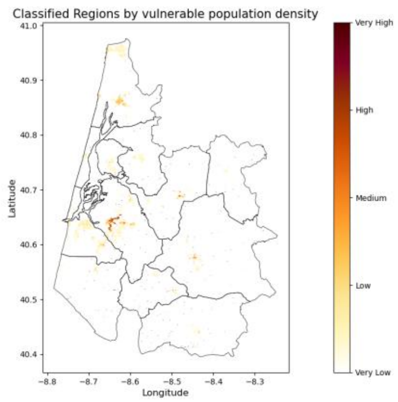

Figure 2-8 Classified regions by vulnerable population density.

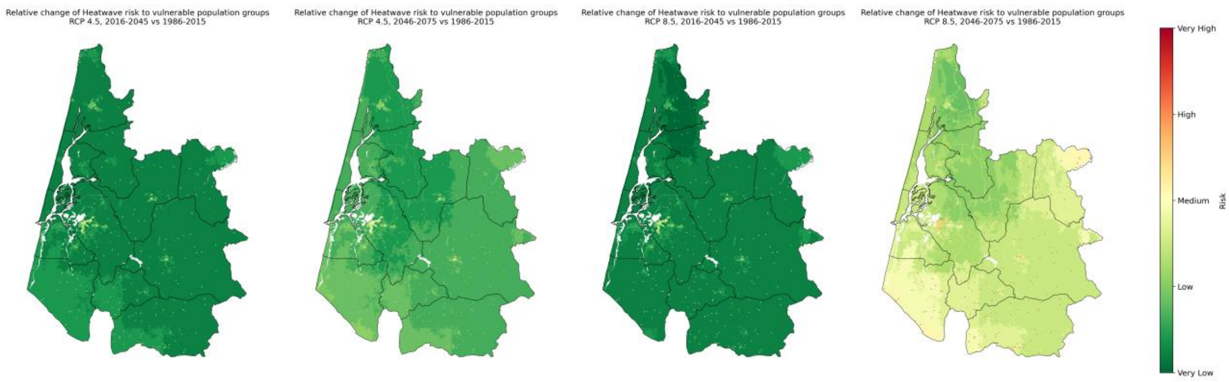

Figure 2-9 Potential projected increase of the heatwave risk to vulnerable population groups, for the short- (2016-2045) and mid-term (2046-2075) future, under RCP4.5 and RCP8.5.

2.3.4. Drought – finetuning to local context

The agricultural drought workflow has been completely overhauled for Phase 2. By adopting the uniform 50m grid framework used across all CLIMAAX4CIRA workflows, agricultural vulnerability has been successfully aligned with local hydrological and soil characteristics. The key methodological advancement is the integration of the COS 2025 dataset, which provides the spatial granularity needed to separate distinct agricultural land uses that were previously generalized in Phase 1.

Table 2-7 Data overview for agricultural drought workflow.

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
EURO-CORDEX EUR-11 climate projections (MPI-SMHI) for future periods (2036–2065) under RCP8.5 scenario	Soil available water capacity	Crop distribution and economic value data (e.g., Global Agro-Ecological Zones (GAEZ), MapSPAM repository)	Revenue loss from precipitation deficit, in thousand euros
Precipitation deficit leading to yield loss in key regional crops	Share of cropland with irrigation systems	Land use Dataset 2025 (COS 2025) (Direção Geral do Território, 2026)	
	Thermal climate zone		
	Elevation		

2.3.4.1. Risk assessment

By mapping the drought hazard onto the 50m COS grid, it has been identified that revenue loss is not uniformly distributed across the region, but highly concentrated in specific agricultural clusters. The analysis indicates that potato and rice crops face critical risks, exacerbated by projected precipitation deficits under RCP8.5. Unlike the Phase 1 results, which provided a general overview of agricultural impact, the Phase 2 assessment using COS 2025 identifies specific vineyard plots in the Bairrada region that, due to high-value crop type, exhibit higher economic vulnerability than surrounding areas. This precision enables the identification of specific agricultural zones where immediate investment in drought-tolerant varieties and improved irrigation efficiency will yield the highest return on adaptation efforts (Figure 2-10).

