Deliverable Phase 1 – 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
CARE_X	Climaax Action and Risk Evaluation of Xanthi
CLIMAAX	CLIMAte risk and vulnerability Assessment framework and toolboX
CRA	Climate Risk Assessment
RCP	Representative Concentration Pathway
CDS	Climate Data Store
ERA5	ECMWF Reanalysis 5th Generation Dataset
LUISA	Land Use-based Integrated Sustainability Assessment platform
LST	Land Surface Temperature
HDX	Humanitarian Data Exchange
GCM	Global Climate Model
RCM	Regional Climate Model
HNMS	Hellenic National Meteorological Service
JRC	Joint Research Centre (European Commission)
FWI	Fire Weather Index
REMTh	Region of Eastern Macedonia and Thrace
RiskAC	Risk and Resilience Assessment Center
DUTH	Democritus University of Thrace
VI	Vulnerability Index
XCLIM	Climate Indicators Computation Library

6. Executive summary

This deliverable presents the outcomes of Phase 1 of the Climate Risk Assessment conducted under the CLIMAAX project framework for the Municipality of Xanthi, Greece. The document addresses the critical need to systematically assess climate risks, supporting informed decision-making and enhancing resilience against climate change. Readers will gain comprehensive insights into the assessment of primary climate-related hazards affecting Xanthi, including heatwaves, river flooding (specifically, the Kosynthos River), windstorms, and wildfires.

The main actions undertaken during this initial phase involved applying the standardized CLIMAAX Climate Risk Assessment (CRA) methodology utilizing the CLIMAAX Toolbox and datasets sourced from established repositories, including EURO-CORDEX, Landsat8, and ERA5. The analysis provided a detailed hazard evaluation, identifying critical vulnerabilities and exposure factors for each climate risk.

The results for heatwaves revealed a marked upward trend in frequency and severity, with significant increases anticipated especially under the RCP8.5 scenario towards the end of the 21st century. Urban areas, due to the Urban Heat Island effect, and vulnerable populations (elderly and young children), were highlighted as particularly at-risk groups.

For flooding from the Kosynthos River, the assessment pinpointed areas with significant inundation potential, particularly highlighting the northern part of Xanthi city, especially in scenarios representing extreme events (return periods of 100-500 years). Critical urban infrastructures were identified as notably exposed, indicating the necessity for targeted flood management strategies.

The analysis of windstorm scenarios demonstrated minimal risk from historically recorded windstorms in the broader region; however, a local windstorm event scenario indicated potential vulnerabilities within the built environment under more extreme conditions.

Wildfire risk evaluation identified high-risk areas based on fuel availability and climatic conditions conducive to wildfire outbreaks. The interaction between weather extremes and forested areas near inhabited regions emerged as a critical factor amplifying risk.

Overall, Phase 1 significantly advanced the understanding of climate risks in Xanthi, creating a solid foundation for subsequent phases. It provides actionable knowledge that can inform adaptation strategies, land-use planning, and emergency preparedness efforts.

Key conclusions drawn from this phase emphasize the urgency of addressing urban heat exposure, improving flood resilience infrastructure, preparing contingency plans for local-scale windstorm impacts, and strengthening wildfire management practices through community engagement and proactive risk reduction measures.

1 Introduction

1.1 Background

The Municipality of Xanthi is located in northeastern Greece within the Region of Eastern Macedonia and Thrace. The city, home to approximately 58,500 inhabitants, sits within a geographical basin surrounded by the Rhodope Mountains, creating diverse topographic conditions ranging from flat urban areas near the Kosynthos River to hilly landscapes towards the outskirts. Xanthi's rich historical and architectural heritage, particularly in its well-preserved old town, further emphasizes the importance of protecting local cultural assets from climate-induced risks.

Characterized by a Mediterranean climate with hot summers and cool, wet winters, Xanthi is particularly susceptible to several climate-related hazards, including extreme heatwaves, river flooding, wildfires, and windstorms. These climate events have historically posed significant threats to public health, critical infrastructure, economic stability, and overall quality of life. Within this context, the CLIMAAX project aims to systematically assess and address these risks, thereby building resilience, informing strategic planning, and promoting sustainable urban and regional development.

1.2 Main objectives of the project

The CARE_X project aims to conduct a comprehensive climate risk assessment in the Municipality of Xanthi, addressing the city's multiple climate-related threats—heatwaves, river flooding, windstorms, and wildfires. By leveraging the methods and tools provided in the CLIMAAX Handbook, the project seeks to establish a robust, standardized basis for understanding current and future hazards, thereby informing local decision-making and enhancing climate resilience.

The specific objectives of CARE_X include:

- **Evaluating and mapping climate risks** using established methodologies to identify the critical areas, infrastructure, and populations most at risk.
- **Providing actionable insights** into the region's current and projected climate scenarios to support targeted adaptation measures and policy development.
- **Highlighting vulnerable groups** and high-exposure locations within Xanthi's urban and peri-urban environments.
- **Generating data-driven visualizations** that can be readily used by municipal authorities and local stakeholders to strengthen emergency preparedness and resource allocation.

Applying the CLIMAAX Handbook methodology offers significant benefits to the local community. It ensures alignment with a harmonized, scientifically grounded approach to climate risk assessment, facilitating consistency with European standards and best practices. Through this standardized framework, Xanthi can systematically prioritize interventions, optimize resource management, and foster a shared understanding of the city's climate challenges. In doing so, CARE_X not only advances short-term protective measures but also contributes to long-term urban resilience and sustainable regional development.

1.3 Project team

The CARE_X project brings together municipal leadership and academic expertise in a close partnership, ensuring both strategic oversight and scientific rigor. The project is spearheaded by the

Mayor of Xanthi, Mr. Eustratios Kontos, who guides overall objectives and stakeholder engagement. Operational coordination, particularly regarding civil protection responsibilities, is entrusted to the Vice Mayor of Xanthi, Mr Ioannis Tsapalis, who leads a dedicated team from the city's Civil Protection Office.

Scientific analyses and the application of the CLIMAAX Climate Risk Assessment (CRA) methodology are conducted by the Risk and Resilience Assessment Center (RiskAC) of Democritus University of Thrace. Under the direction of Professor Ioannis Dokas, RiskAC engages a multidisciplinary team, including Professor Nikolaos Klimis, Professor Anastasia Pashalidou, and AssistantProfessor Emmanouil Rovithis who provide supervisory oversight. The RiskAC academics lead a group of four early-career researchers tasked with implementing the specialized Climaax Toolbox workflows.

This integrated approach—uniting municipal officials, civil protection personnel, and an academic research network—ensures that local governance, policy needs, and cutting-edge scientific practices remain closely aligned throughout the CARE_X project.

1.4 Outline of the document's structure

The document begins with the Introduction, which sets the context by presenting background information, outlining the project's main objectives, and describing the project team. Following the introductory sections, the core of the document outlines the climate risk assessment process itself, including scoping, risk exploration, and risk analysis, with specific workflows tailored to different hazards. The report then presents preliminary key risk findings, followed by conclusions, an evaluation of progress, and a discussion of how this phase will inform subsequent project phases. Finally, the document concludes with supporting documentation and references, ensuring that all methodologies and results are traceable and verifiable.

2 Climate risk assessment – phase 1

2.1 Scoping

This phase defines the objectives and context of the climate risk assessment, while identifying stakeholders essential for project preparation.

2.1.1 Objectives

The principal objective of the CARE_X climate risk assessment is to provide a clear, data-driven understanding of four critical hazards for the Municipality of Xanthi: heatwaves, river flooding (Kosynthos River), windstorms, and wildfires. By leveraging the CLIMAAX Climate Risk Assessment (CRA) methodology and Toolbox, the project aims to:

- **Generate robust risk profiles** for each hazard, highlighting the most vulnerable populations, infrastructures, and economic sectors.
- **Support local policy-making and decision processes** through scientific evidence and practical recommendations for adaptation planning and civil protection measures.
- **Establish clear boundaries** by focusing on hazards deemed most relevant to Xanthi's urban and peri-urban settings, given the Phase 1 reliance on existing CLIMAAX Toolbox datasets (EURO-CORDEX, Landsat8, ERA5). The project's reliance on these standard resources imposes certain limitations, notably the absence of local high-resolution data, which will be addressed in subsequent phases.

2.1.2 Context

Until now, Xanthi's climate hazards have been managed primarily through baseline civil protection plans aimed at emergencies such as floods and extreme weather. However, limited local resources and a lack of integrated multi-hazard assessment tools have constrained comprehensive planning and adaptive responses. The CARE_X project addresses this gap by situating Xanthi's challenges in a broader regional context, where aging demographics, lower GDP per capita, and varied topography—ranging from low-lying urban areas near the Kosynthos River to forested uplands—magnify vulnerability to climate extremes.

The governance context includes local civil protection regulations and broader frameworks set by regional or national authorities for disaster risk management. While emergency response mechanisms exist, formalized multi-hazard adaptation strategies remain underdeveloped. The sectors expected to be most affected by the identified hazards are urban infrastructure, public health, and the forested areas adjacent to inhabited zones. Coordination with regional institutions and potential external partners, such as the CLIMAAX consortium, is key to securing financial and technical resources.

Potential adaptation interventions include upgrading drainage and flood defenses, refining heatwave contingency measures, and strengthening wildfire prevention strategies. They also encompass targeted policy initiatives, such as integrating climate risk considerations into urban planning and resource allocation.

2.1.3 Participation and risk ownership

The project's first steps to ensure stakeholder engagement involved establishing a collaborative framework between Xanthi's municipal leadership and the Risk and Resilience Assessment Center (RiskAC). Key stakeholders include:

- **Municipal authorities** (Mayor, Vice Mayor for Civil Protection, Civil Protection Office staff), who oversee day-to-day risk management and emergency readiness.
- **Academic and research partners** at RiskAC, who apply the CLIMAAX CRA methodology, supervise data analysis, and develop specialized workflows.
- **Local communities and interest groups**, including residents, businesses, and NGOs in high-risk areas.
- **Regional and national institutions** responsible for overarching disaster management policies and potential funding or regulatory support.

Risk ownership formally resides with the Municipality of Xanthi, as it holds legal responsibility for civil protection and public safety. However, RiskAC provides ongoing technical guidance, reinforcing the municipality's capacity to absorb, implement, and monitor CRA findings. Acceptable levels of risk are determined through municipal policy objectives and public consultation, balancing feasibility with community expectations. Communication of results will primarily target local decision-makers, civil society representatives, and any external entities offering complementary expertise or resources.

2.2 Risk Exploration

Phase 1 of CARE_X commences with a comprehensive exploration of climate hazards, involving the review of existing data and an initial screening that identifies where vulnerabilities and exposures intersect most critically.

