CLIMAAX
climate ready regions

Deliverable Phase 1 – Climate risk assessment

Viana do Castelo: Climate Action (VC_Climaax)

Portugal, Viana do Castelo Municipality

Version 2.0 | May 2025

HORIZON-MISS-2021-CLIMA-02-01 - Development of climate change risk assessments in European regions and communities based on a transparent and harmonised Climate Risk Assessment approach

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Document Information

Deliverable Title	Phase 1 – Climate risk assessment
Brief Description	The deliverable 1 presents the initial outcomes of the climate risk assessment (CRA) for Viana do Castelo, conducted using the CLIMAAX framework. Phase 1 provided essential insights into the region's vulnerability to climate-related hazards such as floods, wildfires, extreme precipitation and storms. The value of adopting a structured, workflow-based approach to climate risk assessment has been demonstrated, as has the ability to consistently and systematically evaluate the main hazards affecting the region. However, it has also highlighted several challenges that must be addressed to improve the assessment's quality (in terms of accuracy and usability).
Project name	Viana do Castelo: Climate Action
Country	Portugal
Region/Municipality	Viana do Castelo Municipality
Leading Institution	
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		CLIMAAX's FSTP team	Review completed
5.0	...		Final version to be submitted

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Abbreviations and acronyms

Abbreviation / acronym	Description
CMVC	Municipality of Viana do Castelo
CRA	Climate Risk Assessment
DAAC	Environment and Climate Adaptation Division
DGTS	Territorial Management and Sustainability Department
EMAAC	Municipal Climate Change Adaptation Strategy for Viana do Castelo
GIS	Geographic Information Systems
NUTS	Nomenclature of Territorial Units for Statistics
PC	Civil Protection organic unit
PDEPC	Viana do Castelo District Civil Protection Emergency Plan
PGRI	Flood Risk Management Plan
PIAAC do Alto Minho	Alto Minho Intermunicipal Climate Change Adaptation Plan
PMAC	Municipal Climate Action Plan for Viana do Castelo
PMEPC	Viana do Castelo Municipal Civil Protection Emergency Plan
PNGIFR	National Integrated Management Plan for Rural Fires
POC Caminha-Espinho	Programa da Orla Costeira Caminha - Espinho
PT111	Alto Minho
RCP	Representative Concentration Pathway
RH1	Minho and Lima Hydrographic Region
RNA 2100	National Roadmap for Adaptation 2100
RP	Return periods
SSP	Shared Socioeconomic Pathways
SUDS	Sustainable urban drainage systems
Uminho-ICT	University of Minho- Institute of Earth Sciences
VC_Climaax	Viana do Castelo: Climate Action

Executive summary

This document (Deliverable 1) summarises the key results and findings of the first phase of the VC_Climaax project, and highlights the challenges associated with implementing risk analysis methodologies within the municipality of Viana do Castelo in Portugal.

D1 presents the initial outcomes of the climate risk assessment (CRA) for Viana do Castelo, conducted using the CLIMAAX framework. Phase 1 provided essential insights into the region's vulnerability to climate-related hazards such as floods, wildfires, extreme precipitation and storms. The value of adopting a structured, workflow-based approach to climate risk assessment has been demonstrated, as has the ability to consistently and systematically evaluate the main hazards affecting the region. However, it has also highlighted several challenges that must be addressed to improve the assessment's quality (in terms of accuracy and usability).

The most significant achievement of this phase was the successful application of the CLIMAAX workflows to the four primary hazards of interest. The flood hazard assessment produced maps illustrating the extent of river flooding under various return periods. The wildfire workflow generated Fire Weather Index (FWI) maps that clearly show how fire risk is expected to evolve under different climate scenarios. The extreme precipitation workflow showed how rainfall events are becoming more intense under future climate scenarios. The storms workflow provided a simulated analysis of the impacts of a major historical storm (Klaus, 2009). These analyses have laid a solid foundation for understanding the key climate risks facing the district of Viana do Castelo.

The main lessons learned was the importance of maintaining clear, structured workflows for each implemented risk type. The adaptable and dynamic nature of the workflows indicates that the tools can be used in multiple geographical regions and with different types of input data. Using more accurate local data could therefore result in a greater level of detail and refinement of the product (i.e., the next steps of the project).

1 Introduction

1.1 Background

The municipality of Viana do Castelo is located in the north of mainland Portugal, in the NUTS3 Alto Minho (PT111), with an area of approximately 319 square kilometres and a coastline of 24 kilometres. With a resident population of 85,8 (INE, 2021), the municipality has seen a negative demographic trend (-3,2% in 20 years).

The Municipality of Viana do Castelo is responsible for the Civil Protection Service (Law No. 98/2021, of December 31), with competencies in the areas of prevention, risk and vulnerability assessment, planning and support for operations, logistics and communications, awareness and public information.

1.2 Main objectives of the project

The VC_Climaax project aims to make Viana do Castelo a more resilient and less vulnerable territory to climate change, in full alignment with the European Union's Climate Change Adaptation mission. The CLIMAAX project also allows the internal and external technical teams to support each other in defining the best methodologies for climate risk assessment (CRA), planning (Municipality Plans), and monitoring (Climate Action).

The specific objectives of VC_Climaax include:

- contribute to a substantial improvement in the Risk Typification Framework and better decision-making regarding the adaptation strategy and priorities, based on harmonization with the methodology applied by CLIMAAX;
- improve the knowledge, information, and awareness of local civil protection agents and communities about adapting to and mitigating climate risks.
- incorporate the results of the risk and vulnerability assessment into the municipal planning documents, namely the Municipal Emergency and Civil Protection Plan, and present to the different entities that make up the Municipal Civil Protection Commission (stakeholders).

1.3 Project team

The internal team of VC_Climaax project is composed of:

- José Vieira has a degree in Forestry Engineering, a postgraduate degree in Integrated Environmental and Landscape Management, head of the Environment and Climate Adaptation Division (DAAC);
- Maria Elizabeth Matos has a degree in Regional and Urban Planning (DAAC);
- António José da Cruz has a degree in Civil Protection engineering, head of the Civil Protection organic unit (PC);
- Ivone Martins has a degree in environmental engineering, a master’s degree in environmental management and land use planning, training in GIS for socio-environmental applications, and experience in data analysis and management (DGTS).

The scientific team (subcontracted – external support) led by Dr. Renato Henriques, Associate Professor at the University of Minho, Integrated Member of the Institute of Earth Sciences (ICT), specialist in natural risks and climate change.

1.4 Outline of the document's structure

The document begins with the Introduction (background of the project, main objectives of the project, project team, outline of the document). Following the introduction, the core of the document outlines the climate risk assessment (CRA) process (scoping, risk exploration, risk analysis (floods-River floods, wildfires, heavy rainfall, and storms), preliminary key risk assessment findings, preliminary monitoring and evaluation). Finally, the document conclusions of the phase 1, and progress evaluation and contribution to future phases.

2 Climate risk assessment – phase 1

2.1 Scoping

This phase defines the scoping phase of the climate risk assessment defines objectives (desired results of the analysis), context (conditions for implementation) and identifies stakeholders that need to be involved in the project preparation.

2.1.1 Objectives

The CLIMAAX methodological approach is applied, as described in the handbook, following the steps recommended for climate risk assessment and using the toolbox provided, which contains specific data and guidelines for application on a regional/local scale.

The aim is to ensure that all regional/local climate risk assessments funded under the CLIMAAX project have a common configuration for calculating the expected change in terms of risks and impacts, using a common methodological approach. This will allow the results of the assessment to be compared on a regional/local scale at the European level.