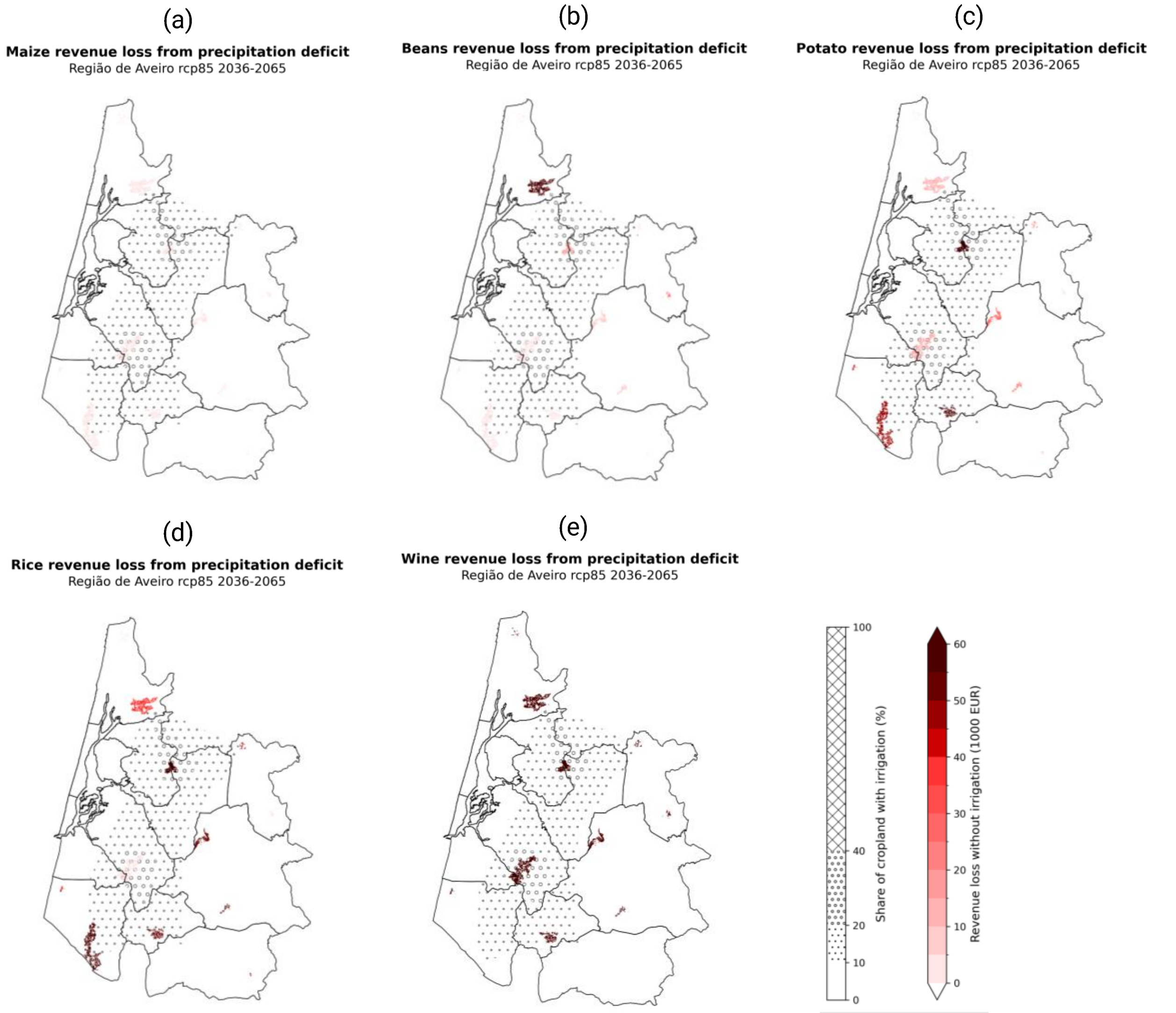

Figure 2-10 Maize (a), beans (b), potato (c), rice (d) and (e) wine revenue loss from precipitation deficit, for the period 2036-2065, considering the RCP8.5 scenario.

2.3.5. Fire – finetuning to local context

The Wildfire workflow was completely overhauled from its original foundation. In this updated iteration, the Fire Weather Index (FWI) was generated within the hazard module and downscaled onto a high-resolution 50m grid. In the risk module, this index was integrated alongside COS 2025 and other localized datasets, culminating in the development of a comprehensive composite indicator that simultaneously accounts for hazard, vulnerability, and exposure dynamics.

Table 2-8 Data overview for fire workflow.

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Copernicus Climate Data Store (Copernicus CDS, n.d.)	Digital Elevation Model (DEM) (Direção Geral do Território, 2026)	Portuguese Land use Dataset 2025 (COS 2025) (Direção Geral do Território, 2026)	Combustibility Index; Danger Index; Topographical Index;

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Open Street Maps (OSM) - Fuel Types (OSM, 2023)	DGT – Road Network (Direção Geral do Território, 2026)	Global Administrative Areas (GADM) (GADM, 2026)	Human Vulnerability Index; Parcel Fragmentation Index; Economic Vulnerability Index;
	Open Street Maps (OSM) Building data (OSM, 2023)		Fire Department Access Time
	Portuguese national land registry (BUPI) (Portugal. Estrutura de Missão eBUPi, n.d.)		Pareto Analysis highlighting highest risk locations

2.3.5.1. Risk assessment

For the wildfire risk assessment, a comprehensive composite index was engineered by systematically combining hazard, exposure, and vulnerability layers. This multi-criteria framework was structured as follows:

- Hazard Characterization: Synthesized by combining the downscaled FWI, historical burned area footprints (2-11.d), and three newly calculated sub-indexes: Combustibility (2-11.a), Topography (2-11.c), and Overall Danger (2-11.b) (Figure 2-11).
- Exposure Mapping: Calculated via an Ignition Susceptibility Index, which maps the proximity and density of exposed road networks and building footprints.
- Vulnerability Assessment: Evaluated using a three-pronged approach comprising a socio-economic emergency risk index (SERI) derived from population demographics, a Parcel Fragmentation Index, and an Economic Vulnerability Index based on high-risk structural assets.

