



Deliverable Phase 2 – Climate risk assessment

Multi-Risk Climate Assessment through the CLIMAAX Common Methodology Framework and Toolbox Towards Climate Resilience for the Leiria Region (CLIMAAX4Resilience)

Portugal, Region of Leiria

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Abbreviations and acronyms

Abbrev. / acronym	Description
AGIF	Agency for the Integrated Management of Rural Fires
ANEPC	National Emergency and Civil Protection Authority
APA	Portuguese Environment Agency
AST	Adaptation Support Tool
AWC	Soil Available Water Capacity
BGRI	Geographic Information Reference Base
CAOP	Official Administrative Map of Portugal
CIMRL	Intermunicipal Community of the Leiria Region
CLIMAAX	Climate Risk Assessment Framework/Project
CLIMAAX4Resilience	Multi-Risk Climate Assessment through the CLIMAAX Common Methodology Framework and Toolbox Towards Climate Resilience for the Leiria Region
CORDEX	Coordinated Regional Climate Downscaling Experiment
CORINE	Coordination of Information on the Environment (EU land cover)
COS	Land Use and Land Cover Map
CPI	Consumer Price Index
CRA	Climate Risk Assessment
GDP	Gross Domestic Product
DEM	Digital Elevation Model
DGT	Directorate-General for Territory
DRMKC	Disaster Risk Management Knowledge Centre
EAD	Expected Annual Damage
EAPD	Expected Annual People Displaced
FAO	Food and Agriculture Organization
FWI	Fire Weather Index
GAEZ	Global Agro-Ecological Zones
GHS-POP	Global Human Settlement – Population grid
GIS	Geographic Information System
GNR	National Republican Guard
GTSM	Global Tide and Surge Model
HR-DEM	High-Resolution Digital Elevation Model
ICNF	Institute for Nature Conservation and Forests
INE	National Statistics Institute
IPMA	Portuguese Institute for Sea and Atmosphere
IPSS	Private Institutions of Social Solidarity
ISRIC	International Soil Reference and Information Centre
JRC	Joint Research Centre
KPI	Key Performance Indicators
LiDAR	Light Detection and Ranging
LST	Land Surface Temperature
LUISA	Land Cover and Land Use Data
MCA	Multi-Criteria Analysis

Abbrev. / acronym	Description
NbS	Nature-Based Solutions
NUTS	Nomenclature of Territorial Units for Statistics
OSM	OpenStreetMap
PET	Potential Evapotranspiration
PGI / IGP	Protected Geographical Indication
PIAAC	Intermunicipal Climate Change Adaptation Plan
PMAC	Municipal Climate Action Plan
PMEPC	Municipal Emergency and Civil Protection Plan
POC	Coastal Zone Management Program
PSP	Public Security Police
REN	National Energy Networks
RCP	Representative Concentration Pathway
SMPC	Municipal Civil Protection Service
SPI	Standardized Precipitation Index
TWL	Total Water Levels
WUI	Wildland-Urban Interface

Executive summary

This report embodies the Climate Risk Assessment (Phase 2) for the Leiria Region, developed under the framework of the CLIMAAX4Resilience project. The core purpose of this document is to move from a macro-scale, indicative European assessment (Phase 1) to a high-resolution, operational territorial knowledge base. This transition is made urgent by the region's lived experience of climate extremes, from the 2017 wildfires to the 2026 storm-and-flood disaster. Its objective is to bridge the utility gap by providing the ten municipalities of the Intermunicipal Community of the Leiria Region (CIMRL) with the quantitative information needed for the operational updating of Municipal Emergency and Civil Protection Plans (PMEPC) and Municipal Climate Action Plans (PMAC).

The regionalized assessment focused on four priority climate hazards. The primary technical achievement of this phase was the widespread replacement of pan-European datasets with official Portuguese data, statistics and cartography, ensuring full integration with the territory's biophysical and socioeconomic reality.

- **Wildfires:** The transition to Machine Learning algorithms proved that hazard is structurally saturated by the production-forestry matrix – extreme-hazard classes already cover 41.1% of the region and rise to 47.1% under the end-of-century worst case (RCP 4.5). High-resolution mapping, empirically validated against close to 60% of the area burned in 1990–2023, captured human vulnerability at the wildland-urban interface (WUI), with extreme risk concentrated among the elderly population (38.6% at high risk) in inland mountainous municipalities.
- **Coastal Floods:** Physical downscaling based on LiDAR topography revealed with precision the deep estuarine intrusion along the Lis River floodplain and a severe risk of overtopping and damage across consolidated coastal urban fronts. Sea-level rise drives the signal, with end-of-century economic damage reported as a setup–runup envelope of €155.2M–€517.7M and annual population displacement along the western fronts.
- **Heatwaves:** The application of rigorous absolute thermal thresholds (IPMA: $T_{max} \geq 35^{\circ}\text{C}$ for ≥ 6 consecutive days; tropical nights $\geq 20^{\circ}\text{C}$), combined with satellite land-surface-temperature (LST) anomalies, revealed marked vulnerability among the most exposed demographic groups. The highest risk concentrates within urban heat islands over dense elderly populations and healthcare infrastructure in the urban cores of Leiria, Pombal, and Marinha Grande.
- **Droughts:** The agricultural model was recalibrated for the region's high-value, signature permanent crops (olive groves, vineyards, apples, and pears). The water deficit translated into direct revenue losses at the civil-parish scale of about €1.5M in total – a material but spatially dispersed pressure on the agroforestry economy, concentrated in the limestone interior.

The Climate Risk Assessment proves that the Leiria Region faces a tangible increase in the severity and frequency of extreme climate events. Crossing the hazard results with local vulnerability dictates that Rural Wildfires and Coastal Floods carry a Very High Priority, demanding immediate structural or engineering action and planning. Heatwaves carry a High Priority, driven by their silent impacts on public health; Droughts a Moderate Priority, given their material but spatially contained impact on the foundational economy. Beyond the individual figures, the assessment reveals the territory's defining risk signature: the priority hazards converge on two fronts – the exposed Atlantic coastline, where coastal flooding and sea-level rise concentrate population and assets, and the

forest–urban interface of the interior, where wildfire is structurally saturated – with heatwaves and droughts compounding both.

The subsequent Phase 3 of the project will focus on converting these spatial metrics into concrete strategies through a Multi-Criteria Analysis (MCA). This stage will enable the selection and prioritization of the most effective local adaptation measures for the region's municipalities, ensuring the effective mitigation of risks and consolidating the long-term resilience of the CIMRL.

1 Introduction

1.1 Background

Located in the center of mainland Portugal, the Leiria Region covers 2.449 km² across 10 municipalities (Alvaiázere, Ansião, Batalha, Castanheira de Pera, Figueiró dos Vinhos, Leiria, Marinha Grande, Pedrógão Grande, Pombal, and Porto de Mós) with a resident population of 286,752 (INE, 2021). The Intermunicipal Community of the Region of Leiria (CIMRL) coordinates strategic and territorial development across this region.

The Leiria Region's diverse landscape, stretching from mountains to the sea, exposes it to significant climate change impacts. National projections identify the region as highly vulnerable and a priority for climate adaptation. The most critical threats requiring priority action include an increased frequency and intensity of rural fires, heatwaves, droughts, water scarcity, extreme precipitation, and coastal phenomena (overtopping and erosion) exacerbated by rising sea levels.

The territory's exposure to climate extremes is not abstract. In June 2017, the wildfires that began in Pedrógão Grande and spread to neighbouring municipalities caused 66 deaths and burned over 45,000 hectares – the deadliest fire event in the region's recent history. Less than a decade later, in late January 2026, the region was again at the epicentre of disaster, this time of an opposite nature: storm Kristin, an explosive cyclogenesis classified by IPMA as the strongest on record in Portugal, struck with winds above 150 km/h and was followed by days of torrential rain that overflowed the Lis, forced evacuations, and inflicted severe damage across municipalities of the Leiria Region, leading the Government to declare a State of Calamity. Together – fire, and storm and flood – these two events bracket the breadth of the climate threat facing the Leiria Region and underline the urgency of a high-resolution, locally grounded risk assessment.

1.2 Main objectives of the project

Phase 2 of the CLIMAAX4Resilience project represents a central methodological evolution in the resilience strategy for the Leiria Region, transitioning from a macroscopic and generic hazard analysis to the construction of an operational decision-support capacity. The primary objective remains increasing the region's resilience to climate change by empowering local communities and promoting intermunicipal cooperation for a cohesive and sustainable response across the 10 municipalities that make up the territory.

In Phase 1, the use of European datasets provided a solid foundation for the multi-risk assessment but demonstrated spatial resolution limitations, proving insufficient for detailed planning at the level of local infrastructure and strategic assets. To overcome this gap in operational utility, Phase 2 focuses on the regionalization and physical calibration of the models, ensuring that climate projections are strongly anchored in the empirical and historical reality of the territory.

In this regard, the main objectives of this second phase center on transforming raw data into actionable information for risk management and the community, namely through:

- **Operational resolution increase:** Refining the scale of analysis (transitioning, for example, from a global 100-meter grid to 10-meter resolutions) by integrating high-resolution local data, such as High-Resolution Digital Elevation Models (HR-DEM), to ensure that hazard maps and susceptibility areas respect the actual morphology of the terrain and the complexity of the coastline.

- **Validation with historical evidence:** Replacing purely theoretical models with approaches validated against the region's actual history of occurrences. This is particularly critical in the Leiria Region for accurately mapping areas susceptible to rural fires, anchoring the analysis in the lessons learned from the tragic events of 2017.
- **Integration into municipal and regional planning:** Incorporating the refined results of the vulnerability and risk assessment into territorial management instruments. This highlights the revision and direct integration of data into the Municipal Climate Action Plans (PMAC) and the Municipal Emergency and Civil Protection Plans (PMEPC) of the 10 municipalities, as well as coordination with the Ovar-Marinha Grande Coastal Zone Management Program (POC) regarding coastal flooding and erosion phenomena.

The application of the CLIMAAX manual's methodological framework ensures that CIMRL adopts a common, harmonized, and transparent approach, which facilitates the comparability of the region's results and vulnerabilities at a European scale. The technical robustness and reproducibility of the CLIMAAX workflows will allow the technical teams from CIMRL and the municipalities to strengthen their capacities to update the climate database autonomously in the future.

In turn, the integration of local data and models brings immediate and tangible benefits: it allows for the development of adaptation strategies tailored to the region's extreme vulnerabilities. By focusing resources and refining the identification of the areas most vulnerable to the main hazards (rural fires, coastal flooding, heatwaves, and droughts), the assessment will provide evidence-based information capable of guiding regional planning, infrastructure investments, and long-term sustainability policies.

1.3 Project team

The internal team of CLIMAAX4Resilience project is composed of:

- Paulo Batista dos Santos has a background in Accounting and Administration (Business Management) and serves as the 1st Executive Secretary of CIMRL.
- Valério António has a degree in Geography and Regional Planning and a postgraduate degree in Geographic Information Systems. He is a senior technician at CIMRL, working in the areas of Planning, Geographic Information Systems, Environment, Transport, and Forests.

The supporting team (subcontracted – external support) of CLIMAAX4Resilience is composed of:

- Ricardo Almendra has a degree in Geography and Planning, and a master's degree in Geography, with a specialization in Spatial Planning and Management.
- Liliana Sousa has a degree in Biology-Geology and a master's degree in Geological Heritage and Geoconservation;
- Ana Rita Caldas has a degree in Biology-Geology and a master's in Biophysics and Bionanosystems.
- Andreia Mota has a degree in Geography and Planning, a master's in Geography with a specialization in Spatial Planning and Management, and an executive postgraduate degree in Geographic Information Systems.
- Helena Corrêa has a degree in Agronomic Engineering and a master's in Environmental Science and Technology, specializing in Environmental Monitoring and Remediation.

- Manuel Miranda has a degree in Civil Engineering (Spatial Planning Option) and a postgraduate degree in Spatial Planning, Urbanism, and Environmental Law, with a specialization in Municipal Engineering.
- Rosa Silva has a degree in Education and a master's in Management Studies.

1.4 Outline of the document's structure

This document, the Phase 2 Deliverable – Climate Risk Assessment, is organized to clearly and comprehensively present the work developed and the results achieved during this stage of the project.

1. The report begins with an Executive Summary, which provides a complete and self-contained overview of the content, followed by Section 1: Introduction. This Introduction establishes the context of the project, describes the region under study, presents the main objectives, and details the team's composition.
2. Section 2 is the core of the document, focusing on the Phase 2 Climate Risk Assessment (CRA). This section is divided into sequential steps from the CLIMAAX Framework:
 - Scoping (2.1), reviewing objectives, governance context, and risk ownership organization.
 - Risk Exploration (2.2), which includes hazard selection and the definition of future scenarios (climate and socio-economic).
 - Regionalized Risk Analysis (2.3), detailing the fine-tuning of CLIMAAX workflows for selected hazards and the integration of local data/models.
 - Key Risk Assessment Findings (2.4), which describe the evaluation of Severity, Urgency, and Resilience Capacity for risk prioritization.
 - The Monitoring and Evaluation module (2.5) and the Work Plan for Phase 3 (2.6).
3. The report concludes with the Phase 2 Conclusions (Section 3), the Progress Evaluation (Section 4), which measures performance against key indicators and milestones, and the Supporting Documentation (Section 5), which lists all produced outputs. Section 6 presents the References used in the document.

2 Climate risk assessment – phase 2

2.1 Scoping

The scoping phase of the climate risk assessment encompasses the establishment of objectives (the intended outcomes of the analysis) and context (the conditions for its implementation), as well as the identification of stakeholders who are essential for the project's preparation.

2.1.1 Objectives

The CLIMAAX methodological approach is applied in accordance with its manual guidelines, following the recommended steps for climate risk assessment and utilizing the provided toolbox, which contains specific data for local and regional application.

The CLIMAAX4Resilience project delivers a set of outcomes designed to strengthen the capacity of the Leiria Region to face climate change challenges. Through the implementation of a common methodology, the project improves the identification and analysis of climate hazards, resulting in a more precise assessment of current and future vulnerabilities, and enabling effective comparisons with other European regions.

CLIMAAX will support informed and sustainable decision-making regarding climate action strategies and risk management. One of the most critical aspects will be integrating these assessment results into strategic planning instruments—specifically incorporating them into the Municipal Climate Action Plans (PMAC) and Municipal Emergency and Civil Protection Plans (PMEPC) across the 10 municipalities.

Despite recent efforts, the Leiria Region faces several hurdles regarding climate change adaptation and risk assessment, notably:

- **Data Gaps:** The lack of comprehensive, high-resolution data complicates local risk assessments.
- **Coordination and Policies:** Fragmented responsibilities hinder effective collaboration, and integrating climate adaptation into existing policies remains a complex task.
- **Financial and Awareness Constraints:** Limited funding impacts the implementation of measures, while low climate literacy reduces community engagement.
- **Technical Limitations:** Inherent uncertainties in climate models, coupled with legal and institutional barriers, can delay the adoption of measures aligned with emerging climate realities.

2.1.2 Context

The Mediterranean basin, which includes Portugal, faces significant climate vulnerabilities due to its transitional climate. The "National Roadmap for Adaptation 2100" classifies the Leiria Region as a high-priority area for adaptation to rural wildfires, coastal erosion, and coastal flooding/overtopping. According to the Disaster Risk Management Knowledge Centre (DRMKC) of the Joint Research Centre (JRC), the Leiria Region presents a vulnerability index of **5.34**, which is substantially higher than the European average.

The region encompasses a vast and diverse territory extending from the mountains to the sea, where urban and rural areas coexist. The most critical threats requiring priority action include the

increasing frequency and intensity of rural wildfires, heatwaves, droughts and water scarcity, extreme precipitation, and coastal phenomena exacerbated by sea-level rise.

The vulnerability of different sectors within the CIMRL (Intermunicipal Community of the Leiria Region) stems from their dependence on specific environmental conditions:

- **Agriculture:** Severely threatened by recurring droughts.
- **Forestry:** Faces an exponential increase in wildfire risk.
- **Coastal Infrastructure:** Subject to increasing pressures that generate spillover effects on tourism activities.

To frame local strategies, the Coastal Zone Management Program (POC) for Ovar-Marinha Grande serves as a fundamental instrument for the CIMRL, acting as a database and action framework to identify the exposure and vulnerability of both the built environment and coastal ecosystems.

2.1.3 Participation and risk ownership

In Phase 2 of the CLIMAAX4Resilience project, stakeholder engagement evolved from a purely informative process into a model of technical validation and active co-creation. This intensive participatory process is essential to ensure risk ownership and community involvement.

The primary actors are grouped across different levels of governance:

- **Regional Coordination:** The CIMRL acts as the coordinating entity and the strategic management body of the project.
- **Public Administration and Civil Protection:** The 10 municipalities of the Leiria Region (focusing on their Environment and Planning departments and their Municipal Civil Protection Services).
- **Economic Sectors and Civil Society:** Associations from the Agriculture, Forestry, and Tourism sectors, health and social solidarity institutions (IPSS), and school clusters.

Risk responsibility within the Leiria Region is shared. Identification and planning are spearheaded by the CIMRL and the municipalities (through the PMAC and PMEPC), while mitigation in the coastal zone is additionally guided by the POC.

At the operational level, response responsibility is held by the Municipal Civil Protection Commissions, firefighters, and health authorities. The level of acceptable risk will be determined through consensus-building with local stakeholders, balancing community expectations against the available adaptation resources.

2.1.4 Application of principles

The CLIMAAX4Resilience project actively integrates the fundamental principles of the CLIMAAX Framework throughout all stages of the Climate Risk Assessment (CRA), ensuring the analysis is technically robust, ethically informed, and socially responsible.

1. **Social Justice, Equity, and Inclusivity:** The process explicitly identified vulnerable and marginalized groups (such as elderly populations represented by IPSS, and children via schools) to ensure that the risk analysis addresses social vulnerability and territorial inequalities.

2. **Quality, Rigour, and Transparency:** A standardized, workflow-based methodology was adopted, supported by the calibration of local data. The commitment to transparency is fulfilled through the sharing of all reports, databases, and supplementary materials in the Zenodo repository.
3. **Precautionary Approach:** Applied to manage the uncertainties inherent in climate risks, prioritizing early action in the face of potentially irreversible damage (such as that experienced during the 2017 wildfires) by utilizing future climate scenarios (RCP 4.5 and 8.5).

2.1.5 Stakeholder engagement

Stakeholder engagement in the CLIMAAX4Resilience (CIMRL) project strategically progressed from a preliminary diagnostic phase in Phase 1 to a participatory model of co-production and technical validation in Phase 2. This process was designed to bridge the "utility gap" inherent in global analyses by integrating local technical and operational knowledge into the calibration and refinement of risk models. The Intermunicipal Community of the Leiria Region (CIMRL) and the GeoAtributo technical team adopted a multi-channel approach to mobilize strategic regional actors through structured interactions and continuous communication channels:

- **Consultative and Validation Session (15/04/2026):** An in-person working session held within the framework of the Sub-Regional Commission for Integrated Rural Fire Management of the Leiria Region, mobilizing 25 institutional representatives from central and regional administration bodies, municipal technical teams, security forces, civil protection, and concessioned infrastructure managers (Figure 2-1).
- **Direct Contacts for Data Integration:** Bilateral technical working meetings and direct contacts were established with partner entities to collect high-resolution operational geographic datasets (such as municipal mapping and historical incident logs), ensuring a robust calibration of the risk models.
- **News Publication and Dissemination:** News and updates regarding the progress of the CLIMAAX4Resilience project were periodically disseminated through CIMRL's institutional channels (website and social media) and its municipalities and close partner network, promoting transparency and public awareness of climate change.
- **Stakeholder Consultation Survey:** Implementation of a structured online questionnaire (via *Google Forms*) targeted at the members of the Sub-Regional Commission for Integrated Rural Fire Management of the Leiria Region and sectoral partners, gathering validated inputs from highly representative entities within CIMRL's territorial management ecosystem to validate risk perceptions and available datasets (Figure 2-2).
- **Dissemination and Dedicated Point of Contact:** Broad sharing of the Phase 1 Report (D1) and Newsletter #1 to establish a common baseline of technical knowledge, paired with dedicated data-sharing channels for integrating operational GIS datasets.

The stakeholder engagement and communication materials produced throughout Phase 2 are compiled as annexes to this report, documenting the participatory process and its dissemination: the Phase 1 results newsletter (Newsletter #1); the support presentation delivered at the consultative session; the session attendance list; and the Stakeholder consultation survey, together with the cover note circulated to participants following the session.



Figure 2-1 Stakeholder consultative session, Leiria, 15 April 2026.



Figure 2-2 Extract from the local stakeholder consultation survey

The composition of the participant panel reflected the multi-sectoral and institutional diversity required by the CLIMAAX methodology, linking national and regional strategic visions with local tactical expertise. The following actor groups were represented:

- Local Administration and Intermunicipal Cohesion:** Intermunicipal Community of the Leiria Region (CIMRL), alongside municipal technical teams (environment, spatial planning, and civil protection) from CIMRL's constituent municipalities (Leiria, Marinha Grande, Pombal, Batalha, Porto de Mós, Alvaiázere, Ansião, Castanheira de Pera, Figueiró dos Vinhos, and Pedrógão Grande).
- Central, Regional, and Sectoral Administration:** Institute for Nature Conservation and Forests (ICNF), Directorate-General for Territory (DGT), Agency for the Integrated Management of Rural Fires (AGIF) and the Portuguese Environment Agency (APA).
- Civil Protection Authorities and Security Forces:** Leiria Region Sub-regional Emergency and Civil Protection Command of the National Emergency and Civil Protection Authority (ANEPC), Municipal Civil Protection Services (SMPC), the National Republican Guard (GNR), and the Public Security Police (PSP).

- **Infrastructure Managers and Concessionaires:** Technical and safety representatives from Ascendi, REN (Redes Energéticas Nacionais) and E-Redes, essential for validating infrastructure exposure risks and fuel management strips.

The debate during the working session and the analysis of the survey responses generated structural insights that redirected the technical and methodological planning of Phase 2:

1. **Highlighting Priority Hazards:** Through open discussion, participants expressed a primary concern regarding **Rural Wildfires**, identifying them as the most evident physical and demographic challenges for public safety and local emergency planning in the region.
2. **Agricultural Gaps and Reorientation (Droughts):** During the exchange of views, it was noted that the initial focus on generic crops (such as maize) did not fully represent the diversity and economic weight of Leiria's primary sector. Stakeholders suggested including typical, high-value permanent crops, such as apples, pears, vineyards, and olive groves, which were subsequently integrated into the financial loss modeling.
3. **Overcoming the Theoretical and Coarse Nature of Global Models (Cross-cutting):** Stakeholders highlighted that the reliance on macro-scale pan-European datasets (~100 m to 25 km) generated purely "theoretical" maps with poor alignment to local on-the-ground realities. This shared diagnosis motivated a systematic refinement of the entire risk equation (Hazard, Exposure, and Vulnerability) by integrating high-precision national and local datasets.
4. **Critical Infrastructure Integration:** Stakeholder feedback emphasized the importance of assessing the impact of heat and fire hazards on key social facilities and transit networks (schools, nursing homes, hospitals, transport corridors). This led to the inclusion of a complementary exposure analysis for critical infrastructure and roads using OpenStreetMap spatial datasets.
5. **Mobilization for Geospatial Data Sharing:** The consultation successfully facilitated institutional data sharing. Key partners mobilized to make official datasets available.

The following table systematizes how the contributions and concerns raised by local actors were incorporated into the operational refinements executed in Phase 2 of the CLIMAAX4Resilience project:

Table 2-1 Stakeholder Engagement Impact

Phase 1 Limitation	Stakeholder Feedback	Phase 2 Improvement
Coarse models resolution	Need for high-resolution physical models to support local planning and Civil Protection actions.	Integration of high-resolution LiDAR Digital Elevation Models (DGT) downscaled.
Generic Land Use (CORINE) unsuitable for detailed characterization of wildfire hazards	Lacked precision for forest species fuel mapping and wildfire susceptibility.	Integration of national Land Use Map COS 2023 (DGT).
Drought workflow based on generic crops (maize, potatoes) of low regional relevance.	Requirement to integrate high-value, regional identity fruit crops.	Transition to the non-staple crop workflow, integrating real cultivated areas for apples, pears, vineyards, and olive groves (INE RA2019) and raw prices from EUROSTAT (2019–2024).
Uniform demographic vulnerability based on coarse global rasters (WorldPop).	Need to accurately locate isolated elderly populations and vulnerable residential pockets.	Replacement of WorldPop with official national census data at the statistical subsection level from the BGRI 2021 Censuses (INE).

Phase 1 Limitation	Stakeholder Feedback	Phase 2 Improvement
Absence of physical vulnerability assessment at individual asset scales.	Request to evaluate direct risks along transportation networks and critical infrastructures.	Creation of an infrastructure exposure layer evaluating buffers of 250 m around critical assets and 20 m along strategic road segments (OSM).
Theoretical Risks based on purely computational models and macro trends.	Request for real-world validation based on historical footprints and terrain reality.	Data-driven analysis (historical events) and validation practices in literature and official datasets.

The stakeholder engagement process faced three main difficulties:

1. **Methodological Translation:** The technical challenge of translating complex mathematical algorithms and global climate models (such as the machine-learning susceptibility model or TWL oceanographic forcing) into operational, clear, and interpretable language for policymakers and non-technical actors.
2. **Intermunicipal Coordination:** The logistical complexity of aligning schedules and availability across multiple municipalities and infrastructure concessionaires scattered across the Leiria Region, which prevented additional joint in-person workshops midway through the process, consolidating interaction at key sub-regional committee meetings and the online survey.
3. **Climate and Data Literacy Barriers:** Some cultural resistance in adopting probabilistic future climate projections over planning based solely on historical incident memory or traditional primary sector practices, requiring increased awareness-raising and capacity-building efforts in adaptive planning.

2.2 Risk Exploration

Risk exploration builds upon the scoping phase to analyze the climate hazards and risks most relevant to the context of the CIMRL. By integrating stakeholder perspectives with factual and empirical evidence from the region, this phase facilitates the selection of appropriate risk workflows and climate scenarios for the subsequent quantitative analysis.

2.2.1 Screen risks (selection of main hazards)

The Screen Risks stage in Phase 2 focuses on refining and substantiating the hazards previously identified in the Phase 1 report, in strict compliance with the CLIMAAX methodology guidelines. In Phase 1, the Leiria Region identified four crucial workflows for its risk assessment: **Wildfires, Droughts, Heatwaves, and Coastal Flooding**.

The primary development in Phase 2 is the confirmation and formalization of the priority assigned to these four hazards, which serve as the core focus of the Regionalized Risk Analysis (Section 2.3). This selection has proven robust as it covers the most critical spectrum of risks—including both slow-onset and rapid-onset events—within Leiria's territorial context, a region characterized by vast forest areas, intense agricultural activity, and an extensive, exposed coastline. To ensure a comprehensive multi-risk approach, no hazards were excluded during this phase.

These specific hazards were deemed priority and structural threats due to several interrelated factors:

- **Wildfires and Droughts:** Direct and severe impacts on the resilience of the region's core economic pillars: forestry and agriculture.
- **Heatwaves:** A systemic and growing threat to public health and urban mobility.
- **Coastal Flooding:** An unavoidable risk for low-lying coastal areas, heavily amplified by sea-level rise and the increased frequency of extreme weather events.

To scientifically validate and justify this prioritization, Phase 2 included a detailed exploration of the Copernicus Interactive Climate Atlas, whose evidence clearly reinforced the selection. The Atlas data confirms an upward trend in mean temperatures, alongside the frequency and duration of heatwaves. Additionally, projections indicate worsening drought severity and, consequently, an escalating wildfire risk driven by prolonged periods of water stress. The threat of coastal flooding was also confirmed as a rapidly accelerating risk due to global mean sea-level rise.

The major transition from Phase 1 to Phase 2 is the evolution from mere hazard "identification" to true risk "quantification."

The Regionalized Risk Analysis now demands the integration of high-resolution local data. This is achieved by incorporating detailed municipal exposure and vulnerability datasets—such as critical infrastructure inventories, fine-scale demographic and socioeconomic matrices, and high-precision Land Use and Land Cover mapping (COS)—ensuring that the final assessment is directly applicable to territorial planning and local resilience management.

2.2.2 Choose Scenario

The selection of scenarios for the climate risk assessment balances scientific rigor with the Precautionary Approach, ensuring that intermunicipal planning remains robust across different future emission trajectories and socioeconomic developments.

For Phase 2 of the CLIMAAX4Resilience project, reflecting the integration of high-resolution local models, the original baseline assumptions and time horizons were adjusted to the following configurations:

- **Wildfire (hazard and risk):** RCP 4.5 (intermediate scenario) and RCP 8.5 (high scenario) as future scenarios. Historical baseline 1991–2010 and two future 20-year windows: 2041–2060 (mid-century) and 2081–2100 (end-of-century), based on the regional climate model MPI-CSC-REM02009 (ECLIPS-2.0 dataset).
- **Coastal Floods (hazard, risk and damage):** RCP4.5 (intermediate scenario) and RCP8.5 (high scenario) as future scenarios, comparing the historical baseline with the future horizons of 2050 and 2100. The hazard maps are generated for return periods of 1-in-4, 25, and 100 years under a setup–runup uncertainty envelope; the risk, exposure and damage assessments focus on the worst-case end-of-century scenario (1-in-100-year, 2100).
- **Heatwaves (hazard and risk):** RCP4.5 (intermediate scenario) and RCP8.5 (high scenario). All the period available for historical data (1971–2000) and 2 future periods: 2016–2045 (near future) and 2046–2075 (mid-century).
- **Agricultural Droughts (hazard and risk):** RCP2.6 (low scenario), RCP4.5 (intermediate scenario) and RCP8.5 (high scenario) as future scenarios. All the period available for historical data and 3 future periods: 2026–2046 (near future), 2036–2065 (mid-century) and 2071–2090 (end-of-century).

RCP 4.5 and RCP 8.5 were selected to bracket an intermediate-mitigation and a high-emission future, in line with CLIMAAX guidance; RCP 2.6 was additionally explored for agricultural drought, where the dataset allows it. Time horizons and return periods follow the data availability of each workflow.

2.3 Regionalized Risk Analysis

Through the CLIMAAX methodological framework, risk analysis is operationalized as a quantitative estimation that intersects climate hazards with exposure and vulnerability data. In the current Phase 2 of the CLIMAAX4Resilience project, advanced implementation levels were adopted to adapt global and pan-European models to the territorial reality of the Leiria Region, ensuring significantly higher spatial and thematic precision and bridging the "utility gap" identified in Phase 1.

The regionalization strategy rested on three fundamental pillars of methodological refinement:

- **Spatial and Thematic Precision:** The analysis evolved from the global 100-meter scale to an operational 10-meter scale, supported by local High-Resolution Digital Elevation Models (HR-DEM) generated by LiDAR. The thematic precision was strongly reinforced by replacing the European CORINE database with the national Land Cover Map (COS 2023 - DGT), allowing for exact identification at the scale of buildings, agricultural plots, and forest typologies.
- **Socioeconomic Recalibration:** European economic damage functions were localized using a Regional Wealth Factor based on CIMRL's GDP per capita and updated to the Portuguese Consumer Price Index (CPI) of 2024. This calibration ensures that damage estimates reflect the actual reconstruction costs in Portugal.
- **Operational Impact Metrics:** Beyond economic losses, the analysis focused on human life protection metrics, such as Expected Annual People Displaced (EAPD), and on identifying failure points in access to critical infrastructure.

The following subsections detail the specific refinement applied to each of the four priority hazards (Wildfires, Coastal Flooding, Heatwaves, and Droughts).

2.3.1 Hazard #1 - Wildfires fine-tuning to local context

During Phase 1, the rural wildfire risk assessment in the Leiria Region relied exclusively on the meteorological Fire Weather Index (FWI). Although fundamental to understanding the temporal dimension of the hazard (seasonality and "when" fire-conductive conditions exist), the FWI features a resolution that is too coarse (~12 km) for municipal tactical planning.

In Phase 2, the workflow advanced substantially through the implementation of a Machine Learning model (a hybrid logistic-regression and monotonic gradient-boosting algorithm) for structural hazard mapping. This approach does not replace Phase 1, but rather complements it: it shifts the analysis from when wildfire weather occurs to where the territory has the highest physical propensity to burn.

To ensure that the modeling accurately reflects the Portuguese forestry reality and the region's wildfire history (namely the 2017 events), the European global datasets (CORINE) were replaced by the national Land Use and Land Cover Map (COS 2023), and the model was trained using the actual historical burned area data from the last three decades.

Key differences summary:

Aspect	Original Workflow	Enhanced Workflow
Analysis Focus	Temporal / Meteorological (FWI).	Structural / Territorial (Machine Learning Susceptibility).
Resolution	~12 km (EURO-CORDEX grid).	100m baseline modeling, anchored in high-quality DEM derived from DGT's LiDAR.
Land Use Source	CORINE Land Cover (generic).	COS 2023 - DGT (native, with more than 70 detailed thematic classes).
Fuel Classification	Generic European values.	Strict national calibration (Fuel Types 1-4) sustained by official Portuguese literature (CTI 2017/2018; ICNF).
Hazard Validation	Theoretical (climate projection).	Empirical: Validated against actual ICNF burned area polygons (1990–2023).

Key improvements include:

- **National Fuel Calibration (Fuel Types 1–4):** Replacement of uncalibrated European coefficients with an inflammability matrix validated by Portuguese technical literature. Maximum hazard value (Type 4) was assigned to the dominant critical classes in Leiria: Eucalyptus, Maritime Pine, and Shrublands.
- **Broad-Domain Training (Climate Signal Correction):** To prevent the algorithm from confusing climate with elevation (a structural error common in overly restricted models), the Machine Learning model was trained across a macro-regional domain (NUTS II North, Center, West, and Tagus Valley). This ensured that the model correctly learned to associate rising temperatures with an increase in hazard.
- **Empirical Validation (Ground-Truth):** The model proved its accuracy against real-world data. In the Leiria Region (where 40.5% of the territory burned between 1990 and 2023), the new High and Extreme hazard classes generated by the model represent 41.1% of the CIMRL area, yet they precisely capture 59.8% of all historically burned areas (a concentration ratio of 1.45x).
- **Common Baseline for Comparability:** Susceptibility was classified using identical thresholds (quantiles) across the entire training domain, guaranteeing that a "high hazard" designation in Leiria carries exactly the same meaning as a "high hazard" designation in any other region of the country, thereby eliminating statistical artifacts.

Table 2-2 Data overview workflow #1 – Fire

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
• Climate (CHELSA V2.1): Continuous bioclimatic variables MAT, MAP, and SHM (historical 1991–2010; RCP 4.5/8.5 scenarios for 2041–2060 and 2081–2100 horizons; MPI-CSC-REMO2009 model). • Orography (LiDAR DGT): Micro-topographic variables derived from the 100m national DEM: elevation,	• JRC Vulnerability (PESETA IV): European scale (~12.5 km) social, economic, and ecological sensitivity indices (reprojected to EPSG:3763). • Fine Population Vulnerability (BGRI 2021 - INE): Total residential density (inhabitants/km²) and elderly density (aged ≥ 65 years) processed at the scale of contiguous	• Land Use (COS 2023 DGT): Land cover (Series 2) clipped to NUT III and rasterized to 100 m (with non-burnable classes excluded). • Critical Infrastructure (OSM / Municipalities): Tactical inventory of georeferenced public utility assets classified into exposed typologies (healthcare, schools, fire stations, police,	• Continuous Susceptibility (0–1): Spatial probability of occurrence at 100 m generated by the corrected hybrid machine learning model (Logistic Regression Head + Monotonic XGBoost). • Discretized Hazard (1–6): Hazard classes resulting from the 3x4 contingency matrix (historical susceptibility frozen under wide-domain reference

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
slope, aspect, and terrain roughness. Fire History (Target): Official perimeters of cumulative burned areas from 1990 to 2023 (ICNF/DGT) for machine learning training, calibration, and empirical validation.	statistical subsections for the Leiria Region. Risk Structure: Contingency matrix crossing discretized hazard (1–6) with vulnerability classes (1–3), saturating at maximum risk class 5.	social facilities, mountain shelters, campsites, fuel stations). Road Network (OSM): road segments (primary, secondary, tertiary) with a 20m bilateral buffer to simulate fuel management strips.	quantiles [0.348 and 0.688] × 4 national Fuel Types). Area-Based Risk (Layer 1): Percentage (%) of area under severe population, economic, and ecological risk (Risk Classes 4 and 5) aggregated at the civil parish level. Infrastructure Risk (Layer 2): Identification and count of critical assets at high risk (buffer fraction of 250 m exposed to hazard ≥ 5, split into Low <25%, Medium 25–50%, and High >50%) and fine road network risk (1–5). Fine Population Risk (Layer 3): Exposure and risk of isolation of the elderly population (Risk Classes 4 and 5) aggregated and prioritized across the 73 civil parishes (CAOP DGT).

2.3.1.1 Hazard assessment

Hazard expresses the probability and intensity with which a grid cell will burn should an ignition occur. In Phase 2, this assessment results from combining a continuous structural susceptibility (calculated at a 100-meter resolution by a Machine Learning model) with the national fuel load mapped at 10 meters.

The major evolution compared to Phase 1 lies in the architecture of the predictive model. A hybrid algorithm was implemented — featuring a logistic regression head to guarantee climate extrapolation, coupled with an XGBoost model with monotonic constraints — fed by bioclimatic variables and topographic derivatives from the DGT's LiDAR model (elevation, slope, aspect, and roughness). To correct spatial confounding between climate and elevation (where temperature erroneously functioned as an inverse proxy for altitude), the model was trained across a broad domain (NUTS II North, Center, West, and Tagus Valley). This established a physically correct and positive temperature coefficient (Mean Annual Temperature [MAT] +0.606), ensuring that the model responds coherently to global warming.

The baseline susceptibility was crossed with the Land Use and Land Cover Map (COS 2023), whose classes were translated into the national fuel typology (Fuel Types 1 to 4), validated by Portuguese technical literature. The analysis revealed that the territory of the Leiria Region is structurally saturated: 85.6% of the area possesses continuous fuel load. The landscape is overwhelmingly dominated by critical fuels classified under maximum hazard (Type 4), namely Eucalyptus forests (26.3%), Pine forests (24.2%), and Shrublands (12.1%).

To capture the territory's true propensity, the model first generates Continuous Hazard maps. These maps identify the areas of highest structural tension, closely aligning with the burned-area footprint of the 2017 fires in the northern and northeastern parts of the CIMRL.

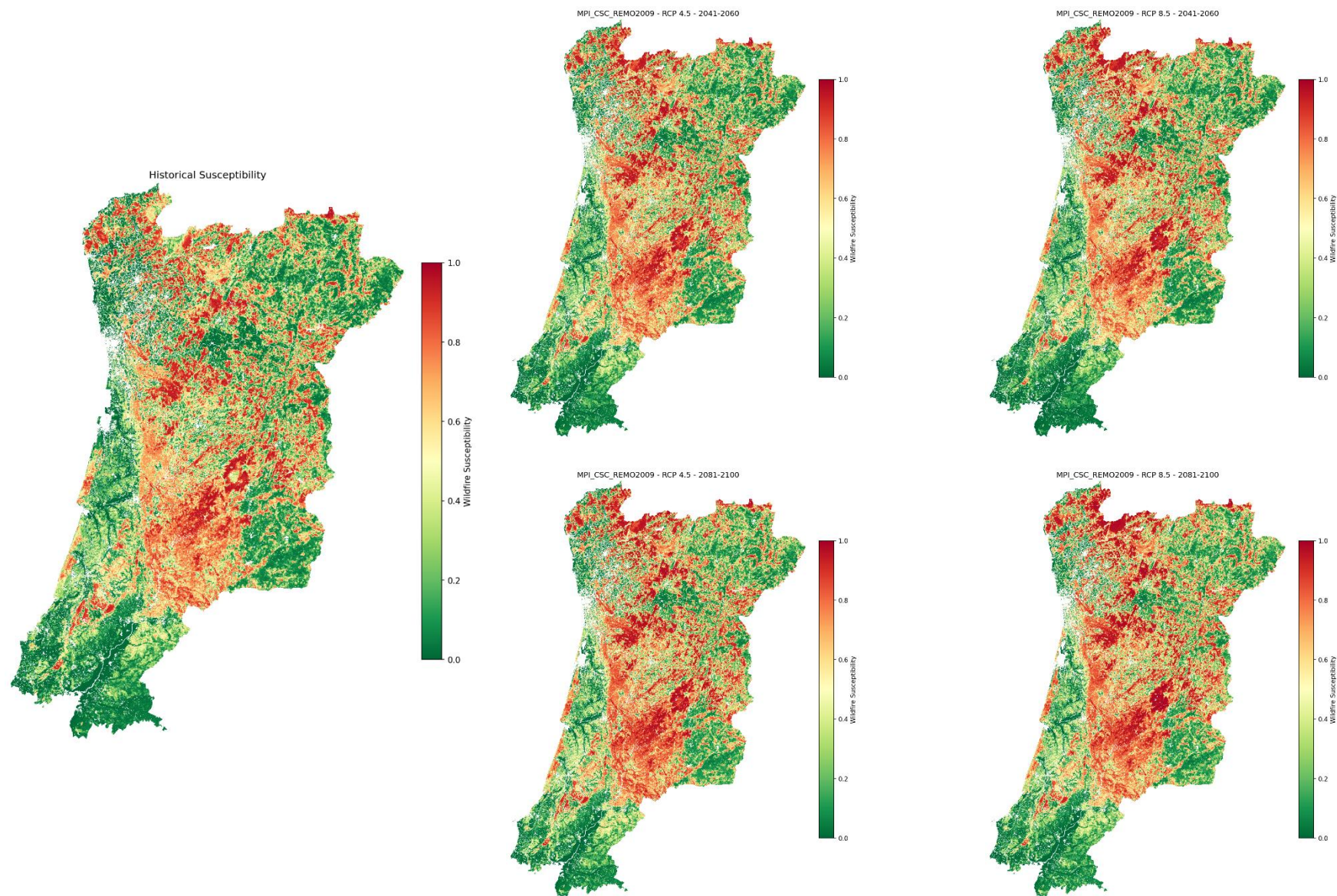


Figure 2-3 Wildfire structural susceptibility (continuous index, 0–1) across the model's training domain (NUTS II Norte, Centro and Oeste e Vale do Tejo): historical baseline (1991–2010) and four climate projections – RCP 4.5 and RCP 8.5, for 2041–2060 and 2081–2100 (regional climate model MPI-CSC-REMO2009).