The main objective of Viana do Castelo participation in the project (VC_Climaax) is making Viana do Castelo a more resilient and less vulnerable territory to climate change, in full alignment with the European Union's Climate Change Adaptation mission.

In particular, the specific objective:

- The implementation of the framework and access to the CLIMAAX toolbox will contribute to a substantial improvement in the Risk Typification Framework and better decision-making regarding the adaptation strategy and priorities, based on harmonization with the methodology applied by CLIMAAX;
- The participation in the CLIMAAX project will make possible to support the internal and external technical teams in defining the best planning, implementation, evaluation and monitoring methodologies;
- The results of the risk and vulnerability assessment will be incorporated into municipal planning documents, namely the Municipal Emergency and Civil Protection Plan and presented to the different entities that make up the Municipal Civil Protection Commission, etc.;
- The participation in the CLIMAAX project, will improve the knowledge, information and awareness of local civil protection agents and communities about adapting to and mitigating climate risks.

2.1.2 Context

Previous studies and initiatives related to the typification of territorial risks and vulnerabilities, and the preparation of risk maps, identified the risk typologies of greatest interest to explore within the scope of the CLIMAAX project.

Historical records of climate-related events from 2000 to the present allow us to identify the locations at greatest risk and the main consequences of each event.

The following initiatives and plans were considered for identifying needs and priorities:

- History of occurrences/events associated with climate change [to periods: 2000-2020, and 2020 to current moment;
- Risk identification and characterization studies;
- Viana do Castelo Municipal Civil Protection Emergency Plan (PMEPC);
- Viana do Castelo District Civil Protection Emergency Plan (PDEPC);
- Flood Risk Management Plan (PGRI) for the Minho and Lima Hydrographic Region (RH1);
- Climatological Normal (1971-2000 and 1981-2010);
- Climate Scenarios for Mainland Portugal in the 21st Century;
- National Roadmap for Adaptation 2100 (RNA 2100);
- Alto Minho Intermunicipal Climate Change Adaptation Plan (PIAAC do Alto Minho);
- POC Caminha-Espinho;
- National Integrated Management Plan for Rural Fires (PNGIFR);
- Municipal Climate Change Adaptation Strategy (EMAAC) for Viana do Castelo;
- Municipal Climate Action Plan (PMAC) for Viana do Castelo.

All these documents, the knowledge about the territory, and the expertise of the team allowed us to identify the main risks associated with climatic events:

- high temperatures and heatwaves;
- excessive rainfall;
- rising sea levels;
- strong winds.

The Municipal Climate Action Plan (PMAC) is currently being drawn up, which will replace the EMAAC 2016 currently in force. CLIMAAX will make a fundamental contribution to deepening and validating the assessment of the territory's risks and vulnerabilities, which is being drawn up based on the collection and processing of local data. The implementation of the framework and access to the CLIMAAX toolbox will contribute to a substantial improvement in the Risk Typification Framework and better decision-making regarding the adaptation strategy and priorities, based on harmonization with the methodology applied by CLIMAAX.

In terms of data availability usefully to apply in this project, were identified the main sources of data for climate related risks assessment in Viana do Castelo:

- Multi-thematic cartography provided by national institutions (DGT, LNEG, IPMA, etc.);
- Aerial and satellite imagery (RGB and multispectral; ESA, DGT, CIGeoE, Instituto Hidrográfico, UM, etc.);
- Meteorological and climate and hydrographic data (IPMA, ESA, APA);
- Low-resolution altimetry data (NASA, ESA, DGT);
- High-resolution altimetry data (HR-DEM and Lidar data; CIM Alto Minho, UM);
- Historical climate related risk events and impact (CMVC, APA, ICNF, UM, etc.);

- Costal dynamics data (UM, APA).

Participation in the project will also make it possible to support the internal and external technical teams in defining the best planning, implementation, evaluation, and monitoring methodologies, which will overcome one of the main limitations/difficulties the municipality has in relation to the process of adapting to climate change.

The results of the risk and vulnerability assessment will also be incorporated into municipal planning documents, namely the Municipal Emergency and Civil Protection Plan, and presented to the different entities that make up the Municipal Civil Protection Commission, etc. In this way, the dissemination of knowledge and greater community awareness are guaranteed.

This dissemination is essential to support technically informed decision-making, based on scientific data, regarding public policies to adapt to climate change, the adoption of new measures by private agents (companies and institutions), and by citizens.

2.1.3 Participation and risk ownership

Implementing the CLIMAAX project will involve all the organisations that make up the Municipal Civil Protection Commission. These include the Fire Brigade, the Portuguese Red Cross, the Public Security Police, the National Republican Guard, the Maritime Police, the Health Authority, the National Forestry Authority, Viana do Castelo Port Administration, Roads of Portugal, the District Union of IPSS, the Amateur Radio Association, the Scout Associations, the Forestry Producers Association, the Integrated Landscape Management Areas, the Local Action Groups, the Higher Education Institutions and the business associations, as well as the Waste Land Grouping.

The main beneficiaries of VC_CLIMAAX are the general public, with a particular focus on farmers, forestry producers, and companies in the agri-food and tourism sectors, as well as children and the elderly.

Interaction with stakeholders will be guaranteed through meetings and workshops with the Municipal Civil Protection Commission, as well as by organising public information sessions aimed at different target audiences and the general population.

With this in mind, a communication and dissemination strategy and plan have been designed. These take into account the target audiences, which include the general public, academia, stakeholders (including economic activities- businesses) and citizens of different age groups.

2.2 Risk Exploration

The climate risk assessment for Viana do Castelo will be carried out (test the CLIMAAX CRA common methodology) for the following risks:

- River floods;
- Coastal flooding;
- Heavy rainfall;
- Heatwaves;
- Droughts;
- Fire;
- Snow;
- Strong wind (now renamed to Storms).

The risk assessment will consider the frequency of occurrence of a climatic event and the magnitude of the consequences of the impacts of that event.

2.2.1 Screen risks (selection of main hazards)

Three main climate-related risks have been identified as priorities for Viana do Castelo:

- River floods (FLOODS workflow);
- Coastal flooding (FLOODS workflow);
- Wildfires (FIRE workflow).

Considering that the Coastal flooding was not able to be used, we tried to also test:

- Heavy Rainfall (HEAVY RAINFALL workflow).
- Storms (STORMS Workflow)

To apply these workflows, global data sets were used in this first phase, identified by the workflow itself for this purpose, mostly coming from the default download sources provided by the CLIMAAX workflows.

2.2.2 Workflow selection

2.2.2.1 Workflow #1 applied to: FLOODS

The city of Viana do Castelo, the Major City in Alto Minho Region (NUTS3 PT111) is a city exposed to flood from river Lima. Flood risk is an important risk assessment for all Viana do Castelo inhabitants without any group distinction in particular.

2.2.2.2 Workflow #2 applied to: FIRE

Considering the low urban occupation and the extensive green areas (a considerable part as forest type, with *Eucalyptus globulus* and *Pinus sylvestris* species, the municipalities of Alto Minho are consistently menaced by the occurrence of wildfires. In rural areas, forest entrepreneurs and people that live from agricultural practices are particularly exposed.

2.2.2.3 Workflow #3 applied to: HEAVY RAINFALL

The Alto Minho region is the first region in Portugal exposed to Atlantic weather fronts of meteorological instability, making it, on average, the rainiest region in Portugal. Intense rainfall events are frequent and can lead to flash floods and urban flooding. It is one of the regions in Portugal most exposed to such events.