2.2.1 Screen risks (selection of main hazards)

Four main climate-related hazards have been confirmed as priorities for Xanthi:

1. **Windstorms:** Historically minimal in impact but featuring potential extreme events (e.g., local tornado episodes). These can result in structural damage and disruptions to critical services.
2. **Heatwaves:** Characterized by rising frequencies and intensities, posing significant public health concerns for the elderly, young children, and socioeconomically vulnerable populations, particularly in urban areas affected by the Urban Heat Island effect.
3. **River Flooding (Kosynthos River):** Involves episodic inundation events of varying magnitude, threatening the city's infrastructure and residential zones, especially during high-return-period scenarios (100 to 500 years).
4. **Wildfires:** Reflecting the region's forested environment and Mediterranean climate conditions, wildfires pose a heightened risk during drought and peak-summer periods, with direct implications for peri-urban and rural communities.

Datasets from the CLIMAAX Toolbox (e.g., EURO-CORDEX, Landsat8, ERA5) were used to gauge hazard severity, exposure, and vulnerability. Additional local data and refined modeling will be incorporated in subsequent phases of the CARE_X project to further improve hazard quantification and facilitate more targeted mitigation strategies.

2.2.2 Workflow selection

Based on the selected hazards for the Municipality of Xanthi—windstorms, river flooding (Kosynthos River), heatwaves, and wildfires—the CARE_X team identified four relevant workflows for the climate risk assessment. Each hazard was analyzed individually using CLIMAAX workflows, supported by regional and local datasets, as well as standardized vulnerability and exposure metrics.

Each workflow reflects distinct hazard characteristics, data requirements, and exposure/vulnerability contexts. The corresponding vulnerable groups and exposed areas were identified as follows:

- **Urban elderly populations and young children** were most vulnerable to heatwaves, especially in high-density zones affected by the Urban Heat Island effect.
- **Residents and infrastructure near the Kosynthos River**, particularly in the northern part of Xanthi, were highly exposed to fluvial flooding.
- **Buildings with outdated construction standards and critical infrastructure** in exposed areas were at risk from windstorm events.
- **Peri-urban communities and forest-edge settlements** were particularly vulnerable to wildfires, which were exacerbated by dry conditions and proximity to ignition sources.

2.2.2.1 Workflow #1 Applied to: Windstorms

The windstorm hazard was evaluated using the CLIMAAX windstorm workflow. Four scenarios were analyzed: two historical storms from the CDS database (Klaus and Martin), a reanalysis-based version of Klaus from ERA5 data, and a recent local storm event ("Ifestionas," January 2020). The workflow incorporated LUISA land cover data for exposure and pre-configured vulnerability curves adapted to building and land use types. The results indicated that only the local storm scenario exceeded damage thresholds, emphasizing the importance of localized event analysis for Xanthi.

2.2.2.2 Workflow #2 Applied to: Heatwaves

Heatwave analysis utilized both EuroHEAT and XCLIM methodologies, drawing on EURO-CORDEX climate projections. Multiple heatwave definitions were explored, including the Hellenic National Meteorological Service (HNMS) criteria and percentile-based indicators. Risk assessment combined satellite-derived Land Surface Temperature (Landsat8) with demographic data on vulnerable groups (children and elderly) and mapped exposure hotspots in urban Xanthi. Projected future conditions under RCP4.5 and RCP8.5 show a marked increase in heatwave frequency and intensity.

2.2.2.3 Workflow #3 Applied to: River Flooding

Fluvial flood risk was assessed using high-resolution JRC flood hazard maps and the LUISA land use dataset. Damage was calculated based on inundation depth for five return periods (10, 50, 100, 200, 500 years), coupled with vulnerability-damage curves and economic exposure metrics (GDP/m²). Results highlighted significant inundation potential in the northern urban area of Xanthi. Climate-adjusted scenarios using the RCP8.5 pathway further emphasized future flood risks. Coarse-resolution Aqueduct data were tested but deemed inadequate for the narrow Kosynthos River basin.

2.2.2.4 Workflow #4 Applied to: Wildfires

The wildfire workflow integrated CLIMAAX's machine learning-based hazard mapping and the Fire Weather Index (FWI). Analysis focused on identifying fuel-rich areas and assessing fire susceptibility near forest-urban interfaces. Data limitations restricted the full application of machine learning, but preliminary risk maps highlighted priority areas for prevention. Partnerships with the local municipality will support improved data collection and to enhance predictive capabilities.

2.2.3 Chose Scenario

For the climate risk assessment in Xanthi, the following scenario assumptions were considered relevant:

- **Short-term (0–5 years):** Current exposure levels and recent events are used to calibrate and validate workflows.
- **Medium-term (20–30 years):** Projected urban expansion, aging population demographics, and moderate warming under RCP4.5.
- **Long-term (50–100 years):** Severe climatic shifts anticipated under RCP8.5, with implications for hazard frequency, intensity, and spatial extent.

The scenarios incorporated in the CLIMAAX workflows aligned well with local needs:

- **EURO-CORDEX RCP4.5 and RCP8.5 projections** for heatwaves and fluvial flood hazard quantification.
- **Return period-based scenarios** (e.g., 100- and 500-year flood) for river flooding using JRC data.
- **Historical storm benchmarks and custom ERA5-based footprints** for windstorm analysis.
- **Future FWI scenarios and evolving urban-wildland interfaces** for wildfire susceptibility modeling.

These scenarios supported both immediate mitigation planning and long-term strategic adaptation, fostering a phased, evidence-driven resilience roadmap for the Municipality of Xanthi.

2.3 Risk Analysis

2.3.1 Workflow #1: Windstorms

With reference to the Windstorm Hazard and Risk assessment, the CARE_X project team has applied the CLIMAAX framework, following the methodology which is described in the associated CRA toolbox of CLIMAAX. It should be emphasized that the primary objective of this first-phase risk assessment was to explore the applicability of the CLIMAAX windstorm risk workflow, considering that wind risk may be highly relevant for the CARE_X project area, which encompasses a broader region around the city of Xanthi in northern Greece. As an example, a strong local tornado, which occurred on November 4, 2023, caused visible damage to building roofs and overturned cars in a parking lot close to the city center of Xanthi (see Figure 2-1).

Figure 2-2 illustrates the area specified using the CLIMAAX Bounding Box Tool to perform the windstorm CRA for the CARE_X project. It refers to a broader region around the city of Xanthi bounded by the coordinates (24.6097, 41.0071, 25.2125, 41.3904).

Figure 2-1 Impact of a strong local tornado occurred in the city of Xanthi: Overturned cars in a parking lot close to the city center (date: November 4, 2023).

Figure 2-2 CARE_X project area for the implementation of the CLIMAAX windstorm risk workflow.

Hazard assessment

Four (4) windstorm scenarios were examined as part of the 1st project phase to assess the applicability of the CLIMAAX windstorm risk workflow (Koks and Haer 2020) for the CARE_X region. These scenarios are (Table 2-1):

- Scenario 1: The windstorm "Klaus" occurred on January 24, 2009, which is preconfigured in the CDS database (use of Option A of the CLIMAAX windstorm workflow)
- Scenario 2: The windstorm "Martin" occurred on December 27, 1999, which has been preconfigured in the CDS database (use of Option A of the CLIMAAX windstorm workflow)
- Scenario 3: Same as Scenario 1 but downloaded from ERA5 wind gusts and aggregated into footprint (use of the new Option B of the CLIMAAX windstorm workflow)
- Scenario 4: A local windstorm event which occurred on 6-7 January, 2020 in Greece (https://confluence.ecmwf.int/display/FCST/202001+-+Windstorm+-+Greece). This event was downloaded from ERA5 and aggregated into footprint (use of the new Option B of the CLIMAAX windstorm workflow)

It is noted that Scenarios 1 and 2 refer to windstorm events which pass from South Europe at the closest distance from the CARE_X region, among the 118 events included in the CDS database. Scenario 3 was employed as an extra check of Option B of the CLIMAAX workflow, while Scenario 4 refers to a local windstorm Greek event. It should be mentioned that running CRA analysis with hazard data as low as 0.25° of the ERA5 reanalysis framework is generally not recommended. However, Option B allows analysis of windstorm events that are not in the CDS database and may, thus, be employed during the next phase of the project to explore local datasets, in case meteorological services can provide gridded observations of wind gusts that can be processed into a storm footprint. An overview of the input and output data from the implementation of the CLIMAAX windstorm workflow in the CARE_X area is reported in Table 2-1, while the windstorm footprint across the examined region is plotted for each one of the 4 cases in Figure 2-3. The large difference in the resolution of the footprint of the same event between Scenario 1, which is derived directly from the CDS database, (Figure 2-3a) and Scenario 3, which is retrieved from the low-resolution ERA5 wind gusts archive (Figure 2.-3c) is evident. Note also that among the four scenarios, the strongest one is the local event with wind speeds above 25 m/s. This aspect is critical for the interpretation of the risk assessment results, as will be shown in the ensuing.

Table 2-1 Data overview for CARE_X project implementation of the CLIMAAX windstorm workflow

Scenario	Hazard data	Hazard data retrieved from	Vulnerability data	Exposure data	Risk output
1	*"Klaus" windstorm*	*CDS database*	*Construction type-based vulnerability curves (Feurstein et al. 2011) adjusted to land cover – based vulnerability curves*	*LUISA base map 2018 of the CARE_X project area*	*Structural damage (€/m²)*
2	*"Martin" windstorm*	*CDS database*			
3	*"Klaus" windstorm*	*ERA5 wind gusts*			
4	*Local Greek windstorm event "Ifestionas" (6-7 January 2020)*	*ERA5 wind gusts*			