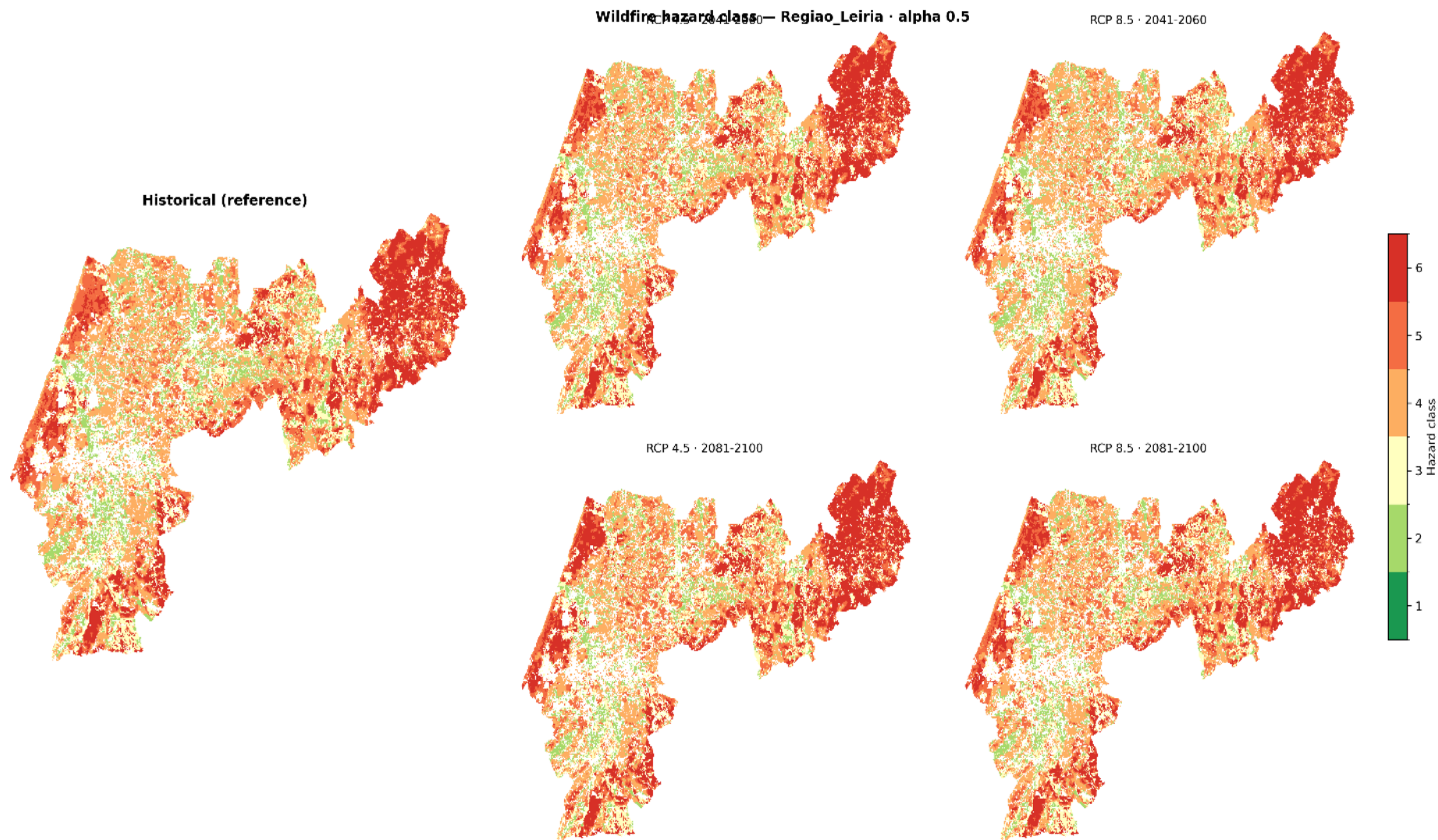


Figure 2-4 Wildfire hazard (discrete classes 1–6) for the Leiria Region: historical baseline (1991–2010) and four climate projections — RCP 4.5 and RCP 8.5, for 2041–2060 and 2081–2100 (regional climate model MPI-CSC-REMO2009).

The hazard results demonstrate a modest worsening across future scenarios, reflecting the coastal climate signature. Unlike the continental interior (which exhibits a severe escalation), the Leiria Region benefits from the Atlantic buffering effect: at the end of the century the high-hazard classes rise only modestly – from 41.1% of the area in the historical baseline to 44.7% under RCP 8.5 and 47.1% under RCP 4.5, an increase of between ~3.6 and ~6 percentage points. For this Atlantic territory it is the intermediate scenario (RCP 4.5 / 2081–2100), rather than the high-emission one, that represents the most adverse end-of-century outcome, and it is therefore adopted as the reference for the risk layers below. This indicates a hazard that is structurally high and persistent, driven primarily by the extreme continuity of forest fuel loads rather than abrupt long-term climate shifts.

2.3.1.2 Risk assessment

Risk results from the intersection, within a contingency matrix, of vulnerability/exposure (1–3) with hazard (1–6), generating risk classes from 1 (very low) to 5 (very high, saturated). It is reported through three layers of increasing detail; values refer to the reference scenario RCP 4.5 / 2081–2100, unless otherwise specified. The magnitude of the risk increases substantially compared to Phase 1 – a reflection of correcting the previous underestimation, which was confirmed by empirical validation against historically burned areas.

- **Layer 1 – Area-Based Vulnerability (JRC, ~12.5 km):** High classes affect 73.5% of the population, 63.7% of economic assets, and 50.4% of ecological areas. The baseline territorial risk of the CIMRL is structurally saturated due to the extensive land cover dominated by production forestry (eucalyptus and pine, which with shrublands make up ~63% of the area in the maximum-hazard Type 4 class). *Limitation:* The JRC index resolves very few distinct values across the entire CIMRL, lacking tactical detail.
- **Layer 2 – Infrastructure Exposure (10 m LiDAR):** The strategic road network faces high risk across 68.1% of its length (using a 20 m buffer), and critical assets (OSM, with classes adapted to the territory) are scored based on the percentage of a 250 m buffer falling within maximum hazard zones (≥ 5). Several assets experience worsening exposure under the future climate (145 facilities, notably 89 schools and 31 gas stations), with the municipalities of Leiria, Marinha Grande, and Figueiró dos Vinhos standing out as tactical priorities. This is the directly actionable product for Civil Protection.
- **Layer 3 – High-Resolution Population (BGRI 2021, 100 m):** The 10,517 INE statistical subsections replace WorldPop data; high risk affects 35.3% of the total population (half of the purely territorial risk projected in Layer 1, proving that the population resides in safer, consolidated urban cores). The elderly population (≥ 65) at high risk stands at 38.6%, reaching extreme values in the União das Freguesias de Castanheira de Pera e Coentral (89.9%).

Adaptation Priorities: Aged rural parishes in the mountainous and forested interior (Castanheira de Pera, Pedrógão Grande, Figueiró dos Vinhos), the top of this demographic ranking coinciding with the areas worst affected by the 2017 wildfires.

Limitations: The economic and ecological components of the JRC remain coarse (~12.5 km) – only the population layer was methodologically refined; exposure and vulnerability are kept at current baseline conditions, meaning that risk variation between scenarios derives solely from climate projections; the results are robust for relative prioritization rather than absolute hazard values.

Risk for Regiao_Leiria

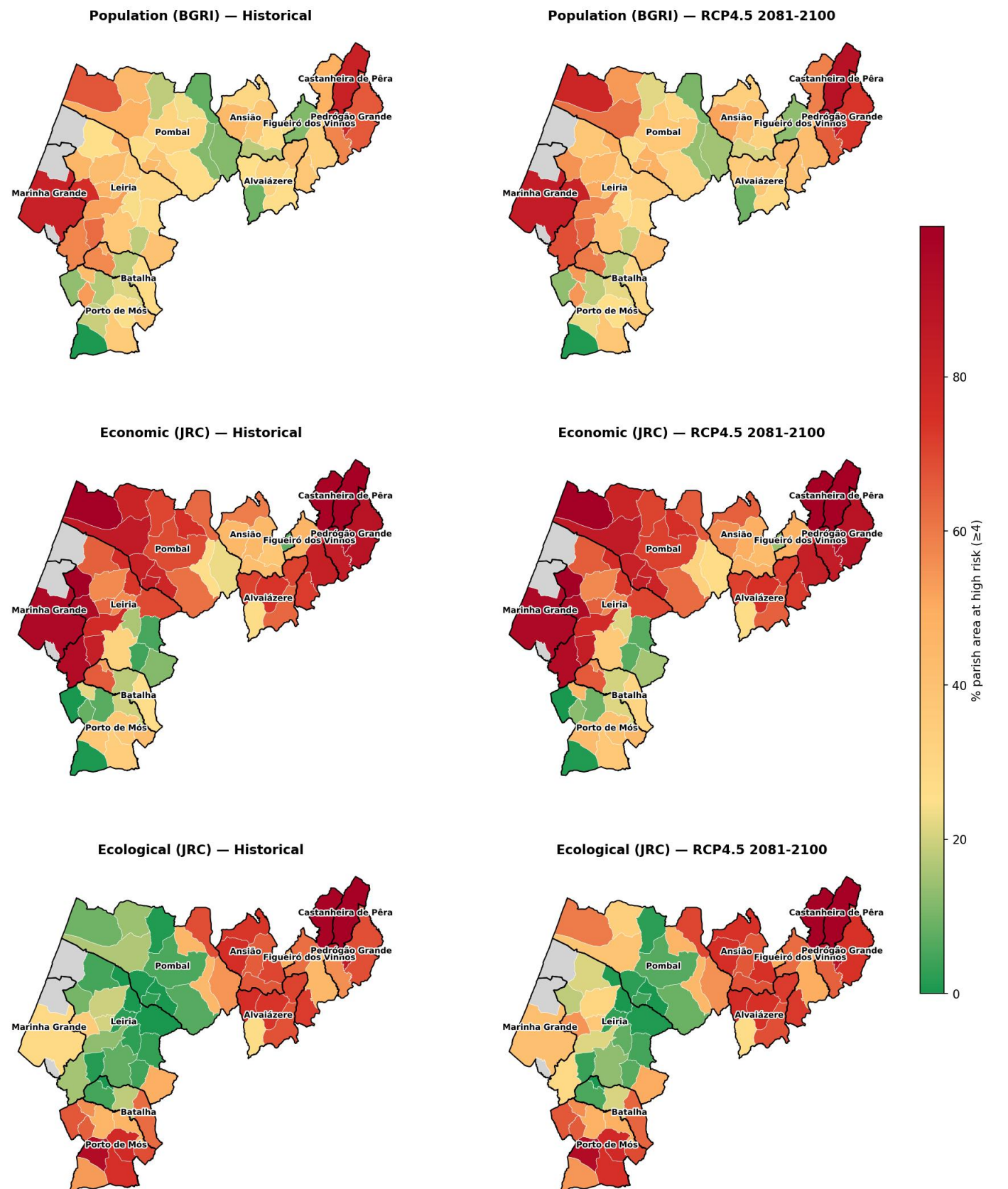
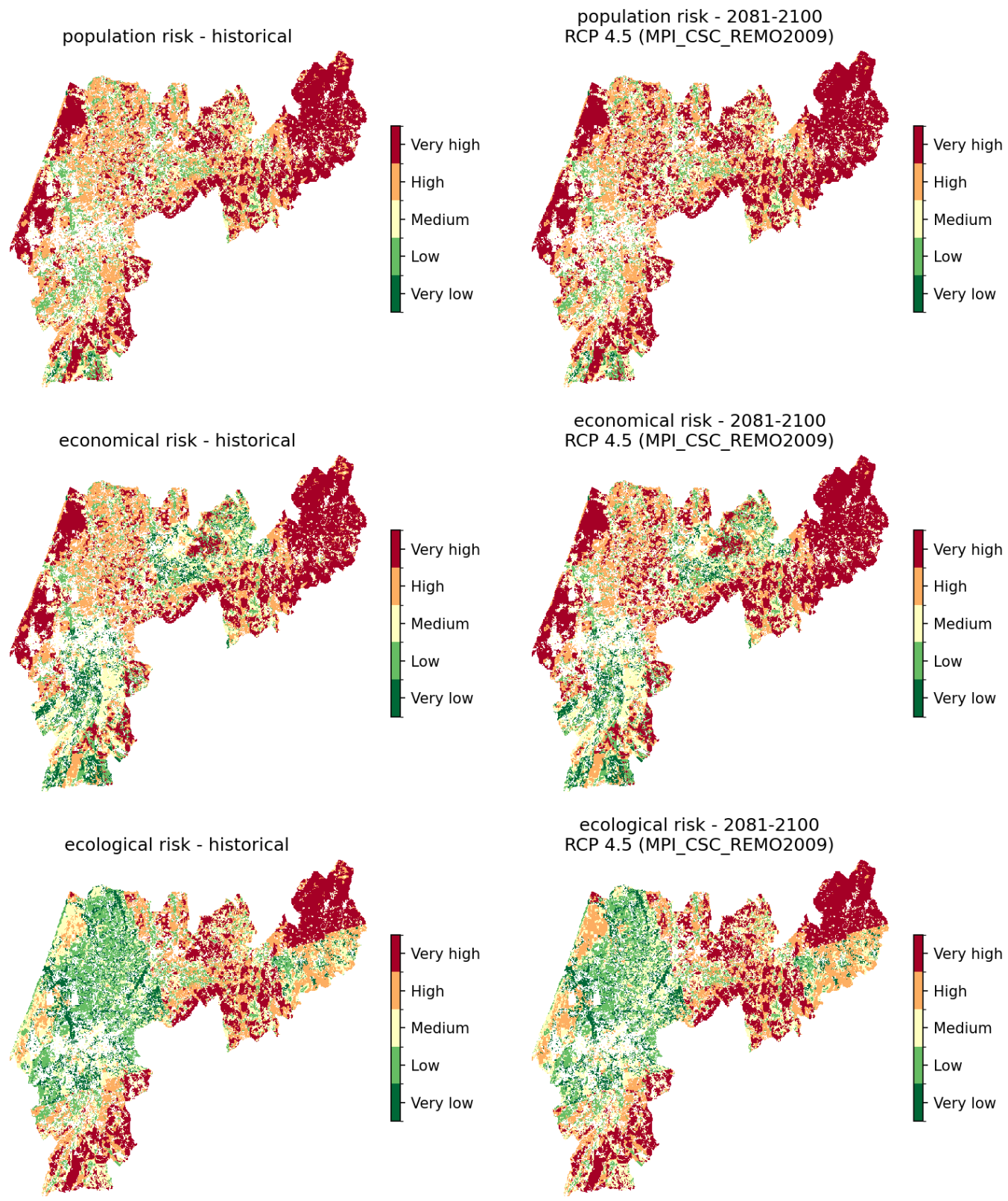


Figure 2-5 Area-based wildfire risk for the Leiria Region across three dimensions — population (BGRI 2021), economic and ecological (JRC) — under the historical baseline and end-of-century RCP 4.5 (2081–2100; MPI-CSC-REMO2009). Left columns: per-pixel risk classes (very low to very high). Right columns: aggregation by parish, expressed as the percentage of each parish's area in high-risk classes (≥ 4), with municipalities labelled. The economic and ecological components derive from the JRC indices (effective resolution ~ 12.5 km) and are therefore spatially smoother than the BGRI-based population.

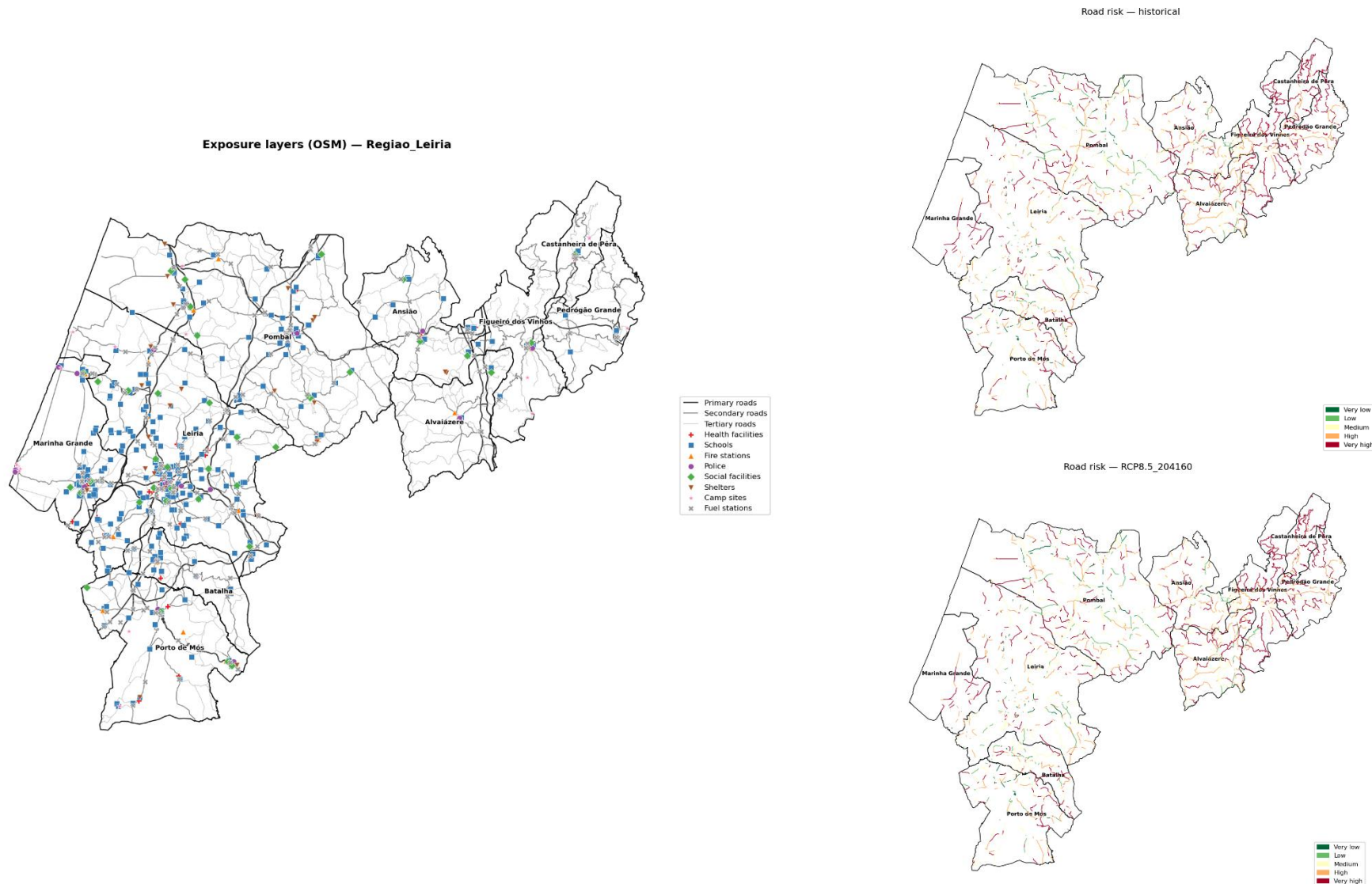


Figure 2-6 Layer 2 — infrastructure and road exposure to wildfire in the Leiria Region. Left: OSM exposure inventory — road network by hierarchy (primary/secondary/tertiary) and point critical assets by type (health, schools, fire/police stations, social facilities, shelters, campsites, fuel stations), with municipalities labelled. Right: road-network risk under the historical baseline and end-of-century RCP 4.5 (2081–2100; MPI-CSC-REMO2009), in five classes (very low to very high). Risk on the road network is obtained by crossing the hazard with the road hierarchy within a 20 m buffer.

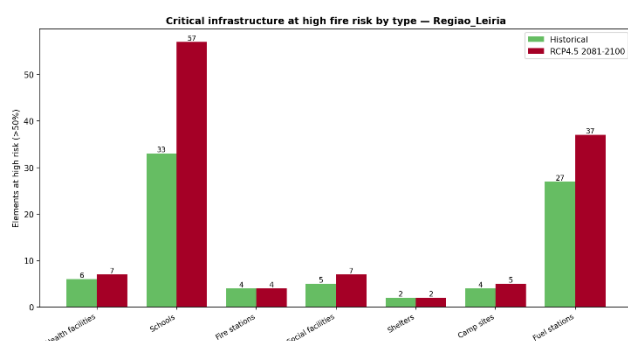


Figure 2-7 Critical infrastructure at high wildfire risk by asset type (Leiria Region), historical baseline vs end-of-century RCP 4.5 (2081–2100). Risk is assessed as the maximum hazard within a 250 m neighborhood of each asset; bars count elements in high-risk classes.

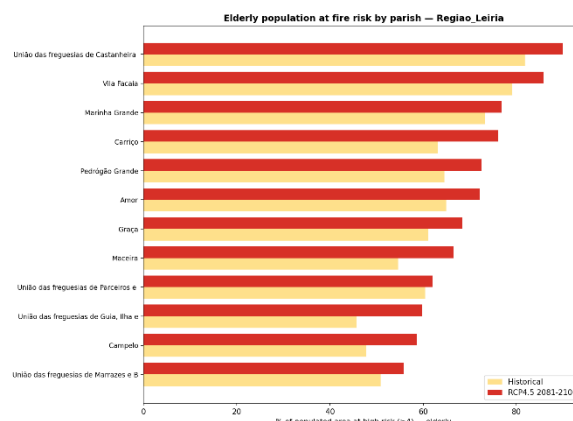


Figure 2-8 Elderly population (≥ 65) at high wildfire risk by parish, historical baseline vs end-of-century RCP 4.5 (2081–2100), expressed as the percentage of each parish's elderly population in high-risk classes (≥ 4).

2.3.2 Hazard #2 - Coastal Floods finetuning to local context

The assessment of coastal flooding risk in Phase 1 relied on global models (Deltares' Global Flood Maps) and low-resolution digital elevation models (MERIT-DEM at ~90 m), using generic assumptions for Sea Level Rise (SLR). While useful for an initial screening, these datasets lacked the specificity and local resolution required for operational planning, failing to distinguish between defended urban waterfronts and low-lying estuarine floodplains.

In Phase 2, the workflow underwent a deep refinement to ensure physical plausibility and operational accuracy. The model evolved from a basic regional hazard-screening approach to an exact quantification of economic and human risk at the local scale, anchoring the simulation to high-resolution topographic data and probabilistic national oceanographic forcing.

Key differences summary:

Aspect	Original Workflow	Enhanced Workflow
Analysis Resolution	Static: ~90m (MERIT-DEM).	Adaptive: 2m (LiDAR DGT), resampled to 10m for exposure analysis.
Water Levels (Forcing)	Global static SLR (~0.2m by 2050) + GTSM levels.	Probabilistic Total Water Levels (TWL) calibrated to Portuguese tide gauges (Antunes & Lemos, 2024).
Vertical Reference	Implicit in the global product.	Unified to National Vertical Datum Cascais1938, eliminating massive conversion errors (1-2m).
Flood Mechanics	Pure Bathtub (inundating all land below threshold regardless of sea connection).	Static filling with strict hydraulic connectivity to the ocean, removing impossible inland floods.
Exposure Scope	LUISA 100m and GHS-POP (~100m).	National COS 2023 (10m), BGRI 2021 (Census tracts), and customized OSM critical infrastructures.
Economic Calculation	Based on EU average GDP values.	Local recalibration using NUTS III Leiria GDP per capita and updated to 2024 Portuguese CPI.

Key improvements include:

- **Integration of LiDAR Topography (2m):** Replacement of global models with continuous, high-resolution cartography from the DGT, ensuring that the flooding strictly respects the micro-relief of the coastline, dunes, and the Lis River estuary.
- **Calibrated Regional Forcing:** Utilization of probabilistic Total Water Levels (TWL) based on national tide gauges, correcting the error of unrealistic deterministic summing of independent extremes (astronomical tide + meteorological storm surge + sea level rise).
- **Hydraulic Connectivity and Boundary Correction:** Implementation of propagation algorithms that require a contiguous connection to the sea, fixing artifacts such as the "Louriçal leakage" (an anomaly that previously flooded inland depressions with no physical connection to the ocean).
- **Uncertainty Envelope (Wave Action):** Modeling the boundary impact of waves through an envelope with two freeboard ceilings: a lower limit focused on wave setup (0.5m Setup) and an upper limit focused on instantaneous wave runup (2.5m Runup R_{2%}), explicitly quantifying the uncertainty of direct sea action.
- **Focus on Human Safety:** Replacement of global population data (GHS-POP) with national census data (BGRI 2021) at the statistical subsection scale, introducing the precise calculation of Expected Annual Population Displaced (EAPD).

Table 2-3 Data overview workflow #2 – Coastal Floods

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
• Probabilistic Total Water Levels (TWL): Coastline water level forcing tied to Cascais tide gauge (Antunes & Lemos, 2024), combining astronomical tide, meteorological storm surge, and Sea Level Rise (SLR) for 2050 and 2100 (RCP 4.5 and RCP 8.5) and return periods (T4, T25, T100). • Local Topography (LiDAR DGT): High-resolution LiDAR Digital Elevation Model (DEM) downscaled to 2 m mesh, referenced to the Cascais1938 National Vertical Datum, clipped to the Atlantic beachfront and Lis estuary. • Connectivity Algorithm: Implementation of strict flood-fill connectivity to exclude low-lying inland depressions lacking physical connection to the sea. • Coastal Uncertainty Envelope: Definition of two hazard boundaries: lower boundary based on setup and upper boundary based on runup R_{2%}.	• Local Economic Calibration: Normalization of European standard reconstruction costs using CIMRL's regional GDP per capita and updated with the 2024 Consumer Price Index (CPI) deflator (1.3176 factor). • Human Safety Metrics: Standard vulnerability threshold for direct risk-to-life and loss of habitability (water depth exceeding 1.0 m) for evacuation modeling.	• Land Use (COS 2023 DGT): National Land Cover Map COS 2023 (DGT, Series 2) downscaled to 10 meters, reclassified to LUISA damage classes. • Building Footprints (OSM): Detailed geometry of building footprints georeferenced along the beachfront and Lis estuary. • Fine Population (BGRI 2021 INE): High-resolution official residential data from the national census processed at the statistical subsection level.	• Area-Based Economic Damage: Aggregate financial losses per class under T=100 and future horizons in million euros (€), dominated by the dune-beach class (~65%). • Damage and Loss Curves: Granular estimates of direct structural damage and Expected Annual Damage (EAD) at the parish level. • Human Exposure and Displacement (EAPD): Cumulative estimates of exposed (setup T100: 2,212; runup T100: 10,919) and displaced (setup T100: 1,152; runup T100: 7,461) populations for mid- and end-of-century. • External Qualitative Validation: Alignment with the Coastal Extreme Flood layer of the snmportugal platform for 2100 and spatial complementarity with the Overtopping Safeguard Strip of the Ovar–Marinha Grande POC.

2.3.2.1 Hazard assessment

The coastal flood hazard assessment has transitioned from a low-resolution European dataset to a modeling framework anchored in the physical reality of the Portuguese territory. The foundation of this transition was the harmonization of all topography and bathymetry to the Cascais1938 National Vertical Datum and the use of DGT's 2-meter LiDAR DEM. This reconciliation eliminated a massive source of error (1–2 meters) previously induced by the vertical conversions of the Phase 1 models.

The model is no longer a simple *Bathtub* approach (which flooded any land below the elevation threshold, even far inland). A strict hydraulic connectivity rule with the ocean was introduced: the sea boundary was explicitly defined, and water now propagates solely through contiguous terrain below the stipulated elevation, eradicating physically impossible inland flooding.

As for climate forcing, global datasets were replaced by the probabilistic levels developed by Antunes & Lemos (2024), which are calibrated specifically for the west coast of Portugal, projecting impacts for the RCP 4.5 and RCP 8.5 scenarios across the 2050 and 2100 horizons. To accurately capture the dynamic nature of storm surge wave action, the workflow innovated by applying a "wave swash uncertainty band" using two distinct thresholds: a more conservative lower bound (0.5m Setup) and a maximum energy upper bound (2.5m Runup R_{2%}).

The tactical resolution (10 meters) achieved in this phase allows the hazard model to meet the operational planning needs at the local scale. The detailed cartography reveals that the hazard is not homogeneously distributed, manifesting instead through two distinct mechanisms that affect vital sectors of the Leiria Region:

- **Estuarine Intrusion:** In the Lis River floodplain, the model demonstrates that overtopping does not occur solely from frontal impact on the beach, but rather through the deep propagation of ocean waters up the riverbed, flooding vast areas of the valley.
- **Overtopping of Urban Waterfronts:** In the coastal centers of Praia do Pedrógão, Praia da Vieira, and São Pedro de Moel, the micro-relief captures the vulnerability of the built environment where, under the extreme swash scenario (maximum Runup), wave energy has the potential to breach coastal defenses and invade the consolidated urban fabric.

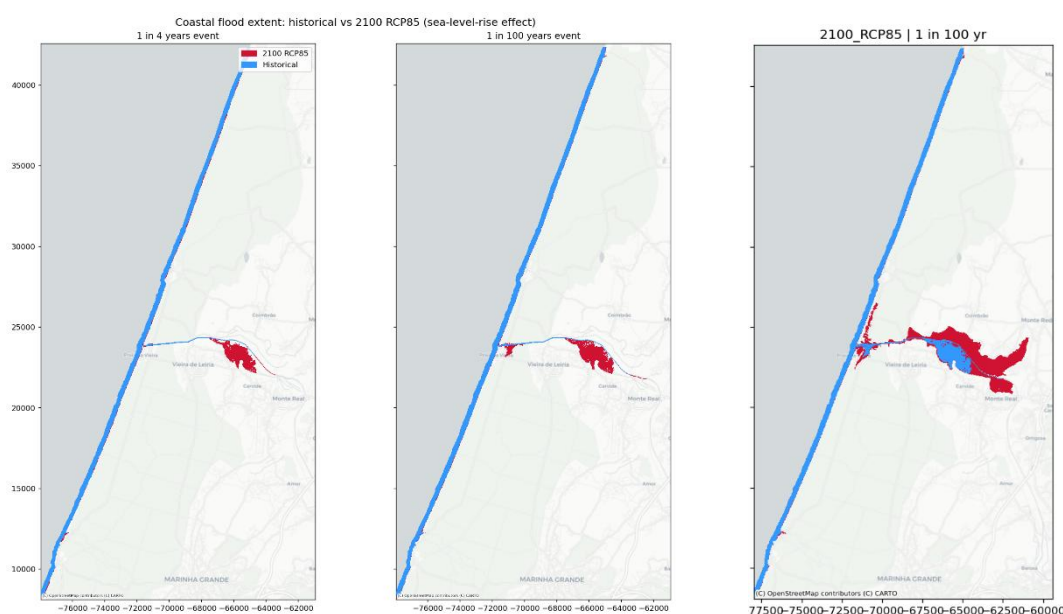


Figure 2-9 Coastal flood extent and uncertainty boundaries. Left/centre: sea-level-rise effect (historical vs 2100 RCP8.5) for 1-in-4-year and 1-in-100-year events. Right: setup–runup uncertainty envelope (2100 RCP8.5, 1-in-100-year). Colours denote historical/2100 in the first two panels and setup/runup in the third.

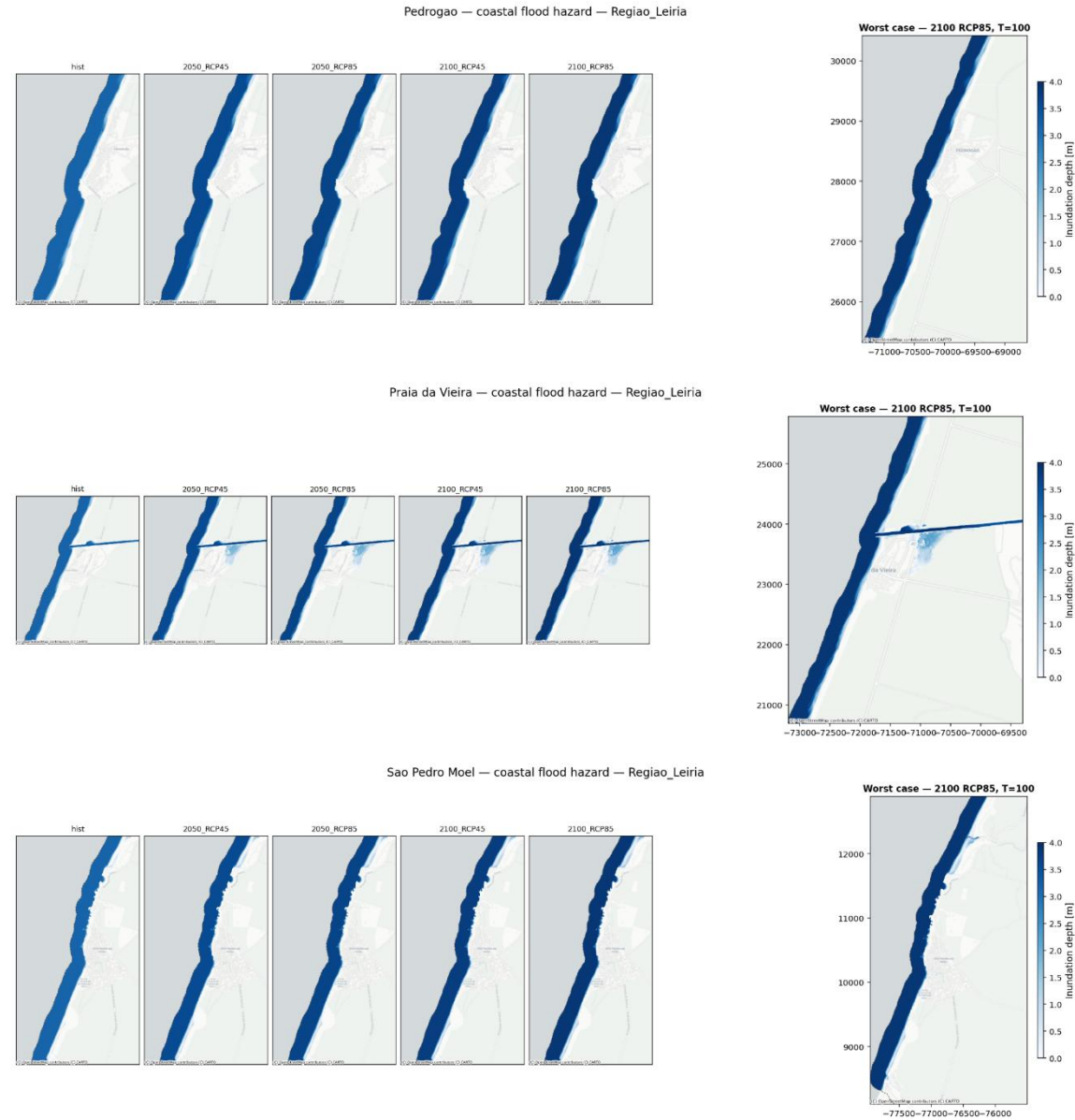


Figure 2-10 High-resolution tactical assessment of coastal flood hazards over terrain hill shades, detailing the estuarine intrusion mechanism in the Lis River plain and the direct exposure of the urban fronts of Praia do Pedrógão, Praia da Vieira, and São Pedro de Moel.

2.3.2.2 Risk assessment

For the financial calculation of losses, the European land-use database (LUISA at 100 m) was replaced by the Land Use and Land Cover Map (COS 2023 from DGT), which allowed the fidelity and boundaries of coastal built environments and agricultural lands to be maintained at a tactical scale of 10 meters. The COS classes were translated using an equivalence matrix (*crosswalk*) to preserve consistency with the depth-damage curves of the Joint Research Centre (JRC).

The original damage curves underwent a deep calibration for the Portuguese context. The model was anchored in wealth transfer by introducing the GDP per capita of NUTS III Leiria. Subsequently, to ensure that the estimates reflect real-world replacement costs, all maximum damage values (*maxdam*) were corrected using the Portuguese Consumer Price Index (CPI) for 2024 (applying an inflation factor of 1.3176).

Economic damage is reported as an envelope between the two wave-action limits: about €155.2M (setup, lower bound) and €517.7M (runup, upper bound). These totals must be read with caution – they are dominated by two template-valued land classes (beaches/dunes and agriculture) whose unit costs are not yet anchored to costs observed in the region, and the upper bound deliberately overestimates inland penetration. The component most relevant for operational planning is the damage to the built environment, set out first:

- **Built environment and infrastructure (the priority signal):** Direct damage to buildings and infrastructure rises from near zero in the historical baseline to about €3.0M (setup) and €35.1M (runup) by the end of the century – the clearest and fastest-accelerating consequence of sea-level rise, and the one carrying direct risk to people and assets on the consolidated ocean fronts (Praia do Pedrógão, Praia da Vieira, and São Pedro de Moel). Modest as a share of the lumped total, it is nonetheless the component that should anchor adaptation decisions.
- **Beaches and dunes (template value, to be anchored):** The sandy-coast class carries the largest share of the lumped total (~€100.5M setup; ~€153.9M runup), but at a unit value (~47 €/m²) taken from the CLIMAAX template. It has a genuine economic basis – the national cost of beach nourishment and coastal defence, as on the Ovar–Marinha Grande stretch – and is best read as a proxy for those maintenance costs rather than as conventional asset damage.
- **Agriculture (upper bound likely overestimated):** Losses in the Lis alluvial floodplain, from saltwater intrusion up the valley, grow from ~€51.0M (setup) to ~€312.4M (runup). The runup figure is the largest single contributor to the upper bound, but it is also where the method is weakest – the instantaneous swash is treated as a fixed water level over an extensive, flat plain – so this share is probably overestimated and should be read as a conservative ceiling, not an expected value.

Two caveats apply throughout. The runup R2% bound is an instantaneous wave-swash excursion, not a static water level; used as a fixed elevation it overstates how far water travels inland, and is therefore a conservative upper bound. And the economic calibration regionalises template damage curves to NUTS III Leiria GDP – a wealth-transfer adjustment rather than a cost observed locally – so the Phase 2 gain is strong in hazard and exposure geometry but only partial in economic valuation.