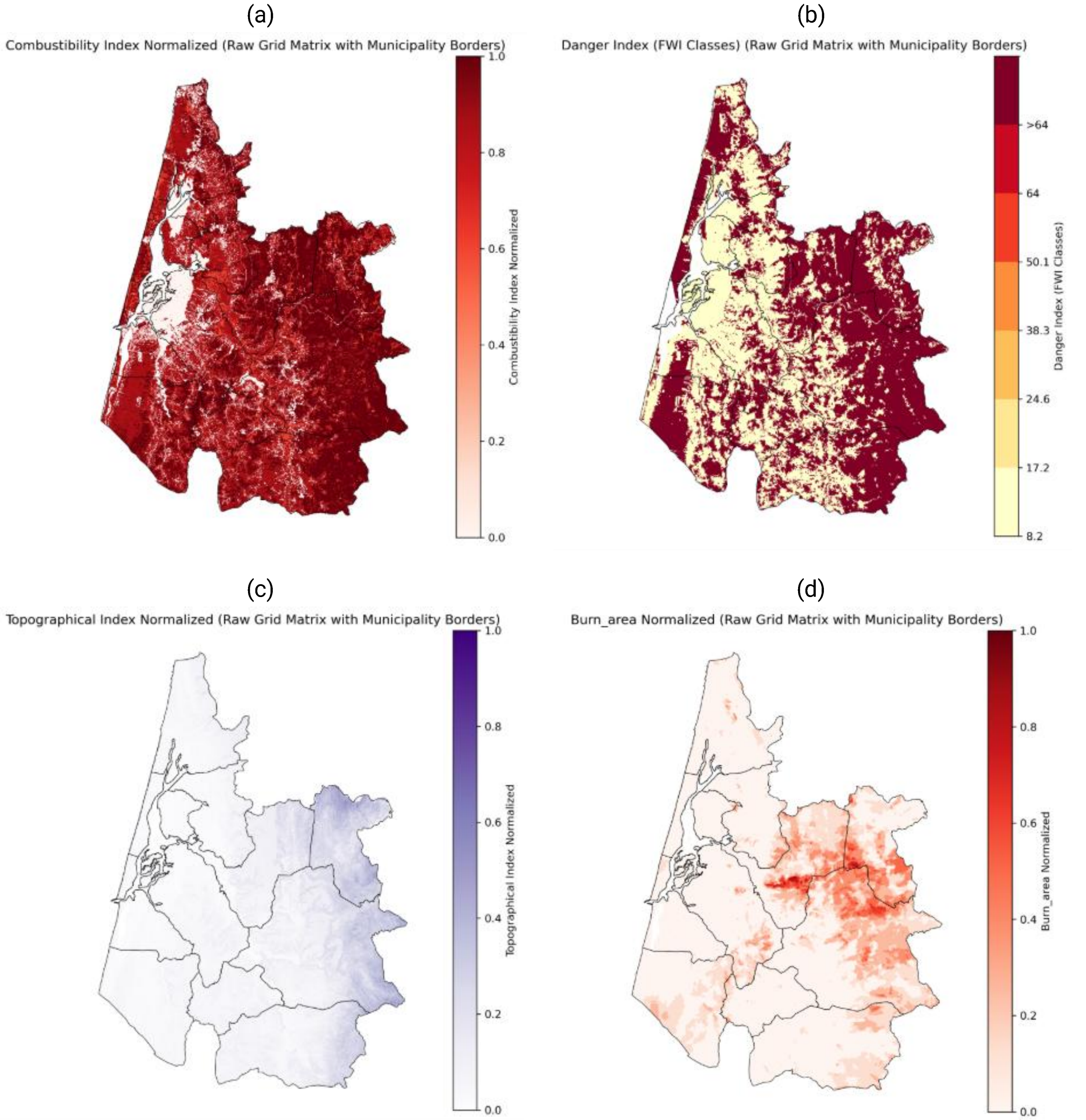

Figure 2-11 Normalized fire baseline risk matrices for the Aveiro region mapping Combustibility Index (a), Danger Index via FWI classes (b), Topographical Index (c), and Normalized Burn Area historical footprints (d).

To incorporate emergency response capacity, the cumulative vulnerability index was divided by an Access Time Factor, which accounts for the localized travel times required for fire departments to reach an ignition site (Figure 2-12).

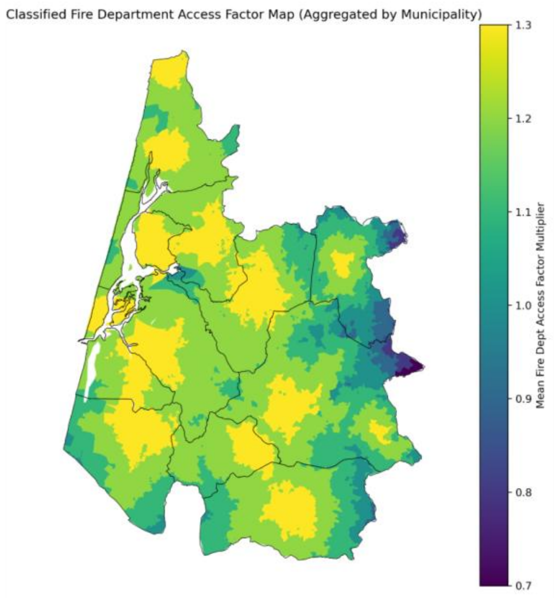

Figure 2-12 Regional multiplier map displaying classified fire department access factors aggregated across individual municipalities.

All underlying spatial datasets were aggregated onto a uniform 50m grid cell framework aligned with COS 25. Finally, in accordance with the baseline CLIMAAX framework, this integrated Fire Risk Indicator was synthesized and mapped using a Pareto Analysis configuration (Figure 2-13).

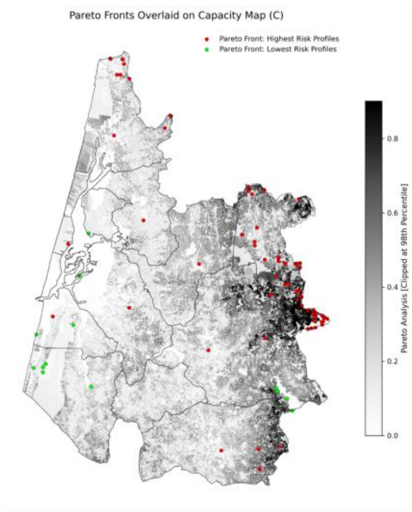

Figure 2-13 Advanced risk profiling map showing optimized Pareto Front indicators highlighting highest-risk (red) and lowest-risk (green) priority asset locations overlaid across a regional capacity backdrop.

