Deliverable Phase 2 – Climate risk assessment

Climaax Action and Risk Evaluation of Xanthi (CARE_X)

Greece, City of Xanthi

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5. Abbreviations and acronyms

Abbreviation / acronym	Description
AF	Attributable fraction
AIC	Akaike information criterion
CARE_X	CLIMAAX Action and Risk Evaluation of Xanthi
CDS	Copernicus Climate Data Store
CI	Confidence interval
CLIMADAT-GRiD	High-resolution gridded precipitation and temperature dataset for Greece
CMIP6	Coupled Model Intercomparison Project Phase 6
CRA	Climate risk assessment
CSV	Comma-separated values
CVD	Cardiovascular disease
DEM	Digital elevation model
DLNM	Distributed lag non-linear model
ECMWF	European Centre for Medium-Range Weather Forecasts
ELSTAT	Hellenic Statistical Authority
ERA5	ECMWF Reanalysis (fifth generation)
ESA-CCI	European Space Agency Climate Change Initiative (Land Cover)
FEX	Folklore and Historical Society of Xanthi
FWI	Fire Weather Index
GCM	Global climate model
GDP	Gross domestic product
ICD-10	International Classification of Diseases, 10th revision
JRC	Joint Research Centre (European Commission)
LUISA	Land Use-based Integrated Sustainability Assessment (JRC platform/datasets)
NDVI	Normalized Difference Vegetation Index
NetCDF	Network Common Data Form
NIR	Near-infrared (spectral band)
NOA	National Observatory of Athens
RCM	Regional climate model
RCP	Representative Concentration Pathway
RiskAC	Risk and Resilience Assessment Center (Democritus University of Thrace)
RR	Relative risk
SSP	Shared Socio-economic Pathway

6. Executive summary

This deliverable reports the Phase 2 for the CARE_X project in the City of Xanthi, Greece. Phase 2 moves beyond a baseline application of CLIMAAX workflows by producing a regionalized, decision-relevant multi-risk assessment, grounded in local conditions and supported by stakeholder-informed interpretation. Phase 2 focused on four priority hazards: windstorms, heatwaves, fluvial flooding, and wildfires. The main action in this phase was the targeted improvement of one or more of the risk components (hazard, exposure, vulnerability) through the inclusion of local and higher-resolution datasets and locally appropriate analytical choices. This approach was implemented at an advanced and expert level within the CLIMAAX toolbox logic and was complemented by explicit reporting of assumptions and residual uncertainties to preserve transparency and reproducibility.

The risk evaluation step drew on hazard-specific outputs that are directly relevant to municipal decision-making. Windstorm evaluation followed an event-based approach for workflow adaptations by implementing exposure data, wind measurements and observations from the wind-induced damage in a local scale to perform a regionalized risk analysis; heatwave evaluation used projections of heat hazard and health-relevant indicators, including relative risk of cardiovascular mortality above a locally derived threshold and its evolution under SSP pathways; flood evaluation used downscaled inundation-depth mapping, associated damage estimation using updated economic exposure proxies, and displacement-relevant indicators; wildfire evaluation used scenario-based Fire Weather Index exceedance probabilities derived through response-surface modelling, together with population exposure metrics and tests of refined fuel representation based on satellite products.

Key Risk Assessment findings indicate that heatwaves represent the most critical and urgent risk for Xanthi. Heatwave severity is assessed as substantial under current conditions and critical under future conditions, with urgency requiring immediate action due to projected intensification and preventable impacts on vulnerable groups and critical services. Fluvial flooding and wildfires are assessed as high-priority risks. Flooding is substantial at present and can become critical for extreme events in future periods; urgency is assessed as more action needed given the potential for major disruption, damages, and cascading impacts. Wildfires are substantial at present and critical in the future; urgency is assessed as more action needed and potentially immediate in priority zones with elevated exposure and vulnerability. Windstorms are rated moderate for both current and future aware scenarios under the Phase 2 workflow configuration and therefore represent a lower-priority risk than heatwaves, flooding, and wildfires. Nevertheless, documented local wind impacts justify continued monitoring and targeted preparedness, with priority given to improved hazard spatialization and post-event validation at municipal scale.

Resilience capacity is assessed as medium across all hazards, reflecting the presence of institutional mechanisms for preparedness and response, but also recognizing structural constraints that limit sustained implementation of prevention and adaptation measures. Capacity building undertaken during Phase 2 strengthened human and organizational readiness by improving technical literacy and shared understanding of workflow outputs, thereby supporting more effective uptake into municipal planning.

Phase 2 also advanced the stakeholder interface required for risk uptake. Risk evaluation was informed through institutional coordination, knowledge transfer activities, and sector-specific consultation, and a broader participation pathway is planned through the Xanthi Resilience Festival (8–10 May 2026) as a mechanism to support public awareness, dialogue, and feedback integration.

The main limitations of Phase 2 arise from uneven data availability across hazards and workflow-dependent scenario constraints. In particular, the assessment did not implement a harmonized, fully coupled modelling of municipal-scale future socio-economic development across hazards; instead, a climate-signal approach was applied where consistent socio-economic inputs were unavailable. In addition, certain regionalization steps (for example, flood map downscaling) improve municipal interpretability but do not replace specialized engineering studies required for design-level interventions, and windstorm analysis remains constrained by limited monitoring density and field validation.

Phase 2 provides a strengthened evidence base for municipal climate risk management. The assessment indicates that heatwaves require immediate and sustained attention, while fluvial flooding and wildfires require intensified action and prioritized prevention and preparedness, and windstorm risk warrants monitoring and targeted preparedness given local event evidence and current validation constraints. The planned final phase will translate these priorities into implementable adaptation and risk management measures, integrate outputs into municipal planning instruments (including updates of risk management plans and preparedness procedures), and address the most consequential evidence gaps through targeted improvements in data, monitoring, and stakeholder validation.

1 Introduction

1.1 Background

CARE_X is implemented in the City of Xanthi, north-eastern Greece (Region of Eastern Macedonia and Thrace - REMTh), within the European CLIMAAX programme, which supports regions in conducting harmonized regional and local multi-risk climate risk assessments through a methodological framework and a dedicated toolbox. Xanthi is located at the foothills of the Rhodope mountain chain and is traversed by the Kosynthos River, which concentrates exposure and potential impacts from fluvial flooding within the urban fabric. The City is exposed to multiple climate-related hazards, including documented impacts from heatwaves, fluvial flooding, wildfires, and windstorms, which affect public health, infrastructure, and local services. In addition, the area's historical and architectural heritage, including a well-preserved old town and cultural institutions, increases the importance of protecting high-consequence local assets from climate-induced risks.

1.2 Main objectives of the project

Phase 1 of CARE_X implemented the CLIMAAX common methodology for multi-risk assessment as a baseline analysis for Xanthi. Phase 2 advances the assessment by regionalizing and refining the risk analysis through the integration of higher-resolution local data and locally appropriate modelling assumptions, aiming to improve decision relevance for municipal planning and climate risk management. The objectives of Phase 2 are to improve the representation of hazard, exposure, and vulnerability for the priority hazards and to produce refined maps and indicators that can support preparedness, prevention, and adaptation decision-making at the municipal scale. The CLIMAAX Handbook and Toolbox provide methodological benefits by ensuring alignment with a transparent, reproducible framework and by enabling advanced and expert users to customize workflows and incorporate local data, thereby increasing analytical fidelity and practical usability of outputs.

1.3 Project team

CARE_X is delivered through a partnership between the City of Xanthi (project owner, decision-making, and implementation interface) and the Risk and Resilience Assessment Center of Democritus University of Thrace – RiskAC[1] (technical lead for data processing, workflow implementation, and risk mapping). Political leadership and the Civil Protection Office provide institutional anchoring and operational relevance, while the research team ensures scientific rigour and traceability of methods, data, and results.

1.4 Outline of the document's structure

This deliverable reports the Phase-2 Climate Risk Assessment results for the City of Xanthi following the CLIMAAX CRA Framework:

- Section 2.1 (Scoping) defines the objectives and context for the CRA, clarifies participation and risk ownership, and describes the application of principles and stakeholder engagement, consistent with CLIMAAX scoping guidance.

[1] https://riskac.eu/wp/en/about/

- Section 2.2 (Risk Exploration) summarizes the risk screening that led to selecting the priority hazards and explains the scenario choices for analyzing current and future risks.
- Section 2.3 (Regionalized Risk Analysis) presents the quantitative risk analysis approach using CLIMAAX risk workflows and reports hazard-by-hazard results for the four priority hazards assessed in Phase 2.
- Subsequent sections (Key Risk Assessment and Monitoring & Evaluation) interpret the risk outcomes within the local decision context to support prioritization and iterative improvement, in line with the CLIMAAX framework cycle.

2 Climate risk assessment – phase 2

2.1 Scoping

Scoping defines the objectives and conditions for implementing the climate risk assessment and identifies stakeholders, experts, and priority groups that support the uptake of results into policy and decision-making. This Phase 2 scoping builds on Phase 1 and is updated to reflect new engagement pathways, local datasets, and sector interfaces that have been developed.

2.1.1 Objectives

CARE_X Phase 2 aims to produce a refined, locally grounded multi-risk assessment for the City of Xanthi that supports climate risk management and adaptation planning. The intended use of Phase 2 outputs is twofold: first, to inform updates of municipal risk management plans and preparedness procedures; second, to provide evidence that can be integrated into local and regional adaptation strategies and risk governance. Phase 2 also strengthens municipal capacity to interpret and apply risk information, consistent with the Phase 1 roadmap.

Key boundaries stem from uneven local data availability across hazards and workflow constraints related to scenario availability and exposure and vulnerability representations. Notably, sparse wind observations limit robust spatialization of wind hazard, and consistent municipal-scale socio-economic projections are not available for harmonized coupling across workflows. These constraints were managed through targeted local data integration where feasible, explicit reporting of assumptions and limitations, and capacity-building activities that support appropriate interpretation by decision-makers.

2.1.2 Context

In Xanthi, climate-related hazards have primarily been addressed through hazard-specific operational instruments (early warning, emergency planning, and recovery), rather than an integrated, municipal-scale quantitative multi-hazard assessment. CARE_X responds to increasing hazard complexity and impacts on people, infrastructure, and services, and to the need for prioritization under constrained resources, where national and regional plans may be insufficient for fine-scale municipal investment and measure targeting.

The governance context includes legal and strategic obligations and available resources shaping local decision-making. The CARE_X proposal positions project outputs as inputs to updated municipal risk management plans and local adaptation strategies and as support for establishing and operating a Climate Change Observatory to strengthen monitoring and evaluation of adaptation effectiveness. It also notes that the municipality maintains hazard plans (including for snowstorms, forest fires, earthquakes, and floods) that can be updated using multi-risk and scenario-informed evidence.

Sectors most affected by the Phase 2 hazard portfolio are public health and social services, the built environment and critical infrastructure, land and ecosystem management, and cultural heritage where high-consequence assets exist. External influences include the CLIMAAX framework and toolbox, which provide harmonized workflows and pan-European datasets while enabling local data integration and workflow customization.

Feasible interventions span cross-cutting measures (risk communication and preparedness, hotspot-based targeting of maintenance and investments, learning through training and iterative plan revision) and hazard-specific measures (heat-health protection for vulnerable groups; flood risk reduction through drainage and asset protection prioritization; wildfire prevention and preparedness in peri-urban and rural zones; windstorm resilience for exposed assets and infrastructure). Final prioritization and selection are addressed through the Key Risk Assessment and subsequent planning steps.

2.1.3 Participation and risk ownership

Phase 2 participation followed a decision–science partnership between the City of Xanthi and the technical team, complemented by engagement with operational actors, data providers, and priority sectors. Phase 1 included an initial stakeholder workshop (December 2024) that established scoping and engagement channels. Phase 2 expanded participation through knowledge transfer activities, including training-oriented engagement to improve the capacity to interpret workflow outputs.

Stakeholders participating in CLIMAAX-related processes include municipal leadership and services (civil protection; technical and infrastructure functions; relevant administrative units), RiskAC, and operational actors engaged through knowledge transfer, including civil protection and emergency response stakeholders and hazard-relevant agencies such as Public Forest Management Services. Institutional roles and interconnections are summarized in the organigram included in this deliverable.

Risk ownership is distributed across governance levels. The municipality is the primary local risk owner for implementing risk-informed decisions and coordinating preparedness and response, while mitigation responsibilities are allocated by hazard across municipal, regional, and sectoral mandates. Priority groups include older adults and other health-sensitive groups affected by heatwaves, residents in flood-prone areas identified through refined mapping, and communities and service operators in wildfire-exposed peri-urban and rural zones. A single quantified municipal risk appetite is not codified across hazards; tolerability is expressed through existing planning instruments, operational trigger systems, and stakeholder judgement on severity, urgency, and capacity, formalized in the Key Risk Assessment. The Organigram of institutions and interconnections is available in the Supporting documentation.