2.2.2.4 Workflow #4 applied to: STORMS

For the same reasons outlined in section 2.2.2.4, weather instability originating from the Atlantic is common in the Alto Minho region. This area has experienced numerous storms in the past, with several episodes of damage caused by strong winds. Strong winds are among the most frequent hazardous meteorological events, leading to moderate structural damage and causing trees to fall.

2.2.3 Choose Scenario

For the climate risk assessment- CLIMAAX CRA approach in Viana do Castelo, the following scenarios were considered relevant:

- **Floods**: RCP 4.5 [intermediate scenario], RCP 8.5 [high and very high scenario], all return period available: 1 in 10 years, 1 in 50 years, 1 in 100 years, 1 in 200 years, 1 in 500 years (considering 2030, 2050, 2080)
- **Fire**: RCP 2.6 [low scenarios], RCP 4.5 [intermediate scenario], all the period available for FWI data and 2045 to 2054 as future scenario
- **Heavy rainfall**: RCP 4.5 [intermediate scenario], considering historical and future scenario (2041 to 2070 timeframe)
- **Storms**: Only simulation for “Klaus” storm (2009) was used.

2.3 Risk Analysis

2.3.1 Workflow #1 – Floods (River Flood)

The main datasets used and produced from the River Flood workflow are identified in the table below, included hazard, exposure and vulnerability datasets. Coastal flood was not used.

Table 2-1 Data overview workflow #1 – Floods (River Flood)

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
• *JRC high-resolution river flood maps (RPs: 10, 50, 100, 200, 500 years)* • *Flood maps for extreme flood events in the baseline climate (ca. 1980) and in the future climates (2030, 2050, 2080 for EURO-CORDEX RCP 4.5 and RCP 8.5 climate scenarios)* • *Aqueduct Floods dataset*	• *JRC damage curves for land use (LUISA)*	• *LUISA land cover 2018*	• *Flood damage maps (economic damage estimate- million €)*

2.3.1.1 Hazard assessment

The workflow successfully produced Hazard maps for river flooding. However, the maps have very low detail to be usable in refine management plans.

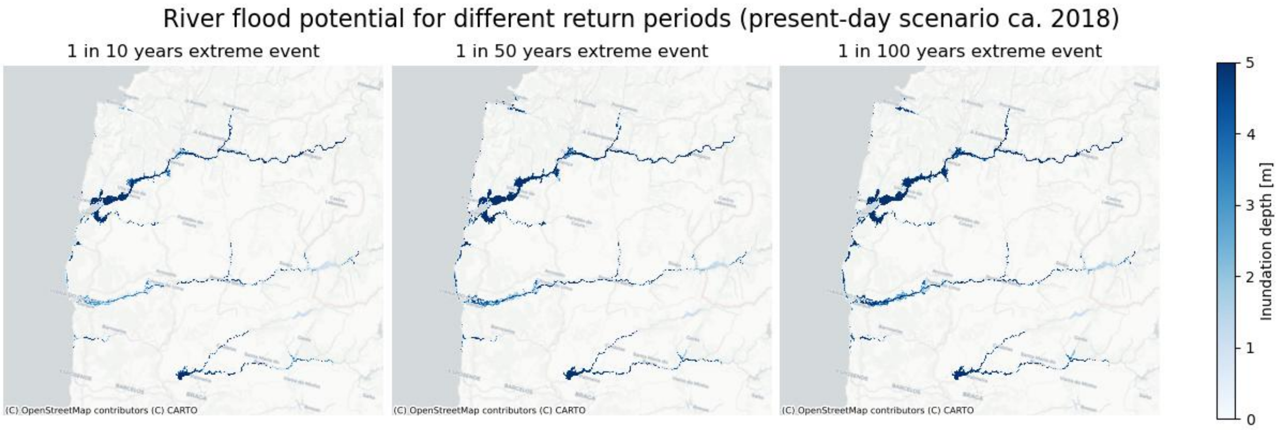

Figure 2-1 – River flood potential (inundation depth [m]) for different return periods: 10, 50 e 100 years (present-day scenario ca. 2018), Alto Minho region.

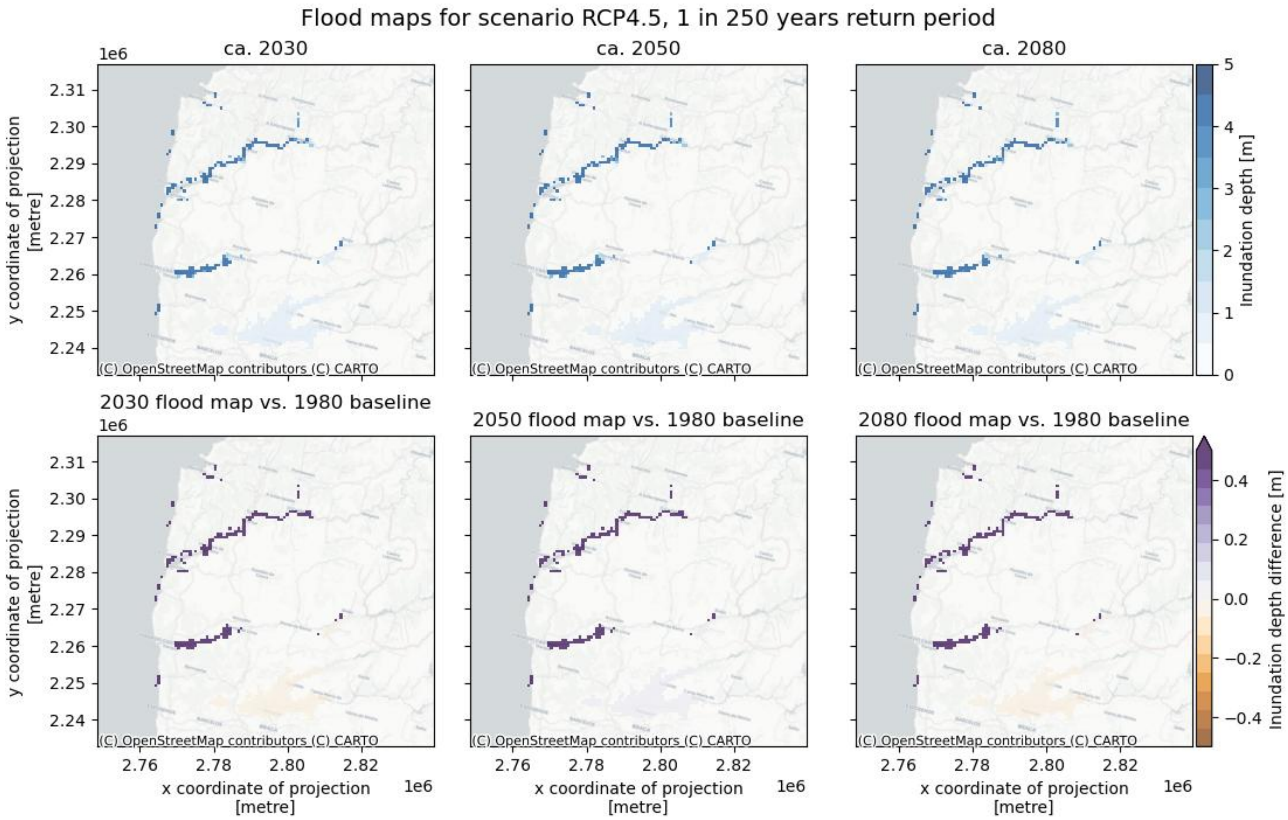

Figure 2-2 – Flood maps (inundation depth [m]) for scenario RCP 4.5 (return period: 250 years), Alto Minho region.