2.4. Key Risk Assessment Findings

2.4.1. Mode of engagement for participation

The engagement process for the risk evaluation phase built upon the collaborative framework established in section 2.1.5, focusing specifically on transitioning from hazard identification to the collective interpretation of risk severity and urgency. During the regional workshop held on May 28, 2026, the engagement mode centred on a structured validation exercise where stakeholders—representing municipal technical services, civil protection, and regional infrastructure managers—interacted directly with the synthesized risk maps.

Rather than a top-down presentation, the session functioned as a participatory review where the technical outputs were scrutinized against the participants' empirical operational experience. This mode of engagement allowed for the qualitative weighting of the quantitative results; for instance, stakeholders were able to clarify why certain high-exposure areas identified in the modelling were considered a lower priority due to existing local adaptation measures, or, conversely, why specific "hotspots" in the mapping required immediate urgency despite appearing as moderate in preliminary analyses. The feedback gathered during this exercise was instrumental in calibrating how the results are represented, and the risk prioritization, shifting the focus from purely statistical exposure to the socio-economic reality of the Aveiro Region. By involving stakeholders in this interpretive process, the project ensured that the subsequent risk evaluation reflects a consensus between modelled climate data and the operational capacity of the local authorities responsible for risk management.

2.4.2. Gather output from Risk Analysis step

Risk evaluation utilized the main outputs generated in the Phase 2 Risk Analysis for the five priority hazards. This included the refined localized results and the new high-resolution risk indicators presented in Section 2.3, encompassing the primary hazard, exposure, vulnerability, and composite risk maps. These key results were compiled and used in the evaluation dashboard to support the structured scoring of severity, urgency, and resilience capacity.

2.4.3. Assess Severity

Severity was assessed for current (C) and future (F) conditions by cross-referencing the Phase 2 modelled hazard outputs with the empirical feedback gathered during the regional stakeholder workshop (May 28, 2026) and the strategic vulnerabilities identified in official regional and local planning instruments (e.g., PROT Centro, EIDT.RA 2030, and Municipal Climate Action Plans).

- **River Floods - current severity: moderate; future severity: substantial.** While major waterways present a known risk, stakeholders emphasized that the most pressing threat with the poorest current management is associated with flash flooding in small waterlines.
- **Coastal Floods - current severity: substantial; future severity: critical.** The mapping accurately reflects the chronic vulnerabilities of the region's estuarine system, particularly the *Baixo Vouga Lagunar* and the *Ria de Aveiro*. Regional and local plans corroborate that the coastal stretch of the region faces some of the most intense erosive processes in Europe, particularly in areas like Esmoriz, Torreira, and Costa Nova. The potential cascading effects include the degradation of natural habitats and the destruction of infrastructure supporting the blue economy and tourism.
- **Heavy Rainfall - current severity: moderate; future severity: substantial.** The evaluation revealed a divergence between macro-models and local perception regarding interior municipalities, where stakeholders experience worsening drought rather than increased

rainfall. Nevertheless, where it occurs, the risk remains a substantial concern due to the high likelihood of infrastructure collapse and road blockages. Local master plans and climate strategies point to the chronic issue of undersized municipal drainage systems struggling against increasing soil sealing, leading to severe localized urban flooding.

- **Heatwaves - current severity: limited; future severity: moderate.** The region's coastal geography and the mitigating effect of maritime breezes keep current impacts relatively contained compared to the deep interior. Stakeholders validated that extreme heat risk primarily falls on denser urban centres due to high population density and a marked deficit of green spaces, which exacerbate pathologies among vulnerable, isolated populations. However, the overall systemic impact on the region's economy and infrastructure remains moderate.
- **Drought - current severity: moderate; future severity: substantial.** The economic impacts of drought are tangible across the region's socio-economic fabric, leading to forced crop alterations, a reduction in horticultural zones, and income losses spanning agriculture, forestry, and nature-based tourism. Regional planning documents stress that drought impacts the ecological sustainability and water reserves of both the coastal and interior transition zones. This severity is pronounced given the projected economic losses for critical regional crops, including viticulture in the Bairrada demarcated region, which serves as a vital economic driver.
- **Fire - current severity: substantial; future severity: critical.** While stakeholders noted some spatial variations between the models and historical fire paths, the overall severity is perceived as critical. The immediate impacts of wildfires generate profound apprehension, particularly due to the extreme risk at the wildland-urban interface, which the PROT Centro identifies as the primary zone for property destruction and potential loss of life. The severity is aggravated by extensive monoculture forest areas and land abandonment, threatening the highly specialized agroforestry sector.

2.4.4. Assess Urgency

Urgency was assessed by analyzing whether hazards are sudden events or slow-onset processes, their projected near-term exacerbation, and the immediate operational gaps identified by stakeholders. This assessment was cross-referenced with regional and local planning instruments, (e.g., PROT Centro, EIDT.RA 2030, and Municipal Climate Action Plans).