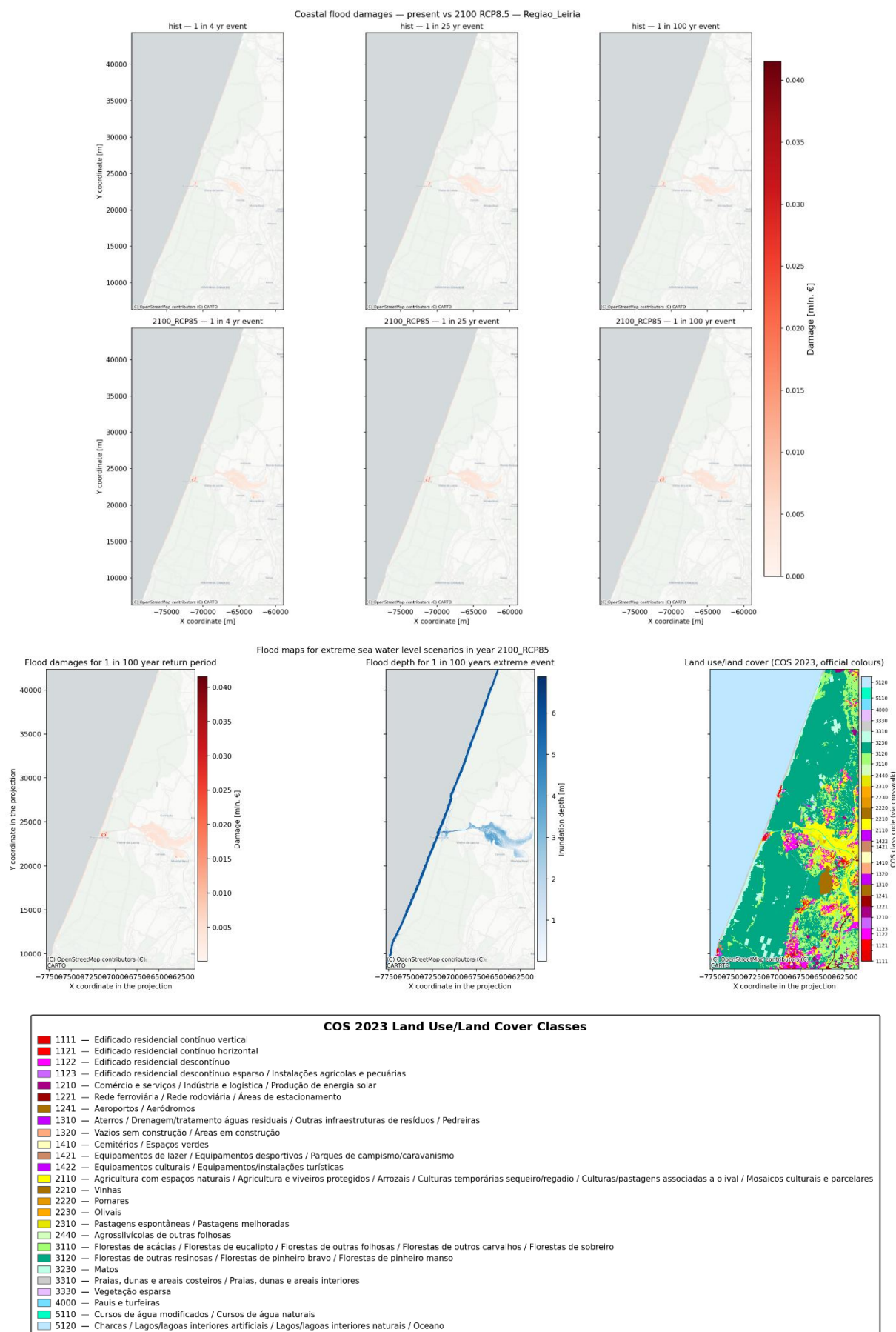


Figure 2-11 Overview of economic damages (mln. €) across multiple scenarios and return periods, and high-resolution detail of the worst-case scenario linking inundation depth, COS 2023 land cover, and resulting financial damage.

2.3.2.3 Flood building damage and population exposure (Complementary Workflow)

To complement the economic loss assessment and directly address the emergency planning needs of Civil Protection, the project implemented a workflow focused exclusively on safeguarding human life and the resilience of critical infrastructure.

The major methodological innovation of this complementary assessment was the total replacement of the global population grid (GHS-POP at 100 m) with Portugal's high-precision census geometry (Geographical Information Reference Base – BGRI 2021 from INE), operating at the statistical subsection level. Additionally, the building footprint layer extracted from OpenStreetMap (OSM) was customized to fit the national coastal context, integrating specific categories of vital equipment (such as lighthouses, coast guard stations, maritime rescue facilities, wastewater treatment plants (WWTPs), and social and healthcare infrastructure).

A. Exposure of Critical Infrastructure

The integration of OSM allowed precise identification of which nodes within the municipal system would fail under extreme climate scenarios. The model demonstrates that maximum wave swash energy (Runup) in the worst-case, end-of-century scenario (2100 RCP8.5) threatens not only the first line of buildings, but directly compromises the sanitation network and social response facilities located on the western fronts, demanding robust engineering mitigation to prevent systemic failures across the territory.

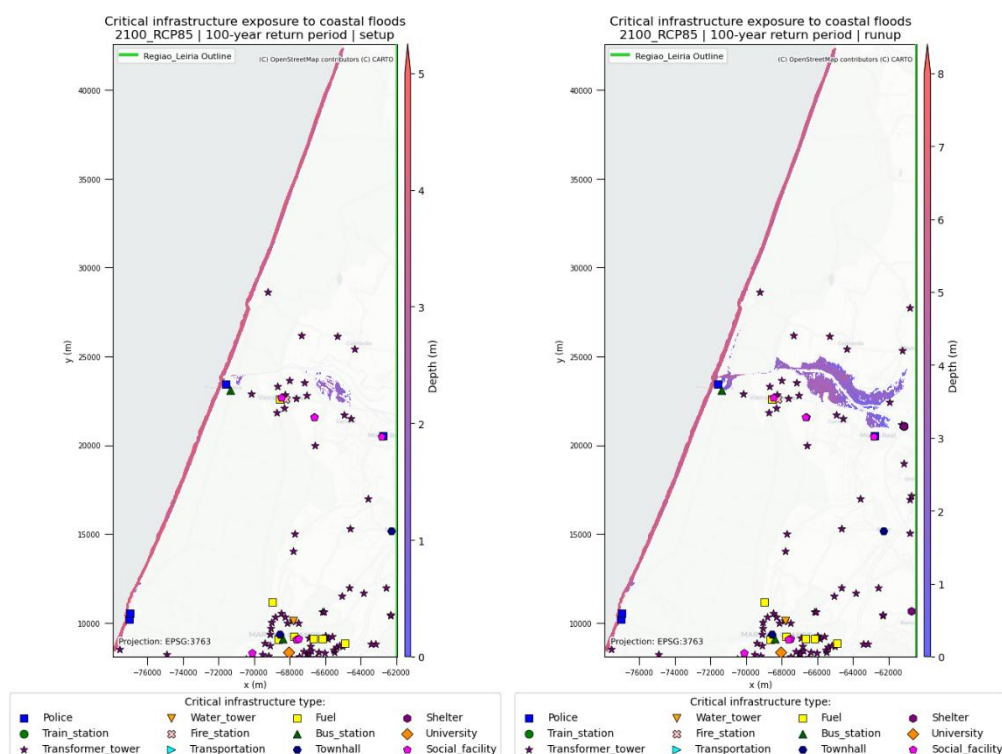


Figure 2-12 Critical infrastructure exposure to coastal floods under the extreme runup scenario (2100 RCP8.5, 100-year return period), highlighting affected health, social, and coastal utility assets.

B. Demographic Exposure and Human Displacement

To differentiate populations that are merely "exposed" from those facing severe residential security risks, the model adopted the metric of Expected Annual People Displaced (EAPD). This metric is based on a critical flooding threshold exceeding 1.0 meter, the depth at which the structural viability, safety, and functionality of residential ground floors are assumed to be lost.

The analysis shows the strong effect that instantaneous wave energy (the swash envelope) has on human safety under the extreme scenario (2100 RCP8.5, 100-year Return Period), revealing two distinct risk dimensions:

- **Storm Surge Boundary (Static Setup Only):** Under gravity-driven flooding from storm sea levels alone, 2,212 people are exposed, with 1,152 residents facing imminent displacement. The model extracts an aggregate risk metric of 168 expected annual people displaced (EAPD).
- **Extreme Swash Envelope (Runup $R_{2\%}$ Boundary):** Should waves overtop urban and estuarine fronts at their maximum projected energy, the population at risk rises sharply: 10,919 residents exposed, which translates to a risk of 7,461 citizens impacted in their homes (>1.0m) and 1,526 expected annual people displaced (EAPD).

This sharp rise in exposure — which under a high-frequency event (4-year Return Period) jumps nearly 15-fold (from 617 to 9,313 exposed individuals — the setup-to-runup envelope at this frequency, not a change over time) — highlights the critical dependence of northern populations (Praia da Vieira) on coastal defense works, as well as the less-visible pathway of water propagation driving deep into the Lis River floodplain.

These population figures are bounded estimates rather than central values: the subsection-overlay method can overstate exposure where census units are large (notably across the Lis plain), and the 1.0 m displacement threshold is the CLIMAAX template default, to be calibrated for the Portuguese context.

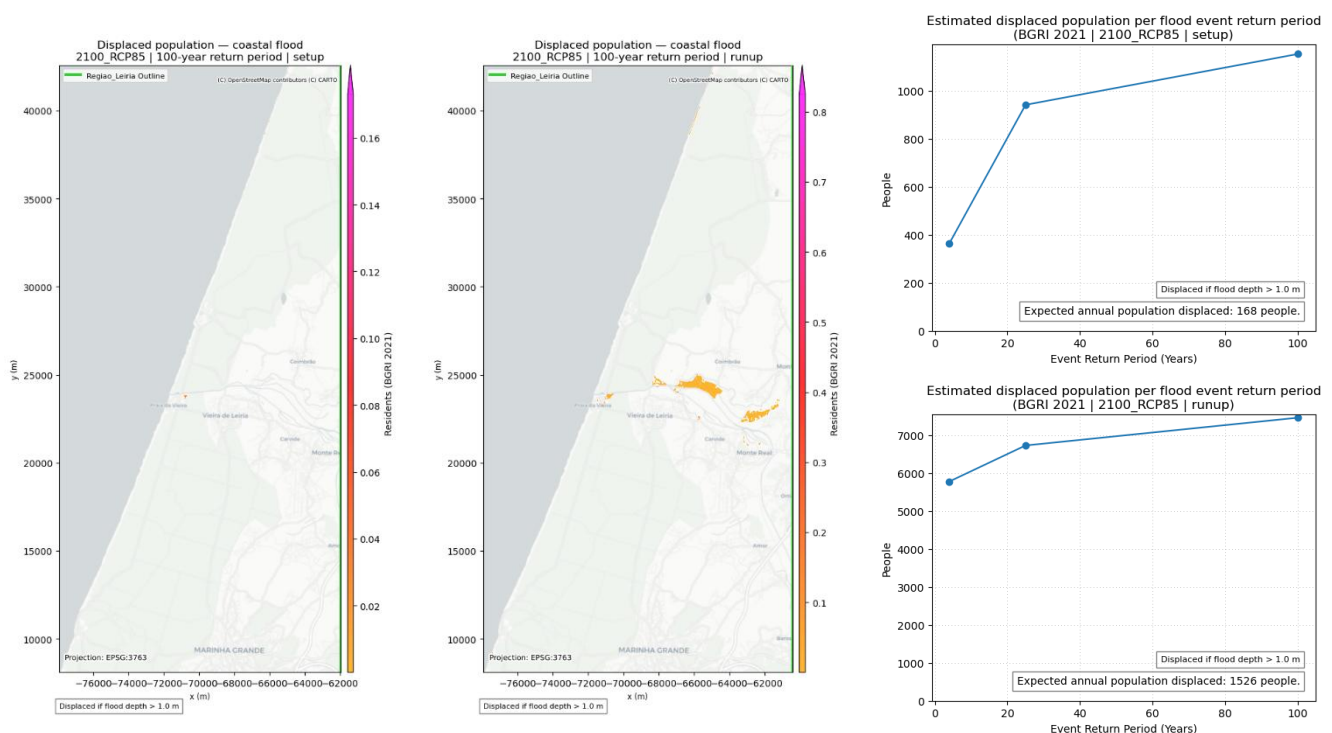


Figure 2-13 Comparative analysis of displaced population distributions contrasting the static inundation limit (Setup) with the extreme wave action limit (Runup). The accompanying Expected Annual People Displaced (EAPD) curve highlights the sharp increase in risk when protective thresholds are breached.

2.3.3 Hazard #3 - Heatwaves finetuning to local context

The heatwave risk assessment in Phase 1 was based on relative and global definitions which, while useful for a macro-regional characterization, lacked specificity for local operational planning. In Phase 2, the heatwave workflow underwent a deep refinement focused on calibrating absolute climate models (Xclim) to national meteorological definitions, ensuring that the model measures extreme heat with real relevance for public health and civil protection within the territory of the Leiria Region.

The cross-cutting principle assumed in this phase is that the climate hazard (limited by the native resolution of ~12.5 km of EURO-CORDEX) expresses the trend and the comparison of scenarios, whereas future high-resolution spatial detail will come from demographic data and satellite readings of urban heat.

Key differences summary:

Aspect	Original Workflow	Enhanced Workflow
Temperature Thresholds	Generic values (e.g., $T_{\max}$ 25.0°C; $T_{\min}$ 22.0°C).	National definitions (IPMA): " <i>Dia muito quente</i> " (Very hot day) ($T_{\max} \geq 35.0^{\circ}\text{C}$) and " <i>Noite tropical</i> " (Tropical night) ($T_{\min} \geq 20.0^{\circ}\text{C}$).
Heatwave Duration	5 consecutive days.	6 consecutive days (IPMA official definition for heatwave).
Validation Points	Random/Interactive points.	Fixed strategic coordinates representing distinct territorial realities (Leiria - urban/coastal influence vs. Pedrógão Grande - interior/altitude).
Model Validation	Single methodology.	Dual approach: calibrated Xclim for absolute thresholds, and EuroHEAT maintained for multi-model trend cross-validation.
Urban Heat Island	Not assessed locally.	Multi-city high-resolution (~100m) Land Surface Temperature (LST) analysis for Leiria, Pombal, and Marinha Grande.

Key improvements include:

- **National Calibration (IPMA):** Replacement of generic thresholds with official metrics from the Portuguese Institute for Sea and Atmosphere (IPMA), isolating true extreme events from normal summer days.
- **Coastal vs. Interior Contrast Validation:** Definition of strategic reading points that allow the model to assess the thermal contrast between the urban core of Leiria (where Atlantic influence moderates absolute temperatures but fosters structural heat islands) and the interior of the territory (Pedrógão Grande), validating the heat signal in the interior.
- **Multi-City Urban Analysis:** Evolution from a regional analysis to a tactical assessment of urban heat across three distinct cities (Leiria, Pombal, and Marinha Grande) using Landsat 8/9 satellite imagery.

Table 2-4 Data overview workflow #3 – Heatwaves

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
Climate (EURO-CORDEX): Large-scale daily temperature series (~12.5 km) of T_{max} and T_{min} (historical 1971–2000; RCP 4.5/8.5 scenarios for 2016–2045 and 2046–2075 horizons). IPMA Thresholds (Xclim): Physical calibration of local extremes: Very hot day ($T_{max} \geq 35.0$ °C) and Tropical night ($T_{min} \geq 20.0$ °C) for at least 6 consecutive days. Satellite Temperature (LST Landsat): Surface temperature at ~100m resolution extracted for the extreme July 2022 heatwave (Planetary Computer).	Demographics (BGRI 2021 INE): Residential density of the elderly population (aged ≥ 65 years)—the cohort of highest epidemiological vulnerability to extreme heat. Vulnerability Classification: Ordinal distribution of demographic data into 10 quantile classes at the civil parish level (preventing flattening by outliers) and equal intervals for pixels. Response Assets: Geospatial location of nursing homes and hospitals integrated as a vector reference layer and qualitative validation of risk.	Official Boundaries (CAOP 2022 DGT): Official boundaries of the civil parishes of the Leiria Region. Critical Assets (OSM): Spatial location of exposed facilities: healthcare facilities, hospitals, elderly nursing homes, day care centers, IPSS, and social support infrastructure. School Exposure (OSM): Spatial location of 27 school facilities in the three urban areas (Leiria, Marinha Grande and Pombal) for complementary exposure analysis of secondary vulnerable groups (children).	Hazard Indicators (1–10): Temporal projections of heatwave days per year, event frequency, and occurrence index, calibrated to IPMA standards. Future Projected Risk (2–20): Combined risk score at the parish scale (sum of hazard class 1–10 and vulnerability class 1–10), highlighting the critical concentration in both coastal and inland urban centers. High-Resolution Urban Heat Risk (~100m): Intra-urban risk map in Leiria, Pombal, and Marinha Grande (LST $\times$ BGRI 2021 density) identifying exposed buildings and characterizing the Scale Paradox.

2.3.3.1 Hazard assessment

The heatwave hazard assessment in Phase 2 was based on a dual methodological approach to ensure robustness: the calibration of the Xclim model (based on user-defined absolute thresholds) and the maintenance of EuroHEAT (based on apparent temperature percentiles). EuroHEAT was kept intact from Phase 1, serving exclusively as a multi-model reference for cross-validating the worsening trends.

The following figure demonstrates this structural validation of the trend. Utilizing the European EuroHEAT definition based on apparent temperature, the multi-model climate ensemble confirms a marked increase in the number of heatwave days in the Leiria Region by the end of the century, especially under the RCP 8.5 emissions scenario.

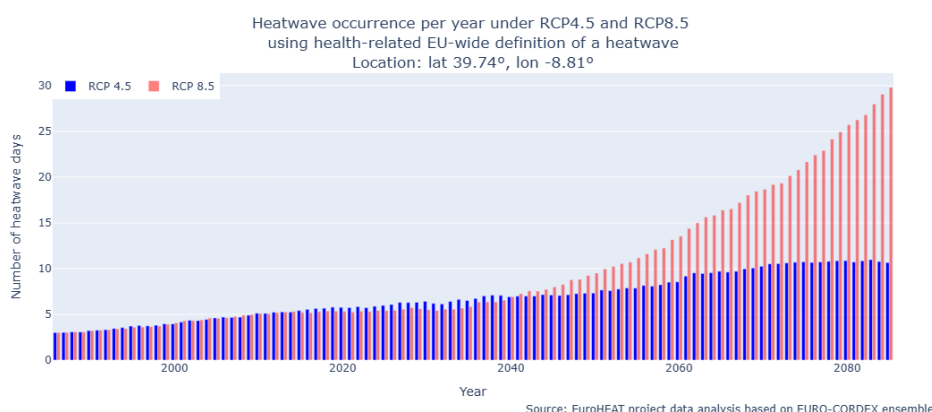


Figure 2-14 Cross-validation of the hazard trend: Heatwave occurrence per year under RCP 4.5 and RCP 8.5 scenarios for the Region of Leiria, using the EuroHEAT multi-model ensemble (EU-wide relative definition).

With the robustness of this baseline climate trend guaranteed, the decisive local calibration occurred in Xclim, where the generic thresholds of the original workflow were fully recalibrated to the official absolute metrics of the IPMA. The heatwave index (`heat_wave_index`) is now calculated only when the maximum temperature ($T_{\max}$) reaches or exceeds 35.0 °C ("Very hot day") for a minimum period of 6 consecutive days. Additionally, in the bivariate indices (day and night), the minimum temperature threshold was adjusted to 20.0 °C ("Tropical night"). This nighttime inclusion is vital for public health, as the lack of nocturnal thermal recovery is a determining factor in heat-related mortality.

To ensure geographic reproducibility and validate the territorial discrepancies of the Leiria Region (which combines Atlantic influence with inland areas), two crucial reading points were pinned directly in the code for trend extraction:

- **Leiria (Urban/Coastal - 39.7436, -8.8071):** Represents the main urban core (Praça Rodrigues Lobo), subject to heat island dynamics and high population density, but under the moderating effect of the ocean.
- **Pedrógão Grande (Interior - 39.9132, -8.1467):** Represents the interior at an altitude of ~400m, a highly aged territory, serving to validate the penetration and signal of extreme heat away from the coast.

Finally, the hazard assessment is bound by an inherent technical limitation ("Scale Paradox"): the climate hazard remains dependent on the native resolution of ~12.5 km from EURO-CORDEX. This means the hazard acts as a broad regional signal, and the results (such as the Xclim indices, which rely on the single climate model `mpi_m_mpi_esm_lr / clmcom_clm_cclm4_8_17`) must be analyzed through period averages (2011–2040 vs. 2041–2070) rather than on a year-by-year basis, given the high sensitivity of rare events to interannual variability.

The point-based assessment allows for an understanding of how the hazard worsens over time. The following panel of graphs illustrates the projection of three distinct hazard metrics (Occurrence Index, Event Frequency, and Total Number of Days), strictly calibrated to the absolute thresholds of the IPMA. This assessment is presented side-by-side for the territory's two strategic validation points: Leiria (urban/coastal) and Pedrógão Grande (interior).

The visual comparison highlights a future worsening trend under both scenarios (RCP 4.5 and 8.5). As anticipated by the model calibration, the urban core of Leiria (left column) is expected to record a higher number of absolute episodes. In contrast, Pedrógão Grande (right column), located at an altitude of around 400 meters in the interior, shows a partial mitigation in the occurrence of extreme tropical nights compared to the coast, but still projects a very significant signal of continuous thermal worsening for the coming decades.

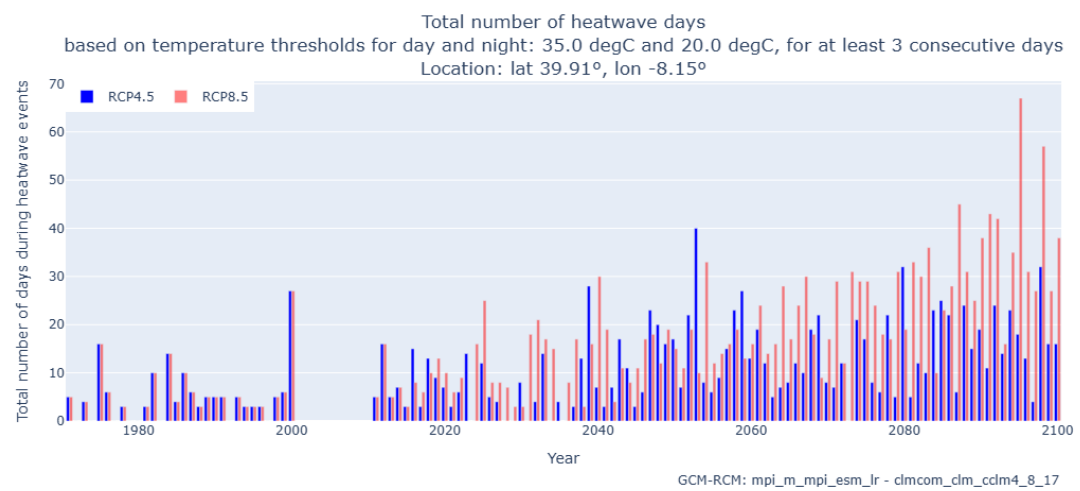
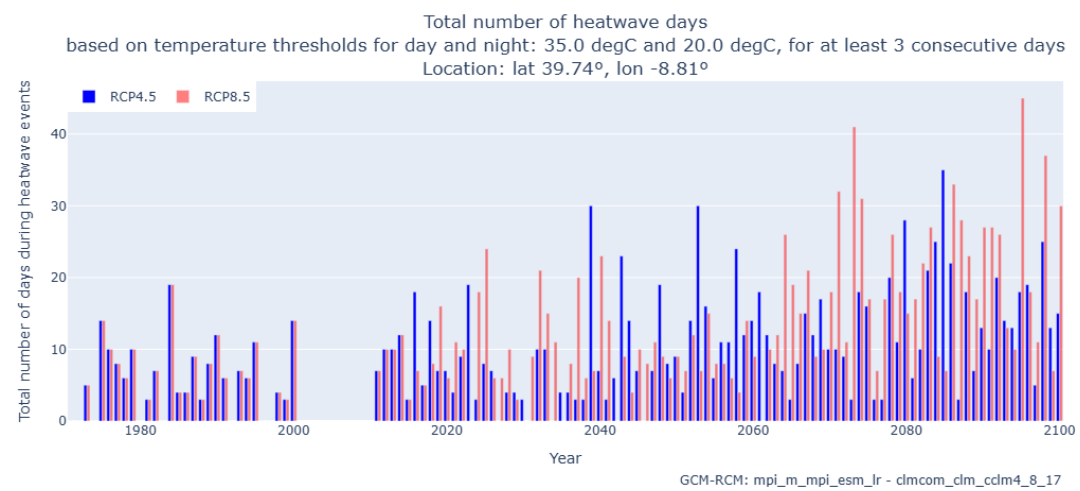
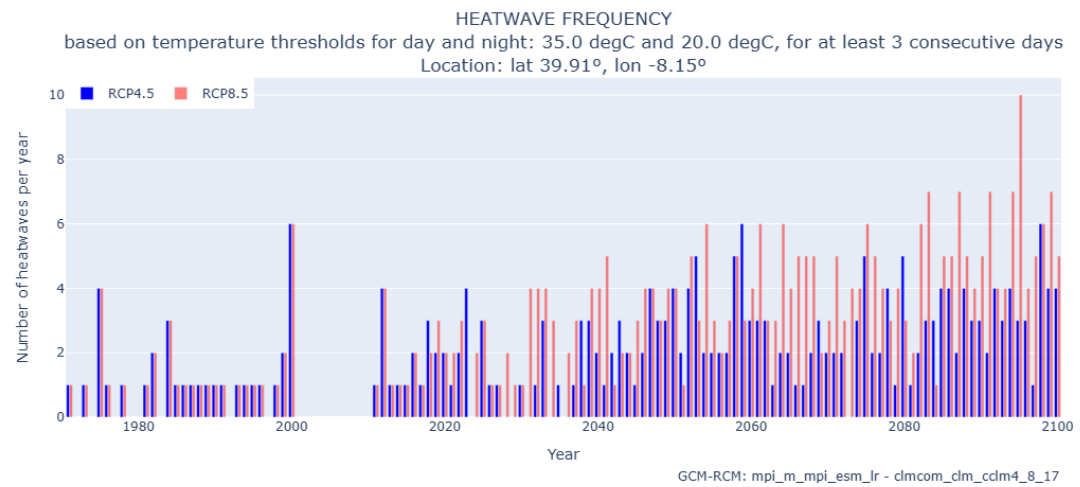
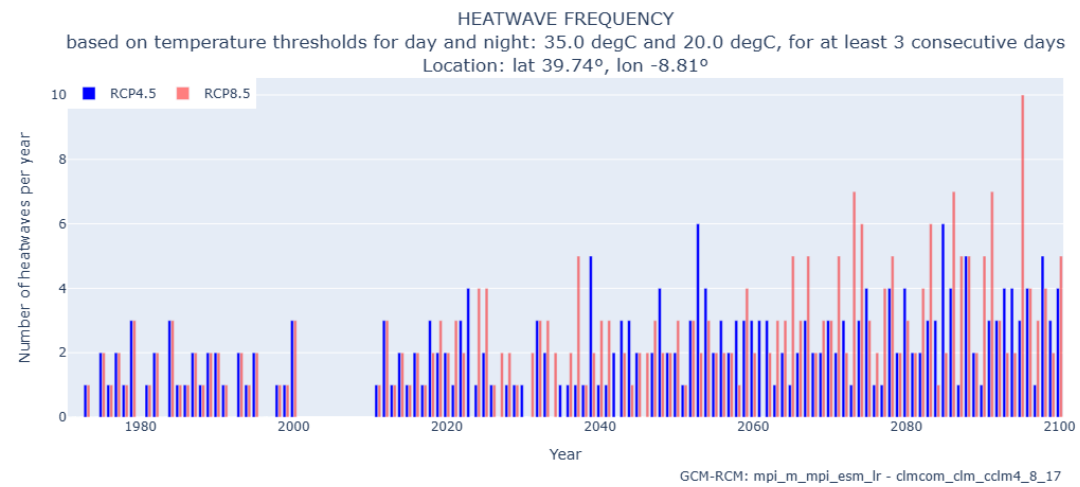
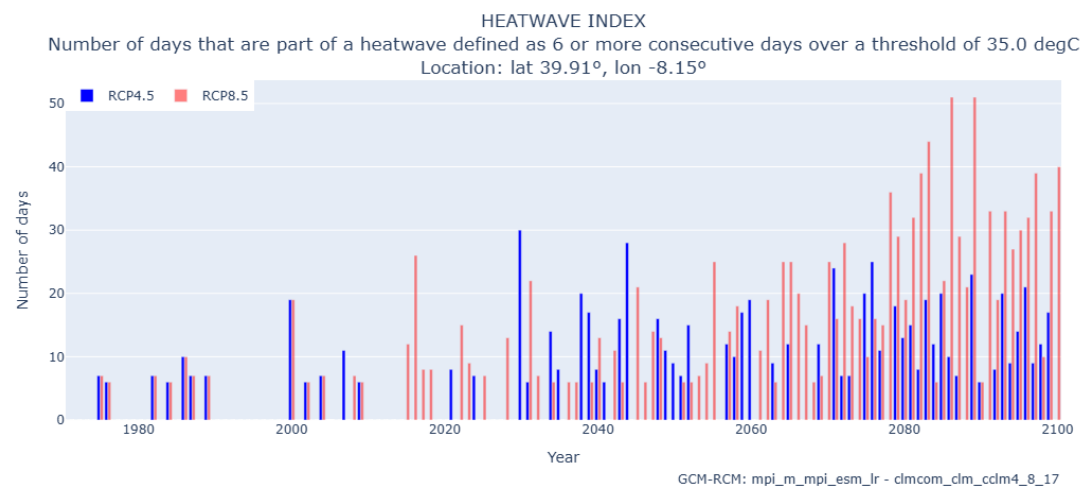
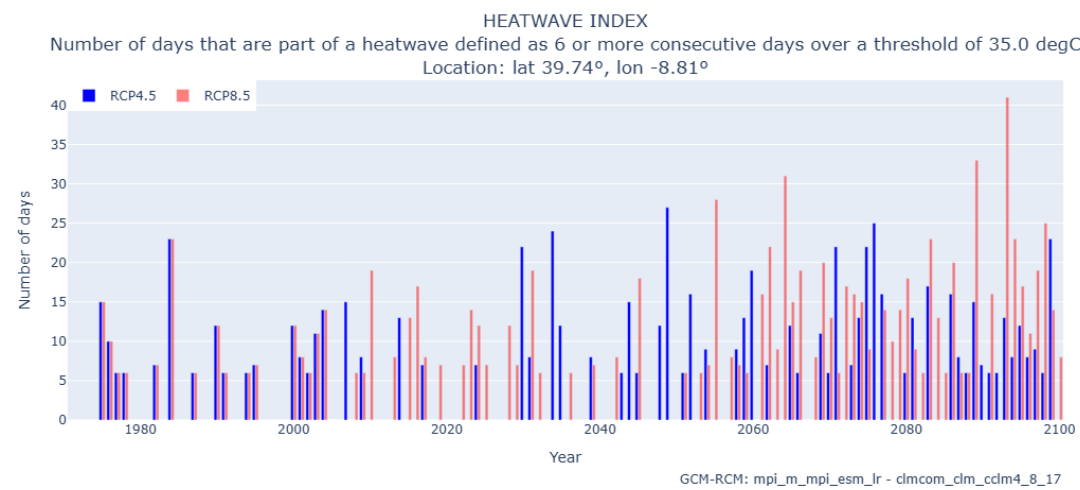


Figure 2-15 Projected heatwave hazard indices (Occurrence, Frequency, and Total Days) based on IPMA absolute thresholds ($T_{max} \geq 35^{\circ}\text{C}$ for ≥ 6 consecutive days). The panel compares the historical baseline with RCP 4.5 and RCP 8.5 scenarios for Leiria (urban/coastal, left column) and Pedrógão Grande (interior, right column).

In addition to point-based readings, it is imperative to understand how climate change is distributed geographically across the civil parishes of the Leiria Region. The hazard maps generated by the workflow reflect the magnitude of the relative change in the occurrence of heatwaves, comparing the baseline historical period (1986–2015) with future horizons (2016–2045 and 2046–2075) under the RCP 4.5 and RCP 8.5 scenarios.

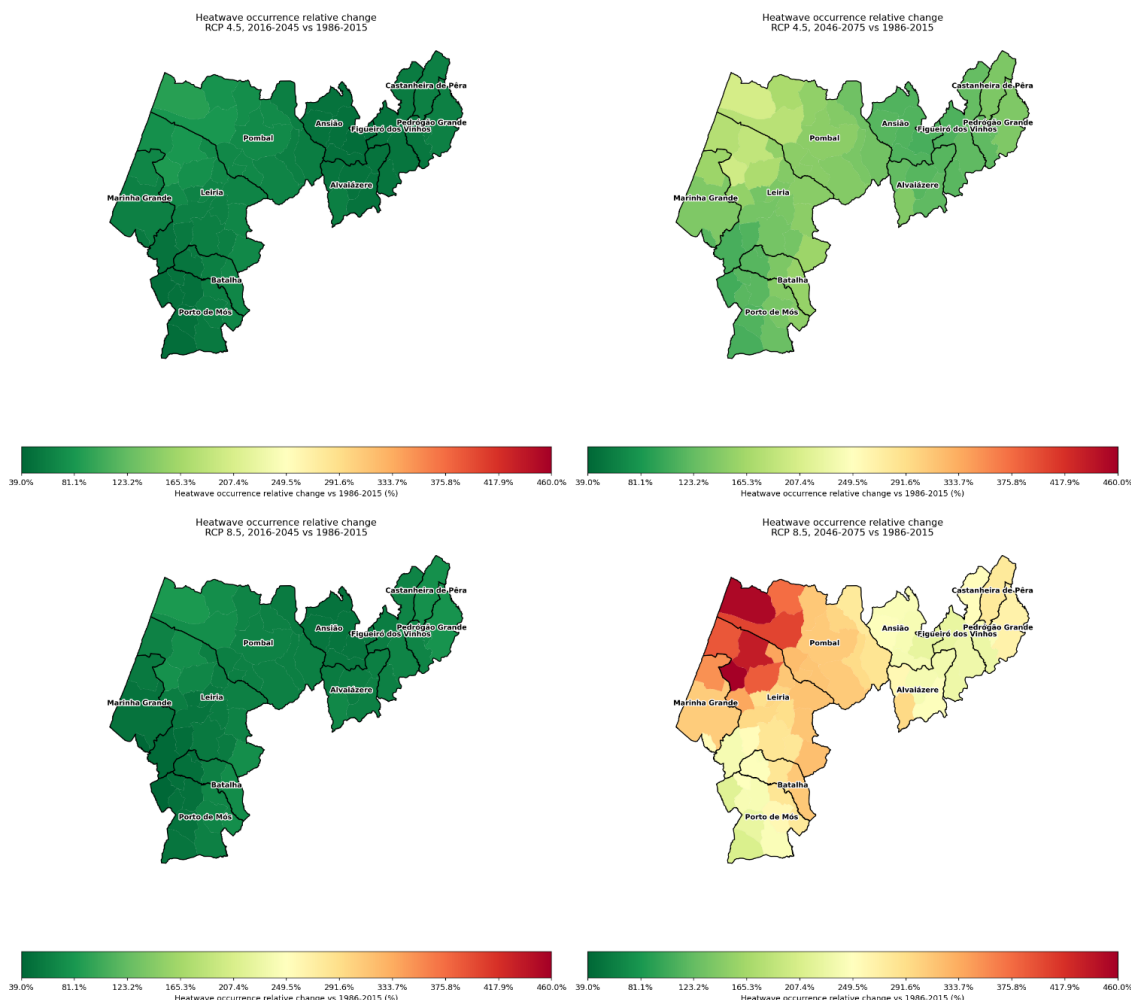


Figure 2-16 Spatial distribution of the relative change in heatwave occurrence across the Region of Leiria, comparing future horizons (2016-2045 and 2046-2075) against the historical baseline under RCP 4.5 and RCP 8.5.

To facilitate the integration and direct reading of this territorial data within the planning instruments of the 10 municipalities (such as the PMAC and PMEPC), the workflow reclassified this magnitude of change onto a standardized operational scale from 1 to 10 (where 10 represents the most severe worsening of the hazard).

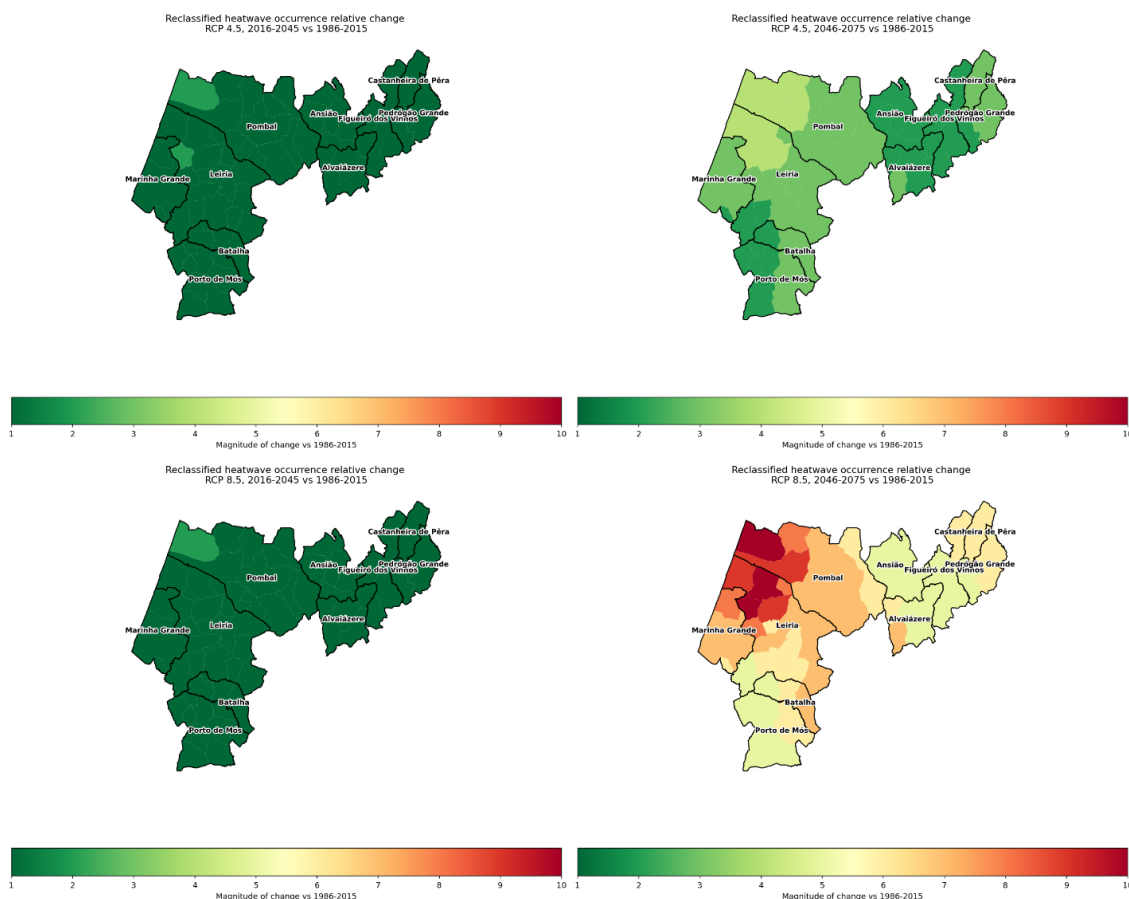


Figure 2-17 Reclassified magnitude of change (scale 1-10) in heatwave occurrence per parish, highlighting the hazard increase patterns across the territory under future climate scenarios.

2.3.3.2 Risk assessment

The heatwave risk assessment in Phase 2 results from cross-referencing the climate hazard (already calibrated to national thresholds) with the socioeconomic vulnerability of the territory. To accurately reflect the demographic reality of the Leiria Region and address the limitations of Phase 1, the global population estimation data (WorldPop) were entirely replaced with the actual contiguous census tracts from the Geographical Information Reference Base (BGRI 2021 - INE).

The vulnerability analysis focused on the most critical age group, which presents the strongest epidemiological evidence of heat-related mortality: the elderly population (≥ 65 years). To ensure maximum precision, the data were processed at the ultra-detailed statistical subsection scale (covering 10,517 subsections within the CIMRL) and subsequently aggregated into the official civil parish geometry. In a crucial technical decision to ensure zero data loss, the CAOP 2022 geometry (contemporary with the Census) was adopted, ensuring the exact mapping of 100% of the population across the 67 territorial entities considered in the analysis.

As the primary indicator of vulnerability, the elderly population density (elderly/km²) was adopted and classified into 10 classes using the quantile method. This methodological choice of quantiles (instead of equal intervals) was decisive for the Leiria Region: it prevented the ultra-high-density extremes in central urban areas from flattening the scale and "wiping out" the signal in the rest of the region, thereby guaranteeing a differentiated and useful map for prioritizing municipal response measures.