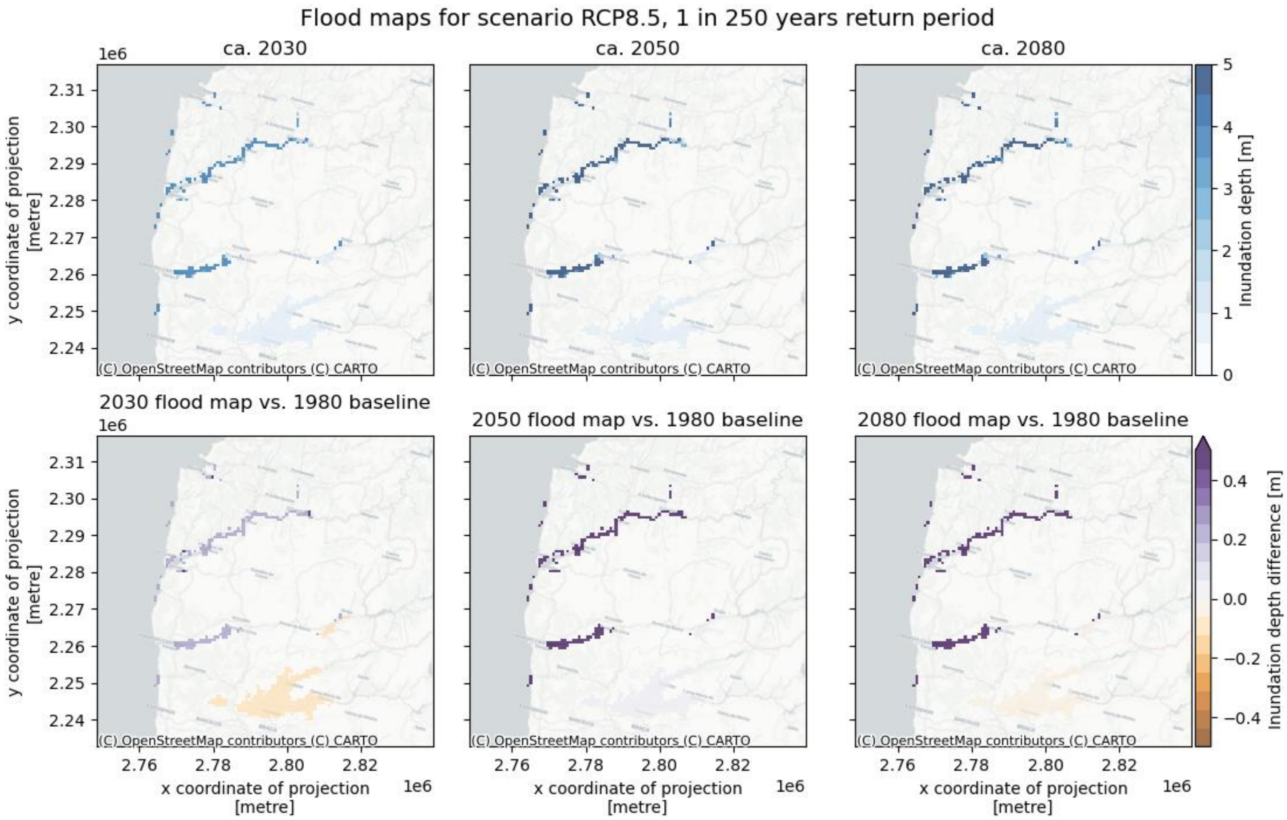

Figure 2-3 – Flood maps (inundation depth [m]) for scenario RCP 8.5 (return period: 250 years), Alto Minho region.

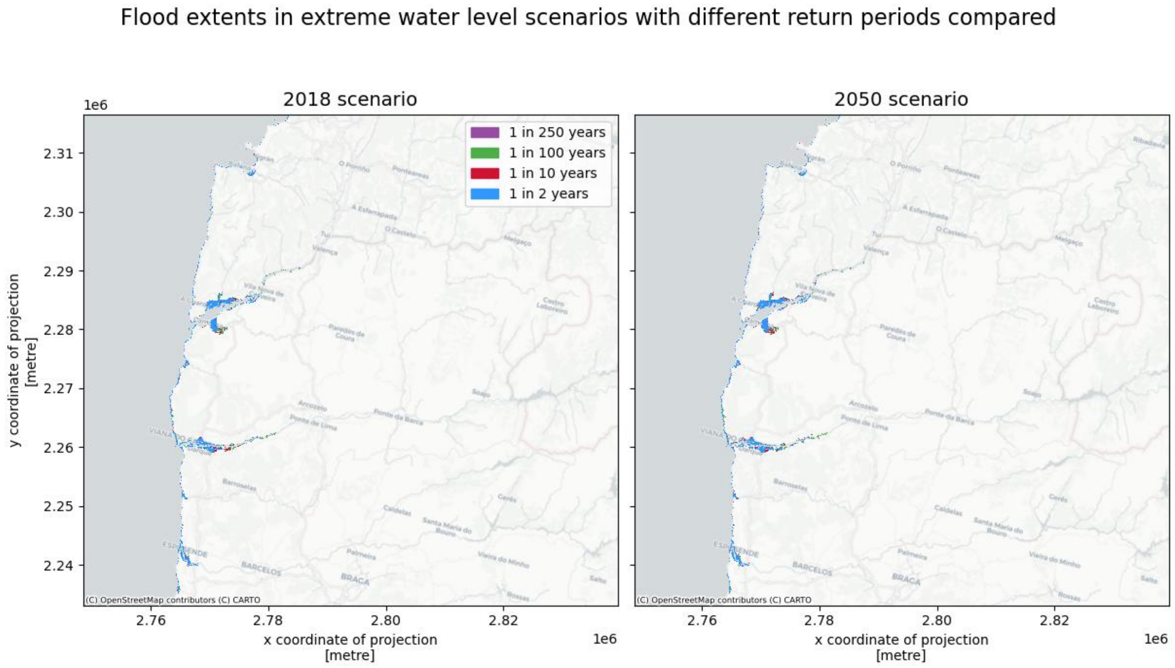

Figure 2-4 – Floods extents in extreme water level scenarios with different return periods (2, 10, 100 and 250 years) compared (2018 and 2050 scenarios), Alto Minho region.