2.1.4 Application of principles

Phase 2 operationalizes CLIMAAX principles through methodological and procedural choices. Social justice, equity, and inclusivity are addressed through explicit treatment of vulnerability, particularly for heat-related impacts and priority-group identification. Quality, rigor, and transparency are ensured through consistent application of workflow logic, hazard-by-hazard documentation of datasets and assumptions, and traceability of inputs and outputs to support review and iterative updates. The precautionary approach is implemented through scenario ranges where supported, explicit communication of limitations and uncertainty, and prioritization of critical functions and vulnerable groups when interpreting results.

2.1.5 Stakeholder engagement

Stakeholder engagement in Phase 2 combined formal coordination, targeted expert consultation, capacity building, sector-specific collaboration, and planned public outreach. A documented coordination meeting among municipal leadership, the Civil Protection Office, and the technical team aligned on objectives, methodological choices, and expected outcomes, providing a governance anchor for Phase 2 refinements. Phase 2 also relied on expert and data-provider engagement to improve hazard monitoring, including availability of local wind gust time series from a nearby meteorological station through expert communication supporting the windstorm refinement.

A major engagement pathway in Phase 2 was knowledge transfer through a structured three-day training activity focusing on risk assessment methodologies and CLIMAAX toolkits, with practical exercises emphasizing wildfire and flood workflows. This activity directly supports the Phase 2 milestone of knowledge transfer between RiskAC and the municipal Civil Protection Office and is intended to strengthen local capacity to interpret risk outputs and translate them into planning actions. In parallel, Phase 2 expanded engagement to a priority sector that is often underrepresented in standard risk assessments, namely cultural heritage. The collaborative framework between the 73-year-old non-profit cultural organization "Progressive Union of Xanthi" (FEX)[2], City of Xanthi, and RiskAC was disseminated internationally and positioned cultural heritage protection as a component of proactive, integrated risk management across floods, wildfires, heatwaves, and windstorms, with planned continued participation in public engagement activities in 2026.

Phase 2 also institutionalized a pathway for wider public engagement through the **Xanthi Resilience Festival**[3], defined as an initiative of RiskAC, the City of Xanthi, and project collaborators such as FEX under CARE_X within CLIMAAX. The festival is scheduled for 8 to 10 May 2026 and is explicitly framed as a mechanism to raise awareness, support participation, and enable public dialogue on resilience and climate risk.

Participants in Phase 2 engagement activities included municipal civil protection personnel, municipal technical services, regional civil protection actors, sectoral agencies linked to wildfire management, and students engaged through training-oriented activities, with cultural heritage stakeholders engaged through the heritage collaboration pathway. Project goals and intermediate results were communicated through structured meetings, training presentations, hands-on workflow exercises, and the sharing of intermediate maps and indicators for interpretation. The reception of results, as reflected in training feedback, emphasized the need for decision-oriented outputs indicating where to act first, consistent interpretation of scenarios and uncertainty across hazards, and explicit attention to priority groups and critical assets, including health-sensitive groups and cultural heritage.

Project outcomes are expected to be used by municipal decision-makers to prioritize preparedness and prevention measures, by civil protection and sectoral responders to strengthen operational planning and coordination, and by cultural institutions to develop safeguarding and preparedness actions aligned with municipal risk governance. Key difficulties encountered included the coordination burden across multiple institutions, limitations in locally representative monitoring for certain hazards, and the time required to validate and integrate heterogeneous local datasets into

[2] https://fex.org.gr/
[3] https://xanthiresfest.civil.duth.gr/

reproducible workflows. These constraints were managed through focused data integration, transparent reporting of limitations, and capacity-building processes that support appropriate use of results.

2.2 Risk Exploration

Risk exploration builds on scoping by screening hazards and risks most relevant to the local context and by selecting appropriate workflows and scenarios for quantitative analysis, consistent with the CLIMAAX framework.

2.2.1 Screen risks (selection of main hazards)

Phase 2 retains the Phase 1 hazard portfolio and focuses on regionalization through local data integration and targeted methodological adjustments that improve municipal-scale decision relevance. The assessed hazards remain **windstorms, heatwaves, fluvial flooding, and wildfires**.

Flood risk is concentrated along river corridors and low-lying areas, with potential damages and displacement; heatwaves affect the whole municipality but disproportionately burden vulnerable groups, motivating health-relevant indicators; wildfire risk is most pronounced in peri-urban and rural zones where fire weather and land cover interact with exposed communities; windstorms affect buildings, infrastructure and lifelines and require improved local representation of extremes and impacts.

The Copernicus Climate Atlas does not provide stable municipal-scale exports suitable for reproducible reporting; screening therefore relies on complementary Copernicus-supported and peer-reviewed evidence consistent with increasing heat stress and wildfire danger under future pathways and the continued relevance of flood risk for scenario-based planning. The Phase 2 evidence base combines Phase 1 outputs and CLIMAAX datasets with local and higher-resolution inputs. Remaining needs include denser wind monitoring and impact documentation, harmonized municipal-scale socio-economic projections, and improved inventories of critical assets and vulnerable groups.

2.2.2 Choose Scenario

Scenario selection follows CLIMAAX guidance: a limited, decision-relevant set constrained by workflow availability, with differences most evident after mid-century. Phase 2 assesses baseline and future climate conditions using the scenarios embedded in the hazard workflows: SSP pathways where available (notably for temperature-driven analyses) and RCP framing where legacy inputs require it.

Future socio-economic change is not modelled consistently across hazards due to the lack of compatible municipal-scale projections. Phase 2 therefore applies a climate-signal approach: hazards evolve under climate scenarios, while exposure and vulnerability use present-day datasets with local refinements, including vulnerability variance where data permit (especially for heat-health impacts). Climate and socio-economic factors are combined qualitatively through interpretation of hazard changes against current exposure and vulnerability patterns, supported by stakeholder engagement and key risk assessment. Time horizons are reported as near-term, mid-century, and long-term, using hazard-specific dataset windows up to end-century where available.

2.3 Regionalized Risk Analysis

The CLIMAAX framework defines risk analysis as the quantitative estimation of climate risk through workflows that combine hazard, exposure, and vulnerability, supported by scenario-based analysis where relevant. In CARE_X Phase 2, risk analysis is implemented using CLIMAAX workflows at advanced and expert levels, enabling local customization and the inclusion of local data to increase spatial and thematic relevance. The analytical focus is the refinement of hazard-specific workflows for windstorms, heatwaves, fluvial flooding, and wildfires, producing municipal-scale maps and impact indicators suitable for subsequent evaluation and prioritization.

Regionalization in Phase 2 is achieved through targeted improvements to one or more of the hazard, exposure, and vulnerability components. Windstorm assessment is refined through local event evidence and local observational support, while explicitly documenting monitoring constraints and residual uncertainty. Heatwave assessment is strengthened through higher-resolution temperature information and health-relevant impact modelling to support the protection of vulnerable groups.

Fluvial flooding assessment is refined through higher-resolution spatial representation and the inclusion of impact metrics beyond direct damage, thereby supporting the prioritization of areas with higher potential for population displacement and disruption. Wildfire assessment is refined through scenario-based fire-weather modelling, supported by Copernicus-aligned inputs and local land-cover considerations, enabling improved identification of priority zones for prevention and preparedness.

Phase 2 outputs constitute a refined evidence base for municipal planning and provide a traceable analytical foundation for the Key Risk Assessment step, including stakeholder-informed interpretation of severity, urgency, and resilience capacity and the identification of candidate adaptation interventions for Phase 3 planning.

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

Building on the Phase 1 application of the CLIMAAX windstorm hazard and risk workflow for the CARE_X area, Phase 2 undertakes a regionalized analysis using local data and targeted workflow adaptations to better reflect wind-related impacts observed in the City of Xanthi. In Phase 1, the assessment was performed for pre-configured CDS windstorm events and ERA5 hazard scenarios drawn from the ECMWF extreme-events list; both produced zero or negligible impacts because wind loads rarely exceeded the vulnerability-curve damage initiation thresholds. This indicates that windstorms are unlikely to constitute a priority risk for Xanthi under the event intensities and vulnerability assumptions embedded in the baseline workflow, a finding that is consistent with reported cross-country patterns of windstorm economic losses in Europe (Koks and Haer 2020).

However, evidence from past strong-wind events in the CARE_X region indicates non-negligible impacts, primarily in the urban area of Xanthi. Phase 2, therefore, implements a localized windstorm risk analysis using available wind-gust records and locally relevant exposure information to better represent the elements at risk. The main Phase 2 advancements relative to Phase 1 are summarized below: Observed damages induced by strong local wind events; Recorded wind gusts (point information) from a local meteorological station close to the city of Xanthi; True building types at the local scale, Updated (2021) GDP / capita for Xanthi; Updated percentage contribution of building types to the relevant land use cover types; “Shifted” vulnerability curves per building type as a rough approximation to adapt better to the observed damages; Modified LUISA damage curves per land-use cover type. Given the current data constraints, the updated CRA presented here should be interpreted not as a new wind hazard and risk workflow for Xanthi, but as an indication that strong-wind events warrant continued monitoring and further investigation in the CARE_X area.

2.3.1.1 Hazard assessment

Three local wind events with considerable impact in the CARE_X area were identified from a Greek database of extreme events[4]. A general description of these events is reported in Table 2.2. The latter was recorded by a meteorological station owned and operated by NOA/Meteo. The station[5] is located close to the city of Xanthi at a distance of about 5 km. With reference to the strongest wind event, which occurred on the 4th of November 2023 (No.3 in Table 2.1), a maximum wind gust of approximately 18 m/s was recorded. Figure 2.1 shows the 10-min records of maximum wind gust during the above day from Xanthi station.

Table 2-1 List of local wind events identified for the CARE_X area in the 2nd phase of the project

Local event	*1*		*2*		*3*	
Date	25 November 2015		14 June 2016		4 November 2023	
Duration	1 day		1 day		1 day	
Intensity	Strong		Strong		Very strong	
Consequences	Extended		Extended		Very extended	
Max wind gust recorded at Xanthi station (NOA)	48 km / h	13 m / s	47 km / h	12 m / s	67 km / h	18 m / s

The above wind event had a substantial local impact on the city of Xanthi referring to overturned cars in a parking lot close to the city center, partially untiled roofs, uprooted trees and broken car windows (Figure 2.2). According to the wind impact scale in Feuerstein et al. (2011), following the pioneering study of Fujita et al. (1992), the wind impact shown in Figure 2.2 may be classified as T2 (F1-). Of course, given the distance between the wind station and the city of Xanthi, the recorded value of 18 m/s cannot be correlated with the observed damage in a straightforward manner.

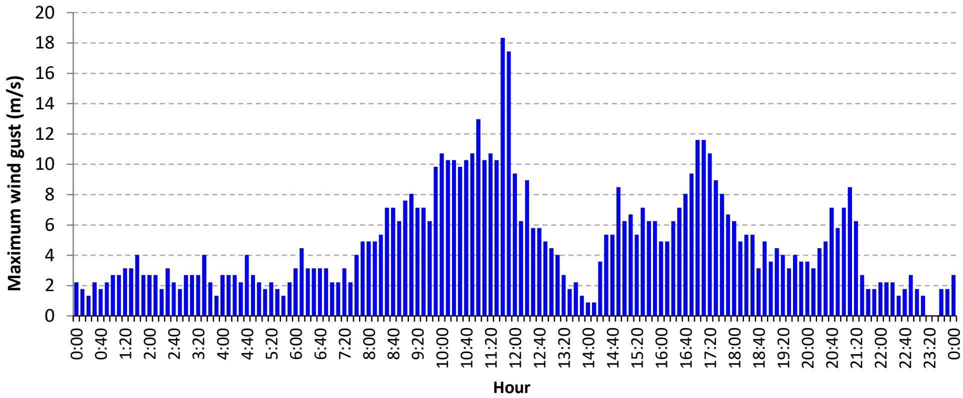

Figure 2-1 10 min records of maximum wind gusts recorded at Xanthi station, located close to the CARE_X area. Data was kindly provided by the Institute of Environmental Research and Sustainable Development of the National Observatory of Athens (NOA) [personal communication with Dr. K. Lagouvardos, PI of METEO https://meteo.gr/index-en.cfm]

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[4] https://meteo.gr/weather_cases.cfm

[5] 41.09041° N - 24.88244° E, altitude: 115m

Thus, this maximum wind gust was considered more as an order-of-magnitude estimate of the wind loading in the area rather than an exact measurement in the city of Xanthi. On the other hand, data from a single station disallows the derivation of a spatial hazard model. For this reason, the preconfigured “Klaus” windstorm event from the CDS database was re-examined as the hazard scenario, upon considering that its footprint in the CARE_X region shows a comparable wind loading magnitude with the actual measurement from the nearby station. A zoomed footprint area of 131 km^2 (compared to 2150 km2 in the first phase) was considered for the second-phase analysis (Figure 2.3).