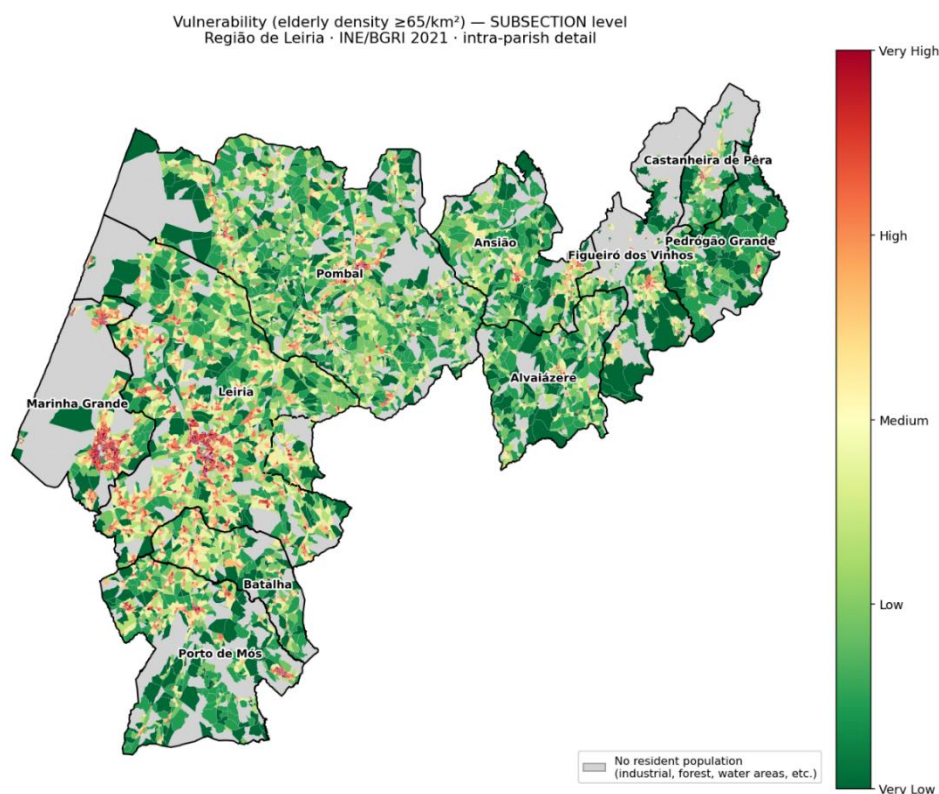


Figure 2-18 High-resolution spatial distribution of heatwave vulnerability in the Region of Leiria, based on the density of the elderly population (≥ 65 years) (BGRI 2021). The map presents the detailed intra-parish vulnerability at the statistical subsection level, classified by quantiles.

The final risk was calculated by directly adding the climate hazard class (1 to 10) to the demographic vulnerability class (1 to 10), generating a risk index with a theoretical score ranging from 2 to 20.

The territorial analysis of risk in Leiria reveals dynamics that are very distinct from other regions of the country. Heat risk appears globally moderate and spatially highly concentrated within the large urban cores (such as the centers of Leiria or Pombal) and in the areas furthest away from the Atlantic's moderating influence.

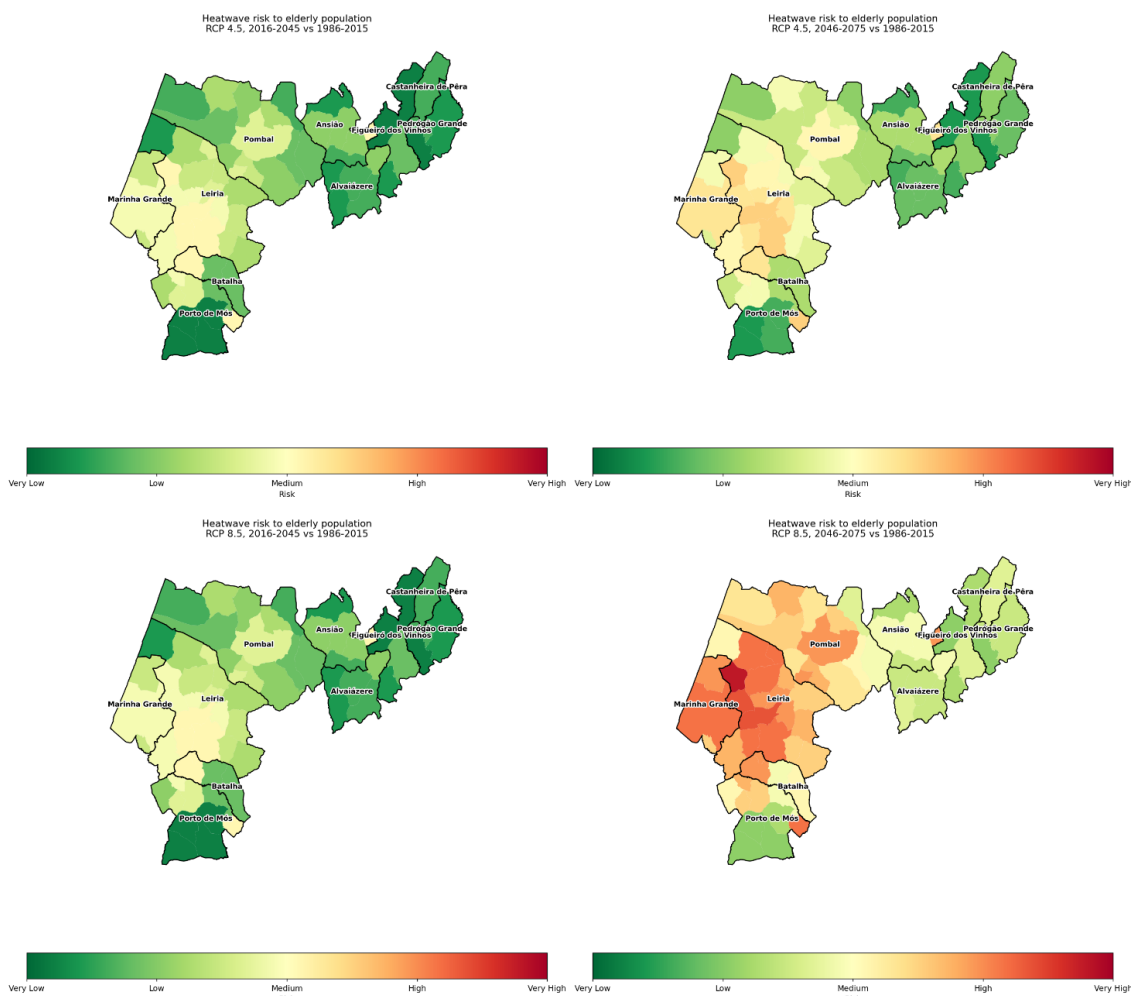


Figure 2-19 Projected heatwave risk at the parish level for the Region of Leiria across future horizons (2016-2045 and 2046-2075) under RCP 4.5 and RCP 8.5 scenarios.

The analysis of the most severe, long-term scenario (RCP 8.5 for the 2046–2075 horizon) demonstrates the progression of this threat, serving as a baseline roadmap for Municipal Emergency Plans. The assessment of the Top 15 civil parishes at highest risk underscores the significant weight that urban fabrics and their immediate peripheries exert on risk concentration, validating the need for tactical approaches to mitigate the heat island effect (as will be demonstrated in the subsequent satellite analysis).

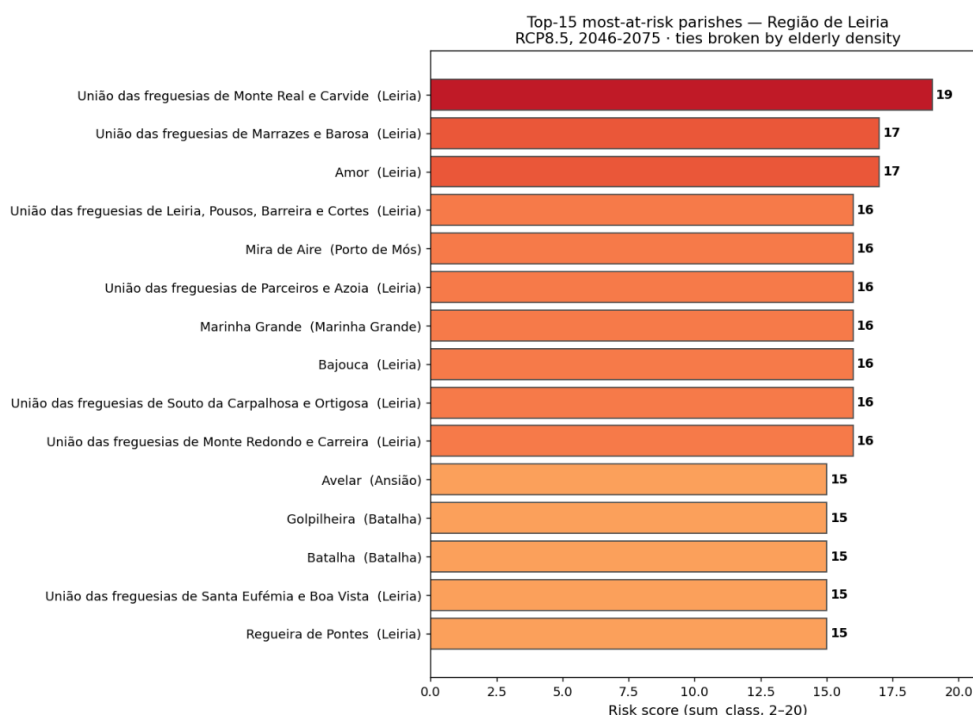


Figure 2-20 Top 15 parishes at highest risk of heatwaves under the worst-case scenario (RCP 8.5, 2046-2075) and a synthesized risk heatmap aggregated at the municipal level.

Observed Urban Heat: Satellite LST Analysis (Leiria, Marinha Grande and Pombal)

While climate projections (EURO-CORDEX) provide insight into future regional trends, their native resolution (~12.5 km) is insufficient to capture the "urban heat island" effect at the street level. To bridge this gap and deliver concrete operational data to the municipalities, the risk assessment was complemented by a high-resolution (~100 meters) observational analysis based on satellite-derived Land Surface Temperature (LST).

Given the heterogeneous territorial matrix of the Leiria Region, the analysis adopted a "multi-city" approach, focusing simultaneously on the three largest urban clusters in the NUTS III region: Leiria, Pombal, and Marinha Grande. Together, these three areas encompass roughly 219,000 of the region's 287,000 inhabitants, representing the main hotspots of urban exposure.

To characterize the structural heat island of these cities, imagery from the Landsat 8/9 satellites (official Level-2 product obtained via the Microsoft Planetary Computer) was utilized. The analysis focused on the severe event of July 2022. To avoid day-to-day anomalies and capture the zones that chronically overheat due to their structure, the model combined two clear-sky scenes (July 7 and 23), extracting the maximum temperature per pixel.

At this urban scale, census details could be fully leveraged. In a fundamental methodological decision, urban vulnerability was calculated using exclusively the density of the elderly population (≥ 65 years) at the statistical subsection level (BGRI 2021). This layer was rasterized to match the satellite's thermal grid.

Methodological Interpretation Note: The generated product strictly maps the risk for the elderly population (the age group with the strongest epidemiological correlation to heat-related mortality) and not the risk for the global population. Consequently, the risk is heavily concentrated within

historical centers and traditional neighborhoods (where the oldest population resides) rather than spreading out into the younger residential outskirts.

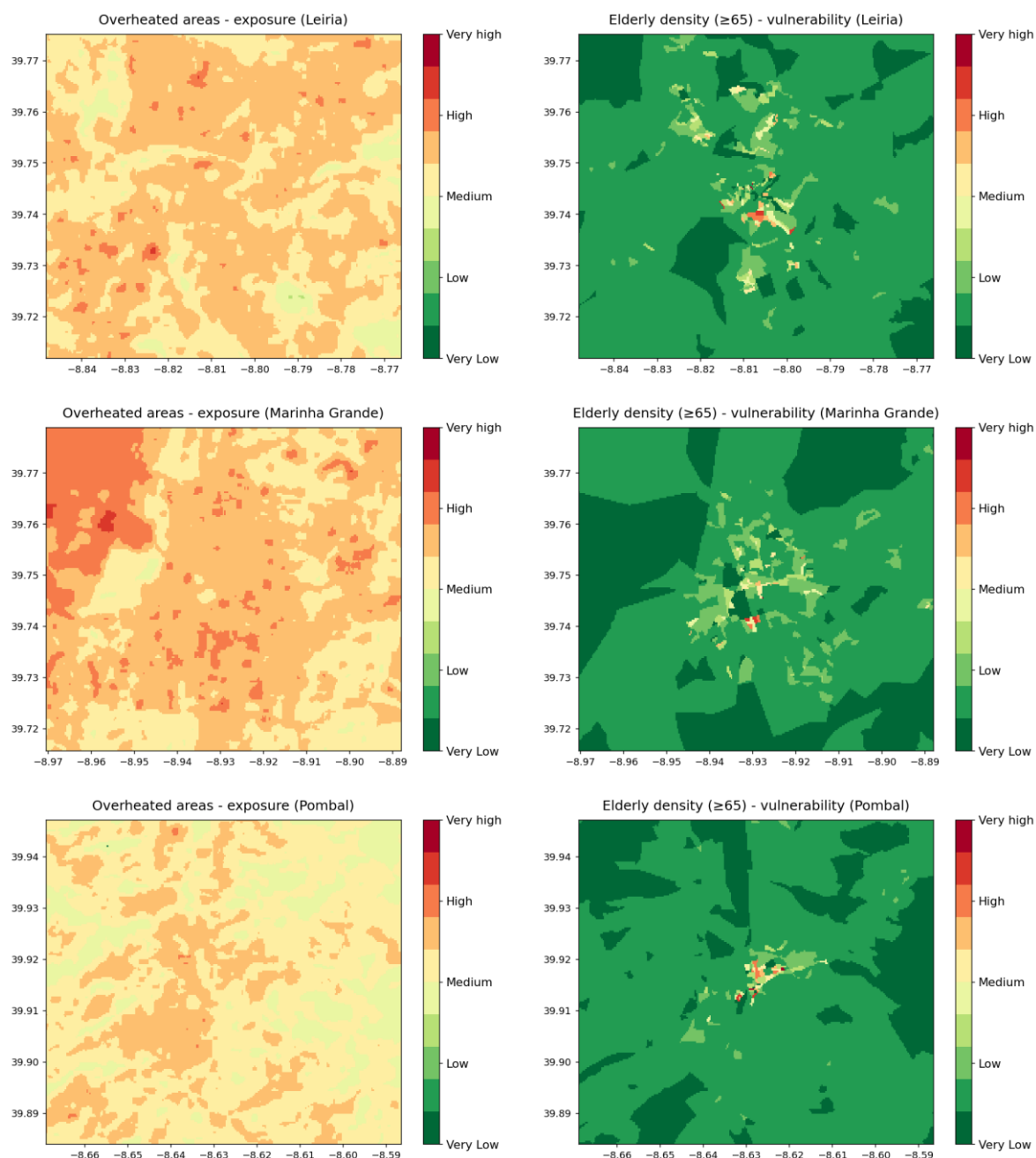


Figure 2-21 Comparison between Land Surface Temperature (LST) and heatwave vulnerability (elderly population density) in the urban areas of Leiria, Marinha Grande and Pombal.

The final risk results from the summation of a matrix combining 10 LST classes with 10 elderly density classes. The territorial assessment reveals that heat risk across the cities of the Leiria Region is globally moderate and highly concentrated (confined to the center of Leiria and the industrial core of Marinha Grande). This moderation, when compared to other regions of the country, reflects the strong Atlantic influence acting as a surface temperature regulator along the coast.

To translate this risk into tactical and response planning, the model overlaid the locations of critical infrastructure extracted from OpenStreetMap (OSM) (specifically filtering for nursing homes, day centers, and healthcare facilities) across the three cities. As a tactical note, the analysis demonstrated that healthcare infrastructure in Pombal and Marinha Grande is located in areas with

lower structural thermal loads, whereas Leiria presents the highest overlap of risk with elderly care and healthcare facilities within its urban core.

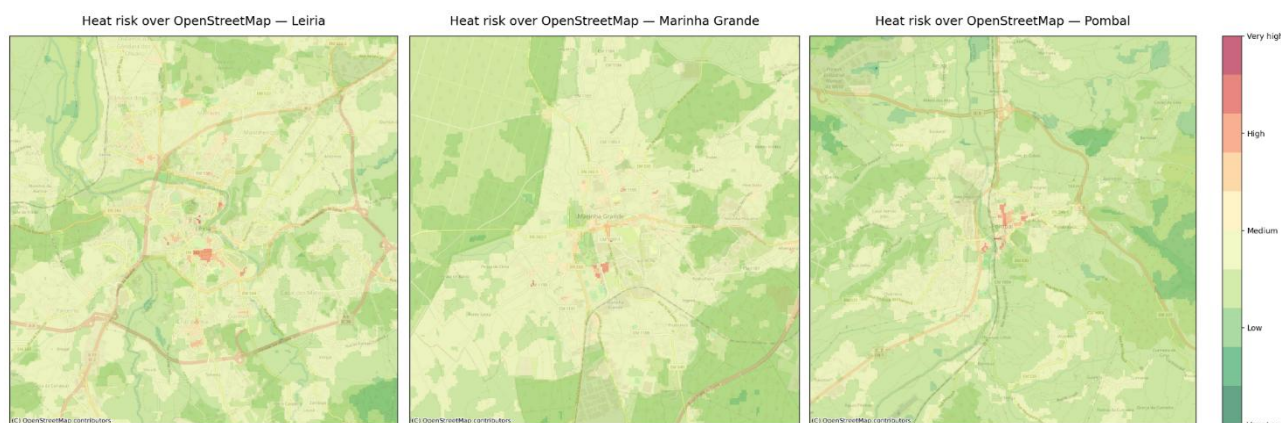


Figure 2-22 High-resolution urban heat risk, highlighting the exposure of critical health and elderly care infrastructure over geographical basemaps for Leiria, Marinha Grande and Pombal.

As a complementary exploratory product, an isolated assessment was generated by cross-referencing the location of educational establishments (OSM) with Land Surface Temperature (LST). This methodological separation is justified because, since these are infrastructures where children spend the hottest periods of the school day, overnight residential density is not the appropriate indicator. The mapping makes it possible to identify which school grounds across the three cities suffer from the greatest structural heat island effect, prioritizing potential shading interventions and Nature-Based Solutions (NbS).

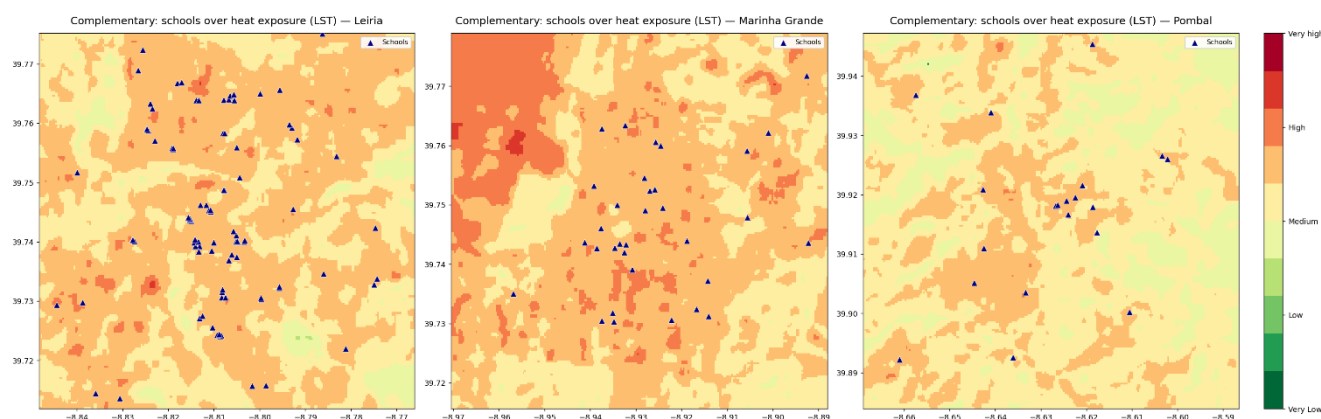


Figure 2-23 Complementary exploratory analysis: Exposure of educational facilities (schools) to structural urban heat islands (LST) in Leiria, Marinha Grande and Pombal.

2.3.4 Hazard #4 - Droughts finetuning to local context

2.3.4.1 Agricultural Drought

The Phase 1 agricultural drought risk assessment relied on pan-European standard crops (such as maize, wheat, and potatoes) which, while useful for a global characterization, did not adequately represent the socioeconomic fabric and main crops of the Leiria Region. Additionally, exposure was based on global databases (SPAM) and global aggregated values (GAEZ), limiting the operational utility of the results for intermunicipal planning.

To bridge this gap in Phase 2, CIMRL adopted a deep regionalization strategy (via the non-staple workflow), replacing generic crops and economic data with high-resolution local data. The focus shifted to the high-value permanent crops that define the agricultural and economic identity of the region: **olive, grapevine, apples, and pears**.

Key differences summary:

Aspect	Original Workflow	Enhanced Workflow
Target Crops	Global staple crops (maize, potato, wheat, etc.)	Local identity crops: Olive, Grapevine, Apple, and Pear.
Exposure Data (Area)	Global SPAM database	INE data (2019 Agricultural Census) at the parish scale (CAOP 2024).
Economic Valuation	Global aggregated values (GAEZ)	Real selling prices (raw material) from EUROSTAT cross-referenced with NUTS2 regional productivity (INE).
Crop Calendars	Global generic calendars (FAO)	Cycle dates adjusted to the agronomic calendar of mainland Portugal (Zone 3).
Spatial Intersection	Point-in-polygon	Area-weighted intersection , correctly distributing the exposure across climate pixels.

Key improvements include:

- **Integration of Local Identity Crops:** The analysis abandoned the generic staple crops from the European tool to focus on the permanent crops of high socioeconomic value in the Leiria Region (olive groves, vineyards, apples, and pears). To ensure greater precision, apples and pears were treated as individual crops instead of being evaluated under the generic "temperate fruits" category.
- **Exposure Based on National Censuses (INE):** Instead of using global databases (SPAM), physical exposure (area in hectares) was extracted at the parish level from the 2019 Agricultural Census (INE), utilizing the official national geometry of CAOP 2024, encompassing the 73 parishes of CIMRL.
- **Economic Valuation Using Market Prices:** The financial impact is now calculated by cross-referencing regional average productivity (NUTS2 - INE) with the real selling price of the raw material (euros/ton) extracted from EUROSTAT (multi-year average from 2019 to 2024).
- **Calibration to the Portuguese Agronomic Calendar:** Crop cycle start and end dates were recalibrated to strictly reflect the actual agronomic calendar of mainland Portugal (Climate Zone 3), eliminating the discrepancies caused by the global FAO dates.
- **Area-Weighted Spatial Intersection and Coastal Treatment:** To ensure accuracy, the initial "point-in-polygon" method was replaced by an area-weighted intersection. Additionally, the limitation of the European CORDEX grid, which did not cover the coastal strip (affecting ~9% of Leiria's area), was resolved, ensuring that the coastal agricultural exposure of these parishes was preserved in the risk calculation by assigning it to the nearest valid pixel.

Table 2-5 summarizes the data sources and the results generated during the refinement of the agricultural drought workflow. This phase of the CLIMAAX4Resilience project marks a decisive technical transition, in which the model underwent a deep national recalibration. Generic and global data from Phase 1 were completely replaced by official local and national statistics. The integration

of the exact geometry of the parishes (CAOP 2024), cross-referenced with real cultivated area data (INE - RA 2019), regional productivity, and real market prices (EUROSTAT), allows the risk assessment to transition from an abstract European index to a rigorous financial estimate (direct revenue losses in euros), perfectly tailored to the socioeconomic reality of the Leiria Region.

Table 2-5 Data overview workflow #4 – Agricultural Droughts

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
Climate (EURO-CORDEX): Downscaled projections (~12.5 km) of cumulative precipitation and potential evapotranspiration (PET) (historical 1986–2015; RCP 2.6/4.5/8.5 scenarios). Soil (AWC): Soil Available Water Capacity (AWC, 250 m, ISRIC/Zenodo) with a neighborhood-average imputation algorithm (3x3 window) to fill data gaps over the coastal strip of Leiria (NaN).	Physiological Parameters (FAO-56/33): Crop coefficients (Kc initial, mid, and late), cycle stages, and yield response factors (Ky) adapted to national conditions for apple, pear, vineyards, and olive groves. Irrigation (GAEZ 2015): Spatial mask identifying irrigated vs. rainfed crop parcels, defining the baseline sensitivity to water stress. JRC Vulnerability (PESETA IV): Standardized regional sensitivity indicators (regional GDP per capita and % of rural population).	Agricultural Area (Censo INE 2019): Actual cultivated rainfed surfaces for Apple (1,291 ha), Pear (1,025 ha), Vineyards (3,463 ha), and Olive groves (6,749 ha) extracted from the 2019 Agricultural Census (INE) for CIMRL's parishes. Regional Yields (INE 2024): Mean crop yields per hectare (ton/ha) based on official 2024 Crop Production statistics for the Centro NUTS II region. Market Prices (EUROSTAT): 2019–2024 annual averages in Portugal for wine grapes, apple, pear, and olives (via "Other olives" proxy). Area-Weighted Intersection: Area-preserving geometric downscaling (EPSG:3763) to map fine vector parishes into coarse climate grid cells, avoiding spatial errors.	Physical Yield Loss (%): Estimated reduction in potential crop yields induced by soil water deficit within each climate grid cell. Economic Losses (€): Direct financial loss estimates per pixel (12 km) computed as: Area × Yield × Price × Yield Loss. Parish-Level Analysis: Estimated economic losses in euros (€) aggregated at the civil parish level (CAOP 2024 DGT) and ranked across priority areas to support municipal adaptation strategies.

Hazard assessment

The agricultural drought hazard assessment focuses on the physical effect of water deficit on crop development and yield. To ensure the model's reliability in the Leiria Region (CIMRL), essential refinements were applied to the baseline climate and agronomic data, overcoming the limitations of the Phase 1 European data.

A fundamental correction concerned the model's spatial coverage in the coastal zone. The original climate grid (EURO-CORDEX) did not fully cover the coastal strip, which affected approximately 9% of CIMRL's territorial area (encompassing 15 parishes). To resolve this limitation and ensure that no agricultural area was excluded, the technical team ensured that the physical exposure of these coastal parishes was assigned to the nearest valid pixel. Figure 2-24 illustrates the corrected baseline layer.

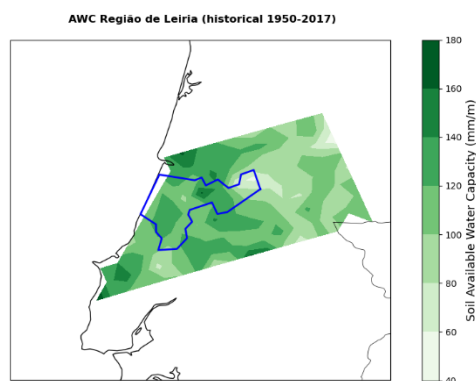


Figure 2-24 Soil Available Water Capacity (AWC), with imputation correction for internal water bodies, representing the physical baseline for agricultural drought.

The second critical refinement focused on plant development dates. The original workflow relied on generic FAO calendars that proved to be misaligned with the national reality. The start and end dates of the crop cycles under analysis were fully recalibrated to strictly reflect the agronomic calendar of mainland Portugal (Climate Zone 3). Additionally, in a methodological decision focused on local precision, apples and pears are now treated as individual high-value crops, rather than being diluted into a generic "temperate fruits" category.

The final hazard is expressed through the Relative Physical Yield Loss metric (in %), which reflects the direct impact of water stress on crop yield. Recognizing the vital importance of these crops to CIMRL's socioeconomic matrix, the analysis evaluated the detailed impact on the region's four strategic permanent crops: apples, pears, olive groves, and vineyards.

For each crop, a panel of maps contrasts the short/medium-term scenario (2026–2046) with the impacts projected for the end of the century (2071–2090) under the different emission trajectories (RCP 2.6, RCP 4.5, and RCP 8.5):

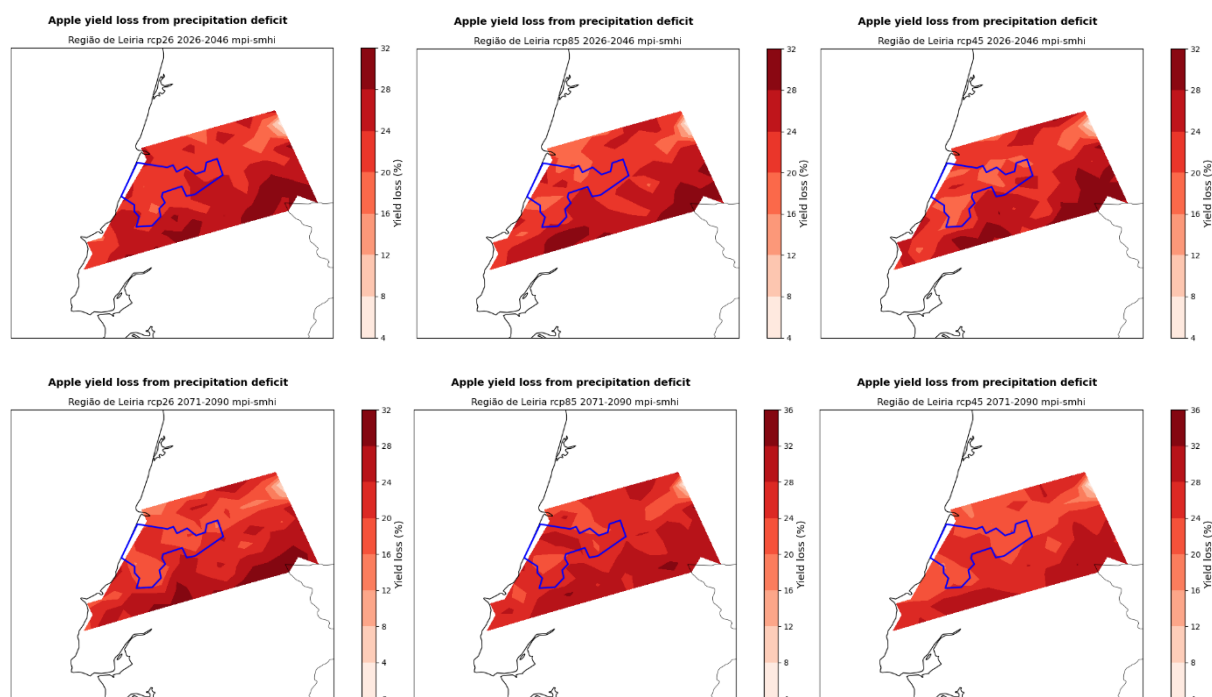


Figure 2-25 Projections of physical yield loss (%) for apple due to precipitation deficit, comparing near future (2026-2046) and end-of-century (2071-2090) horizons under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios.

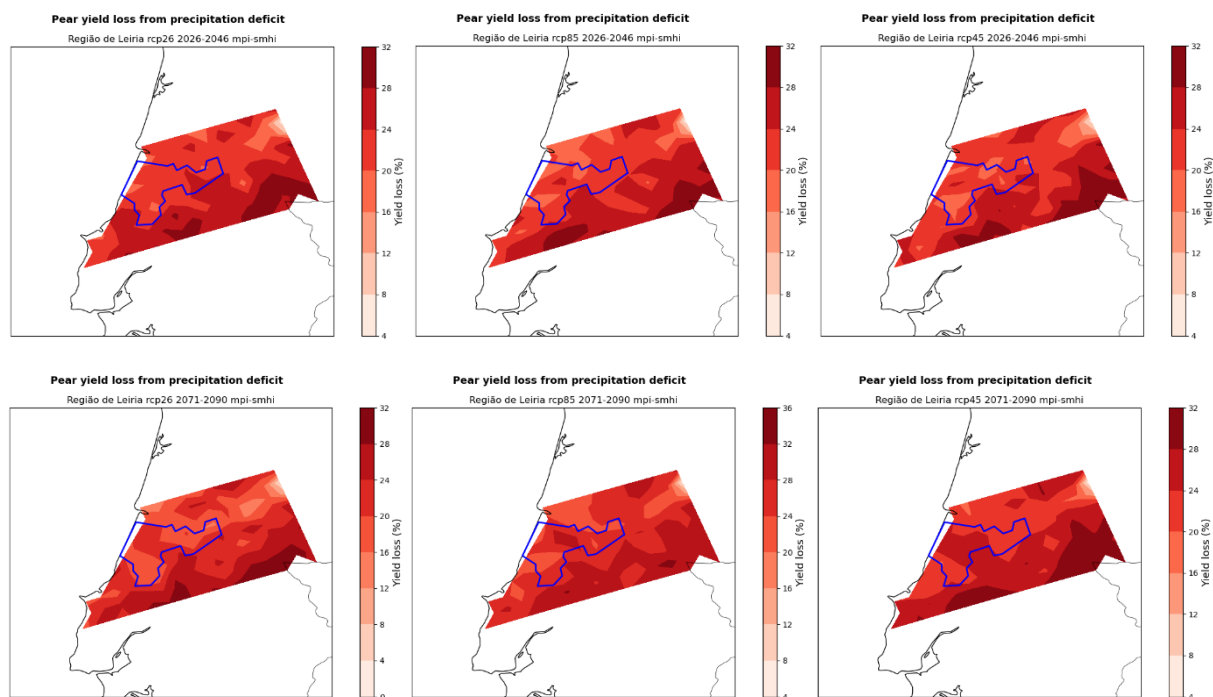


Figure 2-26 Projections of physical yield loss (%) for pear due to precipitation deficit, comparing near future (2026-2046) and end-of-century (2071-2090) horizons under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios.

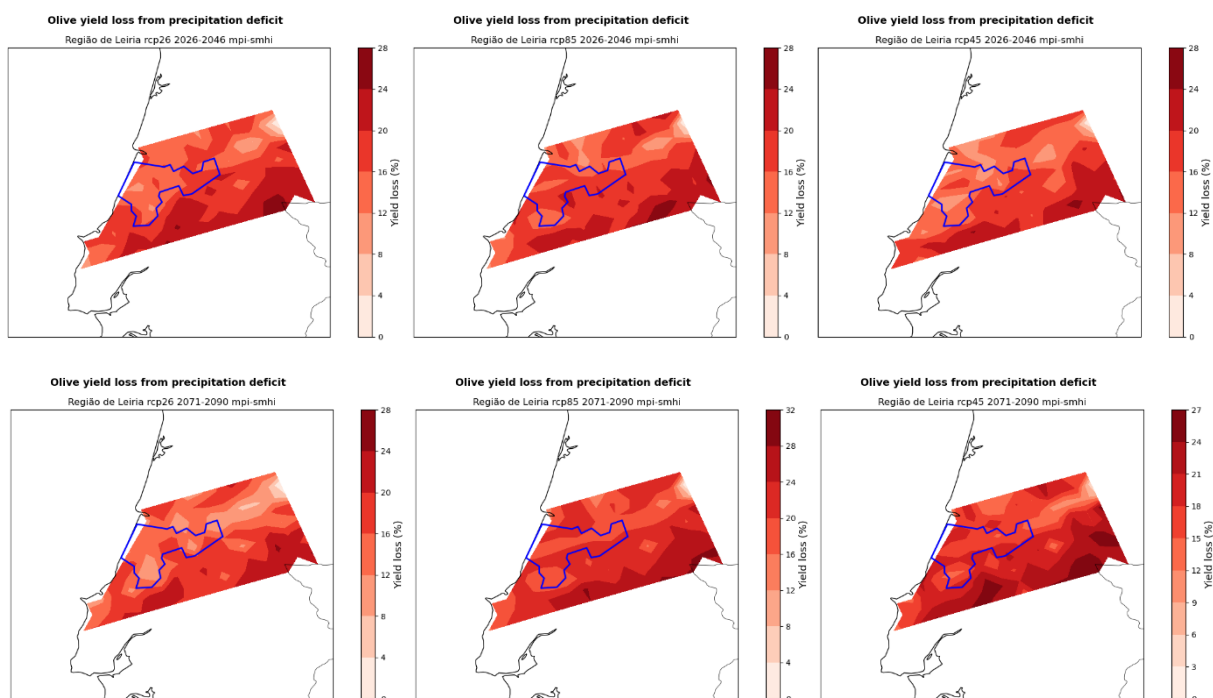


Figure 2-27 Projections of physical yield loss (%) for olive due to precipitation deficit, comparing near future (2026-2046) and end-of-century (2071-2090) horizons under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios.

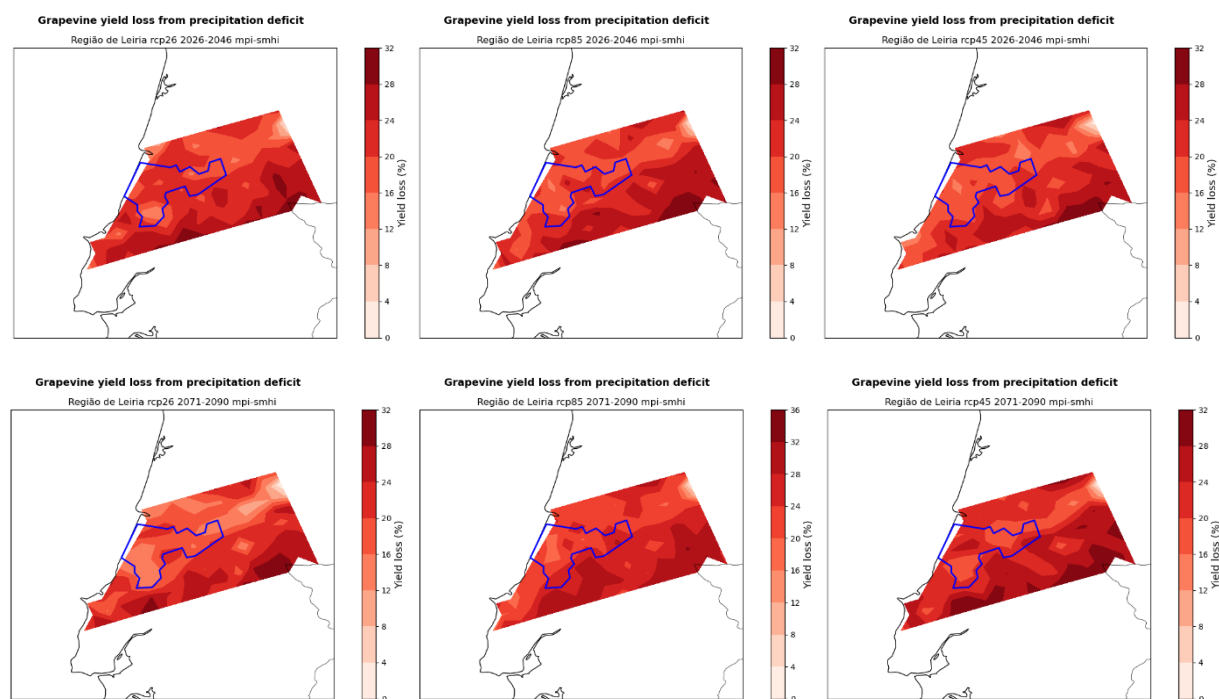


Figure 2-28 Projections of physical yield loss (%) for grapevine due to precipitation deficit, comparing near future (2026-2046) and end-of-century (2071-2090) horizons under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios.

The cross-cutting analysis of the scenarios demonstrates a progressive worsening of physical yield loss throughout the century. This drop in yield serves as the direct basis (input) for the Risk Assessment stage, where this biophysical impact will be converted into concrete financial revenue losses for producers in the Leiria Region.

Risk assessment

The decisive refinement in Phase 2 materializes in the risk calculation. Economic vulnerability is no longer an abstract global estimate (based on aggregated damage functions); it is now calculated using a formula anchored in the socioeconomic reality of the Leiria Region.

The economic loss per crop was quantified by translating the physical yield drop (%) into direct financial revenue losses. The formula applied cross-referenced the following official data:

- Loss (€) = Parish Area (ha) [INE - Agricultural Census] x Productivity (t/ha) [INE - NUTS2] x Raw Material Price (€/t) [EUROSTAT] x Physical Loss (%) [Climate Model]

To ensure maximum spatial precision when transitioning from the administrative boundaries of the parishes (CAOP 2024) to the resolution of the climate grid, the technical team applied an advanced area-weighted intersection method. Additionally, a vital correction was implemented for the Leiria Region: since the European CORDEX grid does not fully cover the coastal strip, approximately 9% of the territorial area (encompassing 15 coastal parishes) ran the risk of being excluded. The agricultural exposure of these parishes was secured by assigning the physical loss corresponding to the nearest valid pixel, ensuring that the economic impact was fully accounted for.

The estimates show that annual losses (revenue loss due to precipitation deficits, assuming a non-irrigated scenario) threaten the pillars of the region's primary sector. Taking the short/medium-term scenario (2026–2046) under a low-emissions trajectory (RCP 2.6) as a baseline reference, the

estimated annual economic losses for CIMRL stand at a total of ~€1.50 Million, distributed as follows:

- **Apple:** ~€0.61 Million / year
- **Olive Grove:** ~€0.47 Million / year
- **Vineyard:** ~€0.24 Million / year
- **Pear:** ~€0.17 Million / year

Figure 2-29, Figure 2-30, Figure 2-31 and Figure 2-32 illustrate the spatial projection of these direct financial losses (in euros) across the territorial grid for each of these four strategic crops. The panels allow for a contrast of risk evolution from the near future (2026–2046) to the end of the century (2071–2090) under the three evaluated emission trajectories (RCP 2.6, RCP 4.5, and RCP 8.5).