- **River Floods - urgency: more action needed.** The sudden overflow of rivers and small waterlines creates imminent threats to local communities and basic infrastructure. To prevent these impacts, stakeholders and local plans demand specific structural interventions, notably the construction of water retention basins and flow regulation mechanisms. Adapting the vast network of small waterlines will require multi-year planning.
- **Coastal Floods - urgency: immediate action needed.** While sea-level rise is a slow-onset phenomenon, its compounding effect with spring tides creates immediate and devastating vulnerabilities, particularly along the coastal front and the delicate *Baixo Vouga Lagunar* system.

- **Heavy Rainfall - urgency: more action needed.** Extreme rainfall events are sudden and cause disruption. There is a need to update municipal urban planning to restrict and reverse soil sealing, actively alleviating the pressure on currently undersized municipal drainage networks before further infrastructure collapses occur. Overhauling urban drainage is a mid-term strategic necessity.
- **Heatwaves - urgency: watching brief.** Heatwaves are acute events projected to gradually increase in frequency. Given the region's coastal climate, conditions are relatively stable but require monitoring. Actions to mitigate urban heat—such as establishing green corridors and cooling shelters—are being planned proactively but do not constitute an immediate existential crisis requiring overnight intervention.
- **Drought - urgency: more action needed.** Drought is a slow-onset process, but its cumulative effects are already forcing crop alterations and causing severe economic losses. The required interventions—such as systemic shifts toward sustainable agricultural practices, forest management, and large-scale water efficiency improvements—require multi-year strategic planning and continuous investment.
- **Fire - urgency: immediate action needed.** Although wildfires are event-driven, the baseline conditions that fuel them are rapidly worsening. The direct and immediate impacts of wildfires on communities raise the greatest apprehension, given the rapid progression of these fires aggravated by moisture deficits and a lack of forest management. Stakeholders emphasized that there is an immediate, pressing need to execute a comprehensive forest land registry to enforce mandatory property cleaning and fuel management.

2.4.5. Understand Resilience Capacity

Resilience capacity was assessed by evaluating the region's existing institutional, financial, and physical frameworks to respond to climate risks. Overall, the Aveiro Region benefits from a robust governance model driven by over 30 years of intermunicipal cooperation and guided by the Integrated Territorial Development Strategy (EIDT.RA 2030). This NUTS III scale provides a substantial advantage in coordinating policies, accessing European funds (e.g., ITI - Integrated Territorial Investments), and implementing regional adaptation measures

- **River Floods - resilience capacity: medium.** Physical capacity remains challenged by aging local infrastructure and the complexity of managing the thousands of small waterlines that intersect urban areas without adequate maintenance.
- **Coastal Floods - resilience capacity: substantial.** The region has a strong institutional and financial foundation for managing coastal risks, spearheaded by large-scale intermunicipal initiatives such as the *Polis Litoral Ria de Aveiro*. The EIDT.RA 2030 explicitly allocates significant investments towards the integrated management of the *Ria de Aveiro* and coastal defence.
- **Heavy rainfall - resilience capacity: medium.** While the region has high institutional capacity to draft updated spatial plans (e.g., PDM revisions and Municipal Climate Action Plans that prioritize sustainable urban drainage and permeable surfaces), the physical capacity is currently strained. The historical undersizing of municipal drainage systems and the

extensive soil impermeabilization in coastal and central urban areas represent significant weak spots that require massive structural overhauls.

- **Heatwaves - resilience capacity: substantial.** Social capacity is strong, supported by regional health networks and inter-institutional collaboration programs addressing the aging population. Municipalities are proactively planning green infrastructure and shading in public spaces.
- **Drought - resilience capacity: medium.** The region possesses organizational capacity in the agricultural sector, supported by initiatives like the *Projeto Agrícola e Ambiental do Baixo Vouga Lagunar* and strategic funding aligned with the Green and Blue Economy. There is a concerted push towards circular economy practices and water reuse. The main weak spots are the heavy economic reliance on climate-sensitive crops (such as viticulture) and the disparity in water availability between the coastal lagoon areas and the more arid interior municipalities.
- **Fire - resilience capacity: low.** Despite an established regional civil protection structure and alignment with the National Integrated Rural Fire Management System (PRA Centro), the region's operational capacity to prevent fires is severely hampered by structural land issues. The predominant fragmented property ownership, high levels of land abandonment, and the absence of a complete forest land registry make it exceedingly difficult to enforce fuel management and create resilient forest mosaics.

2.4.6. Decide on Risk Priority

Risk priority was assigned by integrating the three evaluation dimensions—severity, urgency, and resilience capacity. The integration creates a realistic prioritization hierarchy that distinguishes between existential, immediate threats and those that are manageable or require longer-term adaptation. High severity, high urgency, and low capacity positively contribute to a higher risk prioritization, whereas lower severity, lower urgency, and higher capacity result in a lower risk prioritization.

Based on this multi-dimensional assessment, the final risk prioritization for the Aveiro Region is established as follows, and summarized in Figure 2-14:

- **Fire - Priority: Very High.** This represents the most critical vulnerability for the region. The combination of critical future severity, immediate urgency for action at the wildland-urban interface, and a distinctly low resilience capacity driven by structural land management deficits elevates this risk to the absolute maximum priority.
- **Coastal Floods - Priority: High.** Driven by critical future severity and immediate urgency regarding estuarine erosive processes. However, its position is positively modulated by the region's substantial resilience capacity, supported by robust intermunicipal frameworks like the *Polis Litoral*.
- **River Floods - Priority: Moderate.** The imminent threat of flash floods in small waterlines requires more action. With moderate current severity projecting to substantial and constrained by a medium physical resilience capacity, it represents a significant but manageable priority.