Figure 2-2 Impact of the November, 4 2023 windstorm event (Local Event 3 in Table 2-1) in the city of Xanthi:

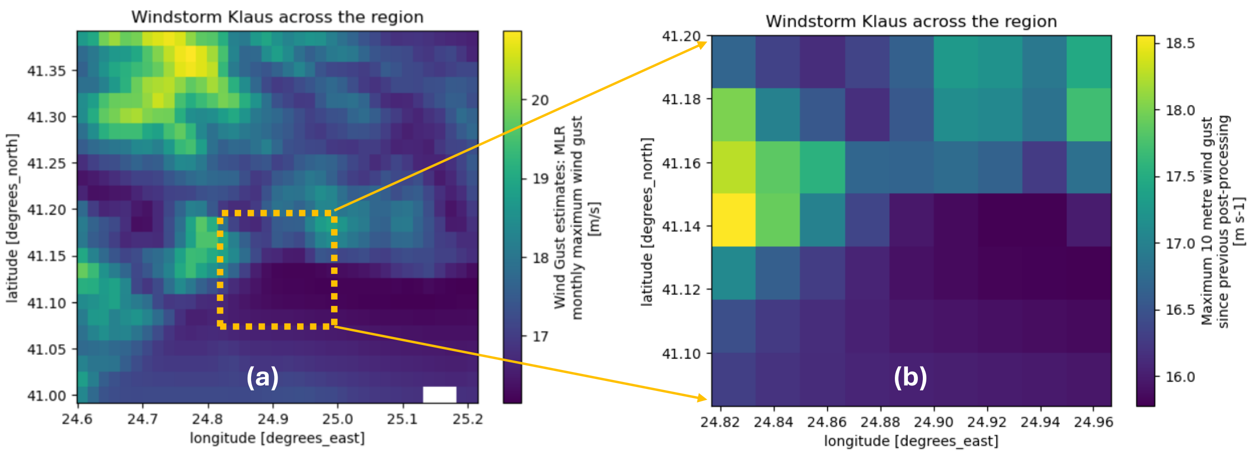

Figure 2-3 The CDS preconfigured “Klaus” windstorm footprint re-examined: (a) Area considered in the 1st phase of the CARE_X project (b) Zoomed footprint elaborated in the 2nd phase.

2.3.1.2 Risk assessment

Local exposure data were collected to update the risk assessment for the CARE_X project area regarding wind loading. For the municipality area of Xanthi, the percentage distribution of building construction materials based on the 2021 data inventory was retrieved from the Hellenic Statistical Authority - ELSTAT[6]. Six categories of building construction materials were specified in the above inventory, referring to (Figure 2.4) Reinforced

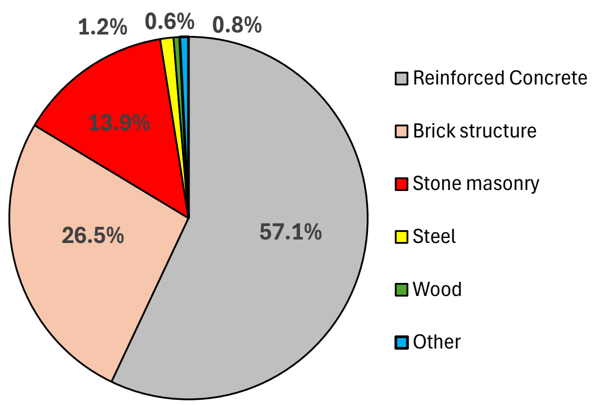

Figure 2-4 Percentage distribution of building construction materials in the City of Xanthi based on the 2021 data inventory from ELSTAT

Concrete (57.1%), Brick Structure (26.5%), Stone Masonry (13.9%), Steel (1.2%), Wood (0.6%) and Other (0.8%). A rough correlation was first performed between the above categories and those included in the CLIMAAX workflow (i.e. "weakest outbuilding", "outbuilding", "strong outbuilding", "weak brick structure", "strong brick structure" and "concrete building") to define a vulnerability curve for each true element at risk in the CARE_X area. Another observational-based adaptation of the vulnerability curves per element at risk was attempted by tentatively shifting the CLIMAAX vulnerability curves to the left by 20 m/s to model higher vulnerability for the "weakest outbuilding" and the "outbuilding" type (Figure 2.5). The above consideration may be relevant in the sense that "outbuilding" damages were observed due to the strong wind events in Xanthi, with gust intensity (also shown in Figure 2.5 with a shaded area) much lower than the threshold, which inflicts damage in the original CLIMAAX curves. The latter were obtained from much stronger wind events such as cyclones and tornados. The common shift of the vulnerability curves for all the building types, including strong brick and concrete buildings, does not affect the overall performance of the region, as the magnitude of the locally measured wind gusts is not enough to trigger damage in these categories.

The vulnerability curves at the level of land cover use were then derived by introducing the local percentages of the corresponding building construction material in the he LUISA damage curves. At the end, the modified LUISA damage curves per land-use type were shifted to lower wind speeds than the original CLIMAAX curves (Figure 2.6).

In summary, the advancements of the second-stage regionalized analysis of wind hazard and risk for the CARE_X project area over the first-stage elaboration are reported in Table 2.2. The CLIMAAX risk assessment workflow was implemented to derive the spatial distribution of the structural damage (in € / m^2) and the relative structural damage in (%) shown in Figure 2.7a and 2.7b, respectively, by also considering the actual GDP/capita for the city of Xanthi.

6 https://www.statistics.gr/en/home/

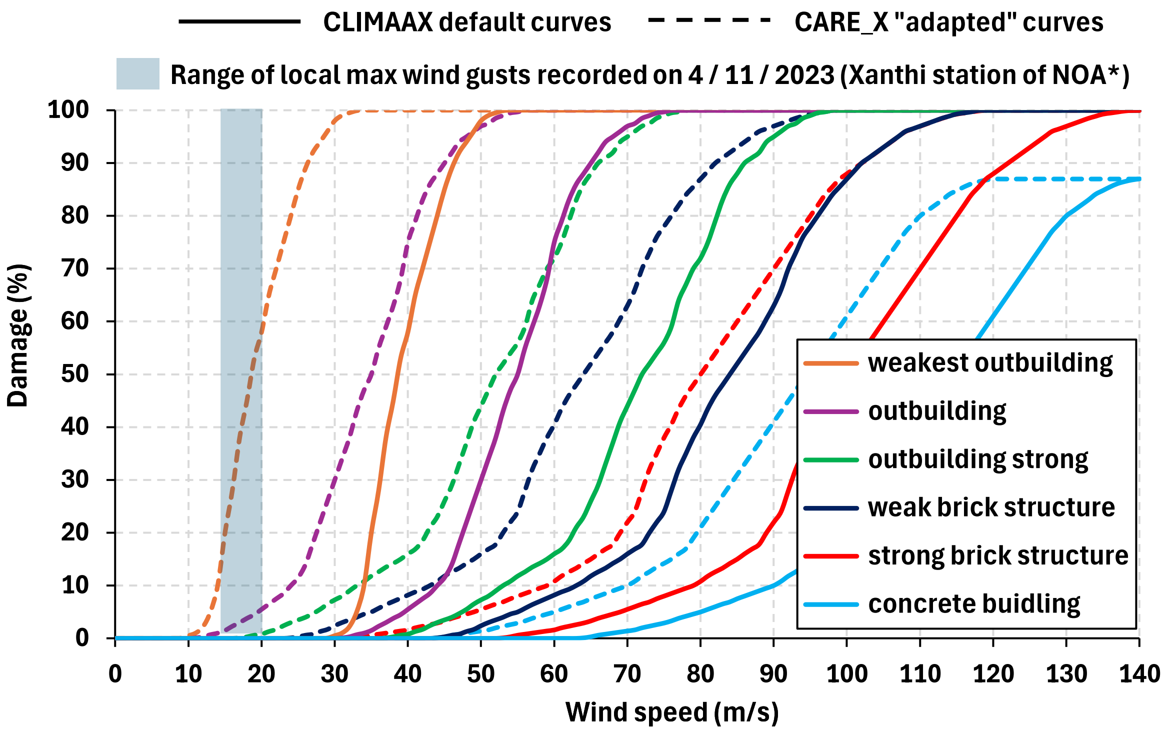

Figure 2-5 Tentative adaptation (dashed lines) of the CLIMAAX windstorm vulnerability curves (solid lines) shifted by 20 m/s to the left (i.e. larger damage for the same wind gust) based on the observed impact of the November, 4, 2023 event induced by the recorded wind gusts in the CARE_X area (shown in the graph with a shaded area). Plots refer to each type of element at risk.

Wind impacts are expected to concentrate in urban and semi-urban areas of medium to high density. Given the assumptions required at multiple stages of the analysis, the spatial pattern shown in Figure 2.7 should not be treated as a fully validated, implementation-ready risk scenario. Instead, it supports the need for more robust local analyses, enabled by denser wind monitoring and systematic post-event field observations of structural and non-structural damage in the CARE_X area.

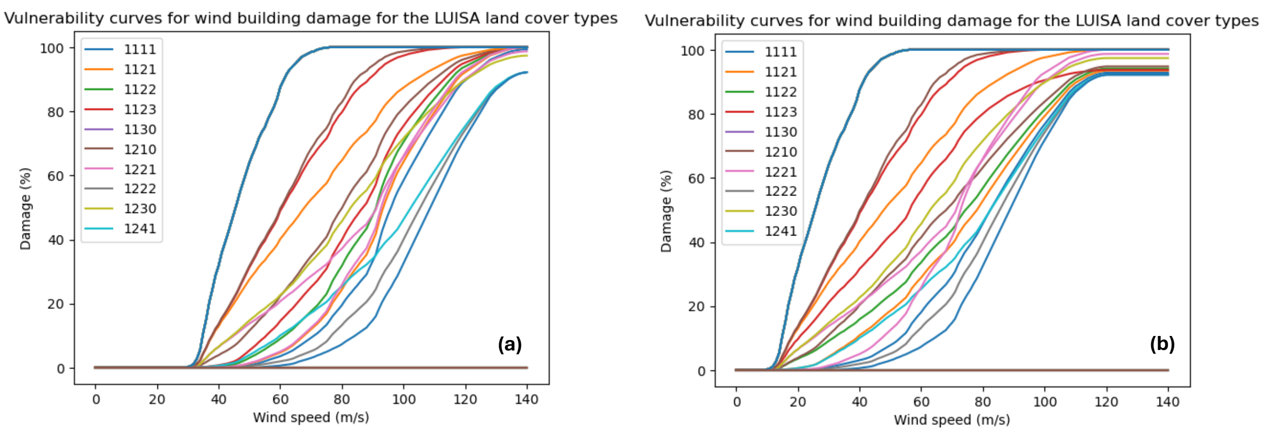

Figure 2-6 Tentative adaptation (right plot) of the CLIMAAX windstorm original vulnerability curves (left plot) in terms of land use cover types.

Table 2-2 Summary of regionalized advancements considered in the 2nd stage of risk analysis compared to the 1st stage elaboration for the CARE_X project area against wind hazard.