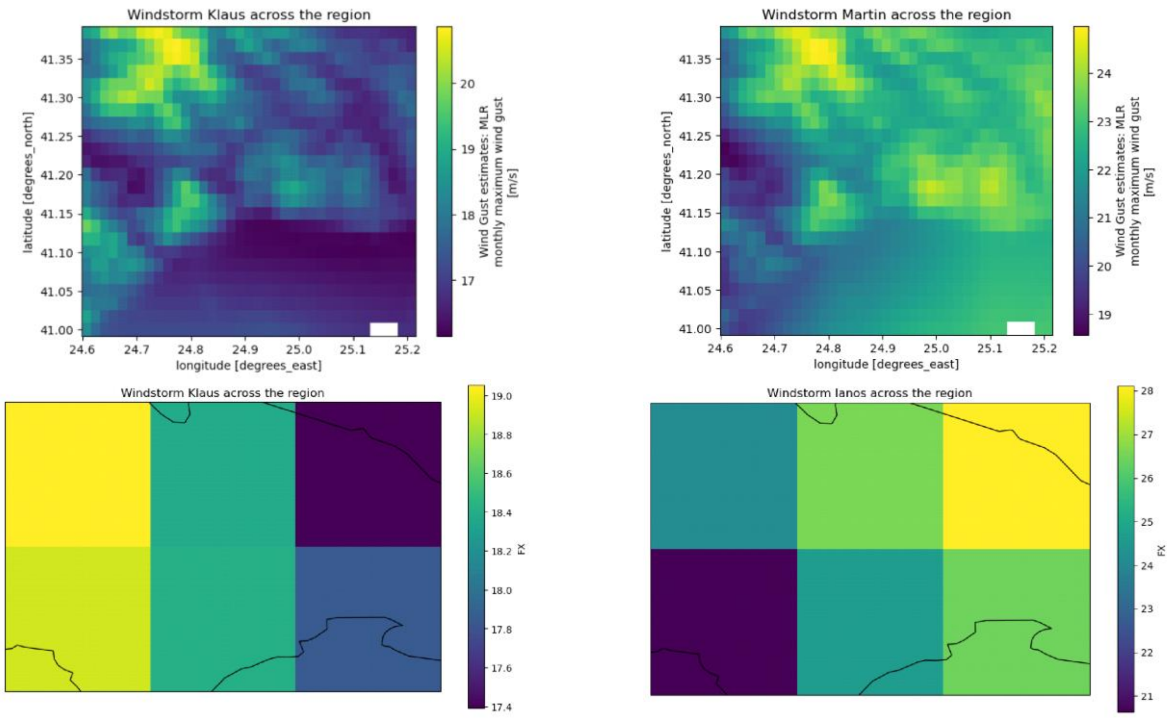

Figure 2-3 Windstorm footprints across the CARE_X region for each windstorm scenario: (a) Scenario 1, (b) Scenario 2, (c) Scenario 3, and (d) Scenario 4.

2.2.3.2 Risk assessment

The risk assessment procedure specified in the CLIMAAX windstorm Python script was followed to obtain the risk output for each one of the four windstorm scenarios. It is reiterated that the main objective of this 1st phase of the project was to check the applicability of the proposed workflow across the CARE_X project area. Thus, the vulnerability models were not adapted to local data, as such a type of analysis will be explored in the second phase of the project. Therefore, the CRA analysis for the CARE_X project was performed at this stage for the same building-type and land-use type vulnerability curves, which are embedded in the CLIMAAX workflow for windstorms. On the other hand, land use cover data for the CARE_X implementation area was based on the updated LUISA base map 2018. The latter is plotted in Figure 2-4 for the CARE_X region, which is superimposed by the windstorm footprint of Scenario 1 (Figure 2-4a) and 4 (Figure 2-4b). The above data

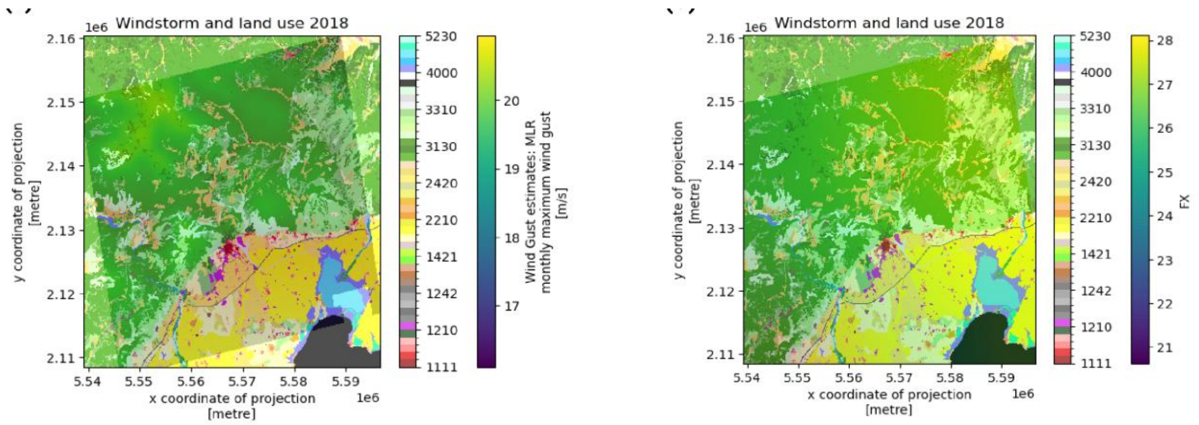

Figure 2-4 Matching layers of land use and windstorm footprint for (a) Scenario 1 and (b) Scenario 4

was then combined with the transformed land use type vulnerability curves (Table 2-1) as introduced in the CLIMAAX risk assessment workflow to obtain event-based estimates of damages. More specifically, the CLIMAAX windstorm workflow suggests that, based on the wind gust speed during the storm, the vulnerability curves proposed by Feuerstein et al. (2011) are applied to determine the extent to which the asset is damaged by this wind speed. Then, the maximum cost of damage to this asset is multiplied by the damage percentage retrieved from the relevant vulnerability curve, resulting in the estimated damage caused by the storm to that asset. Performing this calculation for all asset locations in the region results in a damage map that helps to determine locations that are most affected in terms of the highest costs of the damages. Figure 2-5 illustrates the vulnerability curves for all land cover types, as suggested by the CLIMAAX workflow for wind. Note that the threshold value of wind gust to initiate damage is 27 m/s. This value may explain the distribution of structural damage shown in Figure 2-6. Indeed, the zero impact of Scenarios 1, 2, and 3 on the CARE_X project is likely related to the associated low wind speed values, which seem too low to trigger damage to the land assets in question. On the contrary, Scenario 4 imposes a visible (although negligible) impact on the region, since the imposed wind loading exceeds merely the threshold value of the vulnerability curves. In any case, it may be concluded that the CLIMAAX wind workflow has been successfully applied to the CARE_X region by providing reasonable damage maps and, thus, reaching a certain level of confidence for the analysis in the second phase of the project.

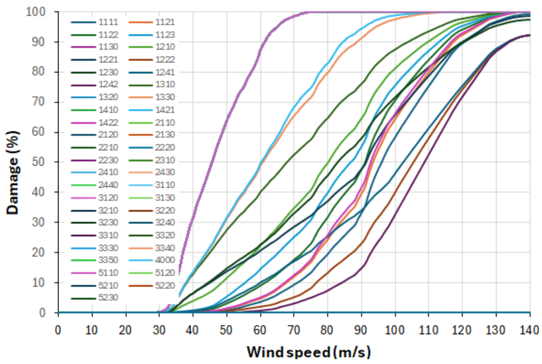

Figure 2-5 Vulnerability curves for all the land cover types.

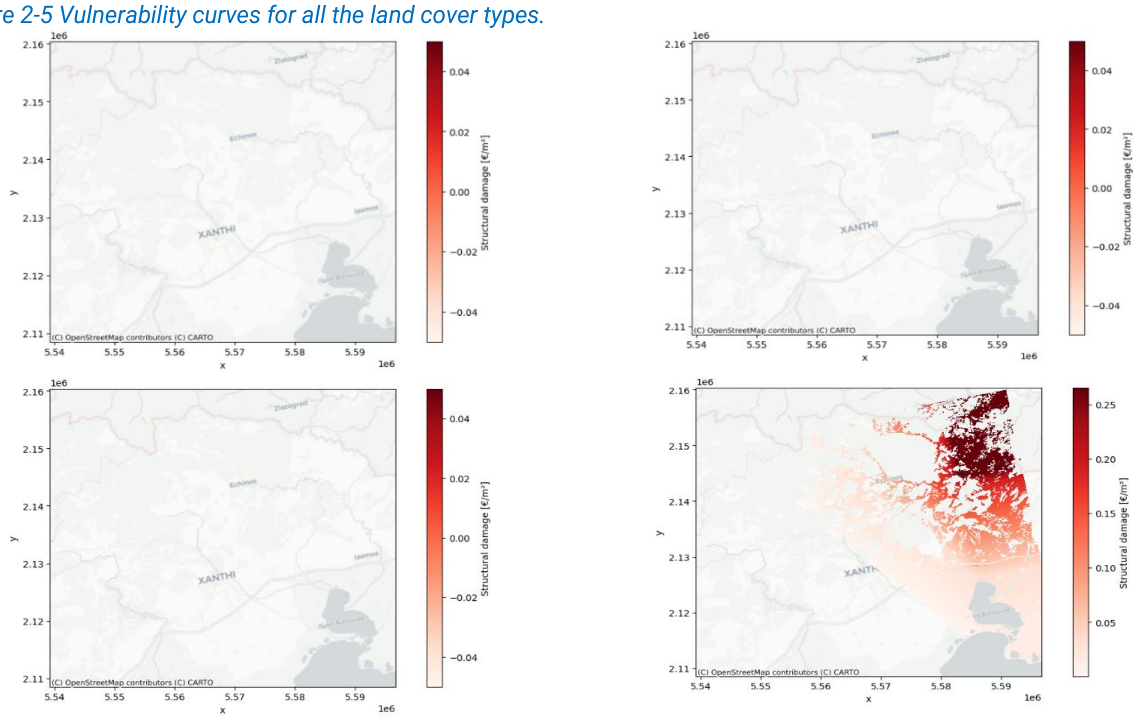

Figure 2-6 Structural damage map across the CARE_X region for each windstorm scenario: (a) Scenario 1, (b) Scenario 2, (c) Scenario 3 and (d) Scenario 4.

2.3.2 Workflow #2: Heatwaves

The CARE_X team applied all methodologies described in the heatwave workflow of the CLIMAAX CRA toolbox for hazard and risk assessment. This first-phase assessment had a twofold objective: firstly, to explore the applicability of the CLIMAAX heatwave workflow in our region, and secondly, to assess the impact of climate change on the heatwave hazard and define the most affected areas, both currently and in the future, under the RCP4.5 and RCP8.5 climate change scenarios. Table 2-2 presents the datasets used for implementing the CLIMAAX heatwave workflow.