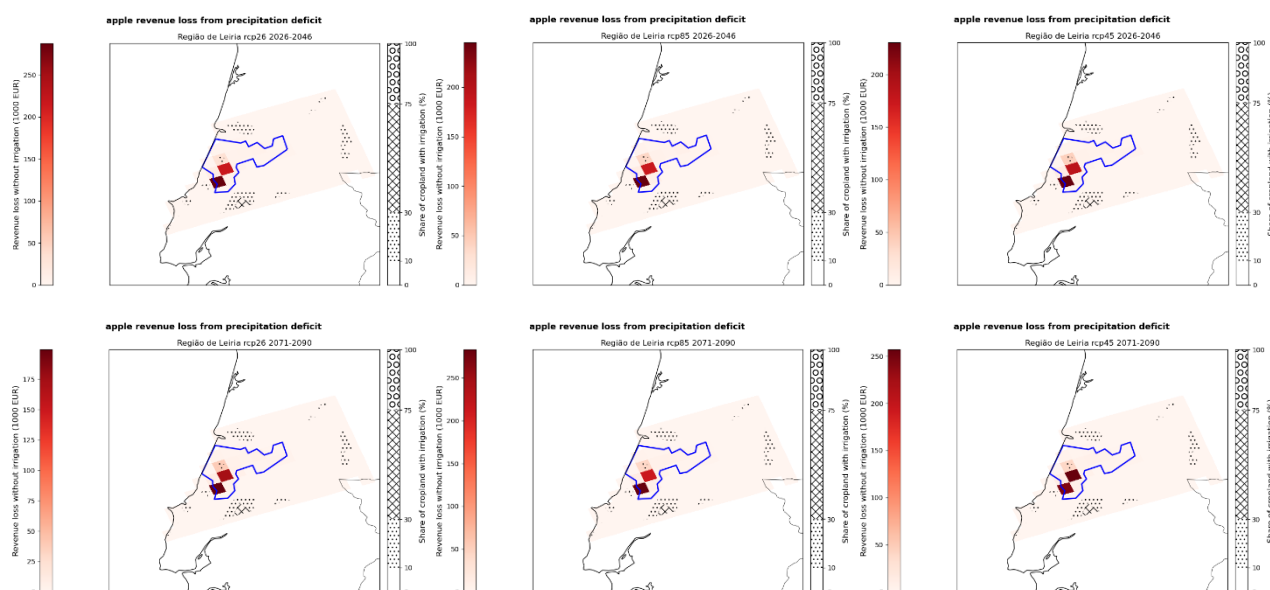


Figure 2-29 Spatial distribution of potential revenue losses (€) for apple due to precipitation deficit, comparing near future (2026-2046) and end-of-century (2071-2090) horizons under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios.

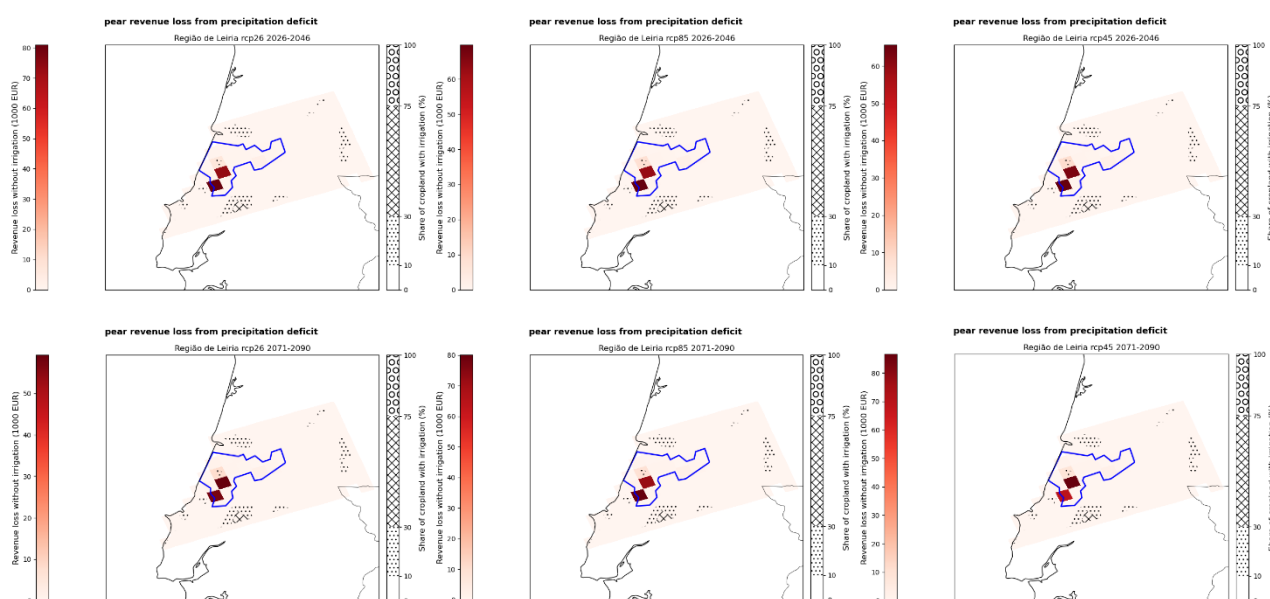


Figure 2-30 Spatial distribution of potential revenue losses (€) for pear due to precipitation deficit, comparing near future (2026-2046) and end-of-century (2071-2090) horizons under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios.

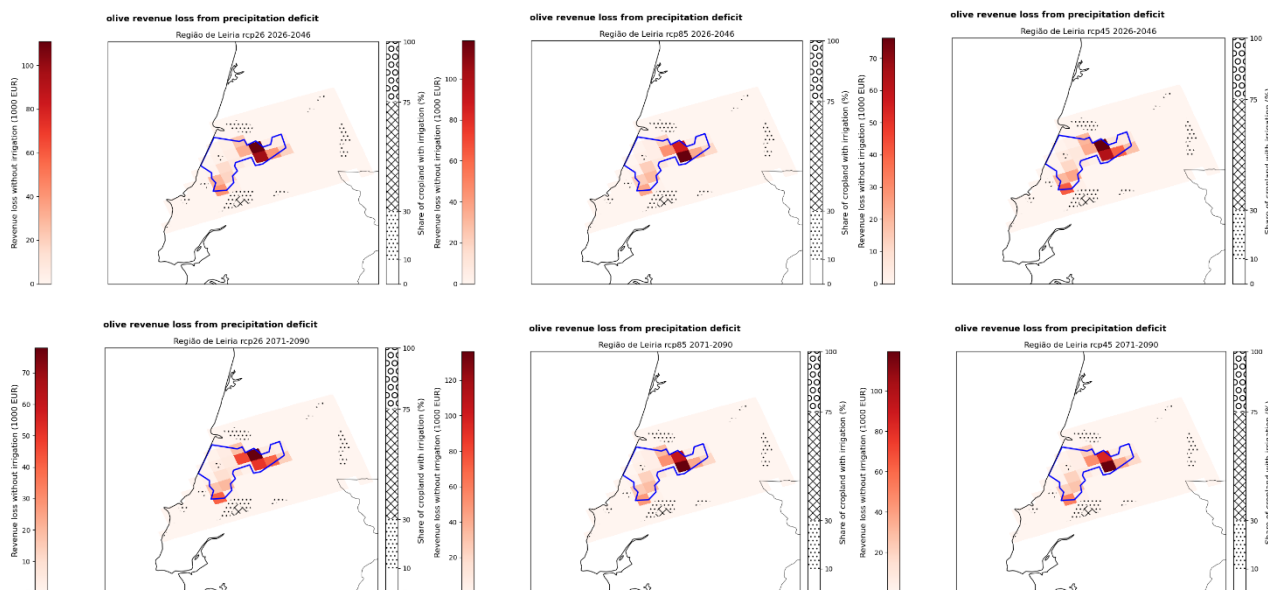


Figure 2-31 Spatial distribution of potential revenue losses (€) for olive due to precipitation deficit, comparing near future (2026-2046) and end-of-century (2071-2090) horizons under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios.

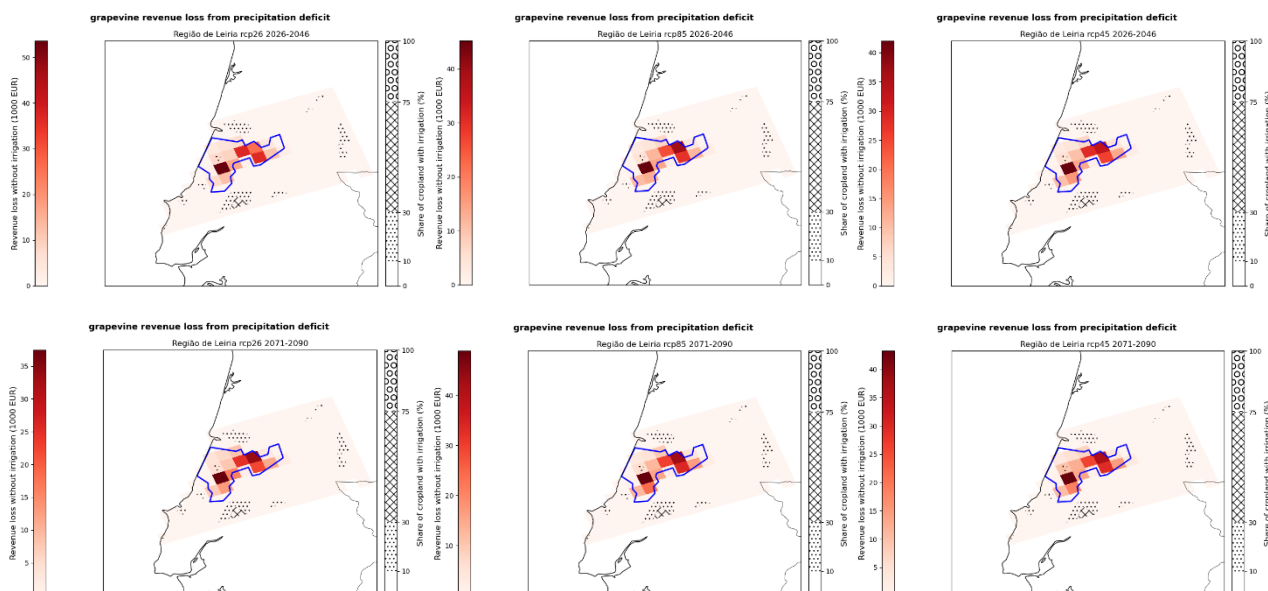
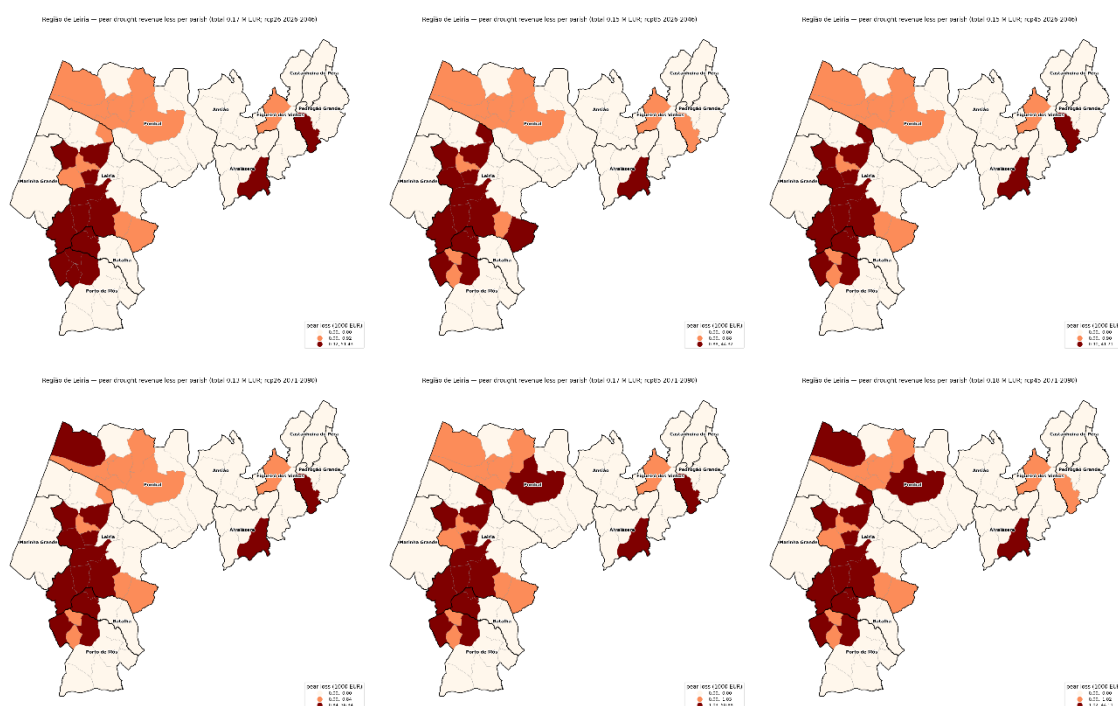
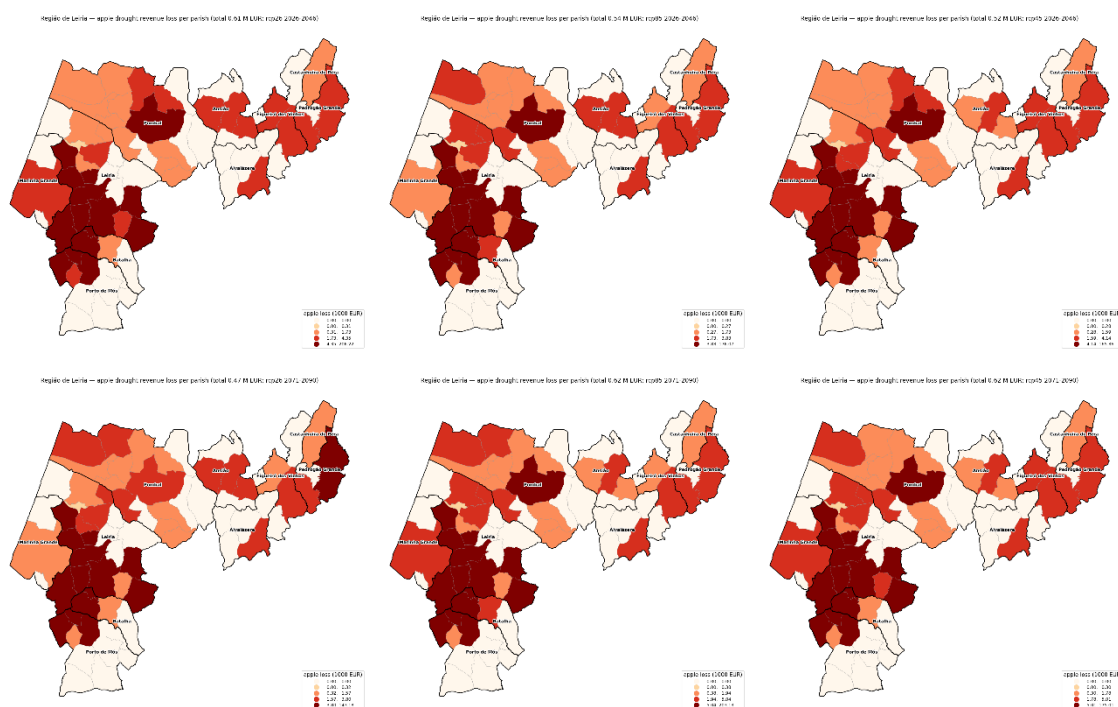


Figure 2-32 Spatial distribution of potential revenue losses (€) for grapevine due to precipitation deficit, comparing near future (2026-2046) and end-of-century (2071-2090) horizons under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios.

To provide local decision-makers with directly actionable data for the revision of Municipal Climate Action Plans (PMAC), the results modeled on the climate grid were aggregated and transposed onto the administrative boundaries of each of CIMRL's 73 parishes.

Figure 2-33, Figure 2-34, Figure 2-35 and Figure 2-36 present the spatial distribution of financial losses at the parish level, disaggregated for each crop. The consolidation of these sectoral impacts culminates in Figure 2-37, which illustrates the overall aggregate economic risk in the territory.



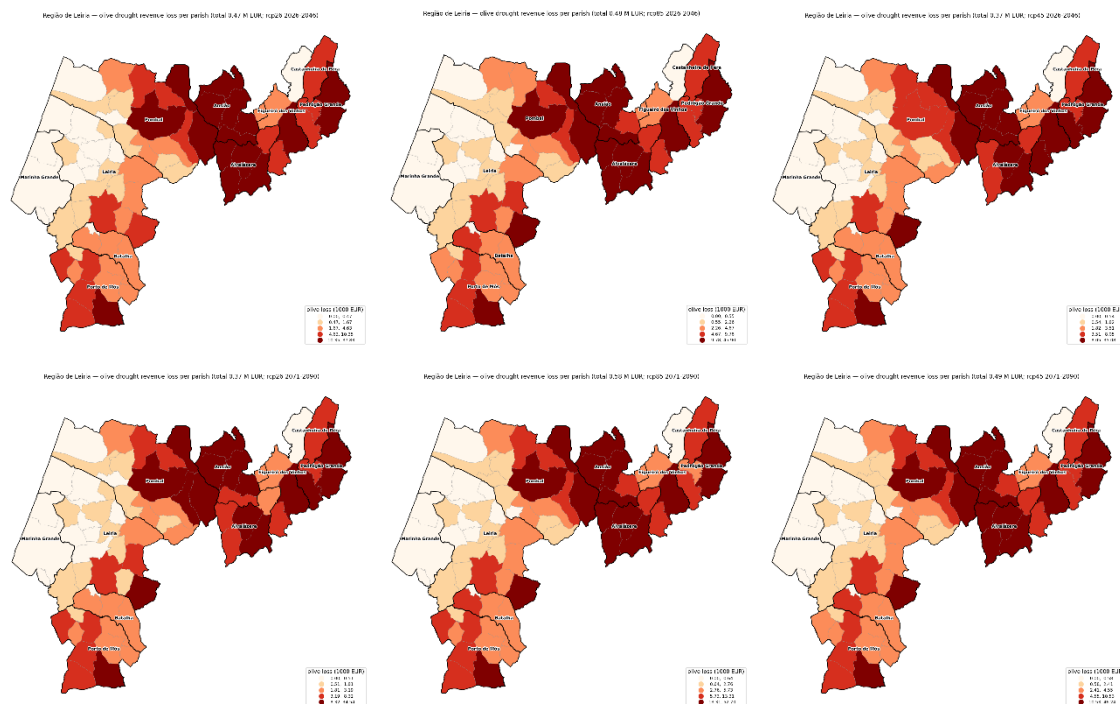


Figure 2-35 Expected revenue loss (€) per parish for olive due to precipitation deficit (2026-2046 vs. 2071-2090, under RCP 2.6, 4.5, and 8.5).

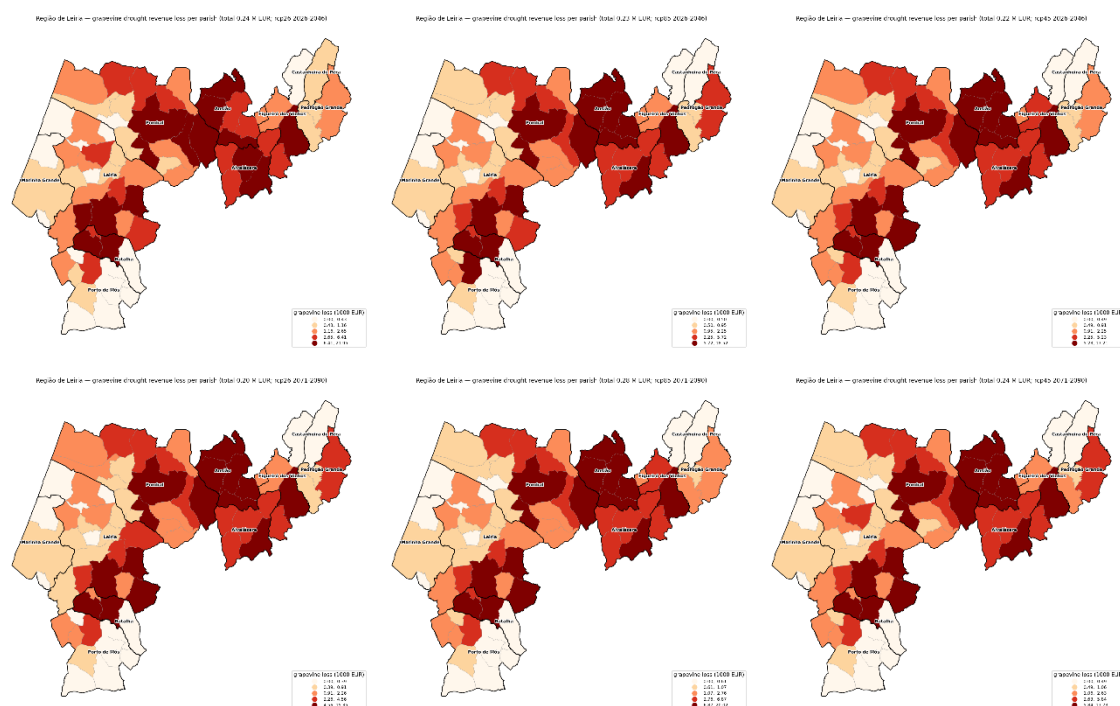


Figure 2-36 Expected revenue loss (€) per parish for grapevine due to precipitation deficit (2026-2046 vs. 2071-2090, under RCP 2.6, 4.5, and 8.5).

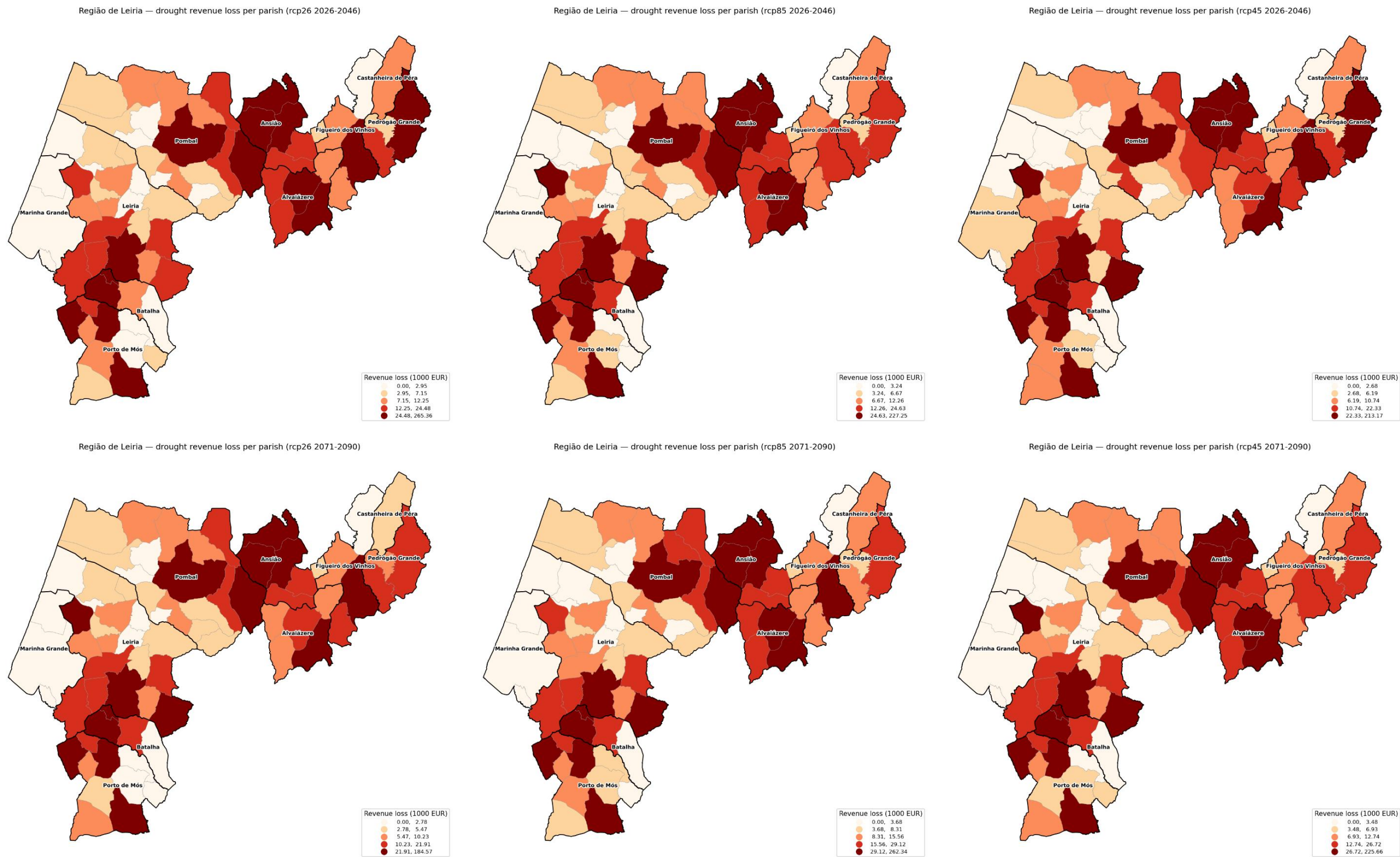


Figure 2-37 Aggregated expected revenue loss (€) per parish (apple, pear, olive, and grapevine combined) due to precipitation deficit (2026-2046 vs. 2071-2090, under RCP 2.6, 4.5, and 8.5).

The cross-referencing of these financial results with geographic distribution reveals that the risk clearly captures the agricultural identity of the region's limestone interior (Serra de Aire e Candeeiros). The analysis of the 15 most affected parishes (Figure 2-17) demonstrates that vulnerability is not homogeneous but varies according to the specific distribution of each crop.

The detailed analysis proves that the risk associated with orchards (apple and pear) is heavily concentrated in the municipalities of Porto de Mós (accounting for 44% of the risk for these crops), Leiria (29–31%), and Batalha (20%). The parish of Juncal, in the municipality of Porto de Mós, stands out across the board as the primary hotspot for economic loss in these crops. In contrast, the risk for olive groves is much more scattered throughout the interior territory, mostly affecting the municipalities of Ansião (24%), Alvaiázere (18%), Pombal, and Porto de Mós, while the impact on vineyards is primarily centered in Leiria and Pombal.

However, interpreting these results requires the declaration of a crucial interpretive limitation: the "Area vs. Identity Value Paradox." The risk model evaluates absolute exposed area rather than symbolic value or Protected Geographical Indication (PGI/IGP) status. Consequently, although the "Maçã de Alcobaça" (Alcobaça Apple) is the region's major identity-defining brand, the absolute financial risk for apples appears mapped with greater intensity in Porto de Mós, Leiria, and Batalha. This occurs because these municipalities hold, in absolute terms (physical hectares), the largest expanses of orchard recorded by the model. This caveat ensures transparency in decision-making: future adaptation measures in Phase 3 must consider that the focus on these municipalities aims to protect the overwhelming majority of the physical production area, without prejudice to the enormous added and identity value that the remaining areas of the region represent.

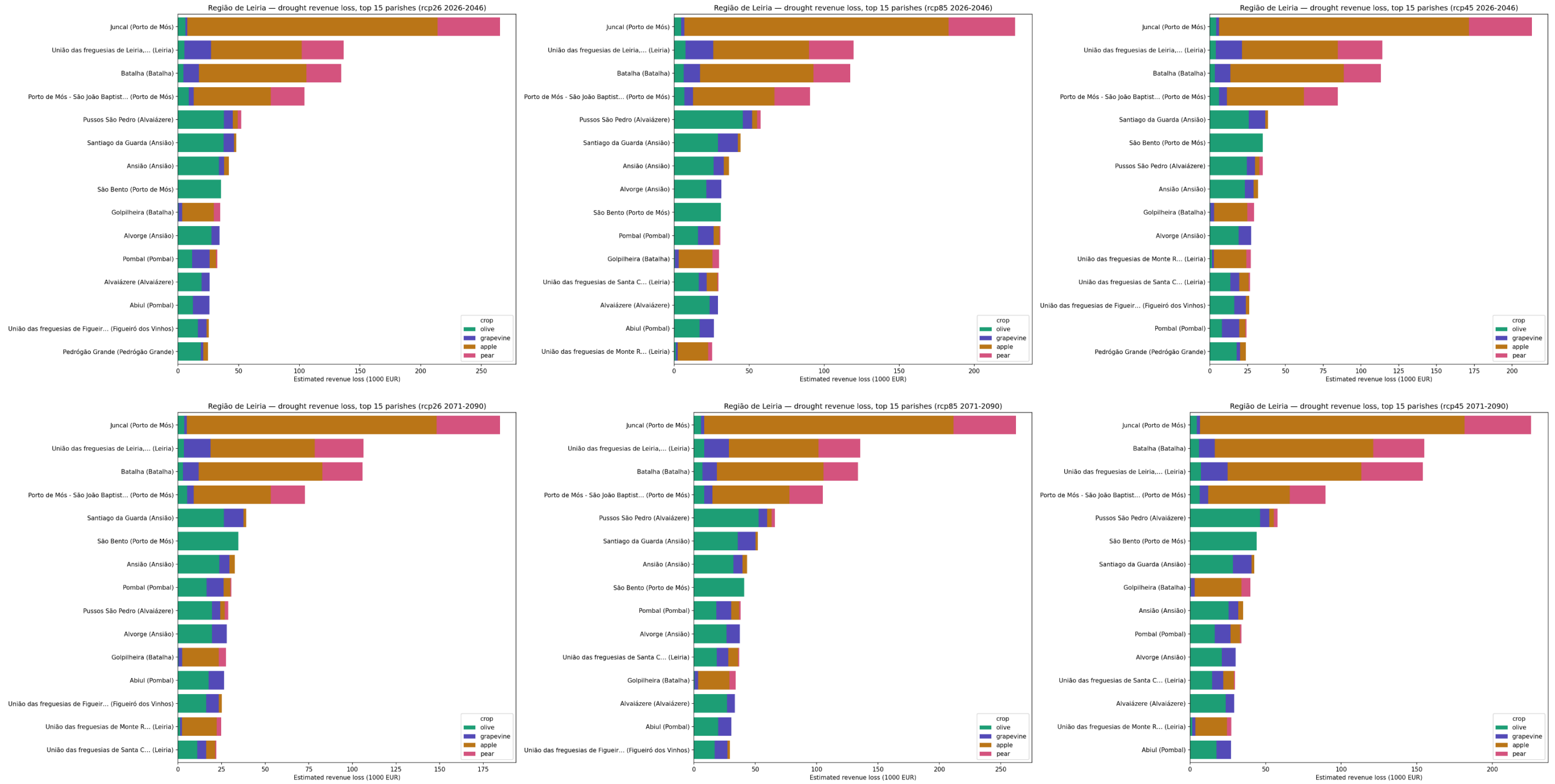


Figure 2-38 Top 15 parishes with the highest expected economic risk (revenue loss in €) from agricultural drought across all scenarios and time horizons, disaggregated by crop.

2.3.5 Additional assessments based on local models and data

In order to complement the standard CLIMAAX workflows and address spatial resolution and physical dynamic limitations of macro-scale European models, the Leiria Region (CIMRL) developed high-resolution additional assessments based on local datasets and models, structured in accordance with the European consortium's guidelines.

2.3.5.1 Hazard assessment

High-resolution local hazard modeling focused on two complementary approaches that refine the physical characterization of coastal and thermal threats:

1. **Dynamic Wave Runup (R2%) Uncertainty Envelope (Coastal Floods):** To address the lack of wave breaking and swash dynamics in static models, a physical envelope was modeled using DGT's 2 m LiDAR DEM and Cascais tide-gauge data (TWL). It comprises a *Lower Boundary (Wave Setup)* with a 0.5 m freeboard (966.9 ha historical, 1,325.2 ha future RCP 8.5 by 2100) and an *Upper Boundary (Runup R2% - dynamic swash)* with a 2.5 m freeboard (1,419.8 ha to 2,281.4 ha), capturing a deep estuarine intrusion (~2.5 km) along the Lis River valley.
2. **Satellite Urban Heat Islands (Heatwaves):** Overcoming the ~12.5 km regional climate grid, a Land Surface Temperature (*Landsat LST* at ~100 m) model was deployed for the extreme July 2022 heatwave peak, mapping surface thermal hotspots (up to 56 °C) across the paved urban soils of Leiria, Pombal, and Marinha Grande.
3. **Hazard Validation against the POC Ovar-Marinha Grande:** Overlaying the modeled footprints with official Coastal Program (POC) Safeguard Zones showed high spatial convergence along sandy beachfronts and confirmed that the Phase 2 local model fills regulatory gaps by mapping Lis estuarine propagation and low-lying beachfront urban fronts under extreme storm overtopping.

2.3.5.2 Risk assessment

Refined hazard boundaries were intersected with local socioeconomic and demographic datasets to characterize risks with municipal tactical relevance:

1. **Granular Building and Population Exposure (Coastal Floods):** Overlaying the flood envelope with individual OpenStreetMap (OSM) building footprints and official BGRI 2021 census subsections (INE) quantified direct structural building damages and human displacement risks (water depth > 1.0 m), proving that losses concentrate along the vulnerable beachfronts of Praia da Vieira, Praia do Pedrógão, and São Pedro de Moel, as well as the Lis River agricultural valley.
2. **School Thermal Exposure (Heatwaves):** The 100 m LST raster was combined with the locations of 27 local elementary and secondary schools. This innovative approach assessed the daytime physical exposure of children (the secondary vulnerable cohort) at educational facilities during peak solar hours, identifying high accumulated thermal severity in Leiria's dense historic center and Marinha Grande's industrial hub.
3. **Complementarity in Emergency Planning:** The assessment proved that Phase 2 risk maps complement official POC cartography by modeling real-world risks along defended urban fronts (where the POC safeguard zone cuts off, assuming absolute defense performance) and across the Lis estuary, delivering defensible operational data for Civil Protection and municipal plan revisions (PDMs and PMACs).

2.4 Key Risk Assessment Findings

This section presents the strategic synthesis and evaluation of the results generated in the Regionalized Risk Analysis (Section 2.3) for the four priority climate hazards in the Leiria Region (CIMRL): rural wildfires, coastal flooding, heatwaves, and agricultural droughts.

Following the methodological guidelines of the European CLIMAAX consortium, the high-resolution physical, infrastructural, and demographic quantitative risk outputs are interpreted and contextualized in an integrated manner to support local decision-making.

The assessment is based on the concurrent coordination of three fundamental analytical dimensions: (i) the **Severity** of biophysical, social, and economic impacts; (ii) the temporal **Urgency** of action given the rate of change and acceleration of hazards under future climate scenarios (RCP 4.5 and RCP 8.5); and (iii) the diagnosis of the local system's **Resilience Capacity**. This evaluation process was enriched by the active participation of regional strategic partners, enabling the translation of refined scientific evidence into tactical and highly actionable intervention priorities for CIMRL's Municipal Climate Action Plans (PMAC) and Municipal Emergency and Civil Protection Plans (PMEPC).

2.4.1 Mode of engagement for participation

The evaluation of key risk findings was developed through a direct link between quantitative numerical modeling and the practical experience of local actors. Stakeholder engagement followed a co-creation and technical validation model during Phase 2, leveraging the inputs gathered during the working and participatory session with the Sub-Regional Commission for Integrated Rural Fire Management of the Leiria Region, and the validated responses from the Stakeholder Survey.

This process made it possible to compare the generated results and projections against the historical incident memory and on-the-ground experience of municipal Civil Protection teams, regional planning and forestry authorities (ICNF, APA), and strategic infrastructure concessionaires (Ascendi, REN, E-Redes). The contributions were decisive for calibrating severity thresholds, characterizing resilience capacity vulnerabilities, and validating the prioritization of key risks in the territory, ensuring the necessary institutional legitimacy for the future integration of these results into municipal planning instruments.

2.4.2 Gather output from Risk Analysis step

The compilation of results extracted from the Regionalized Risk Analysis (Section 2.3) consolidates the high-resolution quantitative data that underpin the assessment of severity and urgency. For the Leiria Region (CIMRL), the following operational outputs were utilized:

- **Wildfires Results:** Continuous and classified hazard maps generated by Machine Learning models operating at a 100 m resolution, empirically validated against the actual historical burned area registry (1990–2023). The quantification of impacts generated three-layer risk matrices: Layer 1 (territorial risk/JRC), Layer 2 (tactical exposure of the strategic road network and municipal critical infrastructure operating at a 10 m resolution), and Layer 3 (strict population risk extracted from the BGRI 2021 subsections).
- **Coastal Flood Results:** Hazard mapping at a 10-meter resolution, supported by DGT's LiDAR topography (2 m) and locally calibrated extreme water levels, identifying the exact flood

boundaries driven by wave setup and runup dynamics. The assessment generated economic damage maps (recalibrated for inflation and regional wealth factors) along with vital metrics for Expected Annual Damage (EAD) and Expected Annual People Displaced (EAPD), documenting the systemic vulnerability to estuarine intrusion along the Lis River and the breaches of urban fronts at Praia do Pedrógão, Praia da Vieira, and São Pedro de Moel.

- **Heatwave Results:** Indexes of climate occurrence, frequency, and duration strictly recalibrated to the national absolute thresholds of the IPMA ($T_{\max} \geq 35^{\circ}\text{C}$ and $T_{\min} \geq 20^{\circ}\text{C}$). To complement the climate signal, high-resolution ($\sim 100\text{ m}$) tactical urban heat risk maps were generated from Land Surface Temperature (LST from Landsat 8/9 satellites), revealing urban heat islands in the cities of Leiria, Pombal, and Marinha Grande, and their critical overlap with the elderly population (BGRI) and healthcare facilities.
- **Drought Results:** The analysis focused on agricultural drought. The results materialized as socioeconomic impact maps disaggregated at the civil parish scale, evaluating the percentage drop in yield and the resulting direct loss of financial revenue. The model was executed specifically for the region's high-value, signature permanent crops (olive groves, vineyards, apples, and pears) under projections of scarce precipitation and the absence of artificial irrigation for the short/medium-term and end-of-century horizons.

These technical results, characterized by the deep integration of official national databases (COS 2023, BGRI 2021, agricultural censuses, and local pricing and IPMA threshold calibrations), ensure that the assessment of severity and urgency transitions from a theoretical exercise to reflect the true operational foundation that will sustain the tactical emergency and adaptation planning for the 10 municipalities of the CIMRL in Phase 3.

2.4.3 Assess Severity

Severity interprets the quantitative results, focusing on the magnitude of impacts and the occurrence of cascading effects that could compromise the systemic functions of CIMRL. Severity assessment for each risk was conducted according to four categories: **limited, moderate, substantial, and critical**.

- **Wildfires** | *Current: Substantial → Future: Critical*: Severity is driven by the consequences already experienced in the region's recent past (namely the destruction of property and loss of life in 2017) and the irreversible potential for destruction of the vast forest ecosystem and industrial sector.
- **Coastal Flooding** | *Current: Substantial → Future: Critical*: Severity reaches a critical level due to the risk of severe overtopping and territory loss from erosion. These dynamics pose a direct physical threat to coastal urban fronts, port infrastructure, and the tourism sector tied to the blue economy.
- **Heatwaves** | *Current: Moderate → Future: Critical*: High severity is associated with spikes in mortality and morbidity among the most vulnerable demographic (the elderly population). Territorially, they act as a severe "risk multiplier," triggering cascading effects that rapidly worsen droughts and rural wildfire hazard levels.
- **Droughts** | *Current: Moderate → Future: Substantial*: This represents a material financial risk to the region's sustainability, with impacts concentrated in high-value permanent crops within the agricultural and forestry sectors ($\approx \text{€}1.5\text{M}$ in modelled revenue losses, spatially dispersed, under a rainfed worst-case).

2.4.4 Assess Urgency

Urgency reflects the temporal dimension of the hazards, evaluating the speed of progression (sudden-onset vs. slow-onset events) and the worsening trends across future scenarios. The urgency assessment for each risk was conducted according to four categories: **no action needed, watching brief, more action needed, and immediate action needed.**

- **Wildfires (Fire)** | immediate action needed: This is a sudden-onset event with violent progression. The urgency is immediate and unquestionable for the physical establishment of fuel management buffers and the reinforcement of early-warning systems for the exposed population, aiming to mitigate imminent threats to human life at the wildland-urban interface.
- **Coastal Flooding** | immediate action needed: In the face of uninterrupted sea-level rise and the increasing intensity of extreme coastal storms, protecting low-lying coastal communities (such as Praia da Vieira or Pedrógão) and waterfront infrastructure demands immediate planning and structural or engineering intervention.
- **Heatwaves** | immediate action needed: Although their perception can sometimes be underestimated, the acute worsening projected in the short and medium term requires immediate action in public health and urban design, actively focused on protecting the vast elderly population highlighted in the Census data.
- **Droughts** | more action needed: Even though it is categorized as a slow-onset hazard, its effects are cumulative and severe. The heightened risk of financial losses in agriculture requires the urgent definition of medium- and long-term structural measures for water resource management and storage.