CARE_X project	*Hazard data*	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
First phase	*"Klaus" windstorm footprint*	*Default vulnerability curves - CLIMAAX windstorm workflow*	*LUISA map with default correlations between structural type of elements at risk and land use cover type*	*Structural damage (€/m^2)*
Second phase	*"Klaus" windstorm footprint in conjunction with local wind data*	*Tentatively adapted vulnerability curves based on observed impact*	*LUISA map with updated correlations between structural types of elements at risk and land use cover type*	*Relative structural damage (%)*

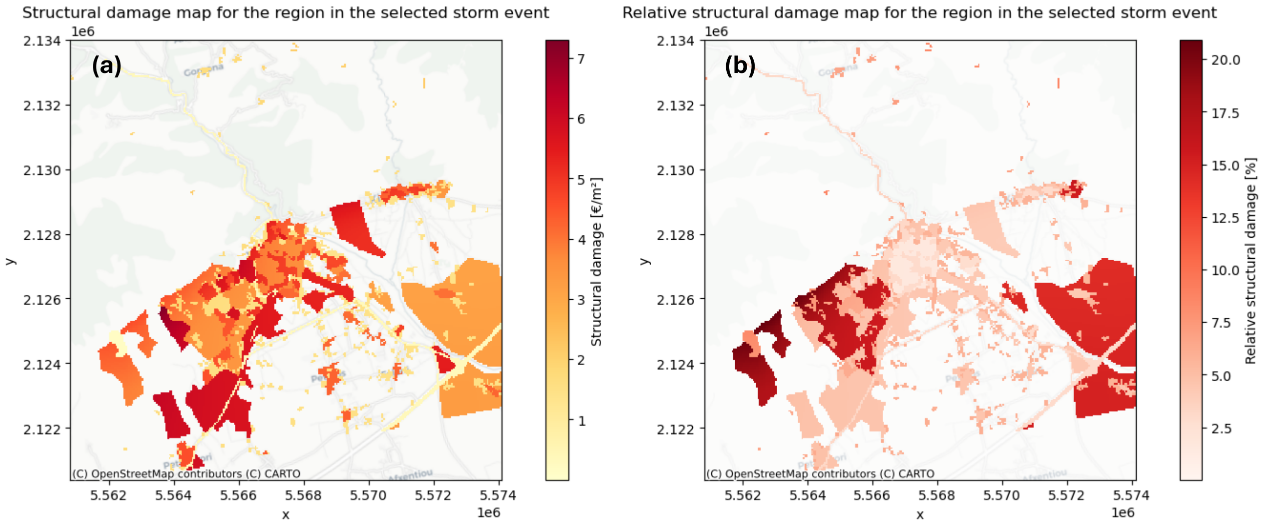

Figure 2-7 Second phase CLIMAAX risk assessment analysis results for the localized wind hazard and vulnerability considerations in the CARE_X project area in terms of (a) Structural damage (in € / m^2) and (b) Relative structural damage (in %)

2.3.2 Hazard #2 Heatwaves - finetuning to local context

Building on insights from the heatwave workflow in the CLIMAAX CRA toolbox, the second phase aimed to expand the hazard and risk assessment by leveraging higher-resolution data and implementing a locally developed methodology. Specifically, it explored the impact of climate change on heatwave hazard, assessed heat-related health risks, and identified the areas of highest risk for both the present and future up to 2100. In this phase, the impact of climate change is assessed using the latest scenarios developed within the framework of the Sixth Phase of the Coupled Model Intercomparison Project (CMIP6), namely SSP2-4.5 and SSP5-8.5.

All analyses were based on the CLIMADAT-GRiD dataset for Greece (Varotsos et al., 2025), which provides daily gridded air temperature data (mean, maximum, and minimum) at a spatial resolution of 1 × 1 km, derived from quality-controlled and homogenized observations from 122 meteorological stations across Greece. For the purposes of this workflow, the analysis focused on the REMTh prefecture, with particular emphasis on the Regional Unit and Municipality of Xanthi. The boundaries used to extract the air temperature data for all regions under study were provided by the Hellenic Cadastral Organisation through the national geospatial portal[7].

Future daily temperature profiles were based on projected monthly temperature changes for REMTh, derived from the multi-model CMIP6 (Coupled Model Intercomparison Project, Phase 6) collection available through the World Bank Climate Change Knowledge Portal[8] (CCKP). Projections were obtained for twenty-year intervals (2020-2039, 2040-2059, 2060-2079, 2080-2099) under the SSP2-4.5 and SSP5-8.5 climate change scenarios. SSP2-4.5 represents a medium radiative forcing pathway (4.5 W/m2), in which greenhouse gas emissions remain approximately at current levels before gradually declining after mid-century. In contrast, SSP5-8.5 presents a high forcing pathway (8.5 W/m²), characterized by intensified fossil fuel use, with increasingly integrated global markets driving technological progress and innovation. Following a commonly applied methodology (Kouis et al., 2021), future temperature profiles were calculated by adding the mean monthly projected temperature change to the daily gridded air temperature profile of the corresponding month of the baseline years 1999-2018.

Additionally, daily mortality data from cardiovascular diseases (CVD) (ICD-10 code: I00-I99) for the general population and the elderly were obtained from the Hellenic Statistical Authority (ELSTAT) for the time-period 1999-2018. Mortality data were provided by ELSTAT at the Regional Unit level. Therefore, mortality was available for the Regional Unit of Xanthi and for the REMTh as the sum of the individual units. It should be noted that since this workflow focuses on heat effects, analyses were restricted to the warm season (May to September) of the year. All statistical analyses and visualization were performed using R software version 4.4.2. Table 2-3 summarizes the datasets used for the project.

2.3.2.1 Hazard assessment

In the first phase of the project, within the framework of hazard assessment, the occurrence of heatwaves for both present and future periods was quantified under the RCP4.5 and RCP8.5 climate change scenarios. This was achieved by estimating six heat-related indicators, including the annual number of days and the maximum number of consecutive days per year with daily maximum temperatures exceeding the 95th percentile of the summer baseline period.

In this phase, the analysis was extended to examine the temporal evolution of these two indicators for the 1999–2099 period under the SSP2-4.5 and SSP5-8.5 scenarios, using a locally defined temperature threshold rather than the conventional 95th percentile. This threshold marks the minimum mortality point, beyond which the risk progressively increases, and is influenced by climatic, socioeconomic, and demographic factors (Gasparrini et al., 2015). For this purpose, mean daily temperature was used instead of the daily maximum, as it provides a more representative measure of overall heat stress throughout the day and is easier for both the general public and stakeholders to interpret.

Given the small number of daily deaths in the Regional Unit of Xanthi and the similarity of its climatic and socioeconomic characteristics with the rest of the REMTh, the threshold was set for the entire REMTh to ensure sufficient statistical power. A standard over-dispersed Poisson time-series regression model coupled with a distributed lag nonlinear model (DLNM) was applied, with

[7] http://geodata.gov.gr/

[8] https://climateknowledgeportal.worldbank.org/

covariates accounting for long-term and seasonal trends. In line with the statistical approach described elsewhere (Armstrong et al., 2011; Tsangari et al., 2016), a linear-threshold function was used to describe the exposure-response relationship, as it is easy to interpret and communicate to decision-makers and stakeholders. The lag period was extended up to 10 days to capture delayed heat effects and potential short-term mortality displacement. Separate models were fitted for the general population and the elderly (aged ≥65 years).

Table 2-3 Data overview for the CARE_X project implementation of the CLIMAAX heatwave workflow

	Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Hazard assessment	*CLIMADAT-GRid data, CCKP data*			*Estimation of two heat indicators for the period 1999-2099, under the SSP2-4.5 and SSP5-8.5 scenarios*
Risk assessment		*CVD mortality data*	*CLIMADAT-GRid data*	*Relative Risk of heat-related CVD mortality for the period 1999-2018*
Risk assessment		*CVD mortality data*	*CLIMADAT-GRid data*	*Heat-related mortality Burden for the period 1999-2099, under the SSP2-4.5 and SSP5-8.5 scenarios*
Risk assessment		*CVD mortality data*	*CLIMADAT-GRid data, CCKP data*	*Spatial risk maps of heat-related mortality for the period 1999-2099, under the SSP2-4.5 and SSP5-8.5 scenarios*

The threshold was determined by testing a range of values derived from visual inspection of the exposure-response curve, in 0.1 °C increments, to identify the value that minimized residual variance and the Akaike Information Criterion (AIC) for over-dispersed data (Tsangari et al., 2016). The temperature threshold, on which both criteria agreed, was almost similar for the general population and the elderly, at 20.4 °C and 20.3 °C respectively, corresponding to the 75th percentile of the all-year temperature distribution (Table 2-4). This finding is consistent with observations from other Mediterranean regions, such as Spain and Italy (Gasparrini et al., 2015).

Figure 2-8 displays the annual number of days with daily mean temperatures exceeding the local temperature threshold of 20.4 °C for the baseline period (1999-2018) and up to 2099, under the two examined climate change scenarios. A similar figure for the number of consecutive days per year with daily mean temperatures above the local temperature threshold is included in the supplementary material (Figure S1). In line with the results of the first phase of the project, both figures show that the frequency of heat days is projected to increase until the end of the century under both scenarios. As expected, the impact of climate change is more pronounced under the high-emission SSP5-8.5 scenario than under the more moderate SSP2-4-5, particularly after the middle of the century.

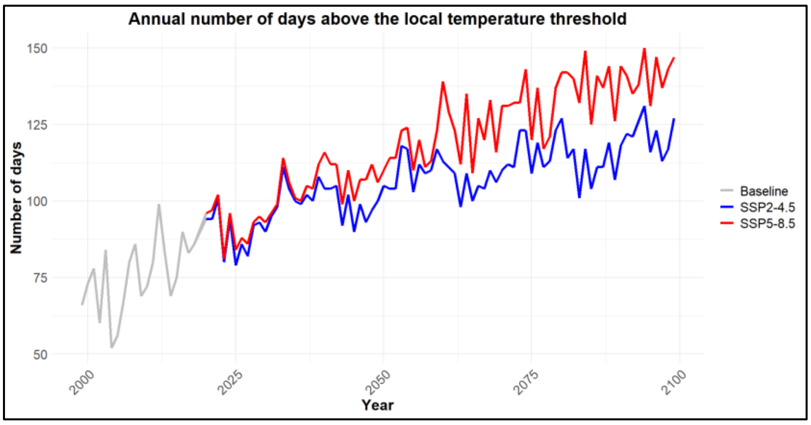

Figure 2-8 The annual number of days with mean daily temperature above the local temperature threshold for the Municipality of Xanthi

2.3.2.2 Risk assessment

The main goal of the heatwave risk assessment during the second phase of the project was to estimate the relative risk of CVD mortality associated with exposure to temperatures above the local threshold, quantify the heat-related mortality burden, and identify the most affected areas within the City of Xanthi. For these purposes, the same data and the models described in the Hazard Assessment section above were used.

At first, the cumulative (over all lag period of 10 days) risks of mortality (RR) associated with a 1 °C increase in mean temperature above the local threshold were estimated for both the general population and the elderly during the baseline period (1999-2018). Additionally, the lag-specific RR of mortality for a 1 °C increase above the local threshold was examined for each day of the lag period to assess how the effect of heat evolved over time.

As shown in Table 2-4, a 5.8% increase (95% CI: 4.3%-7.2%) in CVD mortality risk was observed for each additional degree increase in daily mean temperature above the local threshold for the general population. Similar results were observed among the elderly, reflecting the relatively high proportion of the population aged 65 years and older in REMTh. According to the lag-specific analyses (Table S1), the highest relative risks were observed on the same day (lag 0) and the following day (lag 1) of the exposure, then sharply decreased but remained above 1 up to five days (lag 5). This pattern confirms the immediate impact of heat on cardiovascular mortality and underscores the need for sustained warning systems on the day following an extremely hot day or a heatwave.

Table 2-4 The local temperature threshold, corresponding percentile and Relative Risk (RR) of CVD mortality in REMTh for a 1 °C increase in mean temperature above the temperature threshold.

	Temperature Threshold (°C)	*Temperature Threshold Percentile*	*RR (CI)*
Total Population	*20.4*	*75th*	*1.058 (1.043-1.072)*
The Elderly (≥65 years)	*20.3*	*75th*	*1.062 (1.047-1.077)*

A sensitivity analysis was conducted using different maximum lag days for the temperature-mortality association, while controlling for relative humidity (data obtained from the Hellenic Statistical Authority for selected representative meteorological stations in REMTh), confirming that all results were robust.

Then, consistent with Heaviside et al. (2016), a health impact assessment was conducted to estimate the heat-related attributable number of deaths (AN) and fraction of mortality (AF) for both the total population and the elderly in the REMTh region, as well as separately for the Regional Unit of Xanthi, using mean daily temperature data, daily CVD mortality, and population-specific relative risks previously estimated for REMTh. Mortality rates (deaths per 100,000 population) were calculated using 2011 census population data, corresponding to the midpoint of the baseline period, were obtained from ELSTAT were performed for both present and future periods up to 2099 under

SSP2-4.5 and SSP5-8.5, keeping baseline parameters except temperature (i.e. relative risks, mortality rates, total deaths, and population) constant. Further details of the health impact assessment are provided in the supplementary material.