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

	Hazard data	*Vulnerability data*	*Risk output*
Hazard assessment (EUROheat)	*Heatwave days based on EURO-CORDEX dataset*		*The annual number of heatwave events from 1986 to 2085, under the RCP4.5 and RCP8.5 scenarios*
Hazard assessment (Xclim)	*Daily maximum and daily minimum air temperature at 2 m height from the EURO-CORDEX dataset*		*Estimations of six different heatwave indicators for the period 1986-2100 under the RCP4.5 and RCP8.5 scenarios*

	Hazard data	*Vulnerability data*	*Risk output*
Risk assessment (satellite-derived data)	*Satellite-derived (Landsat8) Land Surface Temperature (LST) data*	*Population aged ≤5 years and ≥65 years, Critical infrastructure*	*Risk assessment (satellite-derived data)*
Heatwave risk under climate change	*Heatwave days based on EURO-CORDEX dataset*	*Population aged ≤5 years and ≥65 years*	*The projected magnitude of change in heatwave occurrence under the RCP4.5 and RCP8.5 scenarios, combined with the distribution of vulnerable population groups*

2.3.2.1 Hazard assessment

The primary focus of the hazard assessment in the CLIMAAX heatwave workflow is to quantify the occurrence of heatwaves in the present and future under different climate change scenarios. In this context, two different methodologies for estimating heatwaves are proposed: Euro Heat and XCLIM. Both of these methodologies are based on the EURO-CORDEX climate projection data, which have a resolution of 12 x 12 km and are available on the Copernicus Data Store (Table 2-2). Considering that there is no universally accepted definition of a heatwave (Conti et al., 2022) and aiming to conduct a comprehensive hazard assessment, the CARE_X team chose to apply both methodologies.

It is noted that, for the XCLIM methodology, given the lack of a universally or nationally accepted definition for heatwaves, the CARE_X team estimated six different heat indicators. Initially, the annual number of heatwave events (Heatwave Frequency) and the annual number of heatwave days (Total Heatwave Days) were estimated based on a definition suggested by the Hellenic National Meteorological Service (HNMS) a few years ago[1]. According to this definition, a heatwave occurs when the daily maximum temperature is equal to or exceeds 39 °C, and the daily minimum temperature remains above 26 °C for at least three consecutive days.

Next, in line with previous studies (Founda & Santamouris, 2017; Founda et al., 2019), the CARE_X team defined a heatwave as a period of at least three consecutive days with daily maximum temperatures exceeding the 95th percentile of the summer period of 1971–2005. Based on this definition, the annual number of heatwave days (Heatwave Index) was estimated for the total period under study (1971-2100). Similarly, the annual number of days and the maximum number of consecutive days per year with daily maximum temperatures exceeding the 95th percentile threshold were calculated. Finally, for the periods 1971–2005 and 2006–2100, the annual number of warm days was estimated, defined as days with daily maximum temperatures exceeding the 90th percentile of each period. It is highlighted that, since the estimated results depend on the GCM-RCM combination of climate models, the CARE_X team performed XCLIM-based analyses for several combinations (*Supplementary material:* Table **S**1) to assess the extent to which the results are dependent on the model selection.

Considering that the EURO-CORDEX data are coarse, all plots created with the EuroHEAT and XCLIM methodologies were centered around the city of Xanthi (latitude: 41.14, longitude: 24.89). Figure 2-7 displays the results from the EuroHeat methodology. The frequency of heatwaves exhibits an increasing trend over time. Specifically, the annual number of heatwaves is expected to almost triple by 2070 under both scenarios, while under RCP8.5, it is expected to increase fivefold by 2100.

[1] http://intranet.emy.gr/emy/el/pdf/heatwave_2021.pdf, accessed on March 7, 2025

Comparing the results of the two scenarios, significant differences are observed from the middle of the century and onwards, as expected.

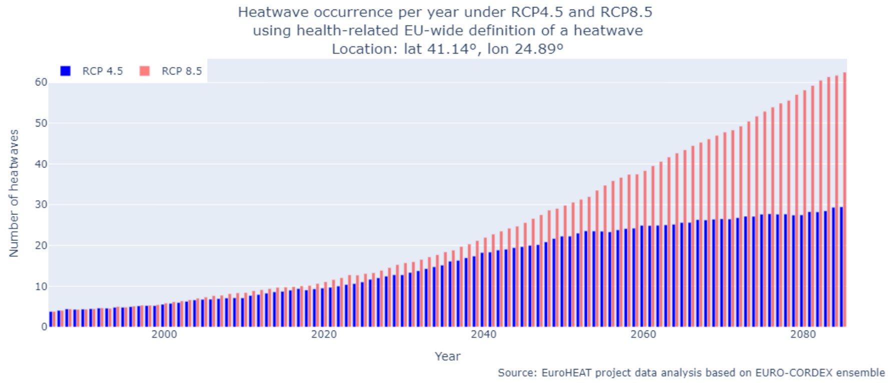

Figure 2-7 The annual heatwave occurrence in the municipality of Xanthi for 1986-2085 under the RCP4.5 and RCP8.5 scenarios using the EuroHEAT methodology.

Results from the XCLIM methodology, under the two scenarios up to 2100 are included in the supplementary material (Figures **S**1 - **S**4). In agreement with the EuroHEAT results, the frequency of heatwaves and hot days is expected to increase by the end of the century, especially under the RCP8.5 scenario. For example, considering the Heatwave Index under RCP8.5, the number of heatwave days will double from 2070 onwards. Moreover, it is evident that the definition of heatwaves or heat indicators used strongly influences the findings. For example, under the HNMS definition, the number of heatwave days is much lower than those based on percentiles. This highlights the importance of selecting the appropriate heatwave definition for the region under study. Finally, comparing the results from the different GCM-RCM combinations (Figures **S**1 - **S**4), it appears that despite some variations, the results generally follow the same trend.

2.3.2.2 Risk assessment for heatwaves based on satellite-derived data

The primary goal of the heatwave risk assessment based on satellite-derived data is to identify heat islands in the urban environment and explore the spatial distribution of the vulnerable population. The final output is a heatwave risk map that combines information on the overheated areas within the region of interest with information on the density of the vulnerable population groups. The necessary data include satellite-derived Land Surface Temperature (LST) for the summer period (June to August, 2013-2024), based on the Landsat8 land surface temperature (spatial resolution: 30 x 30 m), available on the Remote Sensing Lab (RSLab) portal, and 2020 vulnerable population data, from the WorldPop dataset, available from the Humanitarian Data Exchange (HDX) portal (Table 2-2).

At first, the CARE_X team implemented the heatwave risk assessment methodology across the entire municipality of Xanthi. It appeared that the most problematic areas are located in the city of Xanthi (Figures **S**5, **S**6). This was not surprising, as most of the population is concentrated in the city of Xanthi, where, due to the Urban Heat Island effect, temperatures are higher compared to the surrounding areas. Therefore, our risk assessment focused on the city of Xanthi. Following the workflow, the CARE_X team classified the Land Surface Temperatures into five categories (Very Low: < 20-25°C, Low: 25-35°C, Medium: 35-45°C, High: 45-55°C, Very High: 55-60°C), and divided the vulnerable population data into five categories (Very Low to Very High) based on relevant population density. Figure **S**7 illustrates the results, highlighting the most overheated areas and the regions with the highest concentration of vulnerable population.

The level of heat exposure and the density of the vulnerable population groups were combined in a 10x10 risk matrix, as described in the workflow, to assess the severity of potential risks associated with the heatwave hazard. These estimations, combined with information on the location of critical infrastructure in Xanthi, including hospitals, nursing homes, and elderly care homes (Table **S**2), were used to create the heatwave risk map depicted in Figure 2-8. The risk map presents areas at the highest risk, where high temperatures coincide with high density of vulnerable population (based on age), indicating the most significant potential impact. It reveals that the city of Xanthi exhibits the highest risk, likely due to the Urban Heat Island effect and high population density. Moreover, it is apparent that critical infrastructures, including an Elderly Care Center, a Nursing Home, and the General Hospital of Xanthi, face medium to high risk levels. These findings, in combination with the continuously increasing trend of heatwave frequency, particularly after 2040, highlight the urgent need for targeted mitigation strategies. Considering that the population distribution has changed (as the data used here are from 2020) and given the projected increase in the proportion of the elderly in Greece (Lamnisos et al., 2021), the situation may be even more critical in the future than estimated here.

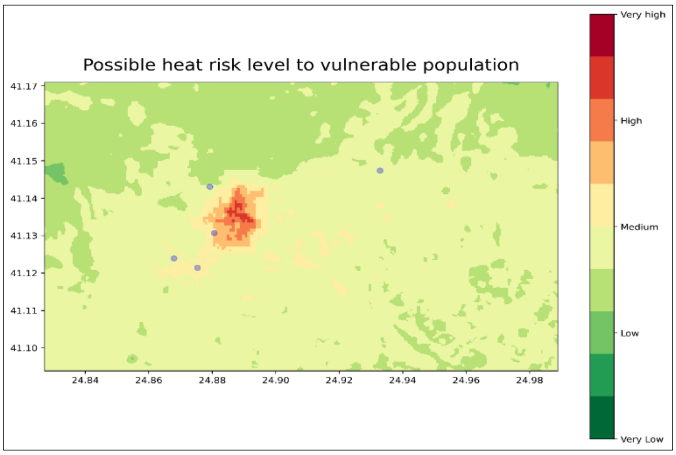

Figure 2-8 Heatwave risk map depicting the most overheated areas, the most densely populated areas with

2.3.2.3 Risk assessment for heatwaves under climate change

The main goal of the heatwave risk assessment under climate change is to identify areas within a chosen region that concentrate the highest proportion of vulnerable population groups and experience the greatest changes in heatwave occurrence for both the near future (2016-2045) and the further future (2046-2075) compared to a reference period (1986-2015), under the RCP4.5 and RCP8.5 scenarios. For this purpose, heatwave days data prepared by the EuroHEAT project and 2020 vulnerable population data from the WorldPop dataset are required (Table 2-2). However, the coarse resolution of hazard data (12×12 km) makes them inappropriate for separately studying the various subregions of the municipality of Xanthi. Considering that funding and decisions related to mitigation and adaptation measures and strategies are often made at the peripheral level, the CARE_X team chose to study the municipality of Xanthi as part of the wider REMTh prefecture.

Following the CLIMAAX workflow, the relative change in heatwave occurrence was estimated for all municipalities that comprise REMTh. In addition, the magnitude of change in the heatwave occurrence was assessed by reclassifying the relative change data into 10 equal interval classes (1-very low change, 10-very high change). According to the results obtained, the most significant differences in the heatwave frequency among the REMTh municipalities were observed during the period 2046-2075, under RCP8.5. Then, the municipalities under study were classified into 10 categories (1-very low, 10-very high) by comparing the density of their vulnerable population. The municipality of Xanthi exhibited high concentrations of vulnerable population groups compared to the other municipalities examined. All relevant plots are presented in the Supplementary Material (Figures **S**8 - **S**10).

Finally, the heatwave risk was estimated by combining the projected magnitude of change in heatwave occurrence for both the near future (2016–2045) and the further future (2046–2075) under the RCP4.5 and RCP8.5 scenarios, with the concentration of vulnerable population data, as described in the workflow. The estimated risks reflect the projected increases in the heatwave risk to vulnerable population groups within the prefecture of REMTh. As shown in Figure 2-9, the municipality of Xanthi presents a higher risk compared to the other municipalities of REMTh, under all scenarios examined. Specifically, it is classified as a medium-risk region for all time periods studied under RCP4.5 and for the near future under RCP8.5, and as a high-risk region for the period 2046-2075. These results can help local authorities prioritise prevention, mitigation, and adaptation strategies, ensuring appropriate funding allocation.