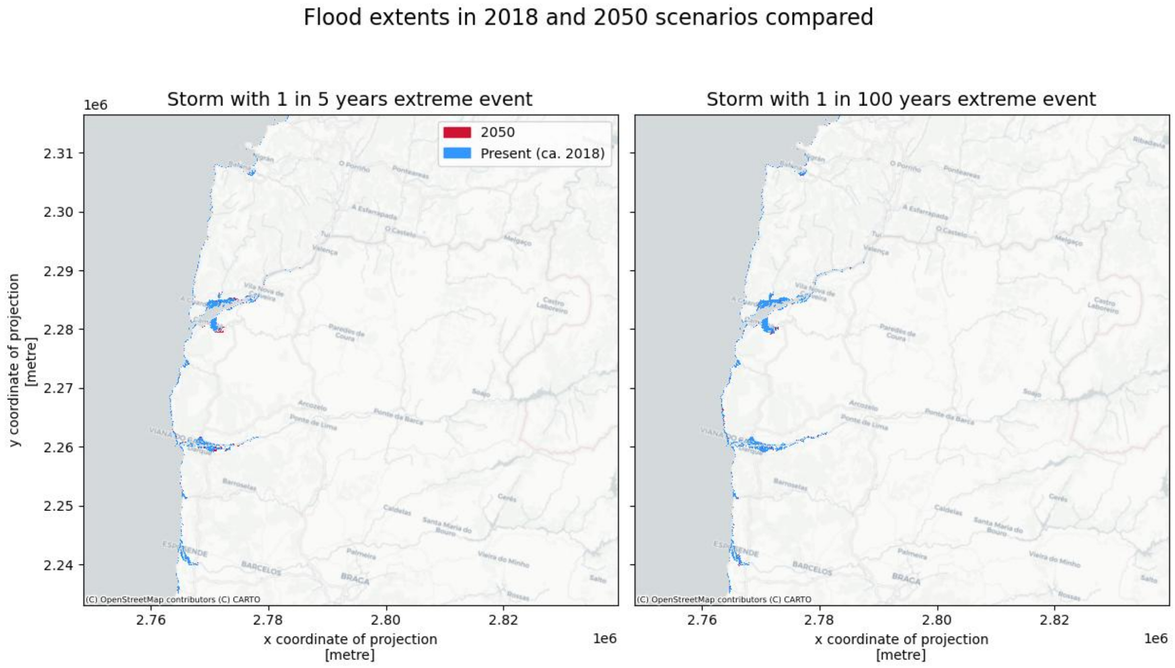

Figure 2-5 – Flood extents in present (c.a. 2018) and 2050 scenarios compared, Alto Minho region.

2.3.1.2 Risk assessment

The workflow successfully produced risk and exposure maps (from the risk and exposure workflow documents) suitable for a rough analysis. However, as in the Hazard case, the maps have very low detail to be usable in finer management plans related to flood management and prevention.

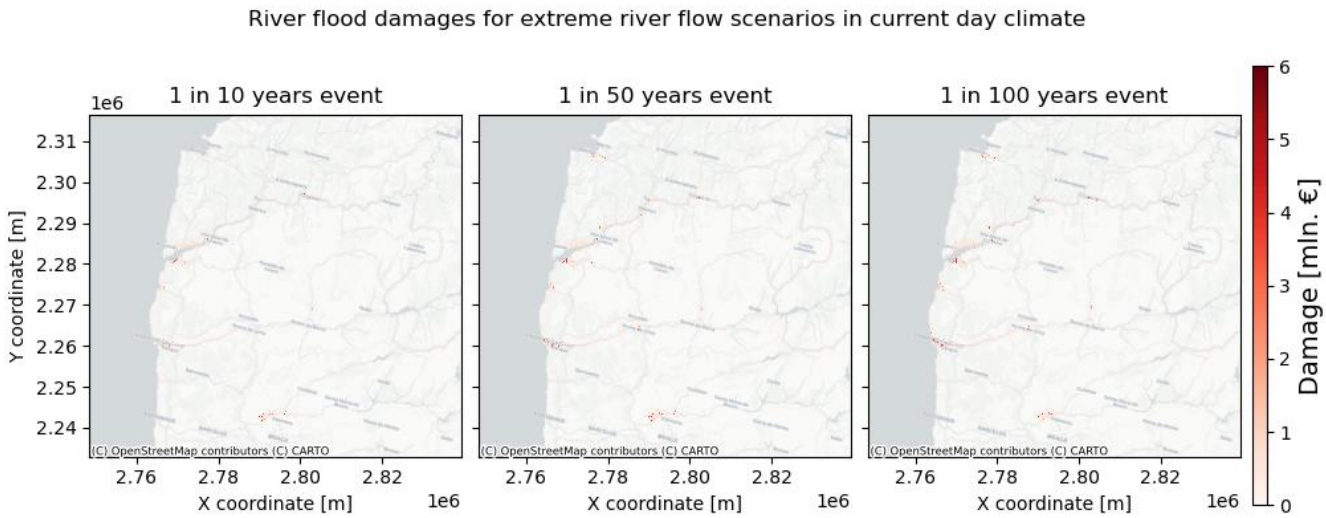

Figure 2-6 – River flood damages (mln. €) for extreme river flow scenarios in current day climate (to different return periods: 10, 50 and 100 years), Alto Minho region.

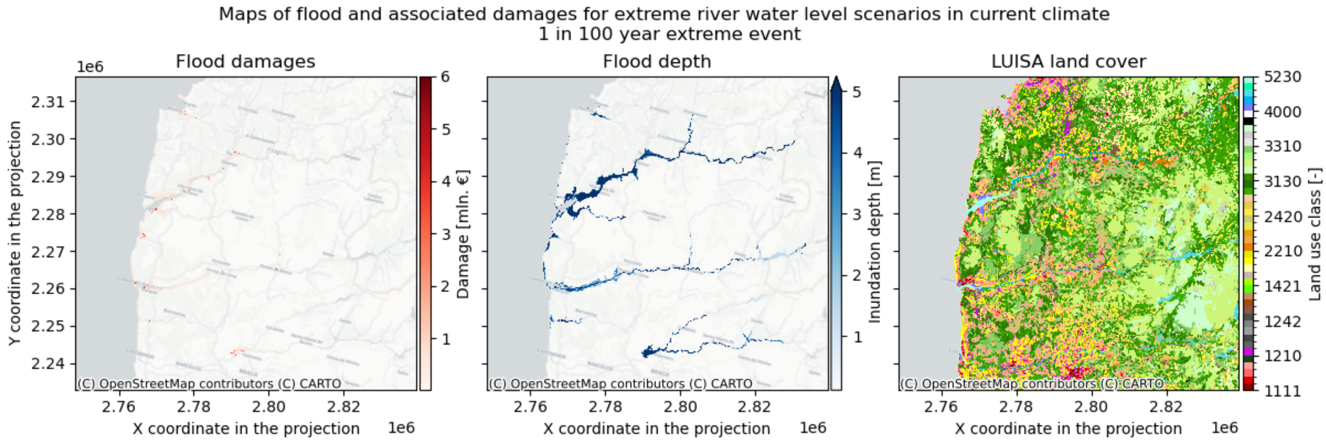

Figure 2-7 – Maps of flood (inundation depth [m]) and associated damages (mln. €) for extreme river water level scenarios in current climate (LUISA land cover 2018), Alto Minho region.

2.3.2 Workflow #2 – Fire

The CLIMAAX methodology for fire risk produces an assessment of wildfire risk based on the seasonal Fire Weather Index (FWI) and a range of parameters linked to wildfire vulnerability description, systematized in the FWI description graphic (Figure below) and detailed in the workflow).