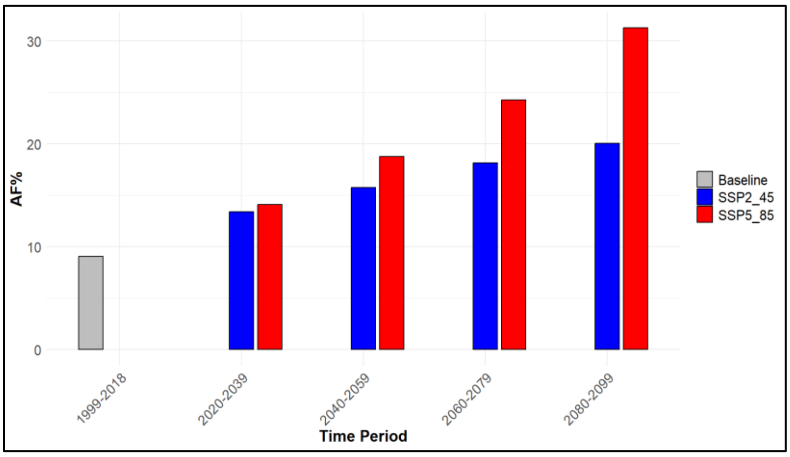

Figure 2-9 The attributable fraction of mortality due to exposure to temperatures higher than the temperature threshold in the Regional Unit of Xanthi

According to Figure 2-9 and results presented in Table S2, the fraction of CVD mortality attributed to temperatures above the threshold is projected to increase throughout the 21st century in both REMTh and the Regional Unit of Xanthi. Under SSP2-4.5, AF rises from around 9-11% at baseline period to approximately 21-22% by 2080-2099, while under SSP5-8.5 it is expected to almost triple, reaching 31-34% till the end of the century. Similar trends were observed for the attributable number of deaths and mortality rates, highlighting the growing public health burden associated with heat and the need for strengthened warning systems and targeted protection of vulnerable populations, particularly the elderly. It should be noted that these estimates do not account for potential population changes, although the general ageing trend is likely to further increase heat-related impacts. Additionally, they do not consider potential adaptation to heat over time, although evidence suggests maladaptation to high temperatures in Greece (Psistaki et al., 2024).

Finally, to identify the most vulnerable areas within the Municipality of Xanthi, spatial risk maps of heat-related mortality were generated for both the general population and the elderly using mean daily gridded temperature data. Based on the estimated change in CVD mortality risk per 1 °C increase in daily temperature above the local threshold, the daily relative risk (RR) of mortality was calculated for each grid cell during the warm season (May-September). These values were then averaged across all season days and years to produce baseline risk maps (1999–2018), which represent the long-term average heat-related mortality risk. The same approach was applied to future projections, producing maps for successive 20-year periods from 2020 to 2099 under SSP2-4.5 and SSP5-8.5, illustrating how the spatial distribution of heat-related mortality risk is expected to evolve over time.

Figure 2-10, along with Figures S2 and S3, illustrates the spatial distribution of relative risk (RR) of CVD mortality for the general population and the elderly across the Municipality of Xanthi during the baseline and future periods, under SSP2-4.5 and SSP5-8.5 scenarios, combined with information on the location of critical infrastructure, including hospitals, nursing homes, and elderly care facilities, used in the previous phase of the project. As shown, the city of Xanthi, where critical infrastructure is concentrated, corresponds to areas of higher risk, which is alarming considering that the highest proportion of the population lives there. These findings are consistent with the results of the first phase of the project, confirming that the city of Xanthi is at a significantly higher risk than the

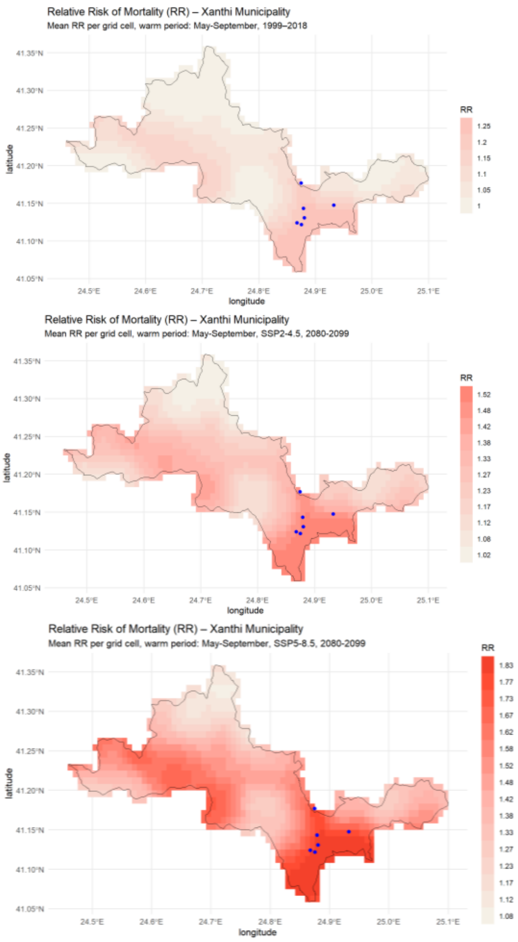

Figure 2-10 Spatial risk maps of heat-related CVD mortality for the general population in the Municipality of Xanthi for the baseline period (1999-2020) and the period 2080-2099 under the SSP2-4.5 and SSP5-8.5 scenarios.

surrounding areas. The maps also present a clear temporal increase in mortality risk, with progressively higher values toward the end of the century, particularly under SSP5-8.5.

Overall, the results of the hazard and risk assessment highlight the critical importance and urgent need for local authorities and stakeholders to develop and implement targeted prevention and adaptation measures to protect the population, particularly the most vulnerable groups, such as the elderly, from the impacts of heatwaves and extremely high temperatures.

2.3.3 Hazard #3 Fluvial Flooding - finetuning to local context

In the 2nd phase of the project, we assessed the flood hazard and risk in the city of Xanthi from the Kosynthos River under different return periods for extreme events and climatic scenarios. The Kosynthos River flows through the town and passes close to many rural and agricultural areas before discharging into the Vistonis Lagoon in the south-east of the Regional Unit of Xanthi (Figure 2-11) (Ntislidou et al., 2012). The socio-economic effects of such flooding examined in greater detail, including its impact on critical infrastructure and the population. To this end, we utilised high-resolution digital elevation model (DEM) data for the region to downscale the initial Joint Research Centre (JRC) flood maps and updated GDP per capita data to determine the realistic damage costs to buildings and infrastructure (See Table 2-5).

Table 2-5 Data overview workflow #3 Fluvial Flooding

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
JRC high-resolution flood hazard maps for Europe in a historical climate	*JRC vulnerability-damage curves*	*LUISA Base Map*	*Flood damage maps expressed in economic value for extreme events with different return periods*
Digital Elevation Model (DEM) of Xanthi from State land service of Xanthi		*European Commission's JRC population distribution maps*	*Gross Domestic Product (GDP) per capita 2022 from the Hellenic Statistical Authority (ELSTAT)*
River discharges (E-HYPEcatch, GCM, RCM models)			

2.3.3.1 Hazard assessment

To assess the fluvial flood hazard in Xanthi, we used the JRC flood maps for various extreme events with different return periods (10, 50, 100, 200 and 500 years). These maps were downscaled using a high-resolution DEM of the region and statistical methods (bilinear interpolation). This process resulted in the production of higher-resolution flood maps (from 90m to 5m), enabling us to examine the regions affected by such events in more detail (Figures 2-12, S4). The maximum inundation depths were found in the upper part of the city. These depths ranged from 12.61 m to 13.56 m, for return periods of 10 to 500 years, respectively. Lower but still significant values were observed inside the urban web and in the southern part of Xanthi. As mentioned in our initial investigation in Phase 1, we did not use the Aqueduct flood maps due to the coarse spatial resolution of the Aqueduct data (30 arc seconds) and the small size of the Kosynthos riverbed.

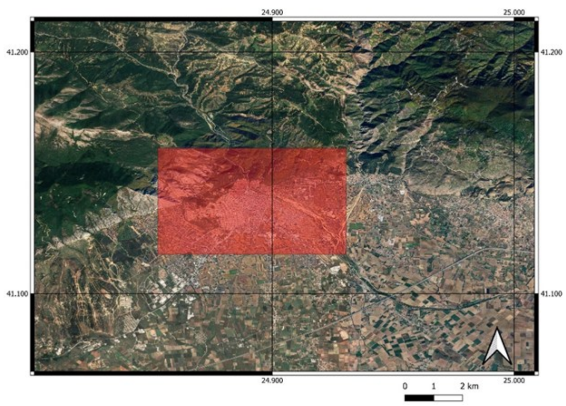

Figure 2-11 Map of the study area, including the city of Xanthi and its suburban area (red rectangle)

Figure 2-12 Inundation depth of Kosynthos River for 10, 50 and 100 extreme event return periods

In addition, we utilised daily timeseries of river discharges for a historical period (1991-2005), monthly means of catchment-level river discharges of different time periods (1971-2000, 2011-2040, 2041-2070, 2071-2100) and extreme river discharges data for different return periods (10 and 50 years) from various models (E-HYPEcatch, GCM, RCM) and their relative changes for different climate models, climate scenarios and timeframes of our catchment, to study the possible change in extremes due to climate change (Figures S5-S8). Our results indicated a significant increase in extreme river discharge between the periods 2011–2040 and 2071–2100, which is expected to result in more flooding events across all RCP scenarios (Figure S5).

2.3.3.2 Risk assessment

A fluvial flood risk assessment was conducted for the city of Xanthi at different return periods (10, 50, 100, 200 and 500 years) and for RCP8.5 in 2050. For this purpose, in Phase 2, the JRC land-use dataset with a spatial resolution of 50m was utilised for Xanthi, in conjunction with downscaled high-resolution JRC flood maps and JRC vulnerability curves. Additionally, the LUISA land cover map with a higher spatial resolution (50 m) was employed to depict the various land cover types in the region, alongside the most recent available Gross Domestic Product per capita data (2022) from the

Hellenic Statistical Authority (ELSTAT) for our study region (11,095 euros). To gain a spatial understanding of which locations could be most economically affected by different return periods, we produced flood maps alongside economic damage maps for each scenario (Figures 2-13, S9-S12).

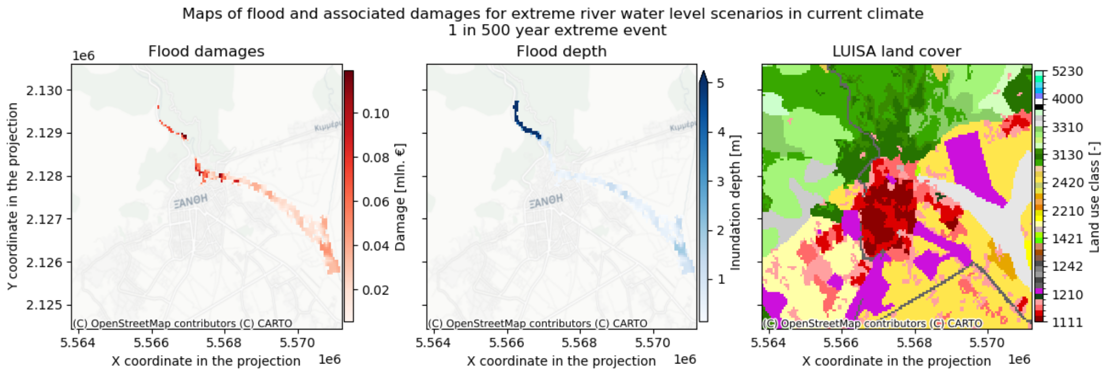

Figure 2-13 Flood and associated damages maps over Xanthi for RCP 8.5 and extreme event return period of 500 years

Using the updated data produced different results across all return periods compared to those from the 1st phase. Specifically, the associated damage to buildings and infrastructure was 3 times less than was initially calculated in Phase 1. This was due to the use of the higher-resolution LUISA map (50 m instead of 100 m) and the updated GDP data. As before, the maximum economic damages in Xanthi are observed for the extreme event return period of 500 years, as the inundation depth covers a broader area of the urban web, without neglecting the effects of flood events at other return periods. Apart from the economic damage on buildings and infrastructure, the expected annual exposed population (the average number of people expected to be exposed in any given year) due to fluvial floodings is also calculated, using the European Commission's JRC population distribution maps for different return periods (10, 50, 100 and 500 years) (Figures S13-S14). Our investigation showed that for an inundation depth greater than 1 meter, the expected population displacement would be 4 people per year, reaching a maximum of 60 people for a 500-year return period event, affecting the population particularly in the south-eastern part of the city. (Figure 2-14).