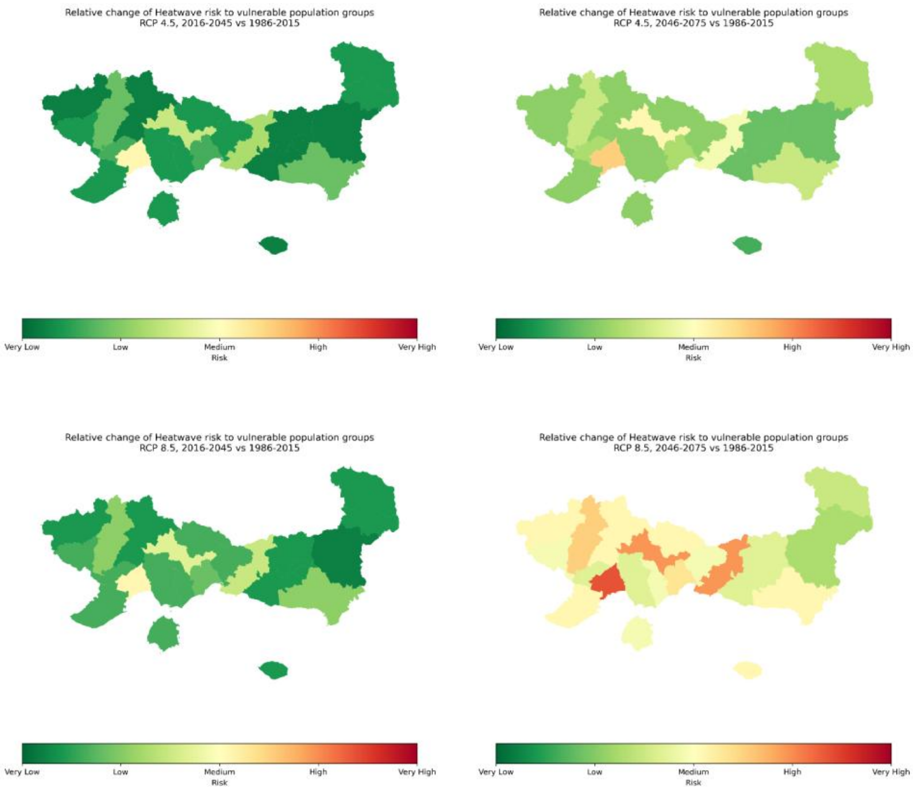

Figure 2-9 Heatwave risk map for the municipalities of REMTh reflecting the projected magnitude of change in heatwave occurrence under the RCP4.5 and RCP8.5 scenarios, combined with the distribution of vulnerable population groups.

2.3.3 Workflow #3: Fluvial Flooding

The Kosynthos River, with a length of approximately 52 km, flows through the city of Xanthi and is considered to be an important socio-economic element for the region, as it passes close to many rural and agricultural areas before discharging into the Vistonis Lagoon in the southeast of the Regional Unit of Xanthi (Figure 2-10) (Ntislidou et al., 2012). In the past, Xanthi has experienced severe fluvial flooding incidents due to heavy rainfall events upstream of the city, resulting in structural damage to many buildings. In addition, a flooding incident of the Kosynthos River caused by extreme rainfall in 1996, resulted in the death of 3 people. It is therefore imperative to be able to assess the future risk of such events that may affect the Xanthi region, and to take preventive measures to protect the citizens and their properties.

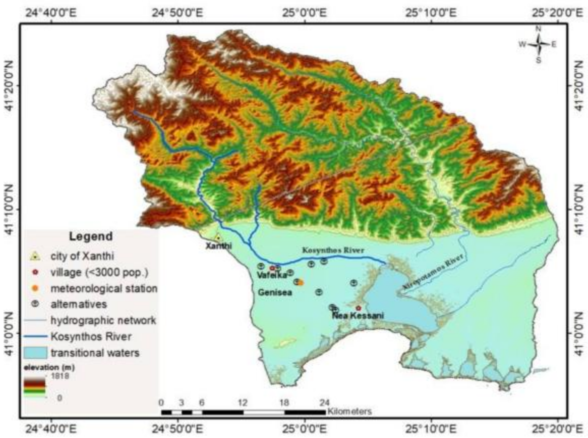

Figure 2-10 Map of Kosynthos River (adopted from Papadopoulos et al., 2022)

Table 2-3 Data overview workflow #3 Fluvial Flooding

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Aqueduct Floods coarse-resolution flood maps - dataset of future river flood potential under climate change / 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.*

2.3.3.1 Hazard assessment

To assess the fluvial flood hazard for the city of Xanthi, the workflow from the CLIMAAX handbook was followed in conjunction with the use of two flood datasets. Specifically, the hazard assessment was carried out by analyzing the Joint Research Centre's (JRC's) high-resolution flood maps in order to investigate the flood extent for different events with different return periods (10, 50, 100, 200 and 500 year return periods). In addition, the coarse resolution flood maps from Aqueduct Floods were also utilized to investigate the impact of climate change on river flood hazard; these are depicted in Table 2-3. Our study area includes the city of Xanthi and its suburbs, as Figure 2-11 shows.

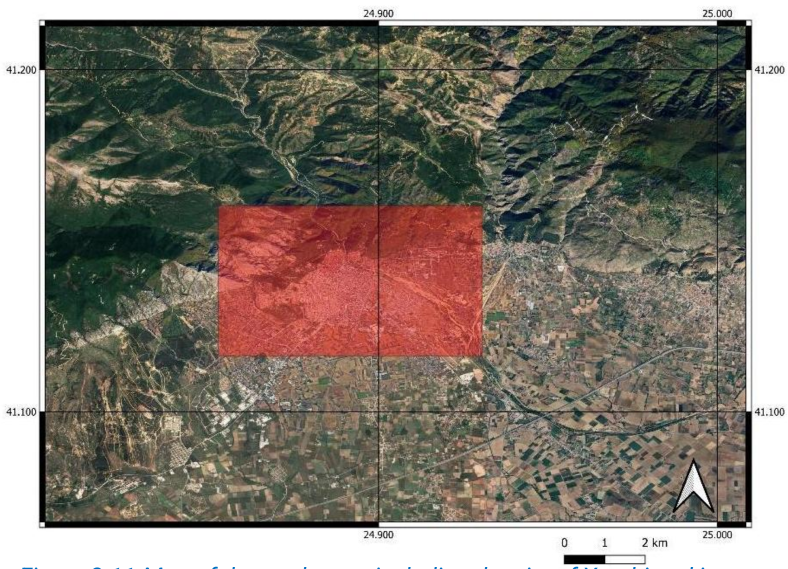

Figure 2-11 Map of the study area including the city of Xanthi and its suburban area (red rectangle)

Using the JRC dataset, the flood potential of the Kosynthos River during extreme events was estimated for the five different return periods, considering 2018 as the present-day scenario (Figure 2-12 and Figure **S**11 in the Supplementary material). For all return periods, the maximum values of inundation depth were found at the upper part of the city (8-13 m), while lower but still significant values were observed inside the urban web and in the southern part of Xanthi. These results demonstrate the importance of the flood risk assessment study for the selected region.

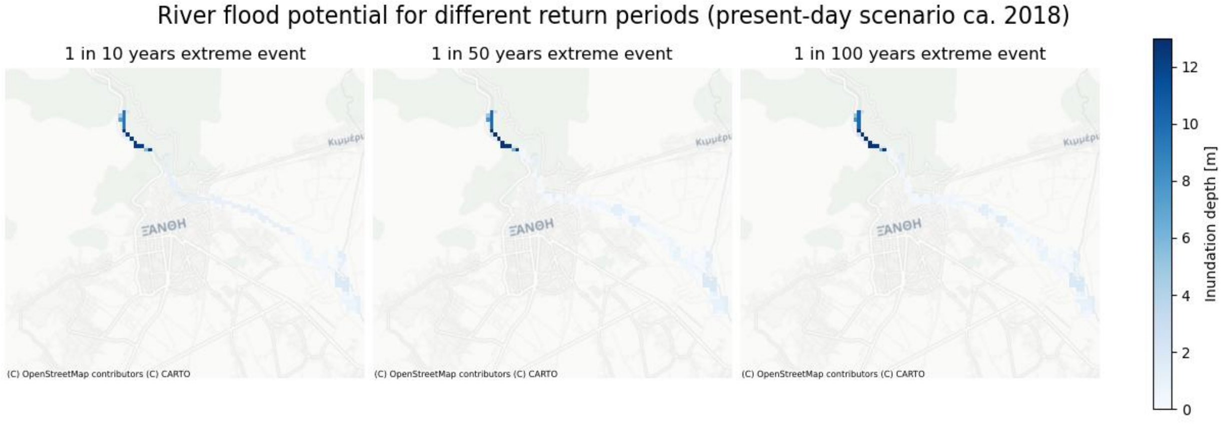

Figure 2-12 Inundation depth of the Kosynthos River for 10, 50, and 100 extreme event return periods.

To investigate the impact of climate change on river flood risk, the Aqueduct flood maps were also used as a means of qualitatively indicating the impact of climate change on extreme river discharges that lead to flooding. Specifically, we used the 1980 Aqueduct flood map with a return period of 1 in 250 years. Unfortunately, we didn't get any results (Figure **S**12). The reason for this is probably the coarse spatial resolution of the Aqueduct data (30 arc seconds) and the small riverbed of the Kosynthos River. To investigate this aspect, the entire Regional Unit of Xanthi was selected to include two additional large rivers in the area, namely the Nestos River (southwest of Xanthi) and the Kompsatos River (southeast of Xanthi) (Figure **S**13). After repeating the proposed methodology, we retrieved the Aqueduct flood map for the base scenario - ca. 1980 - (Figure **S**14), where we obtained results for the Kompsatos River. This was an indication that the coarse spatial resolution of the Aqueduct dataset and the small riverbed of the Kosynthos River were indeed responsible for the lack of results in our area. This prevented us from continuing our qualitative investigation of how climate change affects the inundation depth of the Kosynthos River during extreme events in Xanthi using the Aqueduct flood maps.