- **Heavy Rainfall - Priority: Moderate.** Requiring spatial planning interventions to reverse soil sealing, the risk projects to substantial severity. Given the medium capacity to systematically overhaul urban drainage, it is prioritized as a moderate risk requiring steady, mid-term investment.
- **Drought - Priority: Moderate.** Presenting substantial future severity for the primary sector, its slow-onset nature (classified as requiring more action) and the existence of medium adaptive capacity in agricultural and economic frameworks place it firmly in the moderate prioritization tier.
- **Heatwaves - Priority: Low.** Benefiting from the region's coastal climate, the severity is relatively limited to moderate. Combined with a watching brief urgency and substantial resilience capacity within the social and health sectors, this risk is prioritized as low, signifying that current mitigation trajectories are largely sufficient.

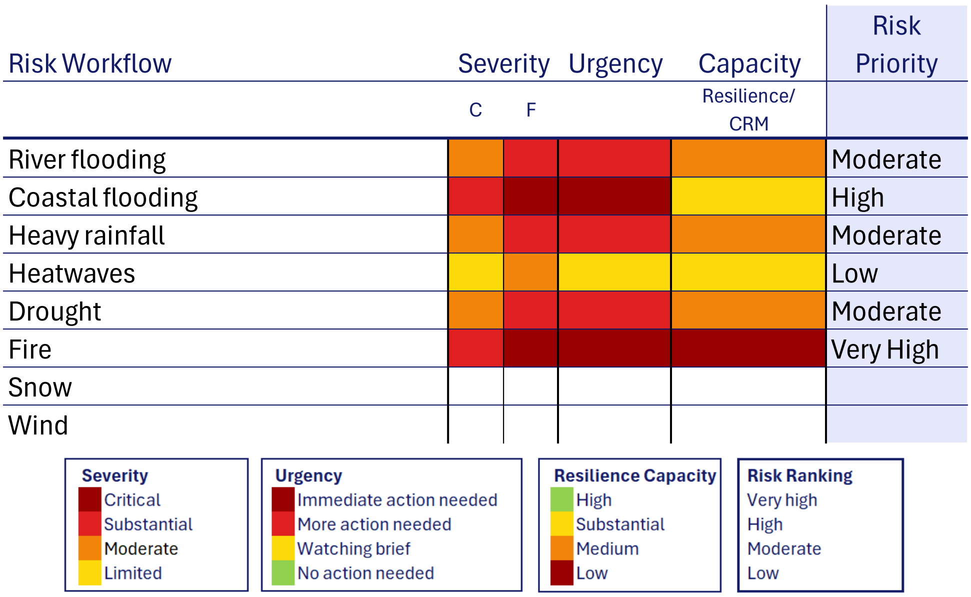

Figure 2-14 Key Risk Assessment.

2.5. Monitoring and Evaluation

The phase 2 of the CRA provided critical insights into both technical modelling and regional governance capacity within the Aveiro region. The process demonstrated that while macro-scale models offer a necessary baseline, they frequently overlook hyper-local vulnerabilities, such as flash flooding in small waterlines or the specific economic exposure of viniculture in the Bairrada region. Reconciling these local empirical observations with the rigid data thresholds of macro-models represented the primary difficulty encountered, requiring iterative adjustments to ensure the final prioritization remained grounded in the region's specific territorial reality.

Stakeholders acted as co-authors throughout the risk evaluation process, transitioning from observers to active validators. This engagement ensured the "social construction of risk," confirming that technical data serves its purpose only when it reflects immediate territorial concerns; consequently, the forest land registry was identified as the single most urgent policy outcome.

Learning is institutionalized through the integration of the evaluation dashboard into the CIRA governance structure. By embedding this assessment within the EIDT.RA 2030 strategy, risk outcomes are no longer viewed as static, but as evidence subject to continuous reassessment during future planning cycles.

Regarding data availability, while robust hazard data were secured, a critical need exists for higher-resolution soil sealing data and a completed national forest land registry to improve precision. Future iterations require more granular socio-economic data at the parish level to better quantify the vulnerability of isolated elderly populations. The communication strategy follows a multi-tiered approach: a technical synthesis for municipal planning departments and a simplified, interactive summary for local citizens to foster public awareness and engagement. The "Key Risk Assessment Dashboard" functions as the primary monitoring system, enabling the tracking of hazard severity shifts and the progress of Climate Risk Management (CRM) measures against identified priorities.

The participatory workshop proved to be the most effective element of the process in bridging technical and local knowledge Resource use was highly efficient, bolstered by existing intermunicipal cooperation, which accelerated stakeholder alignment. This institutional efficiency positively impacted the process by providing a solid evidentiary basis for future funding applications. Overall, the CRA process significantly improved institutional capacity, facilitating the transition from a fragmented view of hazards to a unified understanding of systemic risk in the Aveiro Region.

2.6. Work plan Phase 3

The final phase of the project (M16–M22) facilitates the transition from climate risk assessment to action-oriented planning, with the core objective of operationalizing the Key Risk Assessment findings into concrete resilience strategies for the Aveiro Region. This phase shifts focus from characterizing the nature and drivers of regional risks to determining the most effective strategies for mitigation and adaptation.

The primary activity involves the systematic integration of priority risks into regional and local planning instruments, including the EIDT.RA 2030 strategy and municipal master plans. Given the Very High priority assigned to Fire and the High priority assigned to Coastal Floods, these hazards serve as the primary drivers for this phase. Integration efforts will prioritize the deployment of the forest land registry and fuel management enforcement for Fire, and the alignment of coastal spatial planning with the region's erosive process management, particularly leveraging established frameworks such as the Polis Litoral. For Moderate priority risks, such as River Floods, Heavy Rainfall, and Drought, the work plan integrates urban drainage updates and agricultural sector strategies to ensure that all priority hazards are addressed proportionally to their urgency and severity. This approach provides an evidence-based justification for climate-resilient investment, embedding spatially explicit risk patterns into strategic planning and directing public funding toward high-priority areas.