2.4.5 Understand Resilience Capacity

Resilience capacity analyzes the region's current competence to absorb and adapt to climate damage. The assessment is structured across the five fundamental capitals – physical, financial, human, social, and natural – allowing for the identification of adaptation gaps and the effectiveness of response mechanisms already in place. The resilience capacity assessment for each risk was conducted according to four categories: **low, medium, substantial, and high.**

- **Wildfires:** Medium
 - Human and Physical Capital: The region possesses excellent human capital within its civil protection services, forged through the harsh response experiences of the extreme 2017 events. Physical capital benefits from the existence and comprehensive updates of Municipal Emergency and Civil Protection Plans (PMEPC) and Municipal Climate Action Plans (PMAC) across the municipalities.
 - Social and Natural Capital: The vast continuity of production forest cover, combined with demographic aging in several inland municipalities, represents a structural vulnerability that drastically limits the self-protection capacity of local communities within Wildland-Urban Interface (WUI) zones.
- **Coastal Floods:** Low / Medium
 - Physical and Institutional Capital: The region benefits from a robust regulatory and territorial management instrument, the Ovar-Marinha Grande Coastal Zone Management

Program (POC), which serves as a vital strategic framework for risk mitigation along the coastline.

- Financial Capital: The primary constraint lies in the exceptionally high financial capital required to implement and maintain the large-scale coastal engineering works needed to halt projected erosion (such as dikes, seawalls, and large-scale beach nourishment for dune systems).
- **Heatwaves: Low**
 - Social and Human Capital: Resilience is directly penalized by high demographic vulnerability. The high percentage of the elderly population reduces the social capital necessary to autonomously withstand prolonged thermal shocks.
 - Physical Capital: There is a persistent gap requiring large-scale investment in the structural adaptation of the built environment and the expansion of Nature-Based Solutions (NbS) to promote the passive cooling of consolidated urban spaces.
- **Droughts: Low / Medium**
 - Financial and Physical Capital: The significant exposure of the agroforestry sector limits the financial resilience of CIMRL producers to independently absorb the exceptionally high costs associated with the large-scale modernization of irrigation infrastructure or the systemic transition to crops more resilient to water scarcity.

2.4.6 Decide on Risk Priority

The definition of risk priorities for the Leiria Region synthesizes the technical evidence extracted from the assessment (physical severity and climate urgency) with the diagnostic of local resilience capacity. The result of this intersection provides an evidence-based prioritization to guide adaptation options and strategic investment in Phase 3 (Table 2-6).

The risk priorities for Leiria Region were established as follows:

- **Wildfires: Very High Priority**: Considered a critical and absolute priority risk, driven not only by the technical assessment highlighting future hazard increases projected by the machine-learning susceptibility model but especially by the materialized experience of the 2017 catastrophe. The urgency of action is immediate to protect Wildland-Urban Interface (WUI) areas and mitigate the irreversible potential for loss of human life and destruction of natural capital.
- **Coastal Floods: Very High Priority**: Given that the coastal zone features an exceptionally high concentration of population and economic assets, and since the CIMRL coastline (governed by the POC Ovar-Marinha Grande) is under severe erosion and strong pressure from sea-level rise, immediate and structural interventions for protection, defense, and spatial planning are required.
- **Heatwaves: High Priority**: Priority is classified as high due to the potentially fatal impacts on the most vulnerable demographic cohorts (namely the elderly population) and its pernicious role as a "risk multiplier," as extreme heat events severely amplify drought cycles and the ignition of forest fires. It sits at the upper end of the High band: heat is among the most lethal climate hazards for human health and the region's resilience to it is low, which would argue for elevation; it is held at High because its impacts are diffuse and largely addressable through

health, urban-design and nature-based measures, rather than the irreversible, engineering-bound losses of wildfire and coastal flooding.

- **Droughts: *Moderate Priority***: A slow-onset threat whose modelled impact is material but spatially contained (≈€1.5M, dispersed across high-value crops); it warrants structured medium-term planning for water resources and crop resilience rather than immediate emergency intervention.

The Very High tier is reserved for hazards that combine an irreversible, structural loss potential with a materialized local record – the 2017 fire catastrophe and the active erosion and sea-level pressure on the coast – and that therefore demand immediate engineering or structural intervention. Heatwaves and droughts act primarily as health- and economy-mediated threats and as amplifiers of the first two: heatwaves are held at High, and droughts – slower-onset and more spatially contained – at Moderate. Neither placement reflects a lesser concern, but rather the more diffuse and largely addressable nature of their impacts relative to the irreversible, engineering-bound losses of wildfire and coastal flooding.

Table 2-6 Key Risk Assessment through risk ranking, considering severity, urgency and resilience capacity

Hazard	Severity		Urgency	Resilience capacity	Priority
	current	future			
Wildfires	Substantial	Critical	Immediate action needed	Medium	Very high
Coastal Floods	Substantial	Critical	Immediate action needed	Medium	Very high
Heatwaves	Moderate	Critical	Immediate action needed	Low/Medium	High
Droughts	Moderate	Substantial	More action needed	Low/Medium	Moderate

Severity  Critical  Substantial  Moderate  Limited	Urgency  Immediate action needed  More action needed  Watching brief  No action needed	Resilience Capacity  High  Substantial  Medium  Low	Risk Ranking  Very high  High  Moderate  Low
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2.5 Monitoring and Evaluation

The completion of Phase 2 consolidated the understanding that downscaling the analysis and calibrating it with local data are the key drivers for the operational utility of risk results. The Monitoring and Evaluation (M&E) strategy for the Leiria Region (CIMRL) transitions from abstract European datasets to the dynamic tracking of real biophysical and demographic indicators. The evaluation process highlighted the following structural conclusions:

- **Technical Difficulties and the "Scale Paradox"**: The primary technical bottleneck centered on the contrast between data resolutions. While local exposure and vulnerability were mapped with tactical precision (2 m LiDAR, 10 m rasterized COS 2023, BGRI 2021 subsections), the baseline climate hazard projections (EURO-CORDEX) remain locked in a coarse native resolution (≈12.5 km). This constraint demanded complex GIS and statistical processing, treating regional climate projections as stress factors applied over the territory's high-resolution topographic, fuel, and demographic reality.
- **Role of Stakeholders and Empirical Validation**: Interaction with regional partners (Civil Protection, ICNF, APA, municipal teams) confirmed that the "utility gap" from Phase 1 has been bridged. Stakeholders provided essential qualitative ground-truth feedback that validated the spatial consistency of risk maps and compared theoretical climate projections against historical

occurrence records and tactical on-the-ground experience, securing the scientific legitimacy of the models.

- **Support for Management Tools and Continuous Monitoring:** Although the integration of national datasets (INE, DGT, IPMA) resolved major exposure gaps from Phase 1, the region will benefit from dynamic, continuous tools to track key indicators over time – annual burned area (ICNF), tide-gauge levels and beach-nourishment records (APA), and the number of days with $T_{\max} \geq 35$ °C (IPMA).
- **Learning and Institutional Capacity Building:** The project secured technical knowledge transfer to the teams of CIMRL and its 10 constituent municipalities. The stabilization of automated workflows through structured and documented Jupyter Notebooks ensures that local technicians can autonomously replicate, update, and feed the climate and risk databases in the future.
- **Impact and Communication:** The project's impact is considered high, as it translates abstract climate projections into operational planning tools. Refined spatial hazard and risk maps will be directly integrated into the updating of Municipal Emergency and Civil Protection Plans (PMEPCs) and Municipal Climate Action Plans (PMACs) across the 10 municipalities to secure real tactical utility. External communication will focus on promoting active climate literacy among the community.

In line with the CLIMAAX framework, this prioritization also routes the follow-up: the Very High and High risks (wildfires, coastal flooding and heatwaves) proceed directly to adaptation design in Phase 3, while the Moderate risk (droughts) is flagged for continued monitoring – with the precipitation deficit (SPI) and the modelled losses in permanent crops as its tracking indicators.

2.6 Work plan Phase 3

Phase 3 will represent the final implementation stage of the CLIMAAX4Resilience project in the Leiria Region, focusing on translating the high-resolution metrics and scientific evidence generated in Phase 2 into concrete and prioritized local adaptation strategies. The core objective is to equip the 10 municipalities of CIMRL with tactical decision-making tools to mitigate climate risks and enhance the physical, socioeconomic, and ecological resilience of the territory.

To guarantee the selection of effective, robust, and financially sustainable adaptation measures, CIMRL will apply the methodological framework of the CLIMAAX European consortium's Adaptation Support Tool (AST). This approach relies on a participatory Multi-Criteria Analysis (MCA), where each proposed adaptation option (e.g., fuel management zones, dune restoration and coastal defenses, urban shading, or rainfed crop transition) will be evaluated and ranked based on five structural criteria:

- **Effectiveness:** The degree of direct physical risk reduction, measured by the mitigation of potential economic damages (EAD) or the safeguarding of human life (avoided expected annual people displaced - EAPD).
- **Cost-Benefit Ratio:** A balanced evaluation comparing the investment and maintenance costs of each option against the socioeconomic and ecological value of the protected assets.
- **Nature-Based Potential:** Prioritizing Nature-Based Solutions (NbS) that enhance local biodiversity, promote ecological restoration, and deliver natural thermal or hydraulic regulation.

- **Social Acceptance and Feasibility:** Legal, administrative, and land-tenure feasibility for implementing measures on the ground, considering private property constraints and community consensus.
- **Co-benefits:** Generating positive secondary advantages across multiple sectors, such as urban microclimate cooling, creation of public recreational areas, and forest carbon sequestration.

Main Activities and Roadmap:

The Phase 3 work plan will be implemented in a coordinated and participatory manner through the following activities and milestones:

- **1 | Definition and Assessment of Adaptation Options:** Identification and cataloging of specific local adaptation measures for the four priority hazards (Wildfires, Coastal Flooding, Heatwaves, and Agricultural Droughts), tailored to the biophysical realities of the Leiria Region.
- **2 | Participatory Co-creation Workshops with Stakeholders:** Conducting joint working sessions with the Sub-Regional Civil Protection Commission, technical officers from the 10 municipalities, sectoral authorities (APA, ICNF, DGT), and agricultural and infrastructure representatives to rank and validate the operational feasibility of proposed options via the MCA matrix.
- **3 | Technical Recommendations Formulation and Integration:** Translating the validated priority measures into practical planning guidelines and constraints ready for direct integration into local plans.
- **4 | Capacity Building, Communication, and Presentation to Decision-Makers:** Practical training actions for municipal technicians in model replication, ensuring tool sustainability beyond the project's timeline. Drafting of policy briefs for regional political decision-makers, publishing dissemination articles in local media, and compiling the project's final results publication.
- **5 | International Knowledge Sharing:** Presenting the high-resolution coastal downscaling methodologies and multi-risk adaptation lessons learned by CIMRL at the final CLIMAAX workshop in Brussels, consolidating the project's technical legacy at the European scale.

Milestones and Deliverables:

- **M7:** Subcontracting done (contract 2);
- **M8:** Potential regional/local adaptation options identified;
- **M9:** Stakeholders participatory processes carried out;
- **M10:** Regional/local adaptation options evaluated and prioritized;
- **M11:** Recommendations for improve risk management plans formulated;
- **M12:** Presentation of the results to policy and decision makers in Leiria Region (public final event);
- **M14:** Attend the CLIMAAX workshop held in Brussels;
- **D3:** Contribution to local adaptation strategies and improvement of risk management plans (Final Deliverable 3).

3 Conclusions Phase 2- Climate risk assessment

Phase 2 of the CLIMAAX4Resilience project in the Leiria Region marked a decisive transition from an indicative regional assessment to a strictly operational climate risk mapping anchored in high-resolution data. The core objective of this stage was to bridge the methodological utility gap observed in the previous phase, providing the region's ten municipalities with operational territorial knowledge and tactical cartography capable of directly informing and modernizing Civil Protection planning and Municipal Climate Action Plans at the critical infrastructure level. By crossing climate projections with the empirical reality of the territory, the regionalized analysis generated robust, actionable conclusions for the four priority risks identified by the community.

In the scope of rural wildfires, the transition to Machine Learning modeling operating at a 100-meter resolution and crossed with the Land Use and Land Cover Map (COS 2023) proved that the hazard within the territory is structurally critical, driven by the extreme continuity of production forestry – namely eucalyptus and pine stands. Empirical validation attested to the accuracy of this model, as the new high-hazard classes precisely capture nearly 60% of the entire area that actually burned between 1990 and 2023, closely mirroring the lessons of the 2017 events. Regarding coastal floods, the integration of high-resolution LiDAR topography allowed for decoding the true physics of overtopping and coastal vulnerability. The model identified with precision the deep estuarine intrusion along the Lis River floodplain and the severe structural risk of destruction across the consolidated urban fronts of Praia do Pedrógão, Praia da Vieira, and São Pedro de Moel. As for heatwaves, the adoption of national absolute thresholds confirmed an acute future worsening of the climate threat. By crossing satellite-derived Land Surface Temperatures (LST) with the high-resolution demographic grid, it was possible to isolate the hotspots of risk within urban heat islands, demonstrating the deep vulnerability of the dense elderly population within the core urban centers of Leiria, Pombal, and Marinha Grande. Finally, the refinement of the drought assessment focused strategically on the region's high-value, signature permanent crops, such as olive groves, vineyards, apples, and pears. This analysis translated the projected precipitation deficit into direct financial losses at the civil parish scale, highlighting a material risk to the economic sustainability of the limestone interior municipalities.

Taken together, the Key Risk Assessment ranks Rural Wildfires and Coastal Floods as Very High priorities, Heatwaves as High, and Droughts as Moderate – a gradient that directly orients Phase 3: the Very High and High risks proceed to adaptation design, while the Moderate risk feeds the continued monitoring process.

The primary technical achievement secured in this second phase was the effective resolution of the climate models' utility gap through the exhaustive integration of hyper-local data. Replacing pan-European grids with official Portuguese cartography and statistics ensured that the assessment reflected local realities rather than constituting a purely theoretical exercise. This empirical validation approach secured strong confidence from stakeholders and strategic partners in the generated results. However, the process highlighted persistent limitations that have not yet been fully overcome, most notably the scale paradox. While efforts to quantify territorial exposure and vulnerability achieved a 10-meter granularity, the baseline climate forcings remain locked into a coarser regional resolution. Consequently, climate projections assume the role of macroscopic stress factors applied over a fine topographic and infrastructural reality, maintaining some level of uncertainty inherent to global models. Additionally, vital components of socioeconomic risk still lack dynamic tools capable of capturing, for instance, the large population fluctuations stemming from seasonal tourism in coastal areas.

In summary, the conclusion of Phase 2 has endowed the Intermunicipal Community of the Leiria Region (CIMRL) and its municipalities with a robust technical and scientific foundation, validated against the territory's historical record. This robust territorial knowledge base consolidates the groundwork for Phase 3 of the project, providing the essential quantitative and georeferenced support for the upcoming Multi-Criteria Analysis (MCA). It is on the basis of this assessment and these metrics that the municipalities will be equipped to select, prioritize, and deploy the most effective local adaptation options, ensuring that future spatial planning and emergency measures are well equipped to protect the region's people, economy, and natural capital.

4 Progress evaluation

Phase 2 focused on the regionalized, high-resolution deepening of the CLIMAAX Climate Risk Assessment (CRA) methodology, resulting in a purely operational risk intelligence base for the Leiria Region. The link between the current deliverable (D2) and the subsequent phases is direct: the high-resolution data now consolidated – such as the identification of exposed critical infrastructure and the detailed mapping of vulnerability at the statistical subsection scale – provide the necessary empirical and quantitative foundation for designing the resilience and adaptation strategy in Phase 3.

During the execution of this phase, and with the submission of this deliverable, the essential Milestones and Key Performance Indicators (KPIs) required to meet the proposed objectives were successfully achieved.

Table 4-1 Overview milestones

Milestones	Progress
M1: Subcontracting done (contract 1)	Achieved
M2: Test the CLIMAAX workflows for the prioritized risks	Achieved (4 workflows tested)
M3: Workflows for the prioritized risks successfully applied	Achieved (4 workflows applied)
M4: CLIMAAX common methodology for multi-risk climate assessment applied	Achieved
M5: High-resolution local data collected and compiled	Achieved (data collected and compiled for all prioritized risks)
M6: Workflows for the prioritized risks refined and improved	Achieved (4 refined and improved: Wildfires, Droughts, Heatwaves and Coastal Floods)
M7: Subcontracting done (contract 2)	Planned for Phase 3
M8: Potential regional/local adaptation options identified	Planned for Phase 3
M9: Stakeholders participatory processes carried out	Ongoing (across the project implementation)
M10: Regional/local adaptation options evaluated and prioritized	Planned for Phase 3
M11: Recommendations for improve risk management plans formulated	Planned for Phase 3
M12: Presentation of the results to policy and decision makers in Leiria Region (public final event)	Planned for Phase 3
M13: Attend the CLIMAAX workshop held in Barcelona	Achieved
M14: Attend the CLIMAAX workshop held in Brussels	Planned for Phase 3

Table 4-2 Overview key performance indicators (KPIs)

Key performance indicators	Progress
Phase 1	
[1] scoping exercise will be conducted to determine context, objectives and criteria of the regional climate risk assessments (CRAs)	Achieved

Key performance indicators	Progress
[1] set of climate change-affected hazards with substantial societal impact, known or projected in the Leiria sub-region, will be selected	Achieved
[2] risk workflows will be successfully applied in Deliverable 1 (multi-risk climate assessment)	Achieved (4 workflows applied)
Phase 2	
[1] key risk assessment will be conducted to guide prioritization of upcoming climate risk management strategies	Achieved
[2] risk assessment will be refined and improved using local data of higher resolution on Deliverable 2 (refined regional/local multi-risk assessment)	Achieved (4 refined and improved: Wildfires, Droughts, Heatwaves and Coastal Floods)
[1] set of indicators for meteorological or hydrological hazards and societal or ecological impacts, suitable for designing and monitoring adaptation and risk management strategies, will be selected	Achieved
Phase 3	
[1] regional adaptation strategy (Intermunicipal Climate Change Adaptation Plan) will be explored and improved	Planned for Phase 3
[10] local adaptation strategies (Municipal Climate Action Plans) will be explored and improved	Planned for Phase 3
[10] emergency and risk management plans will be improved based on the results of the risk and vulnerability assessment	Planned for Phase 3
KPIs common to all three phases (at the end of the project)	
More than 20 stakeholders will be engaged in the project's activities	Achieved
At least 5 communication actions will be implemented to disseminate the project's launch, the results of each of the 3 phases, and the final outcomes	Achieved (partially / ongoing)
[1] public final event will take place to present the results to policymakers and decision-makers in the Leiria Region	Planned for the end of the project
[1] final publication, detailing the project's actions and results, will be produced	Planned for the end of the project
[3] policy briefs will be developed for political decision-makers, based on the results of each of the project's 3 phases	Achieved (partially / ongoing)
[3] articles in regional media mentioning the project	Achieved (partially / ongoing)

5 Supporting documentation

The Phase 2 outputs of the CLIMAAX4Resilience project – the main report, the four workflow output packages, and the integrated local databases and methodological notebooks – are provided as the Phase 2 deliverable and catalogued in the CLIMAAX Deliverable Platform. The spatial datasets (High-Resolution Hazard, Exposure, Vulnerability and Risk maps for Wildfires, Droughts, Heatwaves and Coastal Floods) will be uploaded to the CLIMAAX GeoNode repository, where metadata, naming conventions and cartographic styles are standardised; the CLIMAAX team will subsequently manage archival and DOI generation in the Zenodo open-data repository.

The Portuguese/national and European reference datasets listed below were used as model inputs and are credited here for provenance; each remains available from its original provider under the respective licence, rather than being redistributed. The supporting documentation is organised as follows:

- **Main report:**
 - Main Phase 2 Report Document (PDF)
- **Workflows outputs** (High-Resolution Hazard, Exposure, Vulnerability, and Risk Maps):
 - WILDFIRES (FIRE.zip)
 - DROUGHTS (DROUGHTS.zip)
 - HEATWAVES (HEATWAVES.zip)
 - COASTAL FLOODS (FLOODS.zip)
- **Methodological notebooks and integrated local databases (.zip)**
- **Portuguese / local datasets (data used for local refinement):**
 - DGT - High-Resolution Digital Elevation Models (LiDAR HR-DEM);
 - DGT - Land Use and Land Cover Map (COS 2023);
 - DGT - Official Administrative Map of Portugal (CAOP 2022 and 2024);
 - INE – Geographical Information Reference Base (BGRI 2021), Agricultural Census (RA 2019) and Crop Production Statistics / regional yields (NUTS II Centro, 2024);
 - IPMA – Climate normals and heatwave criteria (very hot days and tropical nights);
 - ICNF - Burnt Area Perimeters (1990-2023);
 - Antunes & Lemos (2024) – National representative Total Water Levels (TWL) and sea-level-rise reference (tide-gauge calibrated; Cascais1938 datum) – coastal flood forcing.
- **European and global reference datasets:**
 - EURO-CORDEX – Regional climate projections (RCP 2.6, RCP 4.5 and RCP 8.5);
 - CHELSA v2.1 – Bioclimatic variables (wildfire susceptibility);
 - ECLIPS-2.0 – High-resolution European climate dataset (REMO2009 forcing; wildfire susceptibility);
 - JRC – PESETA IV social, economic and ecological vulnerability indices (~12.5 km);
 - JRC – Depth-damage curves (flood damage functions).
 - EuroHEAT – Multi-model heatwave ensemble (apparent-temperature percentiles);

- ISRIC – Soil Available Water Capacity (AWC, 250 m);
 - SPAM & GAEZ 2015 – Cultivated area and irrigation mask (irrigated vs. rainfed parcels);
 - EUROSTAT – Raw-material prices (2019–2024 averages);
 - Landsat 8/9 Level-2 – Land Surface Temperature, via Microsoft Planetary Computer (heatwaves);
 - OpenStreetMap (OSM) – Building footprints, critical facilities and road network;
 - Copernicus CDS / GTSM (CMIP6 · ERA5) – Extreme sea levels – independent cross-check.
- **Annexes – Stakeholder engagement and communication materials:**
 - Phase 1 results Newsletter (Newsletter #1);
 - Consultative and validation session (15 April 2026): support presentation and attendance list;
 - Stakeholder consultation survey (online questionnaire, Google Forms) and dissemination cover note (circulated post-session).

Annexes – Stakeholder engagement and communication materials



CLIMAAX

climate ready regions



NEWSLETTER #1

CLIMAAX4RESILIENCE

MULTI-RISK CLIMATE ASSESSMENT THROUGH THE CLIMAAX COMMON METHODOLOGY FRAMEWORK AND TOOLBOX TOWARDS CLIMATE RESILIENCE FOR THE LEIRIA REGION



O PROJETO CLIMAAX4RESILIENCE:

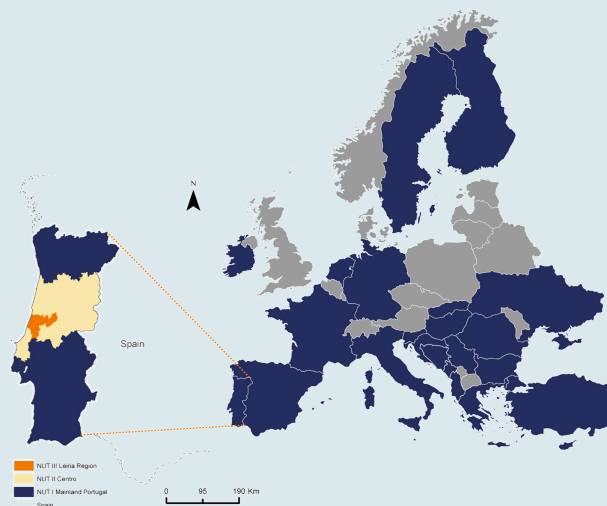
O «**CLIMate risk and vulnerability Assessment framework and toolboX (CLIMAAX)**» é um projeto Horizonte Europa, em curso até final de 2026, que providencia suporte financeiro, analítico e prático para aprimorar os planos de gestão de riscos climáticos e os planos de emergência e proteção civil.

Partindo de um panorama europeu desigual, em matéria de gestão do risco de catástrofes e de adaptação às alterações climáticas, o projeto CLIMAAX foi concebido com o propósito de contribuir para a **harmonização e consolidação da prática de avaliação dos riscos climáticos**, deixando um legado para as próximas iniciativas europeias. Do projeto resultaram:

- 1 metodologia de avaliação de risco climático padronizada;
- 1 conjunto de ferramentas (toolbox) com dados, modelos e recursos;
- 5 territórios-piloto europeus;
- 50 regiões com apoio financeiro para aplicarem a metodologia e o conjunto de ferramentas à escala local;
- Orientações para a avaliação de risco climático e serviço de assistência online para outras regiões europeias.

Visando disseminar os seus resultados, o projeto promoveu a abertura de duas convocatórias, às quais entidades públicas dos diferentes Estados-Membros, poderiam apresentar uma candidatura.

Da 2.^a convocatória foram selecionadas 3 candidaturas portuguesas, entre as quais a “**CLIMAAX4Resilience: Multi-Risk Climate Assessment through the CLIMAAX Common Methodology Framework and Toolbox Towards Climate Resilience for the Leiria Region**”, apresentada pela CIM da Região de Leiria.



CIMRL
Comunidade
Intermunicipal
da Região de Leiria



Funded by
the European Union



IMPLEMENTAÇÃO EM 3 FASES:

O subprojeto CLIMAAX4Resilience desenvolve-se em 3 fases sequenciais ao longo de 22 meses.

Esta newsletter partilha os principais resultados da **Fase 1** – **"Aplicação da metodologia comum CLIMAAX"** – convidando à participação ativa nos passos seguintes.



PRINCIPAIS VULNERABILIDADES DA REGIÃO DE LEIRIA

Com uma área de 2.449 km², a Região de Leiria abrange **10 concelhos** do Centro de Portugal Continental, compreendendo um **território geograficamente diverso**, estendendo-se das montanhas ao mar, com a coexistência de áreas urbanas e rurais.

A região enfrenta uma **alta vulnerabilidade aos impactos das alterações climáticas**, sendo classificada como de alta prioridade para adaptação no Roteiro Nacional de Adaptação 2100 (RNA 2100), especificamente em relação a fogos rurais, erosão costeira, e galgamento e inundações costeiras.

Os **incêndios rurais/florestais** são o perigo climático mais significativo, devido à ameaça severa e agravante, um facto destacado pelos eventos devastadores de 2017, quando uma infeliz confluência de fatores atípicos levou àquele que é classificado como o pior evento de incêndios florestais registado nos últimos anos, resultando numa extensa área ardida, perdas materiais significativas e, tragicamente, na perda de vidas humanas.

A região está ainda exposta a **outros riscos climáticos**, cujo aumento se projeta em cenário de alterações climáticas.

COMO SE AVALIARAM OS RISCOS NA FASE 1?

A Fase 1 focou-se na aplicação da metodologia CLIMAAX aos **4 riscos climáticos prioritários** na região: **Incêndios Rurais** (Wildfires); **Secas** (Droughts); **Ondas de Calor** (Heatwaves); e **Inundações Costeiras** (Coastal Floods).

A metodologia do CLIMAAX é uma abordagem inclusiva e harmonizada, baseada em princípios como a justiça social, equidade e transparência, e pressupõe um papel central para os processos participativos. A Fase 1 implementou **5 as etapas** operacionais: Definição do Âmbito; Identificação dos Riscos; Análise dos Riscos; Avaliação dos Principais Riscos; Monitorização e Avaliação.



Incêndios Florestais



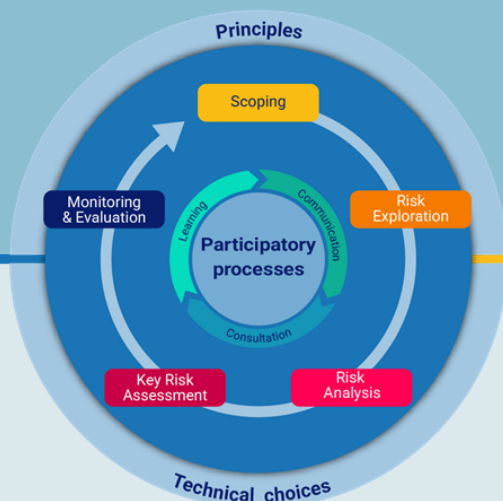
Secas



Ondas de Calor



Inundações costeiras



COCRIAÇÃO COM STAKEHOLDERS

Os processos participativos com os *stakeholders* são uma componente central do CLIMAAX4Resilience, procurando garantir que as preocupações, expectativas e prioridades dos atores locais e da comunidade possam ser refletidas nos resultados alcançados.

Aplicada a metodologia comum do CLIMAAX, na 2.ª fase, o envolvimento dos atores locais será particularmente relevante na validação e melhoria dos modelos e no alinhamento dos resultados com as necessidades operacionais específicas do território.



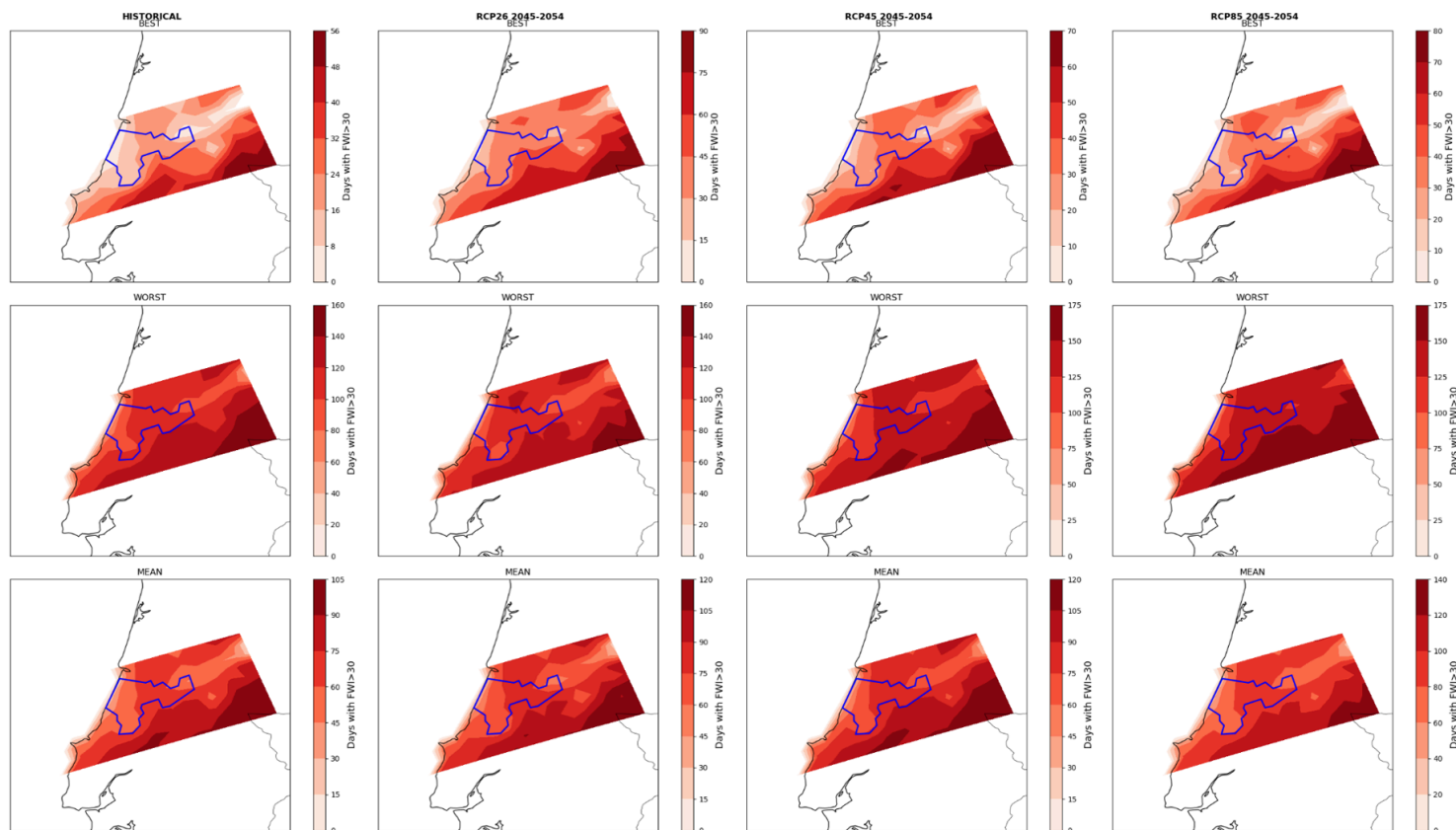
O objetivo final é integrar os resultados desta avaliação nos instrumentos de planeamento regionais e locais, como os Planos Municipais de Ação Climática (PMAC) e os Planos Municipais de Emergência e Proteção Civil (PMEPC), promovendo a resiliência do território.

Nas páginas seguintes, conheça os resultados da avaliação dos 4 riscos prioritários.

OS RESULTADOS DA FASE 1: RISCOS E IMPACTES-CHAVE

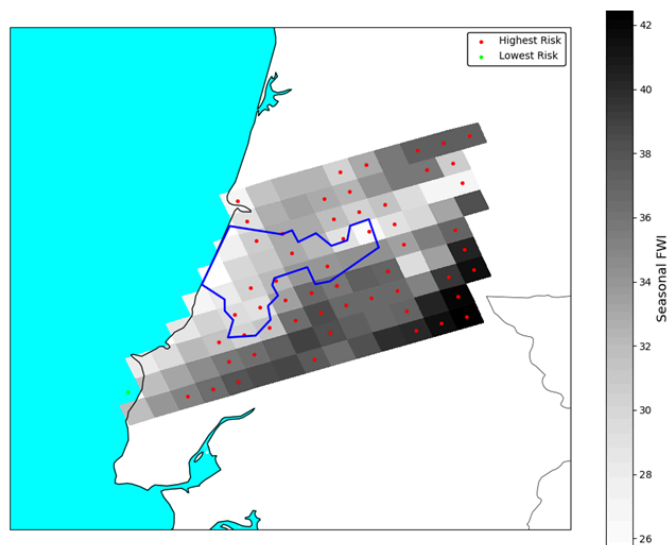
A) INCÊNDIOS FLORESTAIS:

- Os incêndios são o perigo climático mais significativo na região.
- As projeções indicam um aumento substancial nos dias com elevado perigo de incêndio ($FWI > 30$) em todos os cenários futuros avaliados: RCP 2.6 (cenário baixo), RCP 4.5 (cenário intermédio) e RCP 8.5 (cenário alto). Esta projeção quantitativa sugere uma intensificação das condições meteorológicas favoráveis a grandes incêndios, representando uma mudança fundamental no clima regional que agravará o risco de incêndios.



Número anual de dias com $FWI > 30$ na Região de Leiria, comparando o período de referência histórico (1985-2005) com cenários futuros (RCP 2.6, 4.5 e 8.5) para o cenário mais otimista, o mais pessimista e a média.

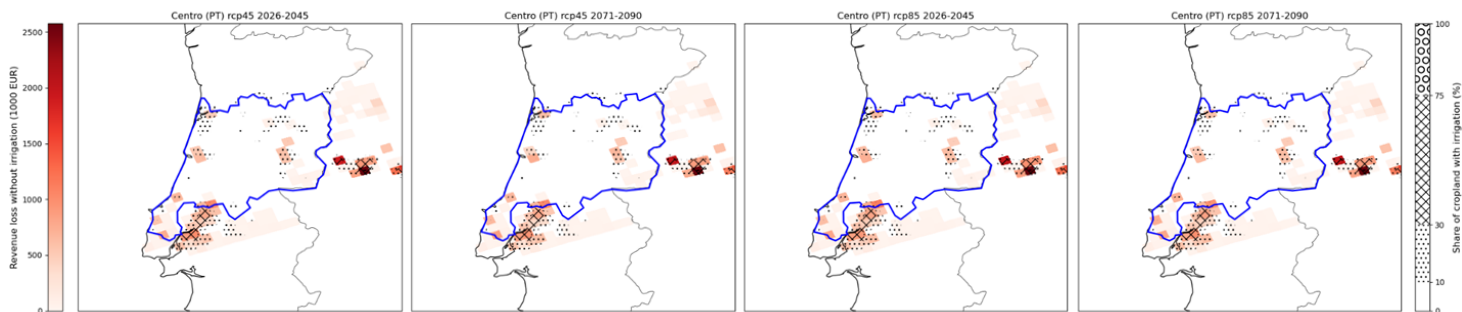
- O mapa final de risco de incêndio identifica "hotspots" críticos, onde o perigo elevado se cruza com áreas de significativa vulnerabilidade socioeconómica e ecológica.
- O indicador principal para o nível de perigosidade é o FWI Sazonal, representado pela grelha em tons de cinzento, onde as tonalidades mais escuras correspondem a um perigo de incêndio mais elevado e persistente.
- Sobreposto ao mapa de perigosidade, são identificados os locais específicos com risco mais elevado (pontos a vermelho) e risco mais baixo (pontos a verde). Estes pontos destacam onde a combinação de perigosidade, exposição e vulnerabilidade atinge os seus valores extremos, permitindo a identificação rápida de pontos críticos para o planeamento e a gestão territorial.



Risco de incêndio (FWI sazonal) na Região de Leiria

B) SECAS:

- A região demonstra suscetibilidade à seca, com ambas as análises de seca realizadas - seca relativa e seca agrícola - a apontar para uma tendência de aumento do risco.
- A avaliação da seca agrícola para 7 culturas (milho, trigo, batata, feijão, cevada, girassol e batata-doce) revelou um risco financeiro generalizado para o setor agrícola da região. O milho foi selecionado como a cultura representativa para a demonstração dos resultados, por ser a cultura dominante em área cultivada na região (concentrada, em particular, no Vale do Lis) e por ser altamente vulnerável à seca (cultura de verão com elevados requisitos hídricos).

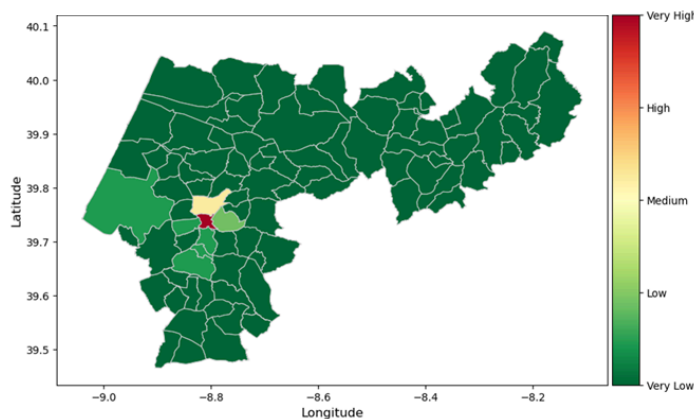


Potenciais perdas de receita (€) na produção de milho, comparando os cenários RCP 4.5 e 8.5 para o futuro próximo e o final do século.

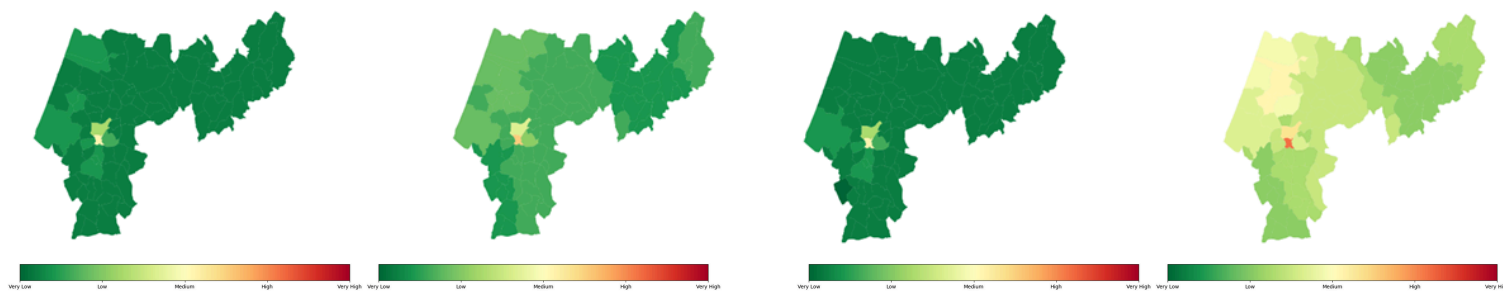
- Foram quantificadas as potenciais perdas de receitas agrícolas (€) causadas pelo défice de precipitação, representando o "custo de oportunidade perdido" caso as culturas não sejam irrigadas. Com efeito, a avaliação de risco traduz a perda física de rendimento em perdas de receitas potenciais (€) para a produção de milho, fornecendo um indicador do risco financeiro para os agricultores.
- A avaliação da seca agrícola realçou um risco financeiro considerável para a cultura do milho, com projeções a indicarem perdas significativas de receitas nos cenários futuros (RCP 4.5 e RCP 8.5).