2.3.3.2. Risk assessment

The fluvial flood risk assessment for the city of Xanthi was carried out according to the CLIMAAX methodology. The risk assessment is expressed in terms of economic damage to infrastructure. For this purpose, the JRC land use dataset with a spatial resolution of 100m was implemented for our region in conjunction with the corresponding JRC flood maps and the JRC vulnerability curves. The flood risk assessment is investigated for different return periods (10, 50, 100, 200 and 500 year return periods) and for RCP8.5 for the year 2050. Firstly, a LUISA land cover map was produced showing the different types of land cover (Figure **S**15). In order to assess the potential damage caused by flooding in our different return period scenarios, we assigned a monetary value (potential loss in €/m²) to the land use categories. To calculate this, we used the GDP per capita for our region

(11,900 euros) and updated the LUISA_damage_info_curves.xlsx file that was available on the CLIMAAX GitHub. Then, the vulnerability curves for the different types of residential, commercial and industrial structures were generated for RCP8.5 (Figure **S**16). Our investigation showed that the percentage of damage increases with increasing inundation depth for all considered building types. In order to get a spatial view of which locations can potentially be most economically affected depending on the different return periods, we produced flood maps with the associated economic damage maps for each scenario (Figure 2-13 and Figures **S**17-**S**20).

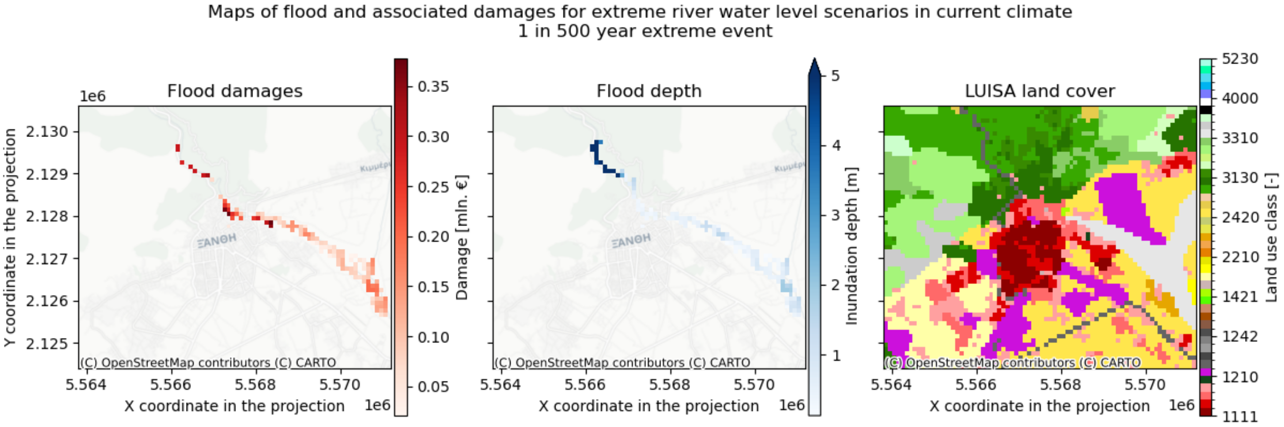

Figure 2-13 Flood and associated damages maps over Xanthi for RCP 8.5 and extreme event return period of 500 years.

From our analysis, we found that the maximum economic damages in Xanthi are observed for the extreme event return period of 500 years, as the inundation depth covers a wider area of the urban web, without neglecting the effects of flood events at other return periods.

These results appear reasonable for the city of Xanthi; however, the use of an updated land cover product and/or a higher spatial resolution flood dataset would likely provide more accurate results. In Phase 2 of the project, we plan to utilize these products, either by applying statistical downscaling methods to the JRC flood dataset or by utilizing an updated high-resolution DEM and land cover dataset provided by the CARE-X team, to achieve more accurate predictions of fluvial flood events.

2.3.4 Workflow #4 Wildfires

The Mediterranean ecosystem stands out as a globally recognized biodiversity hotspot, celebrated for its extraordinary variety of plant and animal life (Siachalou, et al., 2008). However, its forests are under growing threat from catastrophic wildfires, with approximately 50,000 fires erupting annually, scorching 1.3-1.7% of the region's total forested area. Greece, in particular, ranks among Europe's hardest-hit nations. In 2023, wildfires ravaged over 1.8 million acres of Greek forestland, underscoring the severity of the crisis.

The region's extreme climate—marked by intense heat, dry air, and gusty winds—creates ideal conditions for fires to ignite and spread rapidly. To mitigate the mounting ecological toll of these blazes, national forest policies require an urgent overhaul, with a sharp focus on fire prevention, especially in ecologically vital woodlands. The cornerstone of this effort lies in weaving a robust fire management system into land-use planning, built on four key principles: prediction, preservation, response, and restoration (Siachalou, et al., 2008). Pinpointing high-risk zones is crucial for predicting potential fire outbreaks, while preservation relies on utilizing advanced tools and techniques, such as those offered by the Climaax framework. A compelling case study emerges from the Prefecture of Xanthi in Greece, where the Climaax methodology, tools, and data have been applied in the area shown in Figure 2-14 . This region, renowned for its dense forests and scattered settlements, exemplifies the challenges it faces. Local communities rely on these woodlands for their livelihoods and draw tourists with diverse recreational offerings, resulting in frequent human presence that amplifies wildfire risk. By tailoring fire management strategies to areas like Xanthi, where ecological value and human activity intersect, efforts to protect vulnerable forests can be both targeted and effective, offering a model for broader Mediterranean conservation.

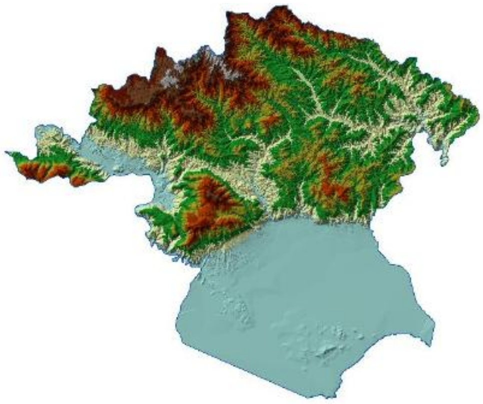

Figure 2-14 The Wildfire study area.

The Climaax framework integrates two advanced strategies for wildfire management: Machine Learning-Based Hazard Mapping and the Fire Weather Index (FWI). The former employs machine learning algorithms to identify high-risk zones by analyzing complex datasets, such as vegetation, topography, and historical fire patterns, while the latter assesses meteorological factors—temperature, humidity, wind speed, and aridity—to provide a daily fire risk index based on conditions conducive to ignition and spread. However, the machine learning approach's accuracy hinges on the quality and volume of training data (Barbierato et al., 2024), and in our case, the scarcity of wildfire data resulted in preliminary findings that underestimated the true fire hazard. To tackle this challenge, we are partnering with the Xanthi municipality to develop a proactive plan. This initiative will enrich the critical dataset needed to refine the machine learning methodology, enhancing its reliability and effectiveness.

2.3.4.1. Hazard assessment

The Climaax methodology for wildfire risk description, as detailed in the FWI Risk Description workflow, focuses on assessing and communicating fire risk through a systematic, data-informed approach. It starts by collecting and processing key datasets, including meteorological conditions, vegetation types, and topographic features, to build a robust foundation for risk analysis. Central to this process is the Fire Weather Index (FWI), which quantifies daily fire danger based on weather parameters such as temperature, humidity, wind speed, and dryness, offering a dynamic measure of ignition potential and fire behavior.

The methodology then evaluates risk by integrating these FWI outputs with additional factors like human presence, land use patterns, and ecological sensitivity, producing a comprehensive risk profile. This profile is visualized through spatial risk maps and enriched with descriptive statistics, highlighting areas of heightened vulnerability. Designed to be region-specific, such as for the Xanthi Prefecture, this approach not only identifies where and when fires are most likely to occur but also informs stakeholders about the underlying drivers, enabling targeted prevention and management strategies without relying on complex coding implementations. The schematic representation of the methodology, along with the danger, hazard, and vulnerability data used, is presented in Figure 2-15.

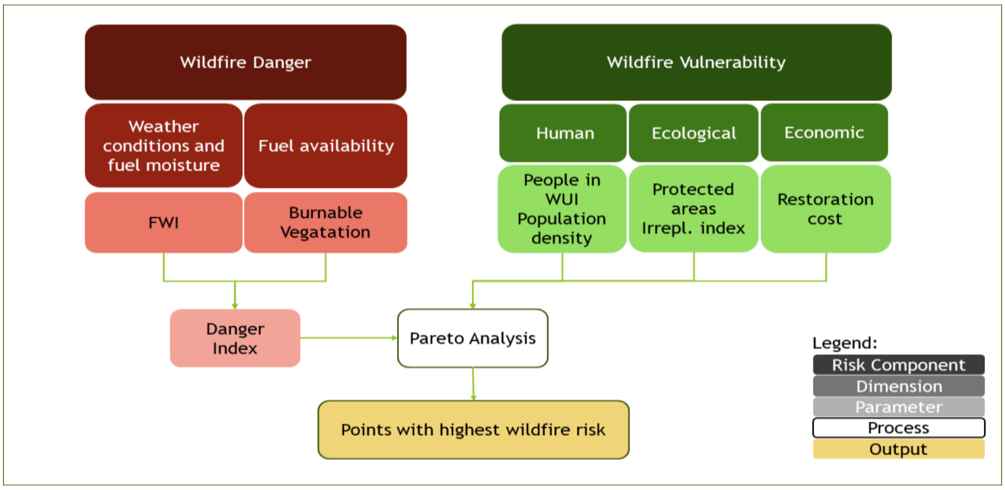

Figure 2-15 Schematic representation of the methodology

The seasonal Fire Weather Index (FWI) data, sourced from the Copernicus Climate Data Store, reflects the average fire weather index across Europe's fire season, spanning June to September. This value is derived by summing the daily FWI values over this period and dividing by the total number of days within that timeframe. Available in five-year increments, the seasonal FWI data in our study area includes the periods 2046-2050 and 2051-2055. Among the four emission scenarios offered—historical, RCP2.6, RCP4.5, and RCP8.5—we opted for RCP2.6. To ensure the greatest reliability, we chose the multi-model ensemble mean as the projection source. For comprehensive analysis (see Figure 2-16 and Figure **S**21in the supplementary material).

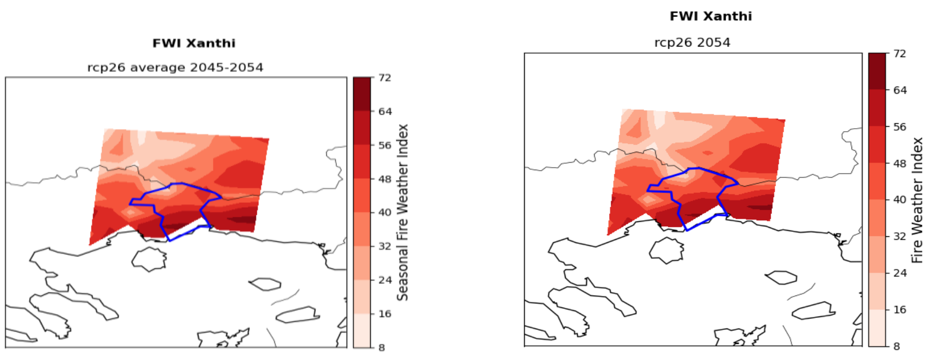

Figure 2-16 Seasonal Fire Weather Index RCP 2.6 (The left image depicts the average for the years 2045–2054, while the right image pertains to the year 2054.)