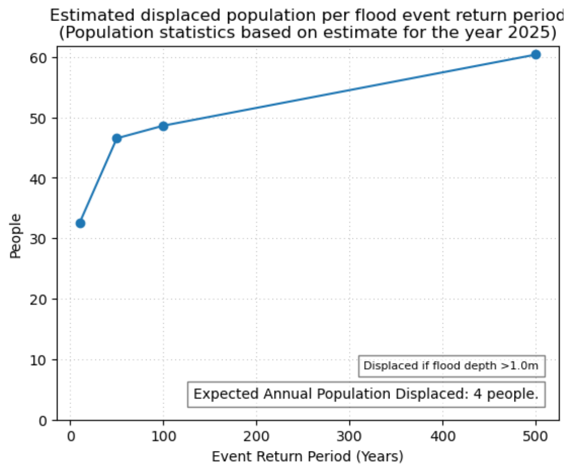

Figure 2-14 Estimated displaced population per different flood event return period

2.3.4 Hazard # 4 Wildfires - finetuning to local context

Before examining the results produced with the updated dataset used to refine the FWI Risk Assessment model, it is important to note that the CLIMAAX project has also developed the FWI response surface model, climate projections and affected population.

This additional modelling framework is essential for our analysis in the city of Xanthi, as it provides a more comprehensive view of how fire-weather risk may evolve under changing climatic conditions and how these changes may affect the local population. In essence, the model is built on the concept of response surfaces, a statistical approach that links the Fire Weather Index (FWI) to combined shifts in mean temperature and precipitation. Using a set of "perturbed climate simulations" (El Garroussi et al., 2024) that explore a wide range of plausible modifications to the regional climate, the model estimates both the probability that the FWI exceeds critical thresholds and the potential changes in the length of the fire season. These calculations generate a two-dimensional surface that describes how the fire-weather hazard responds to different climatic conditions. When this surface is paired with future climate projections from regional climate models, it becomes possible to produce scenario-based assessments of future fire risk. Applying this methodology to Xanthi is particularly relevant, given the region's position in the eastern Mediterranean—an area known for heightened sensitivity to warming, prolonged dry periods, and intensified seasonal extremes. By combining the response surface with projected changes in temperature and precipitation for the coming decades, we can obtain a clearer picture of how meteorological fire danger may evolve locally. Furthermore, integrating spatial population data enables us to quantify the number of people potentially exposed to elevated fire-weather risk, offering valuable insights for regional adaptation planning and civil protection strategies.

2.3.4.1 Hazard assessment

The model builds upon the historical climate analysis described in the CLIMAAX FWI hazard-assessment workflow, where regional Fire Weather Index (FWI) time series are derived from both perturbed and baseline simulations (see supplementary Table S3). This step provides a robust representation of current fire-weather variability, forming the foundation for the subsequent response-surface modelling framework. The results produced through these processes are presented in Figure 2-15.

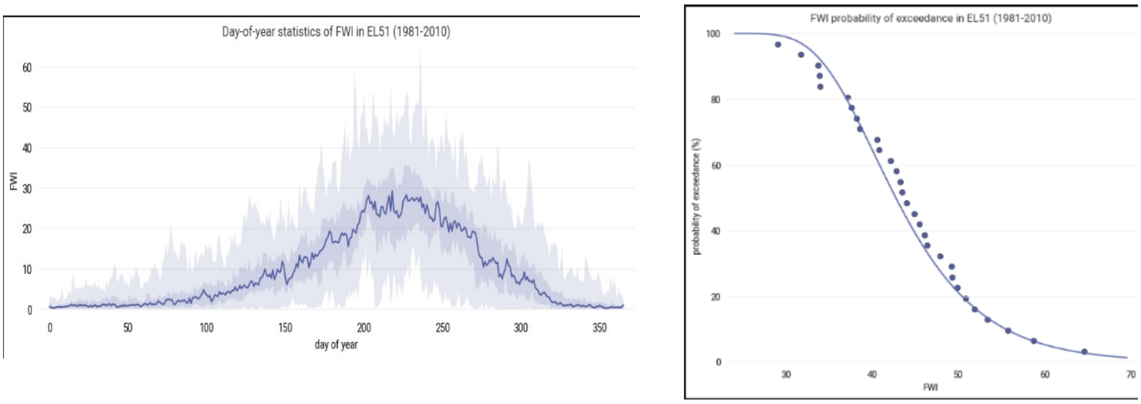

Figure 2-15 Day-of-year statistics of the Fire Weather Index (FWI) in region EL51 for the period 1981–2010 (left) and FWI probability of exceedance for the same region and period (right).

The model employs the response surface methodology to quantify how fire-weather hazard responds to combined shifts in temperature and precipitation. By fitting a statistical surface to the probability that the FWI exceeds critical thresholds across a range of climate perturbations, the model captures the relationship between changing climate conditions and wildfire danger in a continuous and interpretable way. As part of this process, we tested several possible FWI thresholds and selected the one that best reflects the fire-weather characteristics of our study area. The results of this modelling step are illustrated in Figure 2-16.

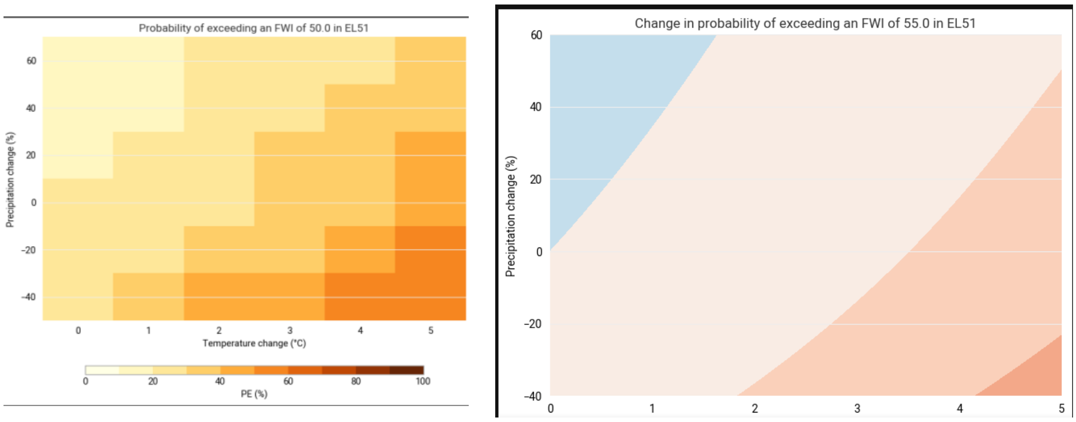

Figure 2-16 Exceedance probability for a threshold of 50 (left) and change in exceedance probability for a threshold of 55 in EL51 (right).

In the final stage of the analysis, the model integrates future climate projections to estimate how fire-weather hazard may evolve under changing temperature and precipitation regimes. By applying the previously constructed response surface to regional climate model outputs, we translate projected climatic shifts into quantitative estimates of future FWI exceedance probabilities and fire-season characteristics. This step enables a forward-looking assessment of wildfire danger, grounded in both physical projections and the locally calibrated threshold selected for our study area (see Figure 2-17).

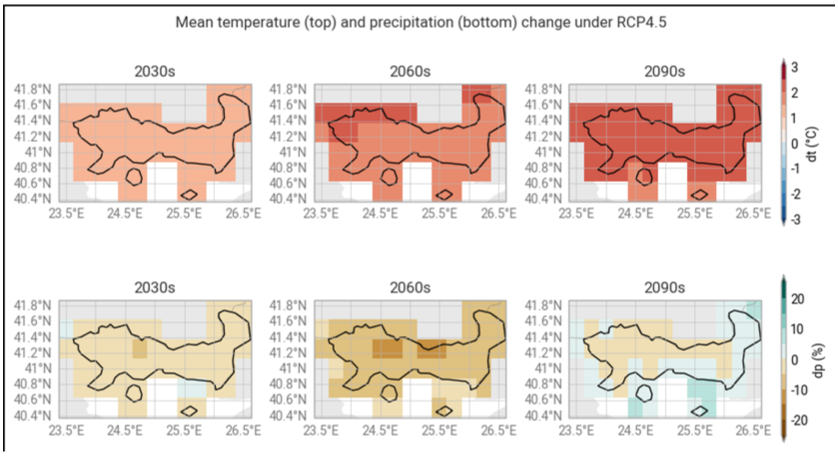

Figure 2-17 Mean Temperature (top) and precipitation(bottom) change under RCP4.5 (2030-2090)

2.3.4.2 Risk assessment

In this stage, the model extends the hazard assessment by estimating the population potentially exposed to elevated fire-weather risk. By overlaying spatial population data with areas where FWI thresholds are exceeded, the model provides a quantitative view of human exposure under both current and projected climate conditions. As part of our tests using different Shared Socioeconomic Pathways (SSPs), see also supplementary Table S4, we observed that the scenario SSP5 has the most significant impact on population exposure, highlighting the influence of rapid population growth and high urbanization on future fire risk. This approach allows for a better understanding of potential societal impacts and supports targeted adaptation and civil protection strategies. The results of this population-based risk assessment are presented in Figure 2-18 and 2-19.

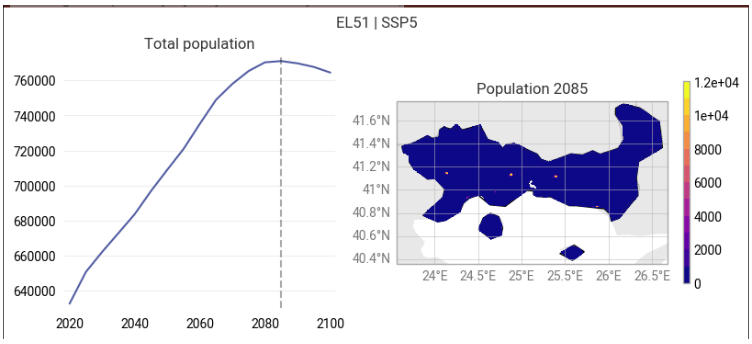

Figure 2-18 Total population in EL51 under the SSP5 scenario

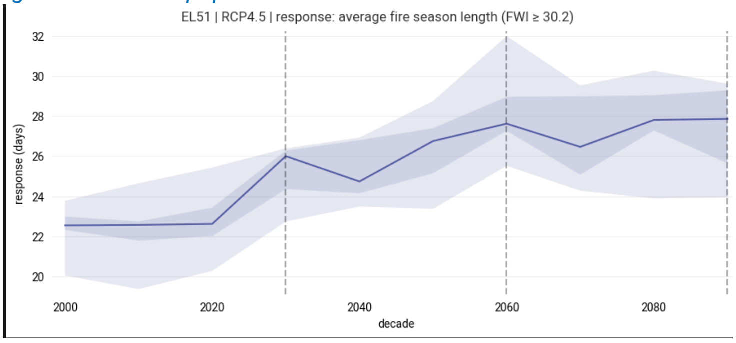

Figure 2-19 Total population in EL51 under the SSP5 scenario

Refining wildfire risk mapping using Sentinel-based fuel and bare-ground data

Fuel-load and bare-ground mapping is a key input for regional wildfire risk assessment because vegetation cover changes rapidly and standard land-cover products (for example, CORINE) can misrepresent current fuels (see supplementary Table S5). To obtain an updated, locally relevant fuel layer, we applied an object-based image analysis workflow using Sentinel-2 imagery in eCognition. Image objects were generated by segmentation (scale 25, shape 0.1, compactness 0.5). We computed NDVI from the red and near-infrared bands NDVI = (NIR – RED) / (NIR + RED) and used a locally calibrated NDVI threshold, supported by training samples from reference orthophotography, to separate vegetation from non-vegetation. Each group was then subdivided using a Nearest Neighbour classifier (distance-to-training approach), allowing class membership estimation and improved handling of mixed or ambiguous pixels. The final classes included: forest; shrub and grass; low vegetation; impervious surfaces (urban areas, roads, industrial sites); bare ground; and water. A majority filter was applied to reduce isolated misclassifications. The classification achieved 82.42% overall accuracy; producer's accuracy (omission error) ranged from 0 to 0.36, while user's accuracy (commission error), which is particularly relevant for practical applications, was used to evaluate reliability of mapped classes.

The classified raster was converted to NetCDF to ensure compatibility with Fire Weather Index and other climate layers and to support consistent overlay analyses across spatial and temporal dimensions while preserving georeferencing. The resulting wildfire risk map did not differ substantially from the baseline map based on ESA-CCI land cover. This convergence is plausible because both datasets capture the main land-cover and fuel-structure patterns that drive regional-scale risk, while the dominant drivers of wildfire danger gradients remain topography and fire-weather inputs; therefore, the higher spatial resolution of Sentinel-2 does not necessarily yield materially different risk patterns at the municipal-to-regional scale (see Figure 2-20).