To translate these findings into practice, a series of strategy-focused discussions will be conducted with key institutional stakeholders, including civil protection authorities, municipal technical departments, and agricultural associations. These sessions facilitate the co-design of feasible, high-impact adaptation measures, such as defining operational thresholds for emergency early warnings or designing decentralized water retention basins to manage flash floods in small waterlines. The outputs will include tailored policy-oriented products, such as recommendation documents for strategic integration and guidance for optimizing local intervention capacity. Concurrently, project results will be consolidated through the regional Climate Hub, an interactive platform designed to ensure transparent access to risk maps and data for all regional actors, thereby sustaining the project's legacy beyond its formal conclusion.

Detailed engineering designs for large-scale gray infrastructure and comprehensive, long-term economic cost-benefit analyses for major engineering works fall outside the scope of this phase, as these activities necessitate specialized engineering and investment-grade planning beyond the current mandate. The current work plan instead concentrates on establishing robust planning and governance foundations—such as policy alignment and operational preparedness guidance—that serve as essential prerequisites for such future implementations. By bridging the gap between technical risk identification and strategic policy development, this final phase establishes a sustainable mechanism for climate adaptation in the Aveiro Region, ensuring that adaptation measures are developed directly in response to the specific spatial and systemic vulnerabilities quantified in the Key Risk Assessment.

3. Conclusions Phase 2- Climate risk assessment

The second phase of the Climate Risk Assessment (CRA) for the Aveiro Region marks a significant evolution in the territory's approach to climate resilience. Building upon the initial risk screening performed in Phase 1, this phase successfully transitioned from a broad, indicative hazard overview to a precise, decision-oriented evidence base. The core achievement of this project stage was the systematic regionalization of the CLIMAAX workflows, which replaced generalized European-scale proxies with high-resolution regional datasets. This refinement allowed the project to move beyond abstract hazard mapping, resulting in a nuanced understanding of risk that reflects the unique physical and socio-economic geography of the region—ranging from the specific agricultural vulnerabilities of the Bairrada viticulture to the complex land-management issues within the forest landscape.

The key findings establish a robust risk prioritization framework that clarifies which hazards demand immediate intervention and which can be managed through longer-term, structural policy adjustments. Wildfire and Coastal flooding were identified as Very High priority risks, reflecting a combination of critical future severity and immediate urgency. These hazards represent the most significant threats to the region's stability, requiring immediate integration into emergency preparedness and spatial planning frameworks. A second tier of risks, comprising River flooding, Heavy rainfall, and Drought, were classified as High priority, highlighting the systemic need for spatial planning interventions, such as mitigating soil sealing and enhancing regional water retention capacity. Conversely, Heatwaves were categorized as Low priority; the analysis indicates that while heat stress is present, the region's coastal climatic moderation and existing social support structures provide a baseline resilience that renders current mitigation trajectories sufficient, provided that localized monitoring continues.

The assessment process successfully addressed several fundamental challenges that persisted after Phase 1. The primary success was the institutionalization of the risk assessment within the broader CIRA governance structure. By embedding the evaluation dashboard into the EIDT.RA 2030 strategy, the regional administration has bridged the traditional gap between academic climate modeling and administrative decision-making. This integration transformed the CRA from a static report into a dynamic tool that directly informs regional policy and investment. Furthermore, the participatory engagement model utilized during this phase succeeded in fostering a unified understanding of risk among fragmented municipal departments. The process effectively moved the regional discourse from a disjointed view—where individual hazards were managed in isolation—toward a systemic understanding of how climatic stressors propagate across sectors, impacting everything from infrastructure stability to public health and the economic viability of the primary sector.

Despite these significant advancements, several technical and structural challenges remain unaddressed, defining the boundaries of the current phase. The analysis identified an urgent need for higher-resolution soil sealing datasets and a finalized national forest land registry, both of which are required to further increase the accuracy of future risk modeling. Additionally, while the assessment provides a solid basis for policy design and strategic prioritization, it does not extend to the level of detailed engineering design for large-scale gray infrastructure. Complex cost-benefit analyses for major engineering works were also excluded from this mandate, as they require specialized engineering and investment-grade planning that typically follow the risk-informed design stage. These limitations are acknowledged not as failings, but as essential boundaries that define the scope for future implementation.

Ultimately, Phase 2 of the project has established the robust planning and governance foundations necessary for sustainable climate adaptation. By establishing a clear link between technical risk identification and strategic policy development, the region now possesses a sustainable mechanism for climate adaptation that functions well beyond the project lifecycle. The findings and prioritized actions defined in this phase provide the necessary roadmap for Phase 3, where the focus will shift toward the practical implementation of adaptation pathways, ensuring that the Aveiro Region remains equipped to face evolving climate realities with informed, equitable, and scientifically sound responses.