To investigate the impact of climate change on wildfire, we selected the 'best', 'worst', and 'mean' case scenarios for both the historical data and RCP8.5, enabling a thorough comparison of fire risk outcomes across diverse emission trajectories and severity levels. (FWI threshold**>**30). The worst- and best-case scenarios are obtained, respectively, by summing and subtracting the inter-model and inter-annual standard deviations of the fire weather season from the mean (Figure 2-17).

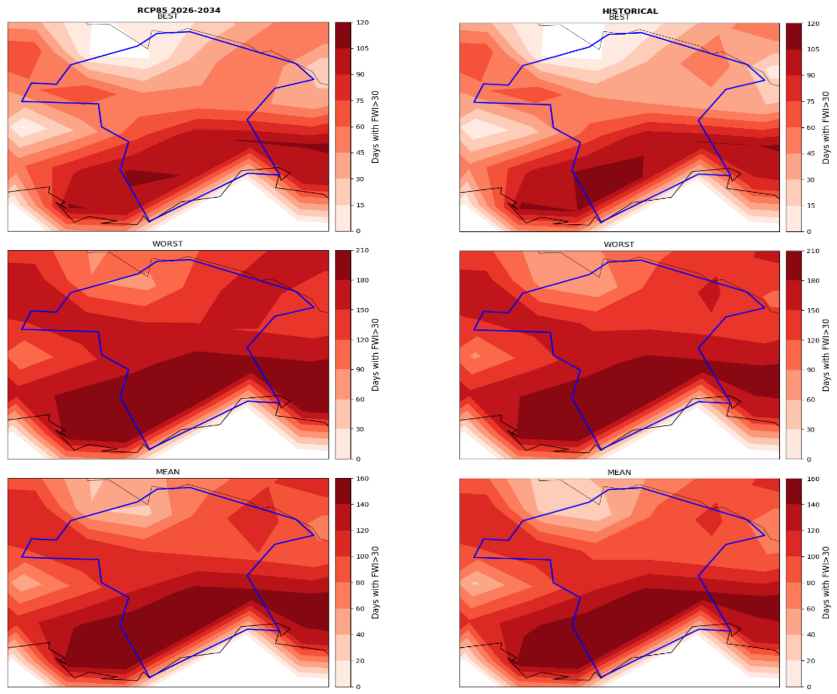

Figure 2-17 FWI worst, mean and best scenario (the left column depicts rcp 8.5 for the years 2026-2035, while the right column illustrates historical data)

2.3.4.2 Risk assessment

Wildfire risk is defined following the approach of the European Forest Fire Information System (EFFIS), characterizing it as the combination of wildfire danger and vulnerability (Jacome Felix Oom et al., 2022). The wildfire danger is first calculated as the combination of Koks climatic danger, represented here by the seasonal FWI, and fuel availability, which is determined by the abundance of burnable vegetation. The FWI data was initially refined by excluding non-flammable areas, as defined by EFFIS, using the ESA-CCI Land Cover dataset to eliminate bare regions. Next, fuel availability is assessed by employing the percentage of burnable vegetation as a proxy, where a higher proportion indicates increased fuel availability, thereby elevating the risk of fire ignition and spread. The burnable area dataset, sourced from EFFIS, covers the entire European domain and is reprojected and interpolated to align with the coordinate system and resolution of the FWI dataset for seamless integration. Subsequently, by combining the climatic and fuel danger components, a wildfire danger index is generated.

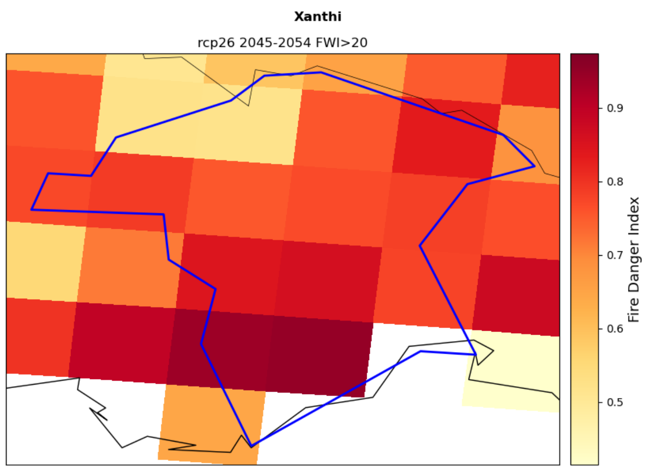

Figure 2-18 Fire danger index rcp2.6

This index is created by normalizing the climate and fuel datasets using the min-max method, followed by averaging them with equal weights assigned to each component, ensuring a balanced representation of both factors. (Figure 2-18 and Figure **S**22). The wildfire vulnerability assessment outlined in the JRC report (Jacome Felix Oom et al., 2022) employs a set of carefully selected indicators to evaluate risk across European regions. These include the Population living in the Wildland Urban Interface, which measures the proportion of people residing in peri urban zones adjacent to forests or vegetated areas, highlighting human exposure to fire-prone landscapes. The Protected Areas distribution indicator quantifies the percentage of each map pixel encompassed by protected natural areas, reflecting their susceptibility to ecological damage. The Ecosystem Irreplaceability Index captures the unique and intrinsic value of ecosystems within each pixel, emphasizing areas where biodiversity loss would be particularly irrecoverable. Population Density provides insight into the concentration of people potentially affected by wildfires, while the Ecosystem Restoration Cost Index estimates the relative cost of restoring land damaged by fire, offering an economic perspective on vulnerability. Together, these indicators form a multidimensional framework for assessing wildfire risk and informing targeted mitigation strategies. (Figure **S**23).

The danger indicator is integrated with vulnerability parameters using a Pareto analysis algorithm, which pinpoints areas within the region that exhibit the highest scores for both danger and vulnerability (see Figure 2-18). This method introduces a key innovation: it empowers users to independently select which vulnerability parameters to include in the risk assessment, allowing them to focus on the most relevant risks—whether human, ecological, or economic. Additionally, this flexible approach enables users to incorporate other vulnerability indicators tailored to their regional needs, seamlessly embedding them into the assessment process.

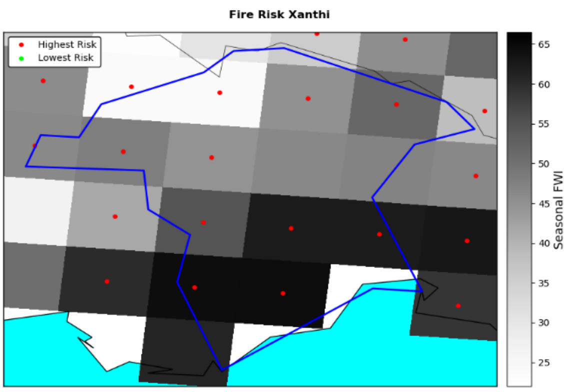

Figure 2-18 Fire risk

In the upcoming phases of the research, priority is given to the validation of the model using real data from past wildfires, ensuring the accuracy and reliability of its predictions. Concurrently, the acquisition of new data is planned. These will enrich the dataset, providing a comprehensive view of the study area. Following this, the application of the machine learning model will take place, which will be retrained with the new data to enhance its ability to predict fire risk. Special emphasis is placed on collaboration with stakeholders such as the municipality, fire department, and civil protection through scheduled meetings. These are essential for determining the degree of participation and the weight of each factor in the final risk map, leveraging local knowledge and experience to optimize the results.

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

The risk analysis carried out during Phase 1 revealed significant exposure and vulnerability to four climate-related hazards in the Municipality of Xanthi: windstorms, river flooding, heatwaves, and wildfires.

- **Heatwaves** are projected to increase significantly in frequency and intensity under both RCP4.5 and RCP8.5 scenarios, with urban zones—particularly the city center—exhibiting high

land surface temperatures and a dense concentration of vulnerable populations. The Urban Heat Island effect exacerbates this risk.
- **River flooding** along the Kosynthos River, particularly for 100- and 500-year return period events, shows the potential for high inundation depths (up to 13 meters in some areas), threatening infrastructure and residential areas in the northern parts of Xanthi.
- **Windstorms**, while historically infrequent, show localized high-intensity potential. The 2020 "Ifestionas" event exceeded damage thresholds, highlighting vulnerabilities in the urban built environment under more extreme storm conditions.
- **Wildfires** pose a growing threat due to increased drought conditions and the proximity of forested areas to settlements. High-risk zones were identified using the Fire Weather Index (FWI), particularly in peri-urban areas.

Taken together, the risk severity is highest for heatwaves and flooding due to their broader spatial impact, recurring nature, and interaction with vulnerable population centers. Wildfires and windstorms represent more localized but still critical risks.

2.4.2 Urgency

The urgency of addressing these hazards varies:

- **Heatwaves** require **immediate action**, particularly due to their projected sharp increase after 2040 and current observed vulnerabilities in urban heat exposure. These are **slow-onset hazards**, allowing for phased interventions but requiring proactive planning.
- **River flooding**, driven by climate-induced changes in precipitation and hydrological behavior, necessitates **medium-term interventions**, with planning required now to mitigate future extreme events. These are **sudden-onset hazards** with potentially catastrophic consequences.
- **Windstorms** remain less frequent but highly impactful during rare events. As **sudden-onset hazards**, they necessitate short-notice preparedness, including updates to building codes and emergency response coordination.
- **Wildfires** are likely to become more frequent and severe in the **near to medium term**, especially in dry summer periods. As **rapid-onset hazards**, they demand pre-season prevention planning, community awareness, and emergency readiness.

2.4.3 Capacity

Current climate risk management capacity in Xanthi reflects mixed levels of preparedness:

- **Institutional and human capacity**: The Civil Protection Office, in collaboration with RiskAC, demonstrates strong technical expertise and planning capacity. However, municipal staffing and resources are limited relative to the complexity of the risks.
- **Physical capacity**: Existing infrastructure (e.g., flood defenses, emergency shelters) is insufficiently adapted for future risk levels. Cooling centers and firebreaks are either limited or absent.

- **Social and natural capital**: Community awareness is increasing but varies across socioeconomic groups. Natural ecosystems near urban areas (e.g., forests, rivers) could play a more prominent role in risk mitigation with appropriate conservation strategies.