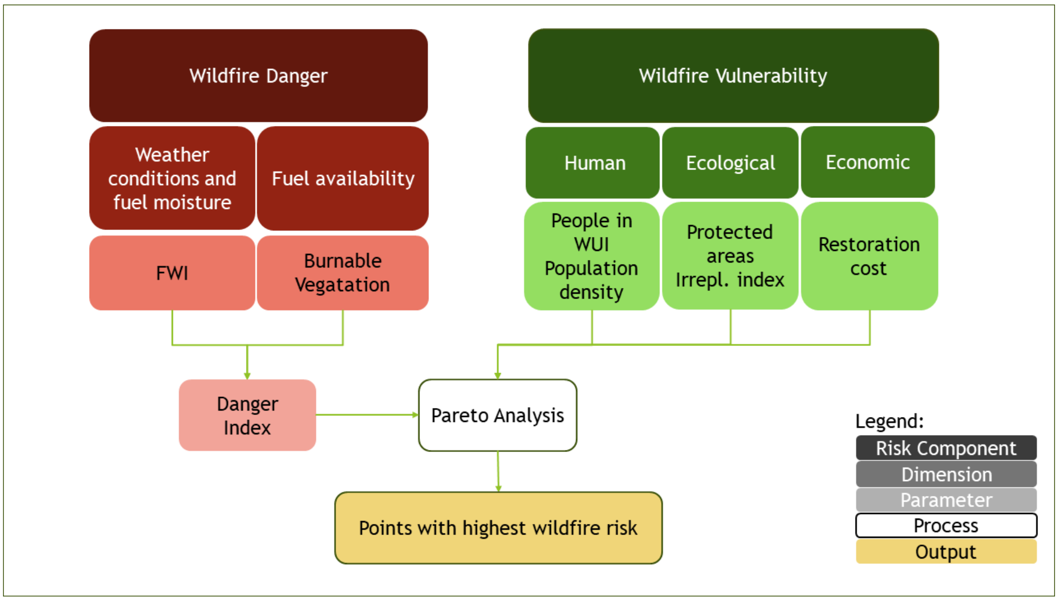

Figure 2-8 – Fire Weather Index (FWI) description graphic. Figure Source: CLIMAAX.

The main datasets used and produced from the Fire workflow are identified in the table below, included hazard, exposure and vulnerability datasets.

Table 2-2 Data overview workflow #2 – Fire

Hazard data	***Vulnerability (and Exposure) data***	***Risk output***
• *Copernicus Climate Data Store – Fire Weather Index (FWI), Seasonal FWI, EURO-CORDEX scenarios: historical and RCP scenarios (low: 2.6, intermediate: 4.5)* • *Burnable areas (EFFIS)*	• *European Forest Fire Information System (EFFIS) – fire danger categorization (it as the combination of wildfire danger and vulnerability)* • *Joint Research Centre Risk Data Hub (JRC RDH) includes several datasets mainly at NUTS2 level* • *Pan-European Wildfire Risk Assessment – vulnerability indicators (Population at the Wildland Urban Interface (WUI), Protected areas fraction, Ecosystems Irreplaceability, Population density, Restoration cost)*	• *Pareto analysis of risk (highlights which areas in the region have the highest wildfire risk)*

2.3.2.1 Hazard assessment

Due to technical difficulties, related with data download in the previous workflow, the Fire Hazard workflow file had to be extensively edited to produce results. It was possible to produce FWI seasonal scenarios for both historical data and future data related with three RCP scenarios (RCP 2.6, RCP 4.5 and RCP 8. 5). Daily data was also used to successfully produce FWI from daily data. Historical and best, mean and worst scenarios were successfully produced for each RCP. The latest Fire Workflow version provided by the CLIMAAX team really was an improvement over the last version, allowing to extract Fire Hazard results that allowed to assess the fire risk by using the Fire Risk assessment workflow. The next images show some examples of the results produced.

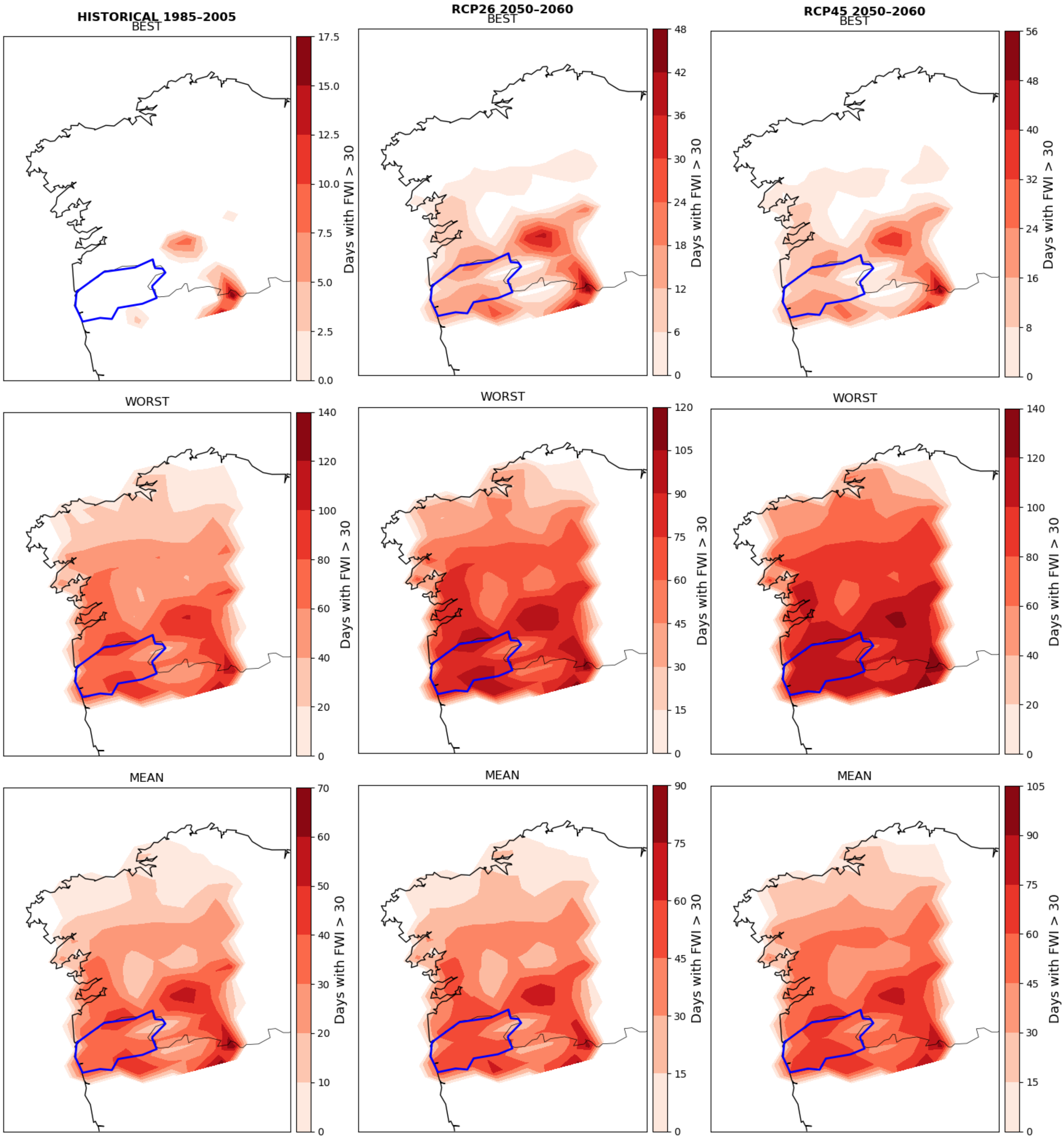

Figure 2-9 – Days with Fire Weather Index (FWI)>30 to historical (1985-2005)-[left], RCP 2.6 (2050-2060)-[middle] and RCP 4.5 (2050-2060)-[right] scenarios, across different cases (i.e., best, worst, mean), Alto Minho region.