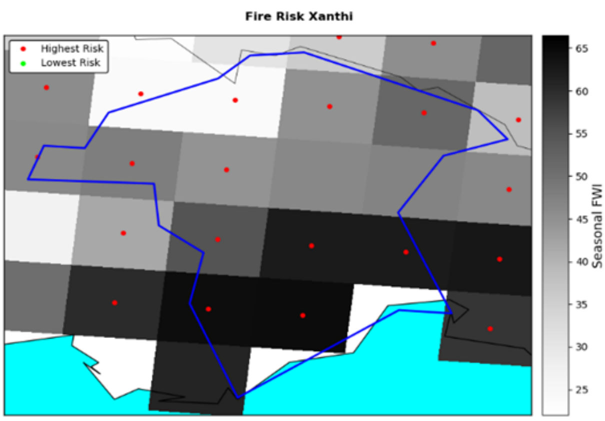

Figure 2-20 Fire risk

2.4 Key Risk Assessment Findings

The Key Risk Assessment step evaluates the Phase 2 risk analysis outputs by jointly considering (i) severity of impacts, (ii) urgency of action given future risk evolution and hazard dynamics, and (iii) resilience capacity of the local system to anticipate, respond, and recover. The evaluation was conducted using the CLIMAAX evaluation logic, with results designed for discussion with decision-makers, experts, and priority groups, and for translation into risk management and adaptation priorities.

2.4.1 Mode of engagement for participation

Risk evaluation in Phase 2 was implemented through an applied engagement process that combined institutional coordination, knowledge transfer, and sector-specific consultation. The municipal Civil Protection Office and technical and infrastructure services were engaged alongside the RiskAC technical team in reviewing intermediate outputs and interpreting implications for local planning. Stakeholder feedback gathered during the structured training and knowledge transfer activities was used to refine the framing of “severity”, “urgency”, and “capacity”, especially the need for decision-oriented outputs, consistent scenario interpretation across hazards, and explicit attention to priority groups and critical assets.

A second participation pathway is planned through the Xanthi Resilience Festival, which is explicitly framed as a mechanism for awareness, participation and public dialogue, thereby enabling broader feedback loops beyond institutional stakeholders and facilitating communication of key risk priorities to community actors and priority groups.

2.4.2 Gather output from Risk Analysis step

Risk evaluation draws on the hazard-specific outputs produced in Section 2.3, prioritising outputs that are comparable across hazards and directly relevant to municipal decision-making. For windstorms, the evaluation uses event-based structural damage outputs (absolute and relative), informed by locally adjusted vulnerability representations and local wind measurements. For heatwaves, the evaluation uses projections of heat-day frequency, relative risk of cardiovascular mortality above the locally derived threshold, and associated spatial patterns and future evolution under SSP pathways.

For fluvial flooding, the evaluation uses downscaled inundation depth maps, associated economic damage mapping using updated GDP per capita, displacement estimates, and evidence of increasing extreme river discharge across future periods and scenarios. For wildfires, the evaluation uses scenario-based Fire Weather Index exceedance probabilities derived through response-surface modelling, projected evolution of fire danger characteristics, population exposure metrics, and refined fuel and bare-ground mapping tests.

2.4.3 Assess Severity

Severity was scored for current and future risk on a four-level scale (limited, moderate, substantial, critical), considering impacts on people, disruption to infrastructure and services, spatial extent, and potential for irreversible or cascading effects. High-consequence cultural heritage assets were treated as severity amplifiers where loss would be irreversible.

Heatwaves (current: substantial; future: critical). Current impacts are municipality-wide and disproportionately affect vulnerable groups, with measurable increases in cardiovascular mortality risk above the local threshold. Future severity becomes critical due to strong projected increases in heat days and health burden, especially under SSP5-8.5, with implications for critical services. **Fluvial flooding (current: substantial; future: substantial to critical for extreme events).** Current severity reflects damaging inundation in urban and peri-urban areas and population displacement potential, with identified hotspots. Future severity remains substantial and can become critical for high-return-period events as extreme discharges increase, raising the likelihood of severe, cascading disruption to mobility, services, and infrastructure. **Wildfires (current: substantial; future: critical).** Current severity derives from ecosystem impacts and threats to settlements, health, and services. Future severity becomes critical as fire-weather danger increases and population exposure may rise under socio-economic pathways; irreversibility for ecosystems and exposed cultural heritage further elevates consequences. **Windstorms (current: moderate; future: moderate).** Current severity is moderate: local impacts and non-negligible damages exist, but assessment confidence is constrained by limited monitoring and event-based assumptions. Future severity remains moderate given the lack of a locally validated climate-change signal for extreme winds in the current setup, although even moderate events can disrupt services and high-consequence assets.

Phase 2 training improved decision-maker understanding of outputs and limitations; continued engagement is needed to ensure consistent interpretation in municipal planning.

2.4.4 Assess Urgency

Urgency was assessed using the four-category scale (no action needed, watching brief, more action needed, immediate action needed), considering near to mid-term changes, the speed of onset, persistence of hazard conditions, and the potential for significant changes from current to future risk.

Heatwaves (immediate action needed). Heatwaves combine a strong future-worsening signal with a slow-onset but persistent seasonal hazard that produces acute impacts during extreme episodes. The projected increase in heat days and associated health risks implies that delayed action increases preventable harm, especially for vulnerable groups, supporting an “immediate action needed” classification. **Fluvial flooding (more action needed)**. Flood events are sudden-onset hazards with the capacity to cause severe disruption when thresholds are exceeded. Phase 2 evidence of increasing extreme discharge across future windows indicates that the risk environment is deteriorating, supporting “more action needed”, particularly for hotspot-based preparedness and targeted infrastructure measures. The urgency is amplified by the need to integrate results into municipal planning cycles for infrastructure maintenance, land-use decisions, and emergency response protocols. **Wildfires (more action needed, approaching immediate for priority zones)**. Wildfires are sudden-onset events conditioned by seasonal and interannual fire weather. The scenario-based modelling indicates worsening fire-weather risk, while the hazard can persist through longer fire seasons and compound with heat and drought conditions. These features support “more action needed”, with “immediate action needed” potentially applying for specific priority zones where exposure and vulnerability are high. **Windstorms (watching brief to more action needed)**. Windstorms are sudden-onset hazards with episodic extremes. Phase 2 highlights local impacts and the need for improved monitoring and validation to strengthen confidence in hazard spatialisation. This supports a “watching brief” classification for long-term climate-change components, combined with “more action needed” for near-term operational readiness, maintenance prioritisation, and protection of vulnerable structures and critical assets.

Stakeholder feedback supports urgency framing by requesting decision-oriented prioritisation and consistent interpretation of uncertainty across hazards, thereby reducing the risk of delayed action due to ambiguity.

2.4.5 Understand Resilience Capacity

Resilience capacity was scored on a four-level scale (low, medium, substantial, high), considering existing measures, institutional capability, resource constraints, and learning capacity. The assessment also accounted for structural constraints relevant to Xanthi, including limited fiscal space and vulnerability drivers that can impede sustained prevention and adaptation. **Heatwaves (medium).** Capacity is supported by existing mechanisms for communication and response and by improved interpretability of heat-health indicators in Phase 2. Nonetheless, reducing future impacts requires sustained outreach, targeted protection of vulnerable groups, and urban heat mitigation that may exceed current resources. **Fluvial flooding (medium).** Preparedness and response are supported by existing planning structures, strengthened by Phase 2 hotspot mapping and displacement-relevant indicators. Constraints persist for implementing structural measures and sustaining risk-informed investment cycles under limited fiscal resources. **Wildfires (medium).** Seasonal preparedness and multi-agency operational structures provide a baseline capacity, and Phase 2 improves evidence for prevention planning and exposure analysis. Capacity limitations remain due to the need for sustained coordination, resource-intensive fuel management, and continuous community engagement. **Windstorms (medium).** Near-term response capacity is in place through civil protection practices and municipal services, but limited monitoring density and post-event validation constrain robust risk characterization and, therefore, the evidence base for structural risk reduction.

Across hazards, Phase 2 capacity-building activities strengthened human and organizational capacity by improving technical literacy and shared understanding of workflows and outputs, supporting more effective uptake into planning.

2.4.6 Decide on Risk Priority

Risk priority was assigned by combining severity, urgency, and resilience capacity results, and by integrating stakeholder feedback on critical assets and vulnerable groups. The prioritization was performed at municipal scale, with the intention that the ranking be validated and refined through subsequent engagement activities, including public-facing dialogue mechanisms.

Table 2-6 Overview key performance indicators

Hazard	*Severity (current)*	*Severity (future)*	*Urgency*	*Resilience capacity*	*Priority*
Heatwaves	Substantial	Critical	Immediate action needed	Medium	Very high
Fluvial flooding	Substantial	Substantial to critical (extreme events)	More action needed	Medium	High
Wildfires	Substantial	Critical	More action needed	Medium	High
Windstorms	Moderate	Moderate	Watching brief to more action needed	Medium	Medium

This prioritization reflects both the strength of the future worsening signal (heat and wildfire), the high consequences for population and services (heat and flood), and stakeholder emphasis on protecting vulnerable groups and high-consequence assets, including cultural heritage.

2.5 Monitoring and Evaluation

Phase 2 demonstrates that regionalization primarily increases decision relevance by integrating local data and refining indicators. The main advances were health-relevant heat metrics and refined fluvial flood mapping using higher-resolution terrain data and updated economic exposure assumptions, complemented by scenario-based wildfire modelling and local fuel-mapping tests. Key challenges were uneven data availability across hazards, limited wind monitoring for extremes, and the effort required to validate and harmonize heterogeneous local datasets into reproducible workflows. Stakeholders support monitoring and evaluation by enabling policy uptake and improving interpretability. Institutional actors align outputs with municipal planning cycles and help define usable evidence for prioritization, while feedback from engagement activities improves communication of scenarios and uncertainty. Phase 2 knowledge transfer strengthens local capacity to interpret results and supports iterative updates of the assessment.

New inputs include higher-resolution terrain data and updated socio-economic proxies for flood estimation, together with enhanced capability for wildfire risk projection and exposure analysis. Remaining needs include denser wind monitoring and systematic post-event impact documentation, improved inventories of critical assets and vulnerable groups, and more harmonized municipal-scale socio-economic projections for consistent use across hazards. Results will be communicated through municipal and partner channels and structured engagement, including the Resilience Festival as a pathway for public communication and feedback. Monitoring currently draws on civil protection practices and operational systems, but Phase 2 highlights the need for a systematic approach linking hazard indicators, exposure and vulnerability dynamics, and measure effectiveness over time; the proposed Climate Change Observatory provides an institutional basis for sustained monitoring and iterative refinement. Efficiency was improved by reusing CLIMAAX workflows and focusing on high-leverage local refinements. This accelerated production of decision-relevant outputs but limited the level of validation achievable within available time and staffing. Overall, Phase 2 improved risk understanding, strengthened technical capacity, and reinforced engagement structures that support public awareness and cross-sector collaboration, including cultural heritage safeguarding.

2.6 Work plan Phase 3

Phase 3 will follow up directly on the Phase 2 key risk priorities by translating priority rankings into feasible adaptation and climate risk management actions, supported by targeted stakeholder validation and integration into municipal planning instruments. The main activities are expected to include: refinement of risk management priorities into action packages for heatwaves, fluvial flooding, and wildfires; definition of implementation pathways including responsible actors, time horizons, and financing opportunities; and targeted strengthening of the evidence base where Phase 2 identified constraints, particularly wind monitoring and validation and improved exposure and vulnerability inventories.

Stakeholder engagement in Phase 3 will expand beyond institutional actors through planned public-facing processes, with the Resilience Festival serving as a key event for presenting results, collecting feedback, and mobilising community participation for risk reduction and preparedness. Phase 3 will also deepen sectoral integration for high-consequence assets, including cultural heritage institutions, to ensure that safeguarding measures are embedded into municipal risk governance and emergency planning.

Phase 3 will not attempt to conduct a full coupled socio-economic scenario modelling exercise across all hazards unless consistent municipal-scale projections become available in a form compatible with the workflows. It will also not replace hazard-specific engineering design studies (for example, detailed hydraulic modelling for flood defense design) where such studies require specialized inputs beyond the CRA scope. These exclusions reflect the need to maintain focus on converting the key risk assessment findings into implementable measures while ensuring that additional technical studies are commissioned only where warranted by priority and feasibility.

The expected Phase 3 outputs include updated local risk management planning elements informed by the Phase 2 risk priorities, clearer definition of monitoring indicators and responsibilities, and a consolidated set of adaptation measures aligned with the municipality's operational capacity and resource constraints, thereby ensuring that the CRA cycle is closed through practical uptake and an improved foundation for iterative monitoring and evaluation.