4. Progress evaluation

The progress achieved during Phase 2 has successfully transitioned the project from initial risk screening to a localized, decision-oriented climate risk assessment. By refining the CLIMAAX framework with high-resolution regional data, the project has established the evidence base necessary for targeted adaptation strategies. The tables below summarize the project's current status, detailing the achievement of key performance indicators and milestones as the project moves into the final implementation phase.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
1 workflow successfully applied in Phase 1	Achieved: 07/2025 (Phase 1)
1 workflow successfully applied in Phase 2	Achieved: 06/2026 (Phase 2)
1 climate risk assessment reports developed and shared with decision-makers	Achieved: 06/2026 (Phase 2)
2 stakeholder engagement activities conducted	Ongoing: 2 activities conducted (Phase 2: Online meeting - 11/2025; In-person workshop- 05/2026). Phase 3 session already scheduled for 09/2026.
3 communication actions taken to share results with local communities and the general public	Ongoing: 1 action conducted (Environmental Justice Conference - 02/2026). To be fully achieved by 12/2026 (Phase 3).
1 policy recommendations document produced based on project findings	Planned: To be achieved by 12/2026 (Phase 3).
1 scientific publication or dissemination activity related to the project outcomes	Ongoing: Methodological framework drafted. To be fully achieved by 12/2026 (Phase 3).

Table 4-2 Overview milestones

Milestones	*Progress*
M1: Subcontracting done	Achieved: 03/2025 (Phase 1)
M2: Attend the first CLIMAAX workshop held in Barcelona	Achieved: 06/2025 (Phase 1)
M3: CLIMAAX CRA successfully applied to Aveiro Region	Achieved: 07/2025 (Phase 1)
M4: Stakeholders meeting & dissemination of CLIMAAX CRA results	Achieved: 11/2025 & 05/2026 (Phase 2)
M5: CLIMAAX CRA successfully refined with Aveiro Region local data	Achieved: 06/2026 (Phase 2)
M6: Stakeholders meeting on adaptation options and local actions	Ongoing: Preparation initiated; planned for 09/2026 (Phase 3)
M7: Adaptation options and local actions successfully defined	Planned: To be fully achieved by 11/2026 (Phase 3)
M8: Attend the final CLIMAAX workshop held in Brussels	Planned: To be fully achieved by 12/2026 (Phase 3)

5. Supporting documentation

The spatial datasets, hazard maps, and composite risk visualizations generated during the Phase 2 Climate Risk Assessment for the Aveiro Region were uploaded to the official CLIMAAX GeoNode repository. The complete package of supporting geospatial files for the Aveiro Region can be accessed at the following link: https://climaax.kajoservices.com/catalogue/#/map/188

As a structural example of the repository's visualization capabilities, the final fire risk composite for the Aveiro Region is provided below (Figure 5-1).

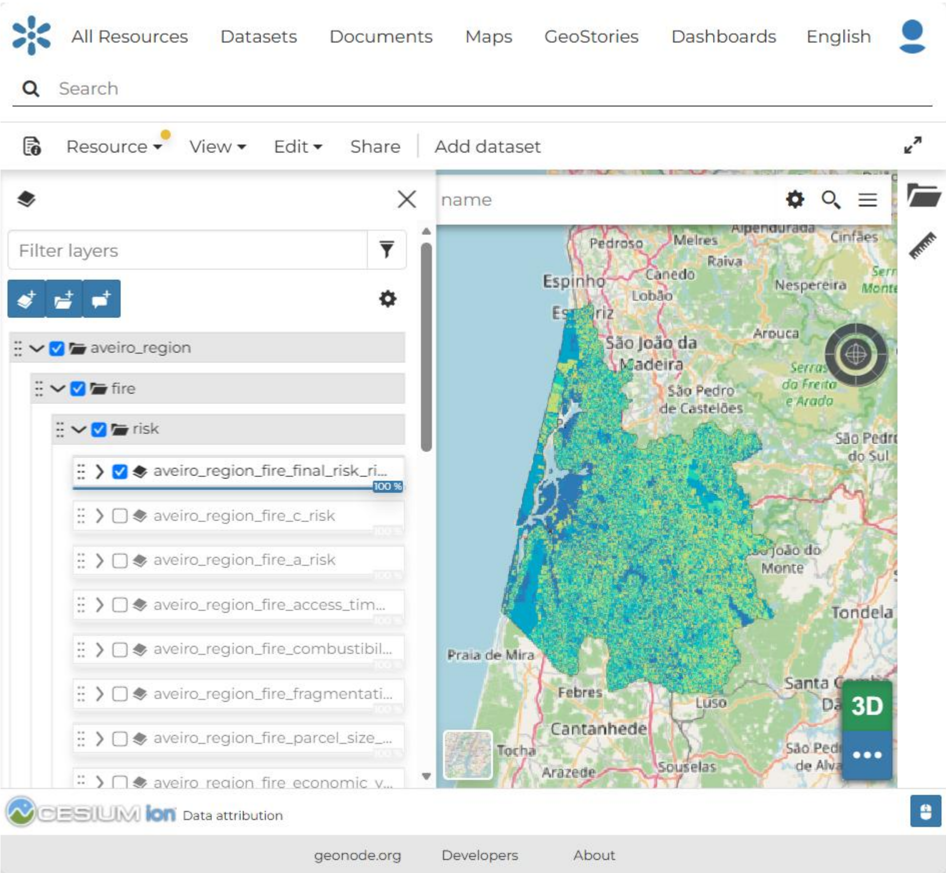

Figure 5-1 Example of the GeoNode interface displaying the final fire risk spatial distribution for the Aveiro Region.

Furthermore, the dissemination materials created during Phase 2 - including workshop materials, conference abstract and presentation, virtual regions forum presentation, and the CRA summary report for policymakers (in Portuguese) - were placed on the Zenodo open-access repository. These materials can be accessed at the following link: https://doi.org/10.5281/zenodo.21044405.

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