C) ONDAS DE CALOR:

- Prevê-se um aumento considerável na frequência e intensidade das ondas de calor, atuando como fator multiplicador de risco, desencadeando efeitos em cascata ao exacerbar as condições de seca e aumentar o perigo de incêndios florestais.
- O risco agudiza-se em função da presença de grupos demográficos vulneráveis, como idosos e crianças.
- O mapeamento da vulnerabilidade identificou áreas específicas onde esta população sensível está concentrada, destacando zonas críticas para intervenção na saúde pública. Os centros urbanos são identificados como "hotspots" onde se concentra um grande número de pessoas vulneráveis.



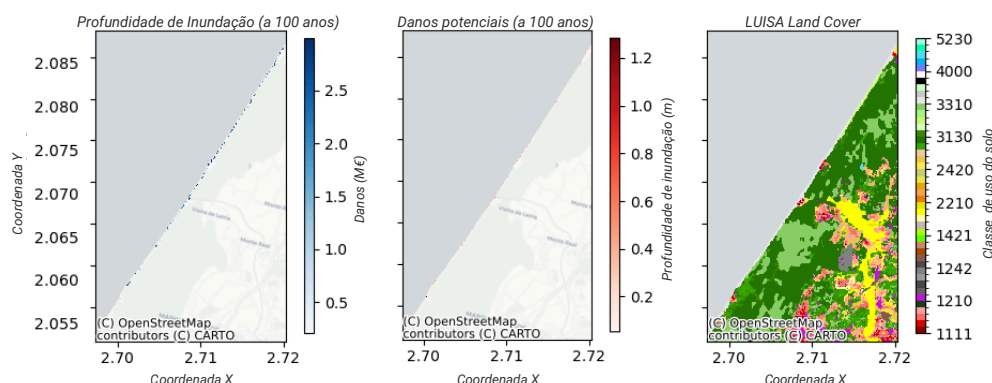
Classificação segundo a densidade de população vulnerável



Mapa de classificação final da vulnerabilidade do território às ondas de calor, com base na densidade de população vulnerável

D) INUNDAÇÕES COSTEIRAS:

- Prevê-se um aumento da frequência e intensidade dos fenómenos que causam galgamento e erosão costeira, exacerbados pela subida do nível do mar e tempestades.
- O risco é avaliado combinando os mapas de inundação (perigo) com dados de uso do solo, valor económico e curvas de vulnerabilidade (dano). A análise quantificou o potencial para danos económicos significativos em edifícios e infraestruturas, com consequências diretas para as comunidades costeiras e atividades económicas como o turismo.
- As projeções para 2050 indicam um aumento na extensão da área inundada e na magnitude das perdas financeiras potenciais.



Profundidade de inundação (m) e danos associados (M€) para cenários de nível extremo do mar no ano de 2050 para a Região de Leiria

PRINCIPAIS LIÇÕES APRENDIDAS NA FASE 1

- A Fase 1 estabeleceu com sucesso a linha de base metodológica para a avaliação de multiriscos. Foram **testados e aplicados** com sucesso os **workflows do CLIMAAX para 4 riscos prioritários** (incêndios florestais, secas, ondas de calor e inundações costeiras).
- A **participação no workshop do CLIMAAX** decorrido a 10 e 11 de junho de 2025 no CosmoCaixa (**Barcelona**), que reuniu mais de 150 representantes de 69 regiões e municípios de 23 países europeus, foi uma oportunidade singular para **discutir desafios**, partilhar **casos de sucesso** na avaliação de riscos climáticos e **trocar conhecimentos**.



DESAFIOS PARA A FASE 2

- **Integração de Dados Locais de Alta Resolução:** embora os *datasets* pan-europeus tenham sido utilizados (como exige a Fase 1 do CLIMAAX), confirmou-se que estes carecem da especificidade local (alta resolução) necessária para o planeamento operacional e a tomada de decisões no terreno (e.g. na proteção civil municipal). A prioridade máxima para a Fase 2 é, portanto, a aquisição e integração de dados locais de alta resolução para refinar e validar os modelos de avaliação de risco.
- **Aprofundamento da cocriação com Stakeholders:** na Fase 2 o envolvimento dos stakeholders locais será mais ativo, passando de um modelo informativo para um modelo de cocriação ativa, onde os agentes locais (e.g. técnicos municipais, agentes de proteção civil) desempenharão um papel decisivo na validação dos modelos, na interpretação dos resultados e no respetivo alinhamento com as suas necessidades operacionais para a gestão dos riscos climáticos na Região de Leiria.

Explore em detalhe os resultados da Fase 1 do CLIMAAX4Resilience em: <https://zenodo.org/records/17199602>

ACOMPANHE O PROJETO CLIMAAX4RESILIENCE!

Mais informações sobre o projeto Horizonte Europa CLIMAAX:



www.climaax.eu

www.linkedin.com/company/climaax/

www.zenodo.org/communities/climaax/

O projeto CLIMAAX4RESILIENCE é:

Financiado por:



Funded by
the European Union

Promovido por:



CIMRL
Comunidade
Intermunicipal
da Região de Leiria

Com a colaboração de:

GEO
ATRIBUTO





CIMRL
Comunidade
Intermunicipal
da Região de Leiria

GEO
ATRIBUTO

CLIMAAX4Resilience

Multi-Risk Climate Assessment through the CLIMAAX Common Methodology Framework and Toolbox Towards Climate Resilience for the Leiria Region

Sessão Participativa com os Stakeholders

15 de abril de 2026



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CLIMAAX
climate ready regions

1 Sub-Região • 10 Municípios • 1 Projeto • 3 Fases • 4 Riscos Climáticos



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Agenda da Sessão



1. Enquadramento

O projeto europeu CLIMAAX
O Subprojeto CLIMAAX4Resilience



2. Metodologia do CLIMAAX

Ciclo metodológico e participativo
Lógica da avaliação de risco
As ferramentas da *toolbox* (*workflows*)



3. Avaliação Inicial de Riscos (Fase 1)

Principais vulnerabilidades
Riscos selecionados para avaliação
Avaliação inicial de riscos – principais resultados
Principais lições aprendidas



4. Desafios e Cocriação (Fase 2)

Desafios para a fase 2
Papel e contributo dos stakeholders



5. Debate e Próximos Passos

Próximos passos
Recolha de contributo dos stakeholders
Acompanhamento do projeto – ligações úteis e acesso aos resultados



1. ENQUADRAMENTO



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1.1. O Projeto Europeu CLIMAAX

- O «**CLIM**ate risk and vulnerability Assessment framework and toolboX (CLIMAAX)» é um projeto Horizonte Europa, em curso até final de 2026, que providencia **suporte financeiro, analítico e prático** para aprimorar os planos de gestão e adaptação climática e os planos de emergência e proteção civil.
- Partindo de um panorama europeu longe de ser uniforme, o CLIMAAX foi concebido com o propósito de contribuir para a **harmonização e consolidação da prática de avaliação dos riscos climáticos**.
- Com o objetivo de disseminar os seus resultados, o projeto promoveu a abertura de duas convocatórias, às quais entidades públicas dos diferentes Estados-Membros poderiam apresentar uma candidatura.
- A 2.^a convocatória resultou na seleção de 3 candidaturas portuguesas, entre as quais a “**CLIMAAX4Resilience:Multi-Risk Climate Assessment through the CLIMAAX Common Methodology Framework and Toolbox Towards Climate Resilience for the Leiria Region**”, apresentada pela CIM Região de Leiria.

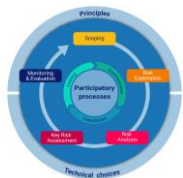


CLIMAAX4Resiliente é um subprojeto do CLIMAAX.



1.1. O Projeto Europeu CLIMAAX

Principais resultados:



1 metodologia de avaliação de risco climático padronizada, baseada na experiência atual e nas melhores práticas

1 conjunto de ferramentas (toolbox) com dados, modelos e recursos

5 territórios-piloto europeus para testarem e moldarem a metodologia e o conjunto de ferramentas

50 regiões com apoio financeiro para aplicarem a metodologia e ferramentas à escala local, aprimorando os respetivos planos de gestão de riscos climáticos e/ou os planos de emergência e proteção civil

Orientações para a avaliação de risco climático e serviço de assistência online para outras regiões europeias



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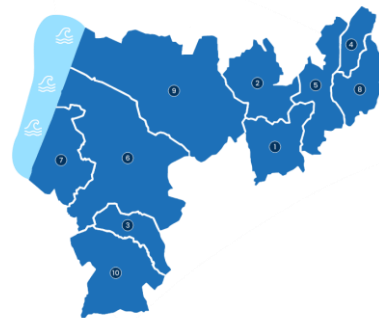


1.1. O Projeto Europeu CLIMAAX



Missão CLIMAAX:
Harmonizar a gestão de
risco de catástrofes e
adaptação climática na
Europa.

- Quadro de avaliação padronizado.
- 50 regiões piloto selecionadas.



Seleção Regional: CIM

- Uma das 3 candidaturas portuguesas aprovadas.
- Objetivo: Melhorar Planos de Gestão de Risco e Emergência.



Suporte: Financeiro,
Analítico e Prático da UE



Legado: Contributo para
futuras iniciativas europeias



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1.1. O Subprojeto CLIMAAX4Resilience

Objetivo:

- **Capacitar para enfrentar os desafios das alterações climáticas**, através da realização de uma **avaliação de riscos múltiplos**, da **integração de medidas de adaptação** nos instrumentos de planeamento e do **envolvimento dos atores locais**, com o objetivo de **aumentar a resiliência** e **reduzir a vulnerabilidade** do território.

3 Fases:



2. METODOLOGIA DO CLIMAAX

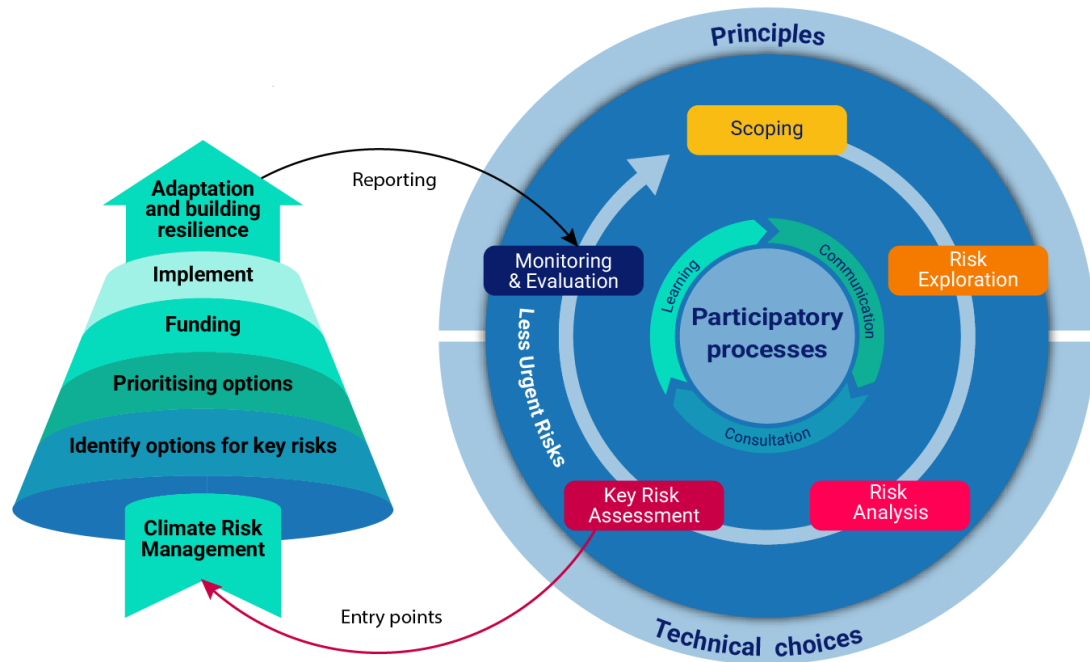


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2.1. A metodologia comum europeia

- Abordagem inclusiva e harmonizada, baseando-se em princípios como a **justiça social, equidade e transparência**, e dando um papel central aos **processos participativos**.
- Pressupõe **5 etapas operacionais**:
 - 1. Definição do âmbito;
 - 2. Identificação dos riscos;
 - 3. Análise dos riscos;
 - 4. Avaliação dos riscos prioritários;
 - 5. Monitorização e avaliação.



2.2. A lógica da avaliação de risco

- O CLIMAAX utiliza um modelo amplamente reconhecido no qual o Risco é uma função de três componentes principais:

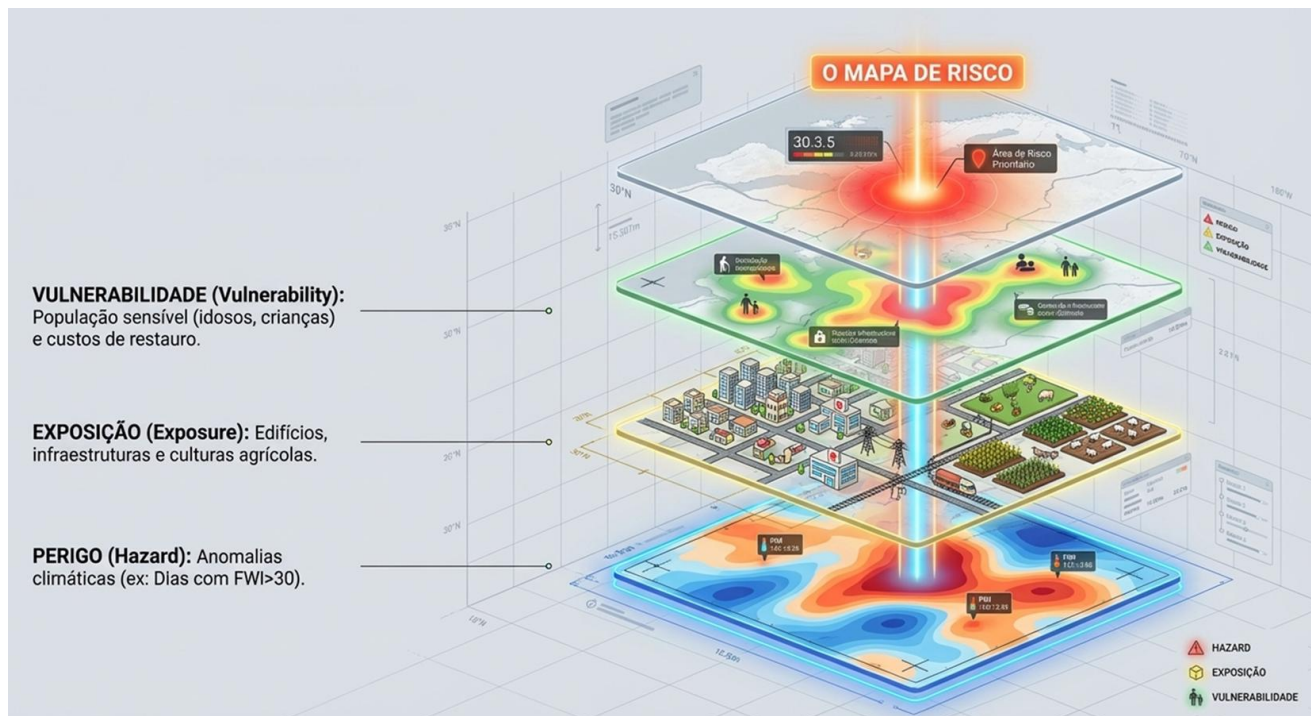


O risco não é apenas o clima; é a interseção do clima com a fragilidade do nosso território.



2.2. A lógica da avaliação de risco

- **Visão Holística:** Permite-nos ver que o “risco não é apenas o clima”. O risco é elevado quando um “perigo” elevado atinge algo “exposto” que, por sua vez, é “vulnerável”.
- **Direcionamento de Ação:** As estratégias de adaptação podem atuar em qualquer um dos 3 fatores:
 1. Reduzir o Perigo;
 2. Reduzir a Exposição;
 3. Reduzir a Vulnerabilidade.



2.2. A lógica da avaliação de risco

- Esta **lógica tripartida** — *Risco como a função da combinação de Perigo, Exposição e Vulnerabilidade* — é a razão de ser de toda a estrutura técnica do CLIMAAX.
- Para cada risco (ex. Incêndios), o CLIMAAX apresenta diferentes ferramentas (workflows / *scripts* em *python*) que abrangem as diferentes componentes da avaliação de risco (que podem perfazer um *workflow* autónomo ou combinar-se com outra componente em diferentes passos do mesmo workflow).
- Exemplos:
 1. Um workflow focado exclusivamente na **Avaliação do Perigo** (que calcula, por exemplo, o Índice Meteorológico de Incêndio).
 2. Um workflow que recolhe os dados de **Exposição e Vulnerabilidade** (população, edifícios, ecossistemas vulneráveis).
 3. Um workflow final que combina todos estes fatores para gerar o **Mapa de Risco final**.



2.3. O que são os *workflows*?

Conceito Base:

- Os *workflows* integram a *toolbox* (conjunto de ferramentas) do CLIMAAX e são a implementação digital da metodologia de avaliação de risco.
- De uma forma simplista, podemos dizer que são a "receita" que pega em dados de clima (históricos ou projeções) e de vulnerabilidade e os transforma em mapas de risco.

A ferramenta:

- Estes *workflows* são escritos em **Jupyter Notebooks** (ficheiros com a extensão .ipynb) – [acesso público](#).
- Cada *Jupyter Notebook* integra:
 1. **Documentação (Texto/Markdown)**: onde constam as explicações e a lógica científica.
 2. **Código (Python)**: onde estão as instruções para o computador (cálculos e processamento de dados).
 3. **Outputs**: Onde aparecem os resultados, como gráficos, tabelas e, mais importante, os Mapas de Risco.



2.3. O que são os *workflows*?

Porquê Python?

- Os *workflows* usam pacotes científicos padrão de Python (como *numpy*, *dask*, *xarray*) porque estes são as melhores ferramentas para lidar com grandes volumes de dados multidimensionais (como dados climáticos, que têm tempo, latitude e longitude).

Alguns exemplos de *notebooks*...



2.3. O que são os *workflows*? - *exemplos*

Wildfire (Fire Weather Index)



FWI_Hazard_Assessment.ipynb

FWI Wildfire Workflow - Hazard

- A workflow from the CLIMAX Handbook and FIRE GitHub repository.
- See our how to use risk workflows page for information on how to run this notebook.

This workflow aims to provide a simple tool to visualise wildfire hazard using the Fire Weather Index (FWI) data available on the Copernicus Climate Data Store. The FWI is a climatic index combining data on daily noon surface air temperature, rainfall intensity, wind speed and relative humidity accounting for the effect of fuel moisture and weather conditions on fire behaviour. It consists of a 0-100 score indicating how suitable the climate conditions are for the occurrence of wildfire.

This workflow allows us to visualise spatial and temporal trends in FWI intensity and to understand changes in the fire weather season duration and onset based on FWI. Variations in seasonal FWI intensity determine how changing climate conditions are influencing the likelihood of wildfire development. An increase in seasonal FWI score suggests a warming and drying pattern in the mean climate leading to more favourable conditions for wildfire development. On the other hand, understanding changes in the fire weather season length is important for adaptation planning as it indicates for how long regions are at risk of wildfire development. This information is fundamental for an effective allocation of resources to wildfire response units, that might need to be significantly reinforced in drying regions experiencing a significant lengthening of the critical fire weather season.

Load libraries

In this notebook we will use the following Python libraries:

```
[1]: import glob
import json
import os
import re
import urllib
import shutil
import zipfile
import shapefile

import pandas as pd
import numpy as np
import geopandas as gpd
import cdsapi
import xarray as xr
import pyproj
import cartopy.crs as ccrs
import cartopy.feature as cfeature
import matplotlib.pyplot as plt
```

Find more info about the libraries used in this workflow here

Create the directory structure

First, we need to set up the directory structure to make the workflow run. The next cell will create the directory called 'FWI_workflow' in the same directory where this notebook is saved. A directory for data and one for results will also be created inside the main workflow directory to store the downloaded data and the final plots.

```
[2]: workflow_dir = "FWI_workflow"
```

Documentação
(explicações e a lógica científica)

Código
(instruções - cálculos e processamento de dados)



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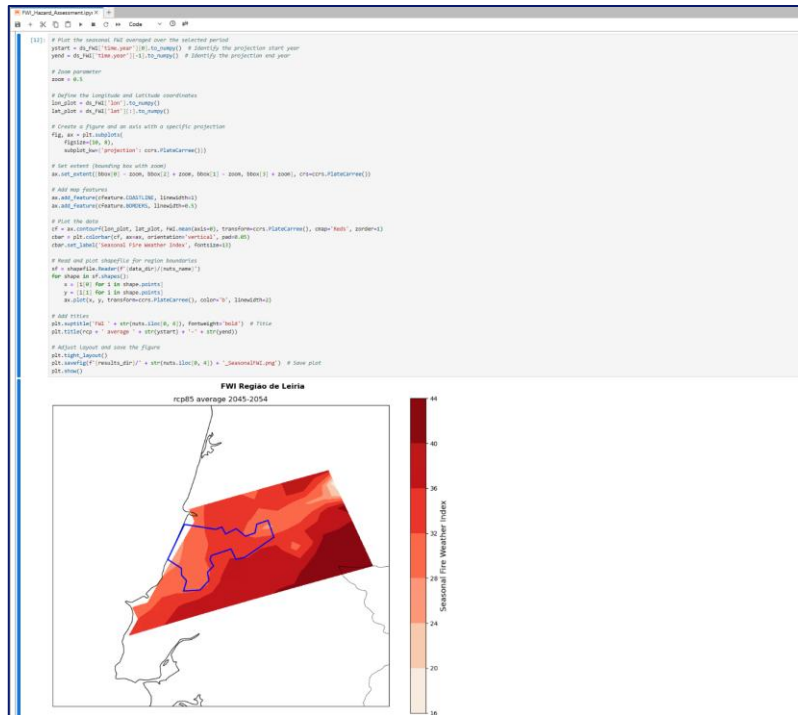
2.3. O que são os *workflows*? - exemplos



Código
(instruções - cálculos e processamento de dados)

Outputs

(resultados – gráficos, tabelas e mapas de risco)



2.3. O que são os *workflows*? – *dados de base*

Dados padrão:

- Os workflows iniciais do CLIMAAX utilizam por defeito **datasets pan-europeus** (dados que cobrem toda a Europa, principalmente do *Copernicus*), tendo sido estes os usados na fase 1 do CLIMAAX4Resilience.
- Daqui decorre o objetivo de refinamento da fase 2, no sentido de conferir maior “resolução” aos dados, melhor ajustando os resultados à realidade do território e à escala adequada para os instrumentos de gestão de riscos.
- O trabalho da Fase 2 consistirá em substituir estes ‘*datasets*’ por dados de alta resolução, com vista a garantir a precisão operacional dos resultados.

Onde estão estes dados?

- Estes dados são acessíveis através do armazenamento *cloud* do CLIMAAX.
- Os *scripts* usam ferramentas para gerir e descarregar estes dados de forma transparente, garantindo que o workflow é replicável por qualquer utilizador.



3. FASE 1 - AVALIAÇÃO INICIAL DE RISCOS



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3.1. Principais vulnerabilidades

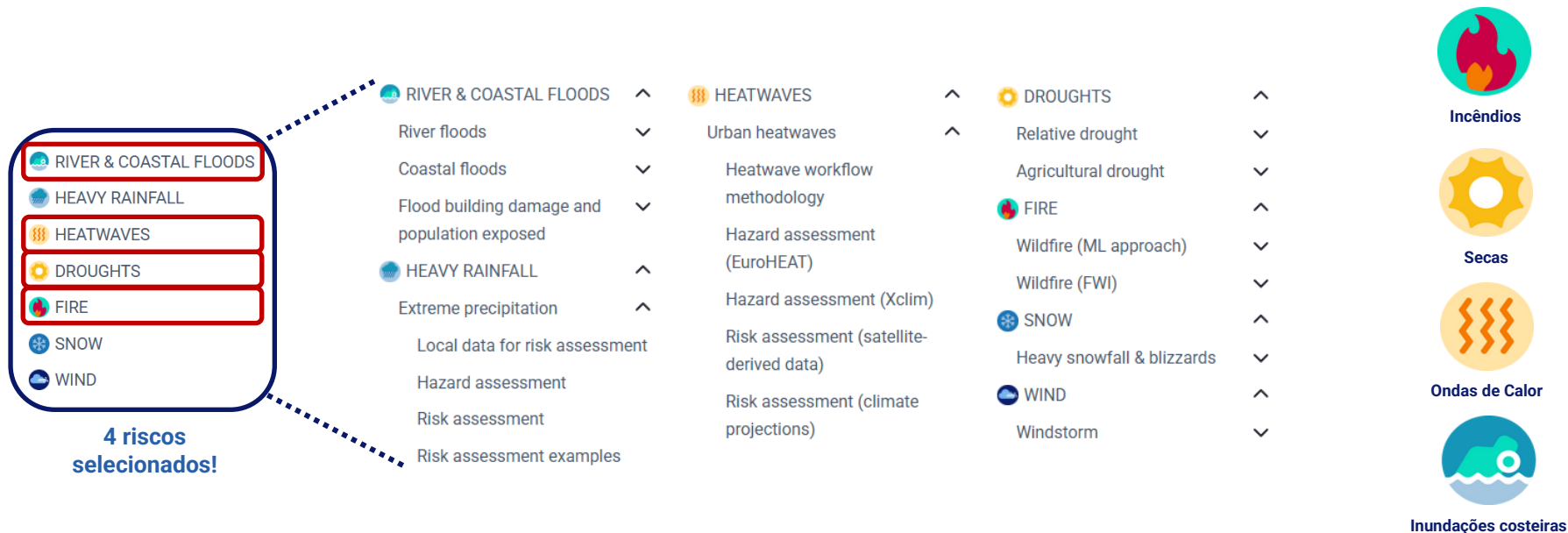
- As primeiras etapas da metodologia CLIMAAX, suportadas pelos estudos prévios e planos que o território dispõe, destacaram que a região é vulnerável a múltiplos impactes das alterações climáticas, cuja severidade e frequência se prevê que aumentem significativamente.
- Existem grupos particularmente vulneráveis, como a população idosa, que é especialmente suscetível a riscos influenciados pelo clima (como as ondas de calor).

- As principais projeções incluem:



3.2. Riscos selecionados para avaliação

- Partindo deste cenário, a fase 1 aplicou a metodologia comum do CLIMAAX para uma "avaliação climática de múltiplos riscos", quantificando os impactos atuais e futuros de 4 riscos prioritários:



3.3. Avaliação inicial de riscos – principais resultados

“Um território a enfrentar riscos climáticos significativos e interligados (efeito cascata), cuja severidade e frequência aumentarão no futuro”



Incêndios



Secas



Ondas de Calor



Inundações costeiras



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3.3. Avaliação inicial de riscos – principais resultados

“Um território a enfrentar riscos climáticos significativos e interligados (efeito cascata), cuja severidade e frequência aumentarão no futuro”



Incêndios Rurais

O perigo climático mais significativo.



Secas

Ameaça sistémica à viabilidade económica agrícola.



Ondas de Calor

Risco crescente para a saúde pública.



Inundações Costeiras

Danos iminentes em infraestruturas litorais.



Incêndios



Secas



Ondas de Calor



Inundações costeiras



3.3. Avaliação inicial de riscos – *principais resultados*

Incêndios (*wildfire*):

- São a **ameaça mais significativa e severa** na região, uma realidade fortemente corroborada pelo histórico recente.
- As projeções do **Índice Meteorológico de Incêndio (FWI)** indicam um **aumento considerável no número de dias com elevado perigo de incêndio (FWI>30)** em todos os cenários climáticos: RCP 2.6 (cenário baixo), RCP 4.5 (cenário intermédio) e RCP 8.5 (cenário alto).
- As projeções sugerem uma **intensificação das condições meteorológicas favoráveis a grandes incêndios**, representando uma mudança fundamental no clima regional que agravará o risco de incêndios.



Incêndios



Secas



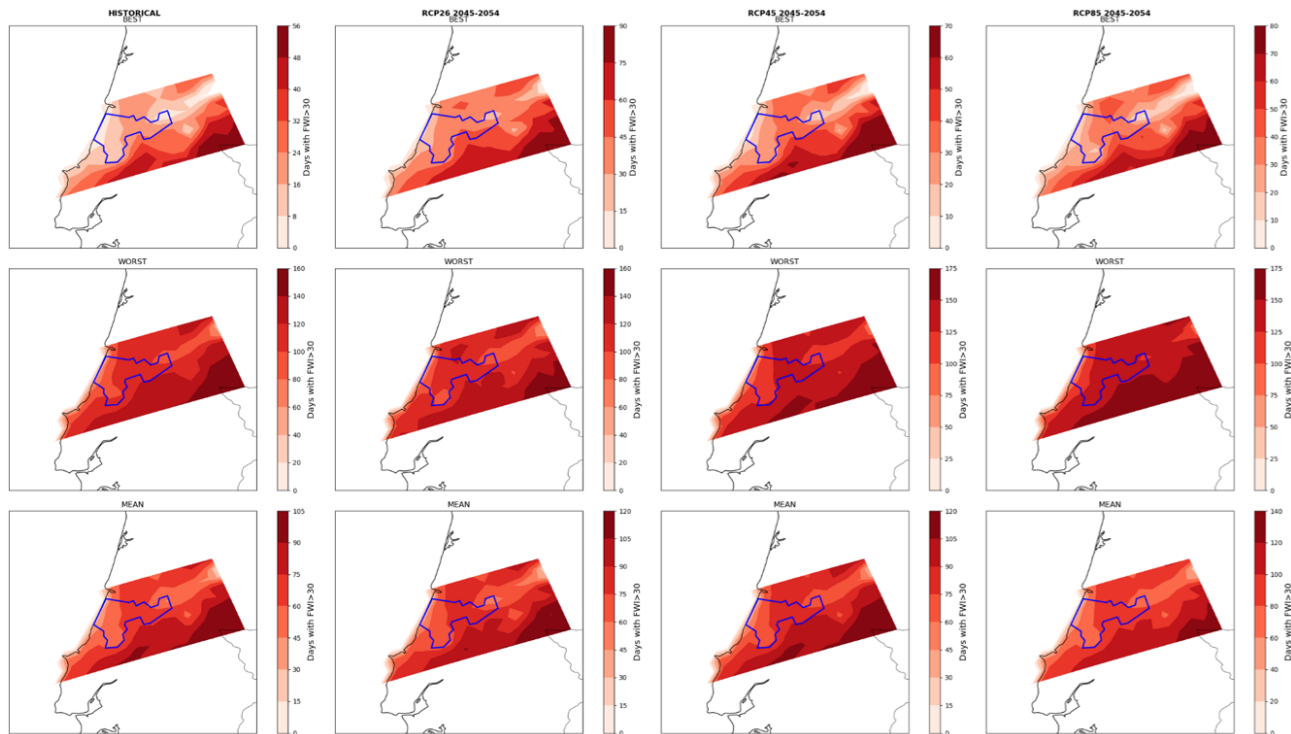
Ondas de Calor



Inundações costeiras



3.3. Avaliação inicial de riscos – principais resultados



Incêndios



Secas



Ondas de Calor



Inundações costeiras



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3.3. Avaliação inicial de riscos – *principais resultados*

Incêndios (*wildfire*):

- O **mapa final de risco** de incêndio identifica "**hotspots**" **críticos**, onde o perigo elevado se cruza com:
 - **Vulnerabilidade Humana:** zonas com alta densidade populacional e elevada percentagem de população a residir na Interface Urbano-Florestal (WUI).
 - **Vulnerabilidade Ecológica e Económica:** áreas naturais protegidas, ecossistemas de elevado valor (medido pelo Índice de Insubstituibilidade) e zonas com elevados custos de restauro ecológico.
- O indicador principal para o nível de perigosidade é o FWI Sazonal (grelha em tons de cinzento, onde as **tonalidades mais escuras correspondem a um perigo mais elevado e persistente**).
- Sobrepostos ao mapa de perigosidade, são identificados os **locais específicos com risco mais elevado** (pontos a vermelho) e **risco mais baixo** (pontos a verde).
- Estes pontos destacam onde a combinação de perigosidade, exposição e vulnerabilidade atinge os seus valores extremos, permitindo a identificação rápida de pontos críticos para o planeamento e a gestão territorial.



Incêndios



Secas



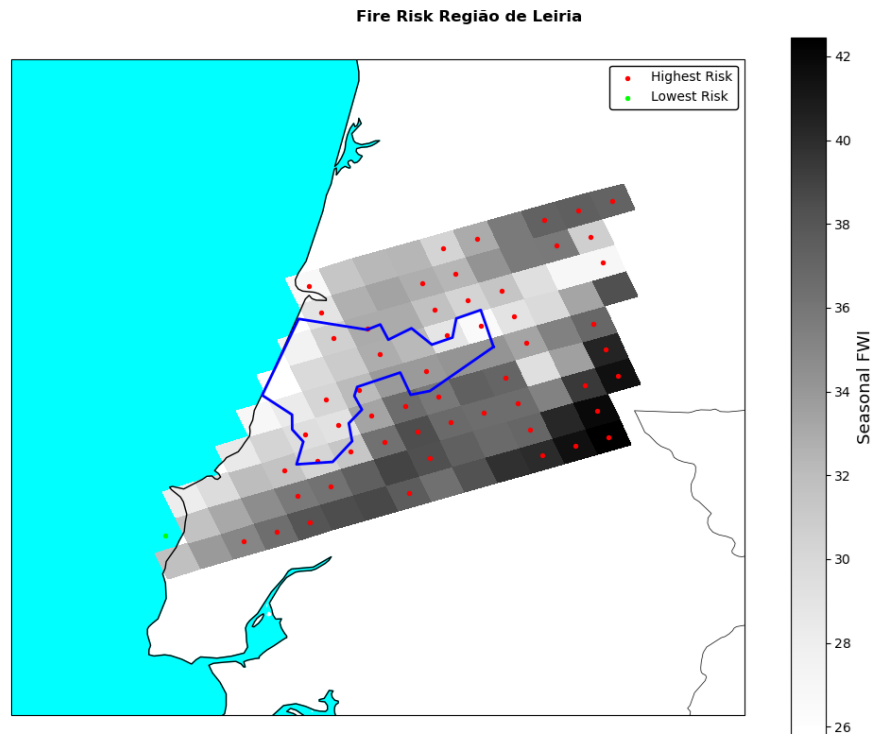
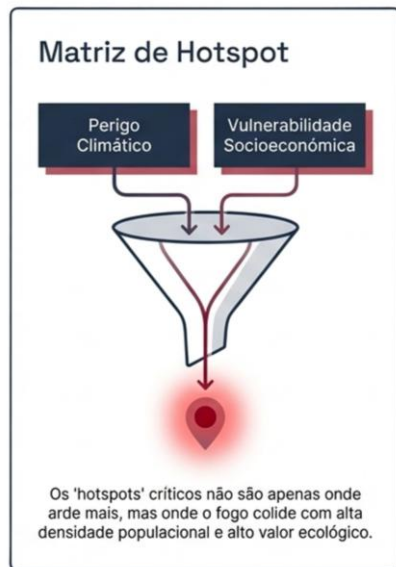
Ondas de Calor



Inundações costeiras



3.3. Avaliação inicial de riscos – principais resultados



Incêndios



Secas



Ondas de Calor



Inundações costeiras



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3.3. Avaliação inicial de riscos – *principais resultados*

Secas (drought):

- A região demonstra **suscetibilidade à seca**, com ambas as análises de seca realizadas - **seca relativa** e **seca agrícola** - a apontar para uma tendência de aumento da frequência e intensidade deste fenómeno.
- A avaliação da **seca agrícola para sete culturas chave** (milho, trigo, batata, feijão, cevada, girassol e batata-doce) revelou um risco financeiro generalizado para o setor agrícola da região.
- Isto é exemplificado pelos resultados obtidos para a **cultura do milho**, de relevância socioeconómica na região e altamente vulnerável à escassez de água (cultura de verão com elevadas necessidades hídricas), que mostram **perdas significativas de rendimento**, particularmente nos cenários de final de século.

Nota: O leque de opções de culturas para seleção nos fluxos de trabalho (workflows) do CLIMAAX utilizados nesta fase é restrito, tendo-se selecionado as culturas mais representativas da produção regional.



Incêndios



Secas



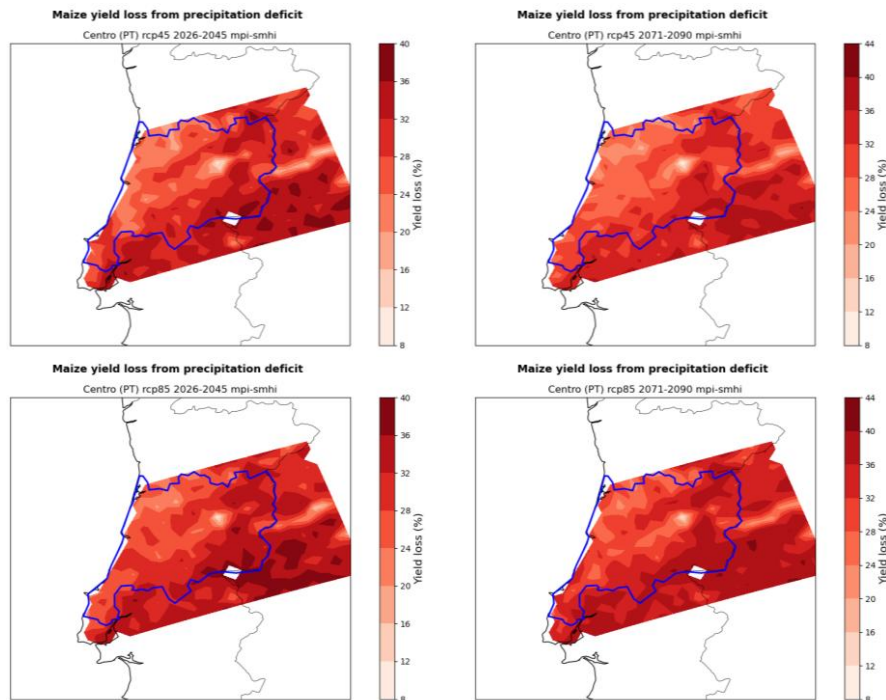
Ondas de Calor



Inundações costeiras



3.3. Avaliação inicial de riscos – principais resultados



Perda de rendimento do milho devido ao défice de precipitação (%), comparando os cenários RCP 4.5 e 8.5 para o futuro próximo e o final do século.



Incêndios



Secas



Ondas de Calor



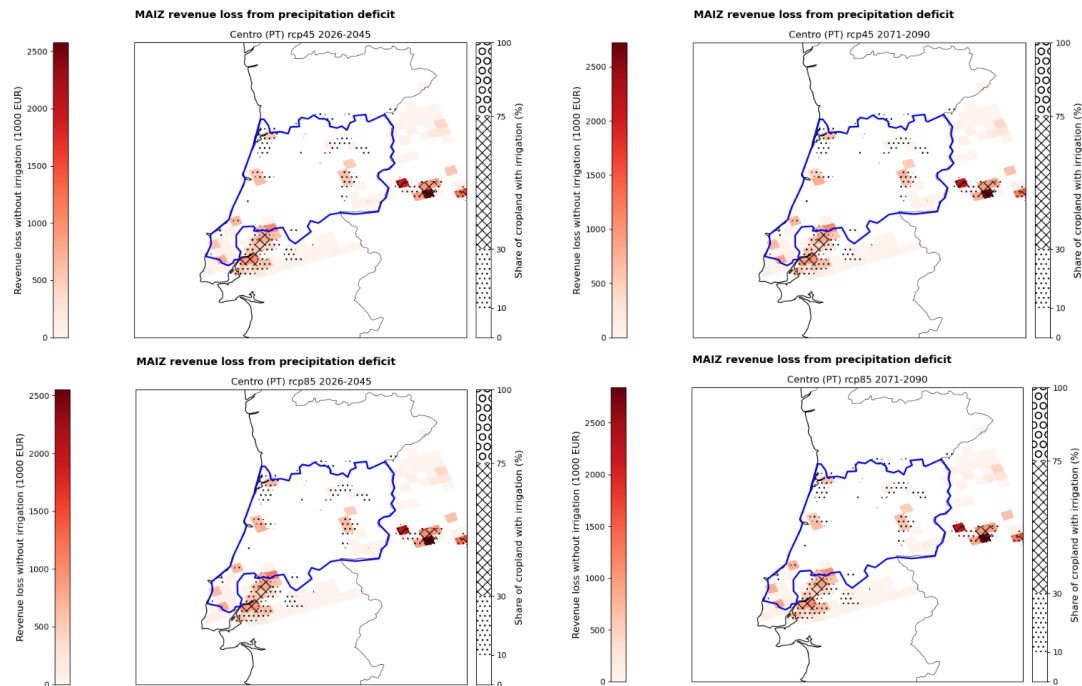
Inundações costeiras



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3.3. Avaliação inicial de riscos – principais resultados



Potencial perda de receitas (€) na produção de batata, comparando os cenários RCP 4.5 e 8.5 para o futuro próximo e o final do século.