3 Conclusions Phase 2- Climate risk assessment

Phase 2 of CARE_X achieved its primary objective of moving beyond a baseline implementation of CLIMAAX workflows by regionalizing the climate risk assessment for Xanthi through the systematic integration of local and higher-resolution datasets and locally appropriate modelling choices. The Phase 2 work strengthened the interpretability and decision relevance of results by refining hazard, exposure and vulnerability representations for the four priority hazards, while maintaining traceability of assumptions and explicitly documenting remaining uncertainties.

The Phase 2 heatwave analysis confirms that heat risk is a dominant and escalating climate risk for the municipality. Heat-related impacts are characterized not only through hazard intensification but also through quantified health-relevant outcomes. The analysis identifies statistically robust temperature–mortality relationships and projects a marked increase in the heat-attributable burden over the century under the examined scenarios, reinforcing the need for sustained warning systems and targeted protection of vulnerable groups, particularly older adults.

For fluvial flooding from the Kosynthos River, Phase 2 demonstrates that higher-resolution representation materially improves local relevance. Downscaling of JRC flood hazard maps using a high-resolution digital elevation model produces flood depth patterns at a scale suitable for municipal interpretation, including maximum inundation depth estimates and improved identification of affected areas. The analysis further indicates increasing extreme river discharge toward late-century periods across scenarios, implying a higher likelihood of damaging floods in the future, and supports the use of refined economic exposure assumptions through updated GDP per capita to derive more realistic damage-cost estimates.

The Phase 2 wildfire analysis advances beyond static hazard characterization by implementing a forward-looking, scenario-based modelling framework. The response-surface approach links fire-weather danger (Fire Weather Index exceedance probability) to climate drivers and enables translation of climate projections into interpretable wildfire danger evolution, complemented by population exposure quantification. The tests indicate that socio-economic pathway assumptions can substantially modify exposure outcomes, with the SSP5 pathway yielding the strongest increase in exposed population due to rapid growth and urbanization assumptions. The work further tests refined fuel and bare-ground mapping using Sentinel-based remote sensing, addressing limitations of generic land-cover products for wildfire-relevant fuel representation.

The Phase 2 windstorm analysis clarifies that, while baseline CLIMAAX windstorm scenarios yielded negligible impacts for Xanthi, locally observed wind events and local exposure characteristics justify continued attention. The workflow was adapted using local wind gust observations, local building-type information, updated local economic proxies and tentative adjustments of vulnerability curves to better reflect observed impacts in the urban environment. The resulting damage patterns concentrate in urban and semi-urban zones, but the analysis also concludes that current outputs should not be treated as fully validated risk scenarios without denser monitoring and systematic post-event impact documentation.

A central challenge in Phase 1 was that pan-European default datasets and generic vulnerability assumptions constrained municipal-scale interpretability. Phase 2 addressed this by integrating local and higher-resolution inputs where available and by adding impact-relevant metrics that better match municipal decision contexts. Examples include the use of local health-impact modelling for heat risk, high-resolution terrain-based refinement for flood mapping, scenario-based fire-weather modelling with population exposure quantification, and localization of windstorm exposure and vulnerability assumptions.

A second challenge was the need for practical uptake by decision-makers and operational actors. Phase 2 strengthened engagement and learning pathways through structured knowledge transfer and stakeholder-oriented communication. The project documented coordinated engagement with municipal leadership and services, technical exchanges with data providers, and a structured training activity focusing on CLIMAAX toolkits, with feedback consistently emphasizing the value of decision-oriented outputs, cross-hazard comparability and explicit attention to priority groups and critical assets.

A third challenge was sector integration beyond conventional civil-protection framing. Phase 2 advanced cross-sector legitimacy by integrating cultural heritage as a high-consequence asset category within climate risk management, supported through collaboration between the Municipality of Xanthi, RiskAC and heritage custodians, and by linking this work to planned public engagement activities.

Several limitations remain structurally important for interpretation and for Phase 3 prioritization. First, locally representative monitoring remains uneven across hazards, with wind risk analysis particularly constrained by limited station density and by the absence of systematic post-event damage inventories, limiting validation of spatial hazard fields and vulnerability assumptions.

Second, Phase 2 did not implement a harmonized, fully coupled modelling of future socio-economic development across hazards. Socio-economic influences were incorporated where available and analytically meaningful (for example, in wildfire exposure tests under different socio-economic pathways), but consistent municipal-scale projections suitable for integrated coupling across all workflows remain unavailable.

Third, while spatial refinement improves decision relevance, some modelling choices remain approximations rather than substitutes for specialized engineering studies. For example, statistical downscaling of flood maps increases local interpretability but does not replace detailed hydraulic modelling where structural design decisions are required.

Finally, stakeholder engagement expanded substantially in Phase 2, but sustained participation by priority groups outside institutional settings remains more difficult than convening public authorities and sector agencies. The project therefore positions the Resilience Festival as a structured mechanism to broaden feedback loops and improve societal uptake of risk evidence.

Overall, Phase 2 provides a strengthened evidence base for risk prioritization and action design, with clear indications that heatwaves, fluvial flooding and wildfires require immediate and sustained attention, while windstorm risk warrants monitoring and targeted preparedness given local event evidence and current validation constraints. The Phase 3 focus should therefore be on translating the Phase 2 key risk priorities into implementable adaptation and climate risk management measures, embedding them in municipal planning and risk management instruments, and strengthening monitoring and data foundations where Phase 2 identified critical gaps.

4 Progress evaluation

This Phase 2 deliverable operationalize the transition from baseline workflow application to a regionalized and decision-relevant climate risk assessment for the Municipality of Xanthi. Its primary contribution is the delivery of refined hazard and risk outputs for the four priority hazards, based on the integration of local and higher-resolution datasets and locally appropriate modelling choices for windstorms, heatwaves, fluvial flooding, and wildfires.

The deliverable connects directly to the planned activities for Phase 3 in three ways. First, it provides the technical foundation for updating existing municipal risk management plans and preparedness procedures by identifying hazard-specific hotspots, impacts, and vulnerabilities at scales that are actionable for local services. Second, it provides the evidence base required for prioritizing and specifying adaptation and climate risk management actions, since Phase 3 is planned to build on refined risk outputs to support the formulation and updating of risk management plans (Milestone M5) and to execute a multi-hazard climate event preparedness exercise (Milestone M6).

Third, it strengthens the stakeholder interface required for uptake: Phase 2 emphasized capacity building and structured engagement (Milestone M4), and it established an explicit public-facing pathway through the Xanthi Resilience Festival, with an announced itinerary for May 8–10, 2026, intended to facilitate wider dissemination, dialogue, and feedback integration.

In line with the Phase 1 roadmap, the central Phase 2 milestones were (i) completion of refined risk analyses for each hazard (M3) and (ii) knowledge transfer sessions between RiskAC and the Civil Protection Office of the City of Xanthi and other stakeholders (M4).

The current deliverable documents refined analyses across all four hazards and includes expanded outputs beyond standard workflow baselines, including heat-related health risk indicators and burden projections under SSP pathways, refined fluvial flooding impacts including economic damages and population displacement estimates, and wildfire risk modelling through response surfaces with population exposure testing under socio-economic pathways.

The Key Performance Indicators and milestones reported below follow the intent of the Individual Follow-up Plan by emphasizing completion of refined analyses, integration of local data, capacity building for uptake, and preparation of engagement and dissemination mechanisms supporting Phase 3 implementation planning.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
KPI 1: Complete risk assessments for 2 identified hazards	**Achieved and exceeded**. Phase 2 includes refined assessments for windstorms, heatwaves, fluvial flooding, and wildfires.
KPI 2: Conduct at least 3 stakeholder workshops throughout the project lifecycle.	**Partially achieved**. An initial stakeholder workshop (Dec 2024) was conducted during Phase1. During Phase 2 a structured three-day training activity (workshop-equivalent) was completed. A further workshop/public-facing engagement remains planned during the Resilience Festival on May 2026.
KPI 3: Engage a minimum of 10 local stakeholders representing different sectors (e.g., government, academia, civil society, vulnerable groups)	**Achieved to a great degree**. During Phase 1, an initial stakeholder workshop was conducted with the Mayor of the City of Xanthi and the municipality's personnel. In Phase 2, a structured three-day training activity was completed with representatives from the

Key performance indicators	*Progress*
	PAMTh, Democritus University of Thrace students, Fire Department personnel, Military personnel, Forest Management Office personnel, and Civil Protection Office Personnel. Furthermore, engagement was made with the cultural non-profit organization FEX. A further public-facing (Xanthi Resilience Festival) engagement remains planned for the 3rd Phase.
KPI 4: Successfully integrate at least 4 local datasets into the risk assessment process.	**Achieved**. Examples documented in this deliverable include local wind observations integrated with hazard modelling and vulnerability adjustment; high-resolution DEM plus updated GDP per capita for flood downscaling and damages; and high-resolution temperature dataset with local health-risk mapping.
KPI 5: Produce at least 1 comprehensive risk map for each assessed hazard.	**Achieved.** Windstorm damage and relative damage maps are produced. Heat-related mortality risk maps are produced for baseline and future periods. Flood and damage maps and population displacement indicator are produced. Wildfire outputs are stated as presented in figures (hazard and exposure results).
KPI 6: Identify at least 5 potential adaptation measures or policy recommendations based on the risk assessment results.	**Not yet fully achieved.** Phase 2 supports prioritization and interpretation, but a clearly enumerated list of ≥5 measures should be consolidated (recommended location: Section 2.4.6 and Section 2.6) and then finalized in Phase 3 deliverable.
KPI 7: Train at least 10 local officials or stakeholders in using and interpreting the risk assessment tools and results.	**Achieved.** During Phase 2 a structured three-day training activity with hands-on exercises was achieved with more than 10 local officials.
KPI 8: Organize at least 1 public event to present the project results to the wider community.	**Not yet Achieved.** It is planned for Phase 3 timeframe via the Xanthi Resilience Festival scheduled for 8–10 May 2026 as the main public-facing event.
KPI 9: Achieve at least 3 local media mentions of the project and its findings.	**Partially evidenced.** Phase 1 reports at least **one press release** sent to media. During Phase 2 local public dissemination documented through partner communication channels, including a FEX website post referencing CLIMAAX and CARE_X in the context of the ICOM Dubai 2025 presentation https://fex.org.gr/politistikes-draseis/27o-synedrio-tou-international-council-of-museums-icom-dubai-2025/ . Additional independent local media mentions to be compiled during Phase 3 to complete KPI 9.
KPI 10: Successfully implement all 5 steps of the CLIMAAX framework (Scoping, Risk Exploration, Risk Analysis, Key Risk Assessment, Monitoring and Evaluation).	**Achieved in Phase 2 deliverable.** The Phase 2 deliverable include Scoping (2.1), Risk Exploration (2.2), Regionalized Risk Analysis (2.3), Key Risk Assessment (2.4) and Monitoring and Evaluation (2.5).

Table 4-2 Overview milestones

Milestones	*Progress*
M1: Initial stakeholder workshop conducted (Phase 1).	**Achieved.** Documented in Phase 1 as conducted in December 2024.
M2: Workflows for all relevant hazards established and customized (Phase 1).	**Achieved.** Phase 1 reports workflows established for four hazards.
M3: Refined risk analysis for each hazard completed (Phase 2).	**Achieved.** Phase 2 contains refined analyses and outputs for windstorms, heatwaves, fluvial flooding, and wildfires.

Milestones	*Progress*
M4: Knowledge transfer sessions between the Research Centre and Civil Protection Office conducted (Phase 2).	**Achieved.** During Phase 2 a structured three-day training and knowledge transfer activity was conducted.
M5: Existing risk management plans updated (Phase 3).	Planned for Phase 3.
M6: Multi-hazard climate event preparedness exercise executed (Phase 3).	Planned for Phase 3.
M7: Attend the CLIMAAX workshop held in Barcelona (May 2025).	**Achieved.** Prof. Ioannis Dokas representing the CARE_X project participated in Barcelona meeting.
M8: Attend the CLIMAAX workshop held in Brussels (December 2026).	Planned.

5 Supporting documentation

1 Main Report (Phase 2)

2. Organigram of Institutions and Interconnections

3. Workflow Supplementary Material

    a. Heatwaves workflow Supplementary Material

    b. Fluvial Flooding workflow Supplementary Material

    c. Wildfires workflow Supplementary Material

4. Communication Outputs (2nd out of 3)

5. Participants of the structured three-day training activity (workshop-equivalent)

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