2.3.2.2 Risk assessment

After the CLIMAAX team successfully resolved some technical issues related to the previous workflow, it became possible to use the Risk Assessment workflow. The results were as follow:

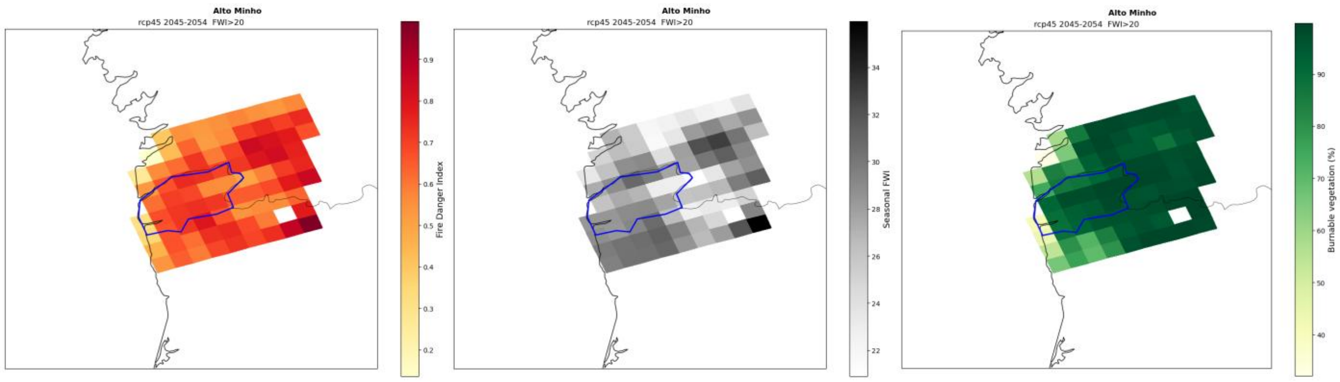

Figure 2-10 – Fire Danger Index-[left], Seasonal FWI-[middle], and Burnable vegetation (%)-[right] for RCP 4.5 (2045-2054) FWI>20, Alto Minho region.

The vulnerability indicators:

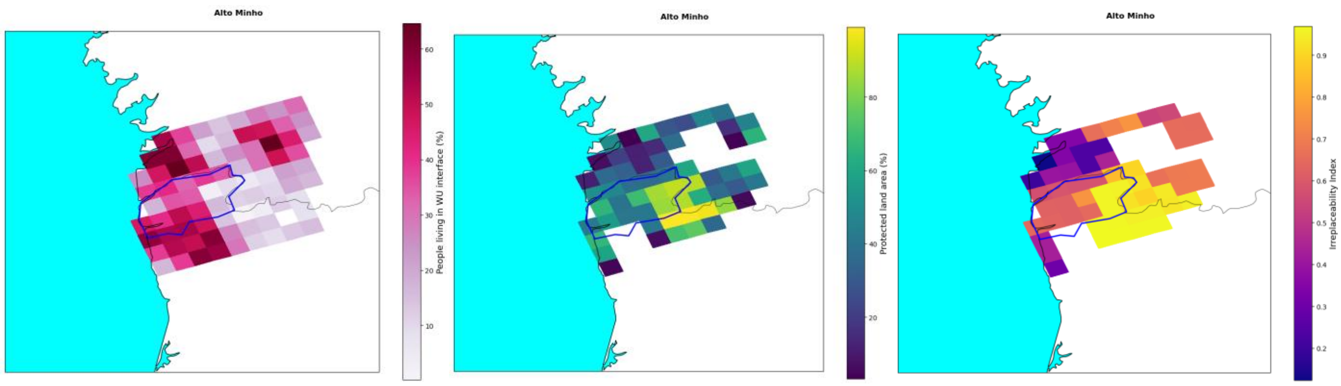

Figure 2-11 – Vulnerability indicators: People living in WU interface (%)-[left], Protected land area (%)-[middle], and Irreplaceability Index-[right], Alto Minho region.

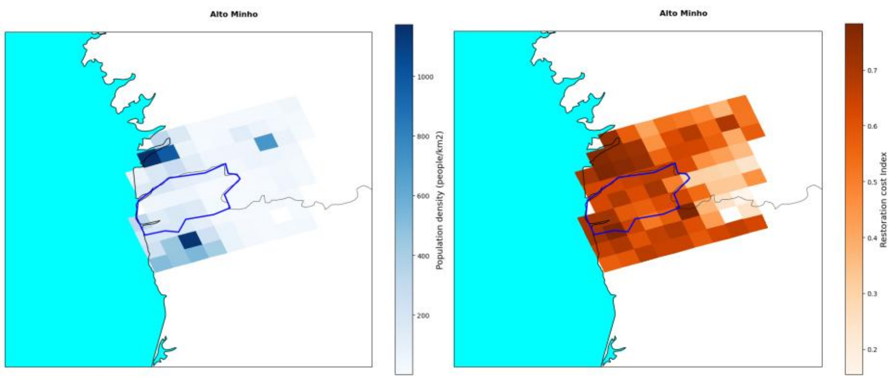

Figure 2-12 – Vulnerability indicators: Population density (people/km^2)-[left], and Restoration cost Index-[right], Alto Minho region.

The Pareto risk analysis produced the following output:

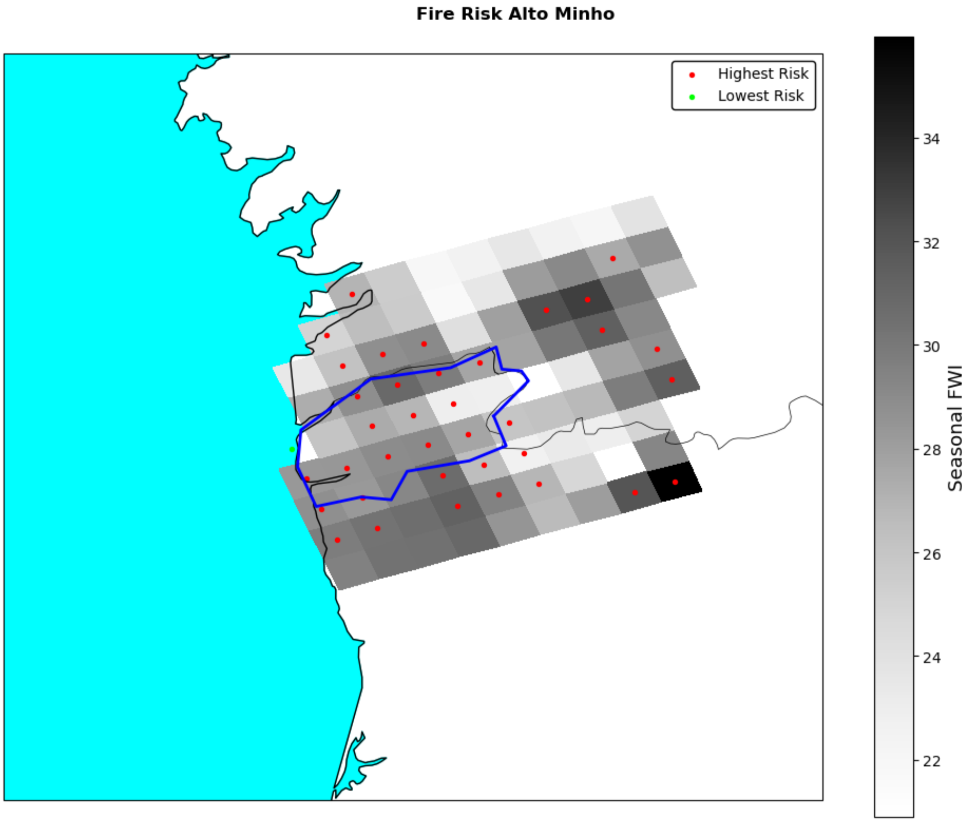

Figure 2-13 – Fire risk (Seasonal FWI), Alto Minho region.