Incêndios



Secas



Ondas de Calor



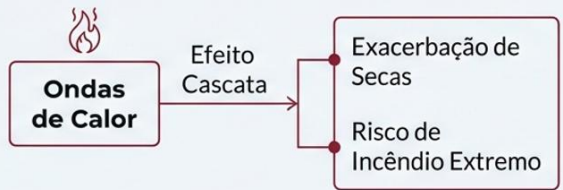
Inundações costeiras



3.3. Avaliação inicial de riscos – *principais resultados*

Ondas de calor (heatwaves):

- Prevê-se um **aumento considerável na frequência e intensidade das ondas de calor**, atuando como fator multiplicador de risco, desencadeando efeitos em cascata ao exacerbar as condições de seca e aumentar o perigo de incêndios florestais.
- O **risco agudiza-se devido ao perfil demográfico da região**, com uma elevada percentagem de residentes idosos (>65 anos) que são especialmente vulneráveis.
- O **mapeamento da vulnerabilidade identificou áreas específicas onde esta população sensível está concentrada**, destacando zonas críticas para intervenção na saúde pública. Os **centros urbanos** são identificados como "hotspots" onde se concentra um grande número de pessoas vulneráveis.



Incêndios



Secas



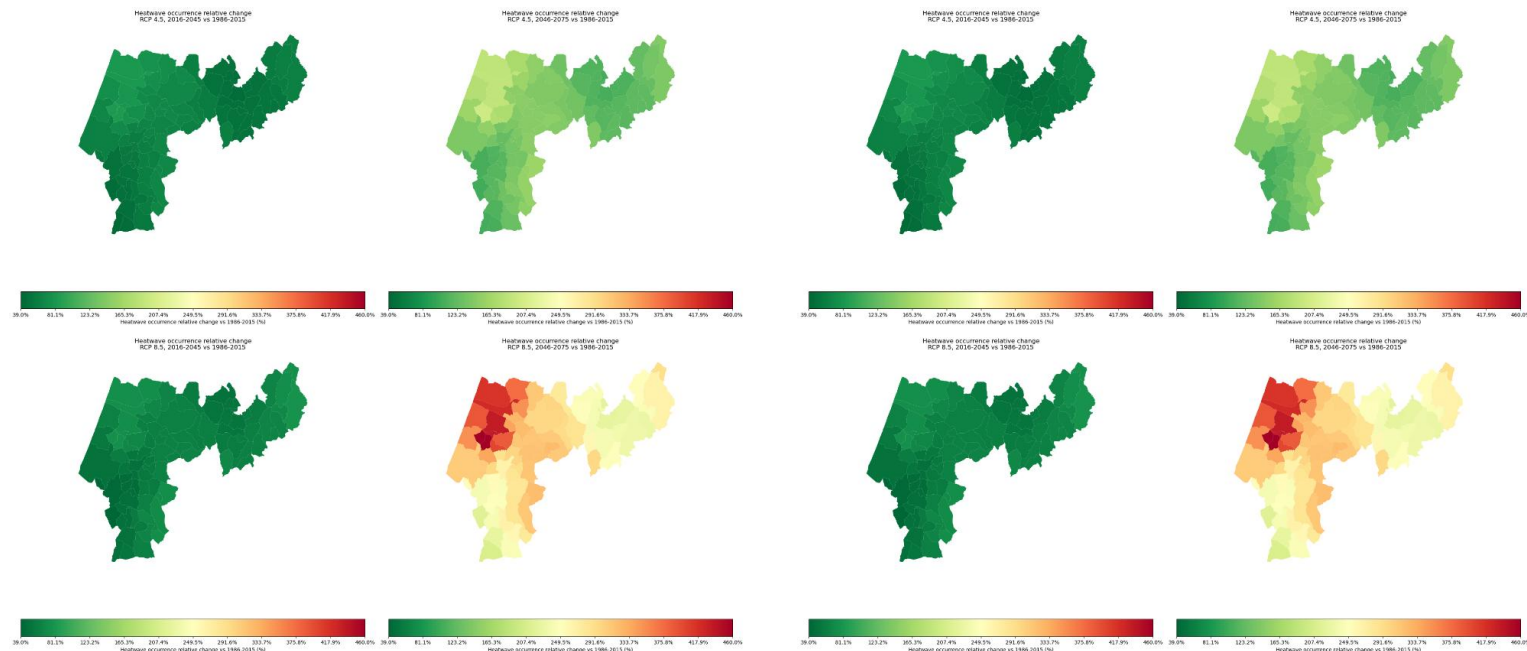
Ondas de Calor



Inundações costeiras



3.3. Avaliação inicial de riscos – principais resultados



Varição relativa na ocorrência de ondas de calor para a Região de Leiria em comparação com a ocorrência de ondas de calor para o período de referência 1976-2015.

Magnitude do aumento potencial projetado da ocorrência de ondas de calor na região de Leiria - 1 a 10 (1 - variação muito baixa, 10 - variação muito alta)..



Incêndios



Secas



Ondas de Calor



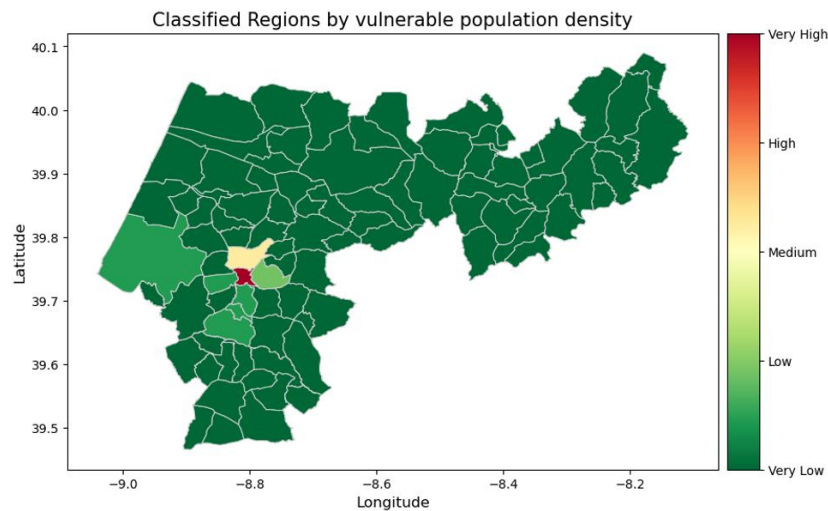
Inundações costeiras



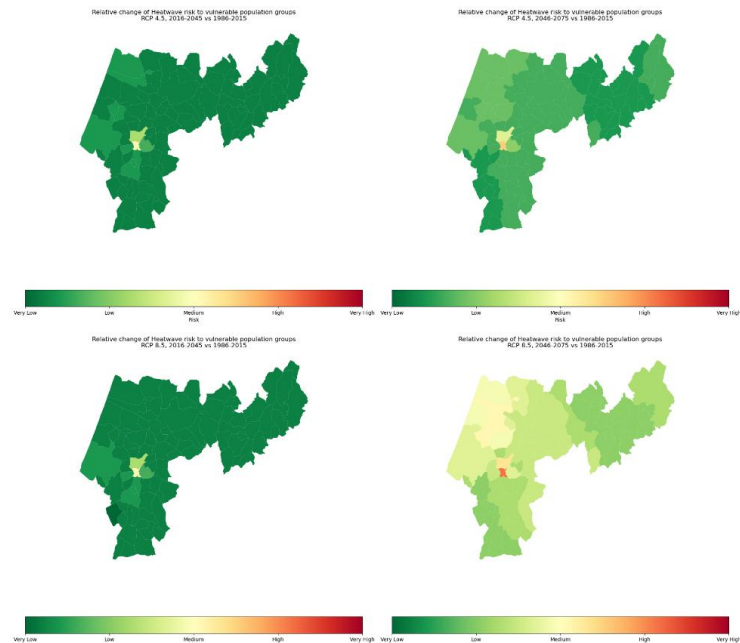
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3.3. Avaliação inicial de riscos – principais resultados



Concentração dos grupos vulneráveis na população da Região de Leiria.



Aumento potencial projetado do risco de ondas de calor para grupos populacionais vulneráveis da Região de Leiria (combinação da magnitude projetada da mudança na ocorrência de ondas de calor com a distribuição dos grupos vulneráveis da população).



Incêndios



Secas



Ondas de Calor



Inundações costeiras



3.3. Avaliação inicial de riscos – *principais resultados*

Inundações costeiras (*coastal floods*):

- Prevê-se um **aumento da frequência e intensidade** dos fenómenos que causam **galgamento e erosão costeira**, exacerbados pela subida do nível do mar e tempestades.
- O risco é avaliado combinando os mapas de inundação (perigo) com dados de uso do solo, valor económico e curvas de vulnerabilidade (dano). A análise quantificou o potencial para danos económicos significativos em edifícios e infraestruturas, com consequências diretas para as comunidades costeiras e atividades económicas como o turismo.
- As projeções para 2050 indicam um **aumento na extensão da área inundada** e na **magnitude das perdas financeiras** potenciais.



Incêndios



Secas



Ondas de Calor

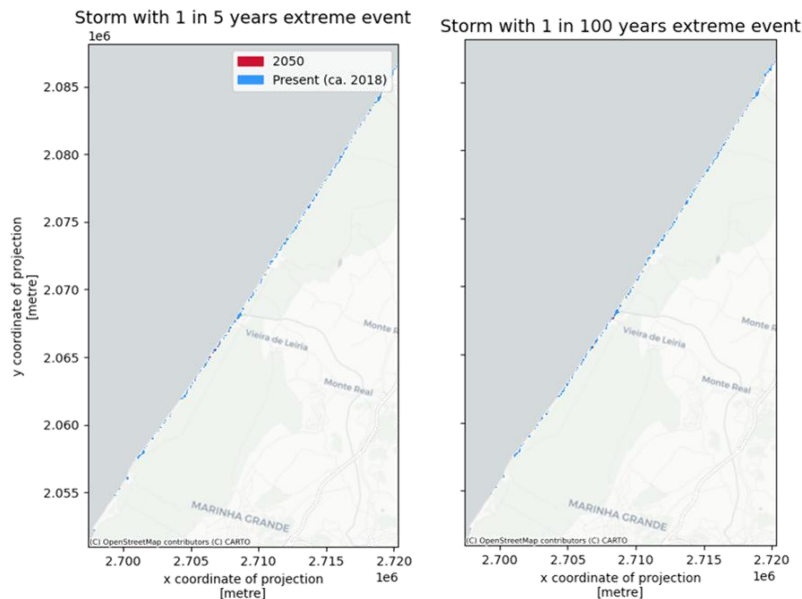


Inundações costeiras



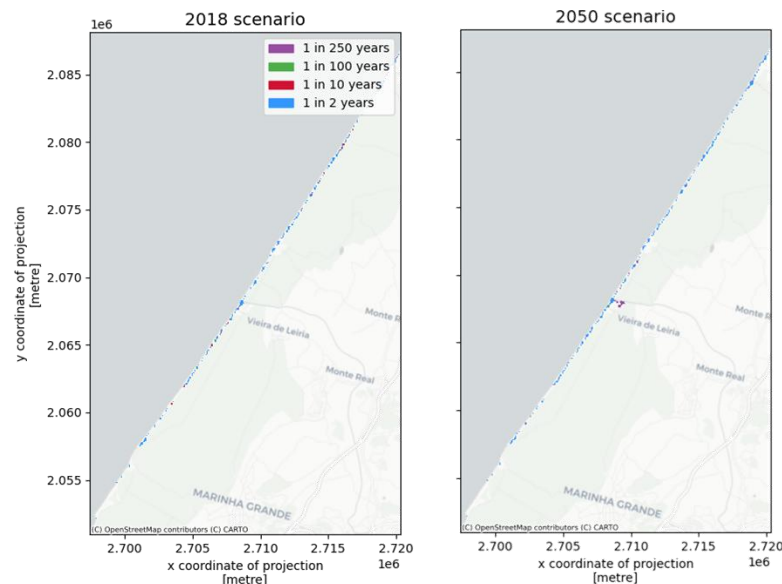
3.3. Avaliação inicial de riscos – principais resultados

Flood extents in 2018 and 2050 scenarios compared



Comparação da extensão das inundações no cenário atual (2018) e no cenário de 2050 para a Região de Leiria.

Flood extents in extreme water level scenarios with different return periods compared



Comparação da extensão das inundações costeiras na Região de Leiria entre 2018 e 2050, considerando níveis extremos do mar com diferentes períodos de retorno (2, 10, 100 e 250 anos).



Incêndios



Secas



Ondas de Calor



Inundações costeiras



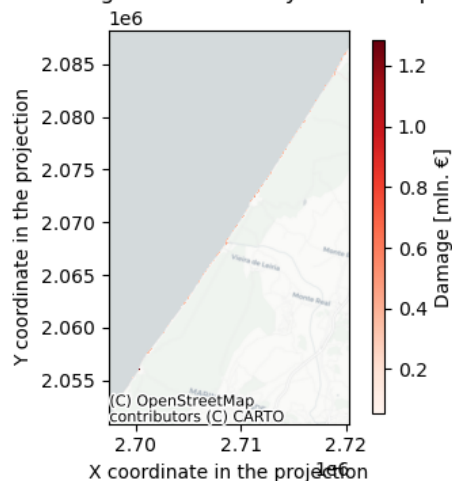
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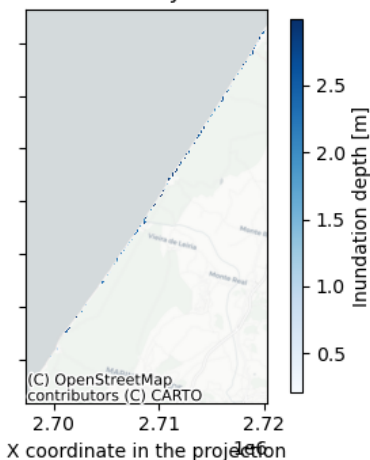
3.3. Avaliação inicial de riscos – principais resultados

Flood maps for extreme sea water level scenarios in year 2050

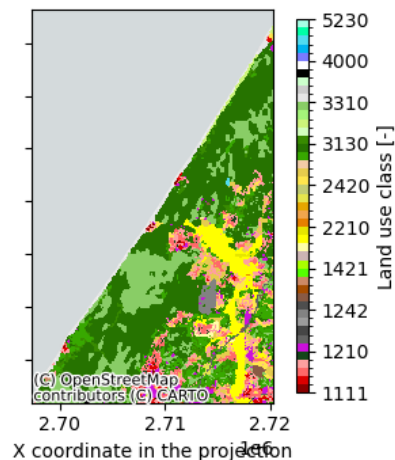
Flood damages for 1 in 100 year return period



Flood depth for 1 in 100 years extreme event



LUISA Land Cover for the defined area



Profundidade de inunda  o (m) e danos associados (M ) para cen rios de n vel extremo do mar no ano de 2050 para a Regi o de Leiria.



Inc ndios



Secas



Ondas de Calor



Inunda  es costeiras



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3.4. Principais lições aprendidas na fase 1

Sucesso na implementação metodológica:

- Foram **aplicados e testados com sucesso os workflows** do CLIMAAX para os 4 riscos selecionados (incêndios florestais, secas, ondas de calor e inundações costeiras), estabelecendo uma linha de base padronizada e replicável para a avaliação multirrisco.

Troca de conhecimento com outras regiões:

- A **participação no workshop do CLIMAAX** (junho de 2025, Barcelona) que reuniu mais de 150 representantes de 69 regiões e municípios de 23 países europeus, foi uma oportunidade singular para discutir desafios, partilhar casos de sucesso na avaliação de riscos climáticos e trocar conhecimentos.

Potencial da *toolbox* e dos “*workflows*” padronizados:

- O uso de scripts (Python) padronizados permitiu **aceder e processar dados** (históricos e projeções), mas também **cruzar variáveis complexas de forma sistemática**.
- A estrutura dos workflows permite cruzar Perigo (ex: mapas de cheias) com Exposição (ex: edifícios) e Vulnerabilidade (ex: demografia), gerando métricas precisas como “danos económicos em M€”. Esta capacidade de cruzamento quantitativo e a consideração dos cenários climáticos futuros é um salto qualitativo.



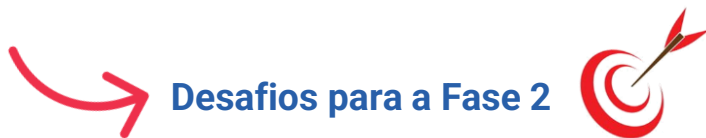
3.4. Principais lições aprendidas na fase 1

Desfasamento entre dados globais e necessidades locais:

- Os **datasets europeus** (Copernicus/JRC) são excelentes para identificar tendências macro, mas a sua **resolução** (geralmente de 25km ou superior) **é insuficiente para o planeamento operacional** da gestão de riscos e da proteção civil. A escala local exige uma precisão que apenas dados próprios (como LiDAR) podem oferecer.

A Importância da validação empírica:

- Os modelos científicos tendem a ser "top-down" (visão macro).
- A Fase 1 ensinou que o conhecimento dos agentes no terreno (*stakeholders* locais) é indispensável para calibrar as simulações. Sem o contributo de quem detém informação de base relevante, conhece os hotspots históricos de ocorrências, os modelos correm o risco de ser academicamente corretos mas operacionalmente ineficazes.



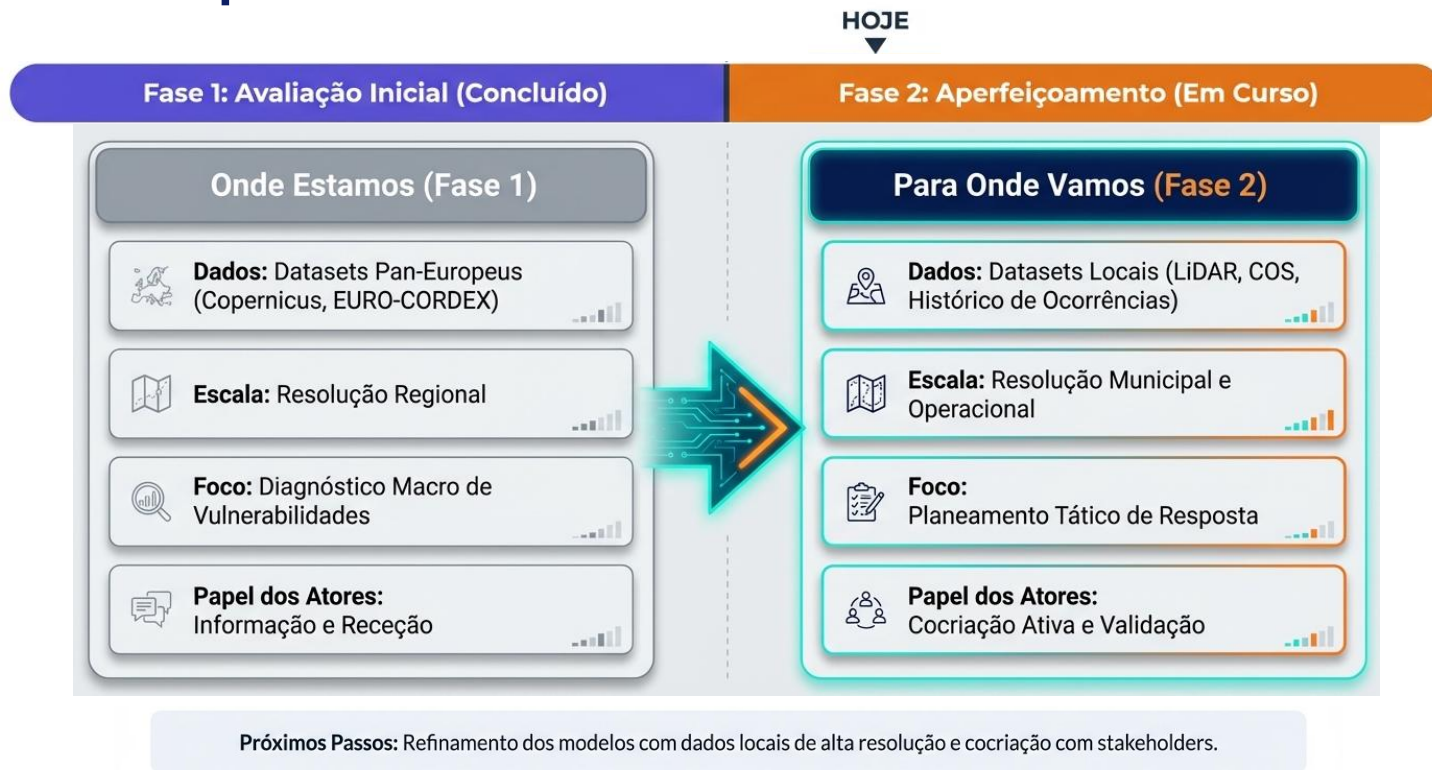
4. FASE 2 – DESAFIOS E COCRIAÇÃO



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4.1. Desafios para a fase 2



4.2. O papel dos stakeholders

Envolvimento ativo e cocriação com Stakeholders:

- Na Fase 2 pretende-se fazer a transição para um modelo de cocriação ativa, onde os agentes locais e regionais desempenharão um papel decisivo na validação dos modelos, na interpretação dos resultados e no respetivo alinhamento com as suas necessidades operacionais específicas do território.

Contributos fundamentais para a consecução dos objetivos da fase:



Integração de dados locais de alta resolução (levantamento LiDAR, uso do solo).



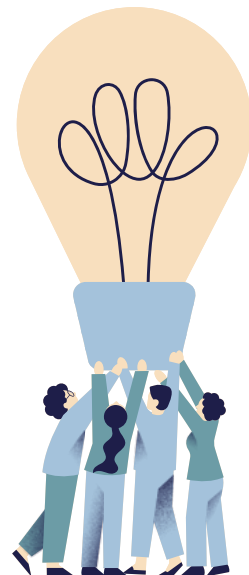
Cocriação e envolvimento ativo dos stakeholders.



Refinamento dos *workflows* (validação dos modelos) para precisão operacional.



Criar bases sólidas para as estratégias de adaptação (fase 3).



5. DEBATE E PRÓXIMOS PASSOS



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5.1. Próximos passos ...



5.2. Recolha de contributos dos stakeholders



CLIMAAX_4Resilience: stakeholders

O Projeto CLIMAAX:

O «CLiMaT risk and vulnerability Assessment» projeto Horizonte Europa, em curso até final analítico e prático para aprimorar os planos emergência e proteção civil.

Partindo de um panorama europeu longe de de catástrofes e de adaptação às alterações com o propósito de contribuir para a **harmónica avaliação dos riscos climáticos**, deixando u europeias. Do projeto resultaram:

- 1 metodologia de avaliação de risco c atual e nas melhores práticas;
- 1 conjunto de ferramentas (toolbox) c
- 5 territórios-piloto europeus para test de ferramentas;
- 50 regiões com apoio financeiro para ferramentas à escala local, aprimorar climáticos e/ou os planos de emergê
- Orientações para a avaliação de risco outras regiões europeias.

Com o objetivo de disseminar os seus resul convocatórias, às quais entidades públicas competências neste domínio, poderiam apr candidaturas, quando aprovadas, resultar e ferramentas desenvolvidas pelo CLIMAAX

Fases de implementação do subprojeto CLIMAAX4Resilience:



Fase 1: Inquérito aos stakeholders:

Este inquérito integra os **processos participativos com Stakeholders**, previstos transversalmente à implementação do CLIMAAX4Resilience, conforme preconizado na metodologia comum do projeto CLIMAAX. O objetivo central destes processos é a **promoção da cocriação e da corresponsabilização dos atores locais e da comunidade**, garantindo que as suas preocupações, expectativas e prioridades sejam refletidas nos resultados. Especificamente, o inquérito online da Fase 1 tem um duplo propósito:

1. Apresentar o projeto e disseminar os **resultados da avaliação inicial de riscos** (deliverable da Fase 1).
2. **Recolher contributos estratégicos** para a refinação e melhoria da análise de risco (previstas na Fase 2).

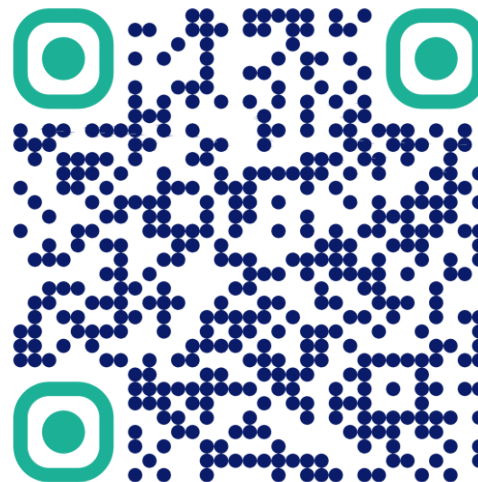
Considerando o contexto e o **desafio primordial da Fase 2**, que é a **integração de dados locais de alta resolução** para refinar a avaliação inicial de riscos climáticos (realizada com recurso a dados pan-europeus), a estrutura deste inquérito deverá foca-se na validação dos resultados preliminares e na identificação das melhores fontes de informação local, nomeadamente aquelas que os **stakeholders** possam deter ou conhecer no âmbito da sua atuação.

[Seguinte](#)

[Limpar formulário](#)

Inquérito online:

<https://forms.gle/p2gQtmkM6TSV57Z3A>



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5.3. Mais informações sobre o projeto

Ligações úteis do projeto:



www.climaax.eu



www.linkedin.com/company/climaax/



www.zenodo.org/communities/climaax/

CLIMAAX4Resilience– relatório da fase 1:



<https://zenodo.org/records/17199602>

Newsletter #1:



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5.4. Debate

Dúvidas?

Contributos?

Feedback?



Agradecemos a atenção!



www.climaax.eu

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Comunidade
Intermunicipal
da Região de Leiria

Com a colaboração de:

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Folha de Presenças

Sessão Participativa com os Stakeholders

A informação recolhida destina-se a efeitos estatísticos, de registo e evidência relativos ao «CLIMAAX4Resilience: Multi-Risk Climate Assessment through the CLIMAAX Common Methodology Framework and Toolbox Towards Climate Resilience for the Leiria Region», subprojeto do projeto Horizonte Europa «CLIMate risk and vulnerability Assessment framework and toolbox (CLIMAAX)».

LISTA DE PRESENCAS

NOME	ENTIDADE	CONTACTO
ORIGENCIO PEREIRA	CIMRL	
Elmano Silva	ICNF	
Luís Piza	ICNF	
Joaquim	ICNF	
João Lindo da Cunha	ASCENDI	
António Freire	REN - Rede Elétrica Nacional	
"	REN - Gaseiros	
Fátima Baptista Santos	E-REDES	
GNR - Cabo Mor Silva	G.N.R. Nucleo Paterna Amieira	
Nuno Oliver	STPC Pato de Leiria	
Paulo Barzinhos	Município de Pato de Leiria	
João João	C.M. Amieira	
Álvaro Rocha	C.M. Amieira	
Álvaro Santos	Município de Pato de Leiria	
Marta Silva	Município de Leiria	
Susana Ferreira	Município de Leiria	
Vasco Fernandes	Município da M ^a Grande	
BRUNO GOMES	MUNICIPIO DE PEDROGÃO GRANDE	
Susana Ferreira	Município de Pedrogão Grande	
Isabel Ascensão	Município da Batalha	
Pedro Quintana	Município de Fig ^a dos Vinhos	
Rui Alves	Município de Fig ^a dos Vinhos	
Carla Fernandes	Município de Alcanhões	
Pedro Barros	Município de M ^a Grande	
EDUARDO VARELA	POLICIA LOCOMOTIVA PUBLICA	

CLIMAAX_4Resilience: Inquérito aos *stakeholders*

* Indica uma pergunta obrigatória

O Projeto CLIMAAX:

O «**CLIM**ate risk and vulnerability Assessment framework and toolbox (CLIMAAX)» é um projeto Horizonte Europa, em curso até final de 2026, que providencia suporte financeiro, analítico e prático para aprimorar os planos de gestão de riscos climáticos e os planos de emergência e proteção civil.

Partindo de um panorama europeu longe de ser uniforme, em matéria de gestão do risco de catástrofes e de adaptação às alterações climáticas, o projeto CLIMAAX foi concebido com o propósito de contribuir para a **harmonização e consolidação da prática de avaliação dos riscos climáticos**, deixando um legado para as próximas iniciativas europeias. Do projeto resultaram:

- 1 metodologia de avaliação de risco climático padronizada, baseada na experiência atual e nas melhores práticas;
- 1 conjunto de ferramentas (toolbox) com dados, modelos e recursos;
- 5 territórios-piloto europeus para testarem e moldarem a metodologia e o conjunto de ferramentas;
- 50 regiões com apoio financeiro para aplicarem a metodologia e o conjunto de ferramentas à escala local, aprimorando os respetivos planos de gestão de riscos climáticos e/ou os planos de emergência e proteção civil;
- Orientações para a avaliação de risco climático e serviço de assistência online para outras regiões europeias.

Com o objetivo de disseminar os seus resultados, o projeto promoveu a abertura de duas convocatórias, às quais entidades públicas dos diferentes Estados-Membros, com competências neste domínio, poderiam apresentar uma candidatura. Dessas candidaturas, quando aprovadas, resultaram subprojetos para aplicação das metodologias e ferramentas desenvolvidas pelo CLIMAAX no território das entidades candidatas.

O subprojeto CLIMAAX4Resilience:

Da 2.^a convocatória foram selecionadas 3 candidaturas portuguesas, entre as quais a **"CLIMAAX4Resilience: Multi-Risk Climate Assessment through the CLIMAAX Common Methodology Framework and Toolbox Towards Climate Resilience for the Leiria Region"**, apresentada pela CIM da Região de Leiria.

O subprojeto CLIMAAX4Resilience desenvolve-se em 3 fases sequenciais ao longo de 22 meses. Concluída a **Fase 1 – "Aplicação da metodologia comum CLIMAAX"**, e com base nos respetivos resultados, sobre os quais incide o presente inquérito aos *stakeholders*, encontramos-nos, atualmente, a implementar a **"Fase 2 – Análise refinada de alta resolução regional / local e avaliação de risco"**.

Fases de implementação do subprojeto CLIMAAX4Resilience:



Fase 1: Inquérito aos *stakeholders*:

Este inquérito integra os **processos participativos com *Stakeholders***, previstos transversalmente à implementação do CLIMAAX4Resilience, conforme preconizado na metodologia comum do projeto CLIMAAX.

O objetivo central destes processos é a **promoção da cocriação e da corresponsabilização dos atores locais e da comunidade**, garantindo que as suas preocupações, expectativas e prioridades sejam refletidas nos resultados.

Especificamente, o inquérito online da Fase 1 tem um duplo propósito:

1. Apresentar o projeto e disseminar os **resultados da avaliação inicial de riscos** (*deliverable* da Fase 1).
2. **Recolher contributos estratégicos** para a refinação e melhoria da análise de risco (previstas na Fase 2).

Considerando o contexto e o **desafio primordial da Fase 2**, que é a **integração de dados locais de alta resolução** para refinar a avaliação inicial de riscos climáticos (realizada com recurso a dados pan-europeus), a estrutura deste inquérito deverá foca-se na validação dos resultados preliminares e na identificação das melhores fontes de informação local, nomeadamente aquelas que os *stakeholders* possam deter ou conhecer no âmbito da sua atuação.

1. Nome da entidade que representa: *

2. Nome do(a) inquirido(a): *

3. Email: *

I. Contextualização e Avaliação da Comunicação

Esta secção visa confirmar o envolvimento e a compreensão dos stakeholders relativamente aos resultados preliminares da Fase 1 (Avaliação Inicial de Riscos).

4. 1. Confirma o conhecimento sobre o subprojeto CLIMAAX4Resilience e a fase atual dos trabalhos? *

Marcar apenas uma oval.

☐ Sim

☐ Não

5. 2. A informação disponibilizada sobre os resultados da Avaliação Inicial de Riscos (Fase 1) é clara, relevante e útil para a sua área de atuação? *

Marcar apenas uma oval.

☐ Sim

☐ Não

☐ Talvez / Não tenho a certeza

6. 3. Na sua perspetiva, os resultados apresentados refletem adequadamente os principais desafios e riscos climáticos (incêndios florestais, secas, ondas de calor e inundações costeiras) percebidos no seu território/setor? *

Marcar apenas uma oval.

- ☐ Sim
- ☐ Não
- ☐ Talvez / Não tenho a certeza

II. Validação da Identificação dos Riscos e Vulnerabilidades Locais

A Fase 1 identificou quatro riscos prioritários e diversas vulnerabilidades. Esta secção procura validar se esta identificação está alinhada com a perceção e a experiência operacional dos atores-locais, essencial para a cocriação na Fase 2.

7. 4. Com base na sua experiência local, qual dos quatro riscos prioritários (incêndios florestais, secas, ondas de calor e inundações costeiras) é, atualmente, o mais severo e/ou urgente na Região de Leiria? *

Marcar apenas uma oval.

- ☐ Incêndios Florestais
- ☐ Secas
- ☐ Ondas de Calor
- ☐ Inundações Costeiras

8. 5. Os setores identificados como mais vulneráveis (agricultura, biodiversidade, florestas, saúde humana, segurança de pessoas e bens) estão corretamente priorizados, ou existe outro setor cuja vulnerabilidade é crítica na sua área? *

9. 6. Existe algum risco climático significativo, com impacto substancial no território, que não tenha sido abrangido na avaliação inicial de riscos (Fase 1)? *

[NOTA: o CLIMAAX disponibiliza recursos para aplicação na avaliação dos seguintes riscos: cheias / inundações (fluviais e costeiras); precipitação intensa; ondas de calor; secas; incêndios florestais; nevões; e ventos fortes / tempestades].

III. Contributo para o Refinamento (Fase 2 - Dados de Alta Resolução)

*A principal limitação identificada na Fase 1 foi a falta de especificidade dos datasets pan-europeus para o planeamento operacional. Para a ultrapassar, a Fase 2 requer a recolha e **integração de dados locais de alta resolução** nos fluxos de trabalho (scripts informáticos) da avaliação dos diferentes riscos selecionados.*

10. 7. O seu serviço/organização possui um registo histórico georreferenciado e detalhado de ocorrências (ex: incêndios, galgamentos costeiros, danos por seca) que possa ser compilado e usado para validar os modelos de risco na Fase 2? *

Marcar apenas uma oval.

☐ Sim (por favor enviar informação para o seguinte email:
coopera@geoatributo.com)

☐ Não

11. 8. Para além da informação publicada e disponível para utilização a nível nacional (ex. levantamento LiDAR de Portugal Continental - DGT), a sua organização dispõe de (ou tem acesso a) outros dados de alta resolução cruciais para a modelação, a nível local, como modelos de combustível florestal atualizados (para incêndios), que tenham sido produzidos pela sua entidade ou obtidos em projetos nos quais esta participou? *

Marcar apenas uma oval.

☐ Sim (por favor enviar informação para o seguinte email:
coopera@geoatributo.com)

☐ Não

12. 9. Na fase 1, devido a restrições da ferramenta de modelação comum disponibilizada pelo projeto europeu, não foi possível incluir algumas culturas importantes e representativas do território. A avaliação da seca agrícola focou-se em seis culturas (incluindo o milho, que revelou o maior risco económico). Na Fase 2 procurar-se-á avaliar a viabilidade de integrar outras culturas de grande relevância económica/social para a região. Quais das seguintes consideraria importante? *

Marcar tudo o que for aplicável.

☐ Fruticultura (Pêra e Maçã)

☐ Tomate

☐ Vinha

☐ Outra: _____

13. 10. O seu município/entidade tem implementados ou planeia a instalação de sistemas de monitorização local (ex: estações meteorológicas, sensores de nível/caudal em rios, sensores de humidade do solo) que possam complementar o subprojeto CLIMAAX4Resilience na Fase 2? *

Marcar apenas uma oval.

☐ Sim (por favor enviar informação para o seguinte email: coopera@geoatributo.com)

☐ Não

14. 11. Se respondeu «sim» a alguma das questões acima acerca da disponibilidade de informação de base e pretende fazer algum comentário ou nota adicional, por favor, utilize este campo para o efeito:

IV: Necessidades Operacionais e Preparação para a Adaptação (Fase 3)

Esta secção prepara o terreno para a Fase 3 (Exploração de Estratégias Locais de Adaptação e Melhoria dos Planos de Gestão dos Riscos), questionando sobre a aplicação prática dos resultados.

15. 12. Na sua opinião, como poderão os resultados refinados da avaliação de risco (Fase 2) ser mais úteis para a melhoria e atualização dos instrumentos de gestão de risco existentes (ex: PMAC, PMEPC, outros)? *

16. 13. No âmbito da sua atuação (ou do seu Município, se aplicável), já foram definidas e priorizadas formalmente medidas de adaptação ou estratégias de gestão de risco para reduzir a vulnerabilidade do território (ex: através de um PMAC - Plano Municipal de Ação Climática ou outro instrumento)? *

Marcar apenas uma oval.

☐ Sim

☐ Não

17. 14. Tendo em conta os resultados preliminares da avaliação de risco CLIMAAX4Resilience (Fase 1), quais são as medidas de adaptação ou estratégias de gestão de risco que a sua organização considera mais urgentes ou que deveriam ser prioritariamente melhoradas/reforçadas para reduzir a vulnerabilidade do território? *

V: Outros Contributos, Comentários ou Sugestões

Nesta secção poderá apresentar outros contributos, comentários ou sugestões ao CLIMAAX4Resilience.

18. 15. Caso tenha contributos, comentários ou sugestões adicionais ao CLIMAAX4Resilience, por favor, utilize este campo para o fazer: *

19. 16. Gostaria de receber, no seu email, a newsletter do CLIMAAX4Resilience? *

Marcar apenas uma oval.

☐

Sim Avançar para a pergunta 20

☐

Não

Avançar para a secção 9 (**Agradecemos a Vossa colaboração e contributo!**)

20. 17. Indique, por favor, o endereço de email onde gostaria de receber a newsletter:

*

Agradecemos a Vossa colaboração e contributo!

Para mais informações, poderá consultar os canais de comunicação do projeto CLIMAAX:

- Website: www.climaax.eu
- LinkedIn: www.linkedin.com/company/climaax/
- Zenodo (repositório do projeto): www.zenodo.org/communities/climaax/

O CLIMAAX4Resilience é um subprojeto do:



Financiado por:



**Funded by
the European Union**

Promovido por:



CIMRL
Comunidade
Intermunicipal
da Região de Leiria

Com a colaboração de:



Sessão participativa: follow-up

Ex.mo(a) Senhor(a),

No seguimento da apresentação referente ao projeto **CLIMAAX4Resilience** realizada na reunião da *Comissão Sub-Regional de Gestão Integrada de Fogos Rurais da Região de Leiria*, cujos membros configuram *stakeholders* de grande relevância para o projeto, a Comunidade Intermunicipal da Região de Leiria (CIMRL) vem, por este meio, agradecer o interesse e a colaboração demonstrados.

Como referido na sessão, o projeto CLIMAAX4Resilience encontra-se numa fase crucial de transição entre a avaliação inicial de riscos (Fase 1) e o seu refinamento com dados locais (Fase 2). Para garantir que os resultados finais sejam verdadeiramente úteis para a gestão do território e para o planeamento de proteção civil e da ação climática, a Vossa participação é determinante.

Neste contexto, e conforme acordado, partilhamos em anexo a seguinte documentação de suporte:

- ◆ **Apresentação realizada na sessão:** Síntese do projeto, metodologia, resultados principais e roteiro de trabalhos;
- ◆ **Newsletter #1 CLIMAAX4Resilience:** Resumo gráfico dos principais resultados da Fase 1 (riscos de incêndios, secas, ondas de calor e inundações costeiras).

Para consolidarmos a avaliação da Fase 1 e avançarmos com recolha de dados de alta resolução para a atual Fase 2, solicitamos o Vosso valioso contributo através do preenchimento de um breve inquérito online, até ao próximo dia 28 de abril de 2026.

A Vossa resposta permitirá validar se os riscos identificados correspondem à realidade sentida no terreno e identificar fontes de informação local indispensáveis para os próximos passos.

Poderá aceder ao inquérito através do link ou QR Code abaixo.

Link de acesso: <https://forms.gle/p2gQtmkM6TSV57Z3A>



Relembramos que toda a informação técnica detalhada (relatório completo da Fase 1) pode ser consultada no nosso repositório oficial: <https://zenodo.org/records/17199602>

Agradecemos, desde já, a Vossa disponibilidade e colaboração contínua na construção de uma região mais resiliente às alterações climáticas.

Subscrevemo-nos com os nossos melhores cumprimentos.