Opportunities emerging from this process include:

- Accessing EU-level funding and technical assistance for infrastructure upgrades.
- Enhancing public engagement and education around climate risks.
- Strengthening collaborations between academic, municipal, and civil society actors.
- Promoting nature-based solutions such as urban greening and forest management.

2.5 Preliminary Monitoring and Evaluation

From Phase 1 of the climate risk assessment, several key lessons emerged:

- The **CLIMAAX workflows proved effective** in supporting standardized assessments of hazard, exposure, and vulnerability.
- The **most significant challenges** included limited resolution of some datasets (e.g., Aqueduct flood maps for small riverbeds), and lack of up-to-date local land cover and socioeconomic data.
- **Data integration** for wildfires was constrained by low availability of past fire event records, limiting the strength of machine learning-based mapping.

Stakeholder feedback emphasized the need for clearer visualization tools and localized outputs. The involvement of **additional stakeholders**, notably from the health sector, education, and local NGOs, will be prioritized in the next phase to broaden societal reach and validation.

New datasets anticipated in Phase 2 include:

- High-resolution digital elevation models (DEMs) and updated land use maps.
- Gridded meteorological observations for more accurate local wind and fire hazard assessment.
- Updated demographic and health vulnerability data to enhance social impact modeling.

Continued technical support from RiskAC and broader stakeholder participation will be key in refining and operationalizing the CRA outcomes in the forthcoming phases.

3 Conclusions Phase 1- Climate risk assessment

Phase 1 of the CARE_X project focused on four key hazards—heatwaves, river flooding, windstorms, and wildfires—using the standard workflows available in the CLIMAAX Toolbox. The findings provide a critical starting point for further analyses and form a robust basis for subsequent phases of the project. This section summarizes the main conclusions, highlights the challenges already addressed, and underscores the gaps that remain to be tackled.

3.1 Main Findings

1. **Heatwaves**

- The assessment identified a pronounced upward trend in both the frequency and severity of heatwaves, particularly under higher-emission scenarios, such as RCP8.5.
- The Urban Heat Island effect intensifies heat impacts within Xanthi's city center, raising concerns for public health, especially among elderly residents and young children.
- The initial screening indicates a need for targeted adaptation measures, including improved cooling infrastructure and community outreach to vulnerable populations.

2. **River Flooding (Kosynthos River)**

- Flood hazard maps derived from high resolution Datasets (e.g., JRC flood maps) showed potential inundation zones within the municipality, particularly in more extreme return period scenarios (100 to 500 years).
- The highest inundation depths are observed in areas near the northern part of the city and along specific sections of the Kosynthos River, underscoring the need for enhanced flood defense measures and effective land-use planning.
- Critical infrastructures, such as roads and public service buildings, were confirmed as being exposed to flood risk.

3. **Windstorms**

- Historically recorded (preconfigured in the CDS database) windstorms which pass from South Europe showed minimal threat to Xanthi; however, a local windstorm event scenario retrieved from the low-resolution ERA5-based datasets, revealed pockets of higher vulnerability, especially for less resilient facilities and land-use types.
- Although the overall risk appears comparatively lower than for other hazards, unexpected local events—such as short-lived tornadoes— may warrant contingency planning for structural integrity and emergency response.

4. **Wildfires**

- The wildfire risk workflow combined climate projections with land-cover data (fuel availability) to pinpoint high-risk forested areas, especially at the urban-forest interface.
- Projected increases in seasonal dryness and temperature can exacerbate the likelihood of ignition, reinforcing the importance of early detection systems and preventive measures to mitigate catastrophic wildfire outbreaks.

3.2 Challenges Addressed

Initial Multi-Hazard Prioritization: This phase successfully established which hazards, out of the broader spectrum, warrant closer attention based on city- and region-specific considerations. **Methodological Consistency**: By strictly following the CLIMAAX CRA workflows and using standardized datasets, Xanthi's Phase 1 analysis is fully compatible with the overarching CLIMAAX framework, laying a consistent foundation for future phases.

3.3 Outstanding Issues and Next Steps

Phase 1 has set the groundwork for a deeper understanding of climate risks in Xanthi, enabling targeted efforts to reduce vulnerabilities and prepare for expected impacts. While the coarse-resolution approach of this initial assessment inevitably leaves specific knowledge gaps, the upcoming phases will address these gaps by leveraging more granular data, sophisticated modeling, and expanded stakeholder participation. A brief description of the next steps follows.

High-Resolution Local Data: The absence of local, high-resolution data (e.g., detailed topographical maps, building-specific vulnerabilities) limits the precision of some hazard estimations. Phase 2 will incorporate refined datasets to improve modeling accuracy and adaptation measures.

Integrated Socioeconomic and Demographic Analyses: Although the project identified vulnerable groups, a more detailed socioeconomic and demographic profile of impacted neighborhoods is needed to strengthen community-level intervention strategies.

Cross-Sector Collaboration: The next stages should deepen engagement among municipal authorities, the private sector, and civil society to develop tailored risk reduction actions and ensure broad support for adaptation measures.

Monitoring and Evaluation Framework: The city currently lacks a formal mechanism to track the progress of implementation and evaluate the effectiveness of climate adaptation actions over time. Future phases must formalize performance indicators and review processes.

4 Progress evaluation and contribution to future phases

Phase 1 focused on the comprehensive application of the CLIMAAX Climate Risk Assessment (CRA) methodology, delivering a preliminary risk baseline for the Municipality of Xanthi. During this Phase, two critical milestones were achieved, as these were defined in the SUB-GRANT AGREEMENT between the CLIMAAX Consortium and Municipality of Xanthi (See Table 4-1).

Table 4-1 Overview of milestones

Milestones	*Progress*
M1 Initial stakeholder workshop conducted (Phase 1)	*Achieved in December 2024*
M2: Workflows for all relevant hazards established and customized (Phase	*Achieved at the end of Phase 1*
M3 Refined risk analysis for each hazard completed (Phase 2)	-
M4 Knowledge transfer sessions between the Research Centre and Civil Protection Office conducted (Phase 2)	-
M5 Existing risk management plans updated (Phase 3)	-
M6 Multi-hazard climate event preparedness exercise executed (Phase 3)	-
M7 Attend the CLIMAAX workshop held in Barcelona (May 2025)	-
M8 Attend the CLIMAAX workshop held in Brussels (December 2026)	-

- **M1: initial stakeholder workshop:** The initial stakeholder workshop was conducted on the 16th of December 2024. This workshop brought together local authorities, civil protection representatives, and academic experts to discuss the scope, data requirements, and expected outcomes of the risk assessment. The workshop not only fostered collaboration and ensured that local needs were captured, but it also established clear channels for continuous stakeholder engagement.

- **M2: Customized workflows for all relevant hazards were established.** The project team successfully applied and adapted the CLIMAAX methodologies for the four targeted hazards (windstorms, heatwaves, fluvial flooding, and wildfires) using a combination of CDS-based data and ERA5 reanalysis products. These customized workflows have produced initial risk maps, vulnerability assessments, and damage estimations that serve as the project's baseline.

In addition to these milestones, Phase 1 achieved one key performance indicator (KPI) integral to the overall project's success: the completion of risk assessments for two identified hazards. Furthermore Phase 1 contributed to the partial completion of the following KPIs as these were defined in the SUB-GRANT AGREEMENT between the CLIMAAX Consortium and Municipality of Xanthi, namely 3 stakeholder workshops throughout the project lifecycle (during Phase 1, one workshop was organized) .▪ Achieve at least 3 local media mentions of the project and its findings (one press release was send to the media informing about CLIMAAX and the project with the City of Xanthin in different media) . and ▪ Successfully implement all 5 steps of the CLIMAAX framework (Scoping, Risk Exploration, Risk Analysis, Key Risk Assessment, Monitoring & Evaluation). (See Table 4-2)

Table 4-2 Overview of key performance indicators

Key performance indicators	*Progress*
Complete risk assessments for 2 identified hazards.	*Completed*
Conduct at least 3 stakeholder workshops throughout the project lifecycle.	*One was conducted in December 2024 between RiskAC the Mayor of the City of Xanthi and representatives of the Civil Protection Office of the city of Xanthi, with the vice Mayor of the Civil Protection*
Engage a minimum of 10 local stakeholders representing different sectors (e.g., government, academia, civil society, vulnerable groups).	-
Successfully integrate at least 4 local datasets into the risk assessment process.	-
Produce at least 1 comprehensive risk map for each assessed hazard.	-
Identify at least 5 potential adaptation measures or policy recommendations based on the risk assessment results.	-
Train at least 10 local officials or stakeholders in the use and interpretation of risk assessment tools and their results.	-
Organize at least 1 public event to present the project results to the wider community.	-
Achieve at least 3 local media mentions of the project and its findings.	*One press release was sent to the media to inform the public about the application of Climaax Tools to the city of Xanthi and of the expected benefits. The press release was published in several media in the region.*
Successfully implement all 5 steps of the CLIMAAX framework (Scoping, Risk Exploration, Risk Analysis, Key Risk Assessment, Monitoring & Evaluation).	*We managed to implement the initial steps of the CLIMAAX framework that accord with the 1st Phase of the project*

Moreover, the outputs of Phase 1 directly inform the planned activities for the following phases. In Phase 2, the focus will shift toward refining these risk assessments by incorporating higher-resolution local data and updating the vulnerability models to reflect localized conditions. Specifically, the milestone for Phase 2 (M3) is the completion of refined risk analyses for each hazard, and M4 is the conduction of knowledge transfer sessions between the Research Centre and the Civil Protection Office. These activities will enhance the precision of hazard modeling and ensure that local decision-makers are well-equipped to interpret and utilize the risk data.

Looking ahead to Phase 3, the refined risk assessments will underpin the formulation and updating of the existing risk management plans (M5). Additionally, a multi-hazard climate event preparedness exercise (M6) will be executed to test and validate resilience strategies. The later phases will also include international engagement, with planned participation in the CLIMAAX workshops in Barcelona (M7, May 2025) and Brussels (M8, December 2026), ensuring that the project aligns with broader European best practices and leverages international expertise.

In summary, Phase 1 has established a strong scientific and operational foundation for the CARE_X project. The achieved milestones (M1 and M2) and the KPIs met during this phase confirm that the initial risk assessments are robust and actionable. These outputs provide the necessary baseline for Phase 2's data refinement and the strategic adaptation planning of Phase 3, ensuring a smooth transition through the project's lifecycle and a significant enhancement in the climate resilience of the Municipality of Xanthi.

5 Supporting documentation

1. Main Report

2. Supplementary Material for the workflows

    a. Heatwaves workflow Supplementary Material

    b. Fluvial Flooding workflow Supplementary Material

    c. Wildfires workflow Supplementary Material

3. Communication Outputs

6 References

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