2.3.3 Workflow #3 – Heavy rainfall

The main datasets used and produced from the Heavy Rainfall workflow are identified in the table below, for hazard datasets.

Table 2-3 Data overview workflow #3 – Heavy rainfall

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
• *EURO-CORDEX from the Climate Data Store: two different 30-year frames (1976-2005 [baseline or historic simulations] and 2041-2070 [climate projections] timeframes RCP 4.5* • *EURO-CORDEX precipitation datasets (temporal series of annual maximum precipitation for sub-daily and daily resolution)*	• -	• -	• -

2.3.3.1 Hazard assessment

Hazard assessment provided by Heavy Rainfall workflow worked well and produced relevant data that, in its present state, it's already usable in refine management plans, even considering that only RCP 4.5 was used. Here are some examples of the produced data:

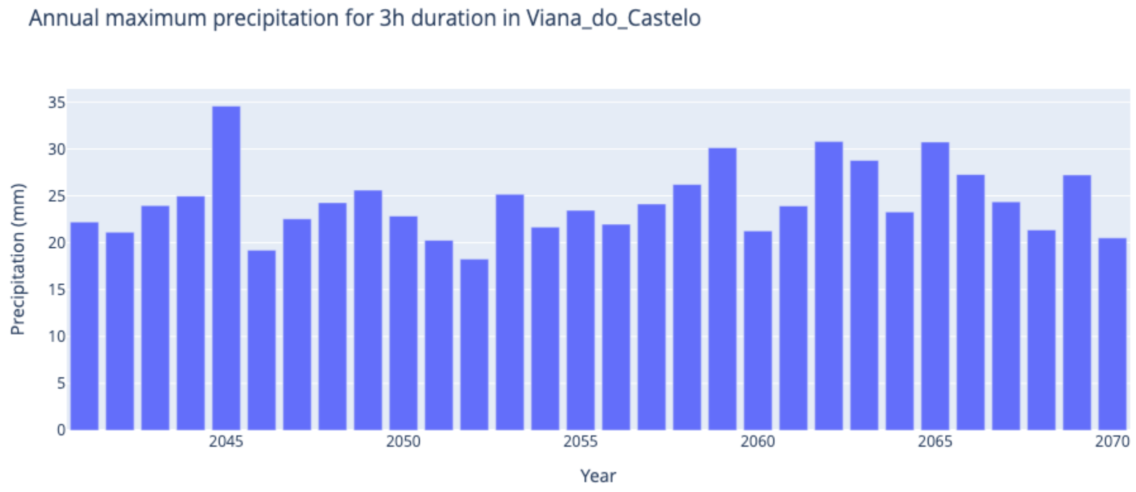

Figure 2-14 – Annual maximum precipitation (mm) for 3h duration in Viana do Castelo.

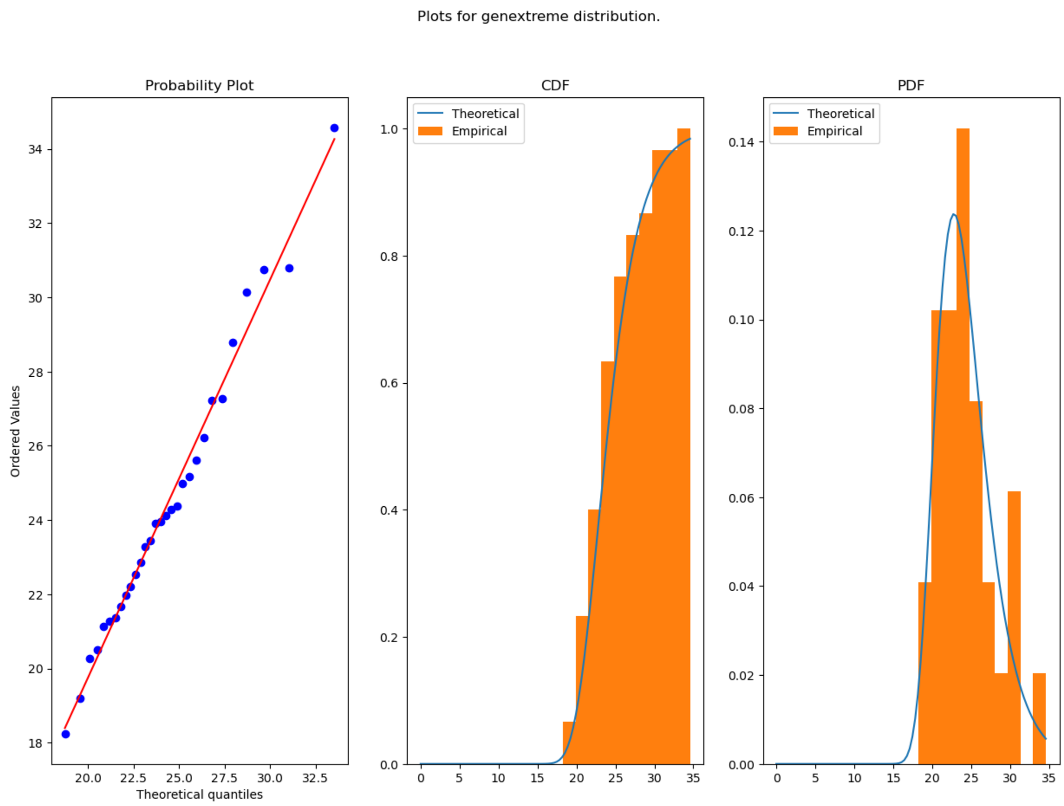

Figure 2-15 – Probability distribution (probability of occurrence) to the annual maximum precipitation series, considering General Extreme Value (GEV) distribution, in Viana do Castelo.

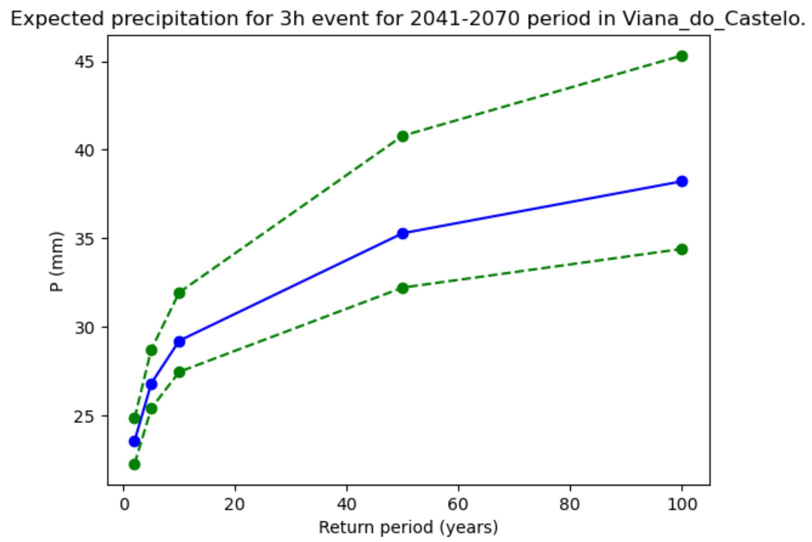

Figure 2-16 – Expected precipitation (mm) for 3h duration event for 2041-2079 period, considering different return periods (2, 5, 10, 50 and 100), in Viana do Castelo.

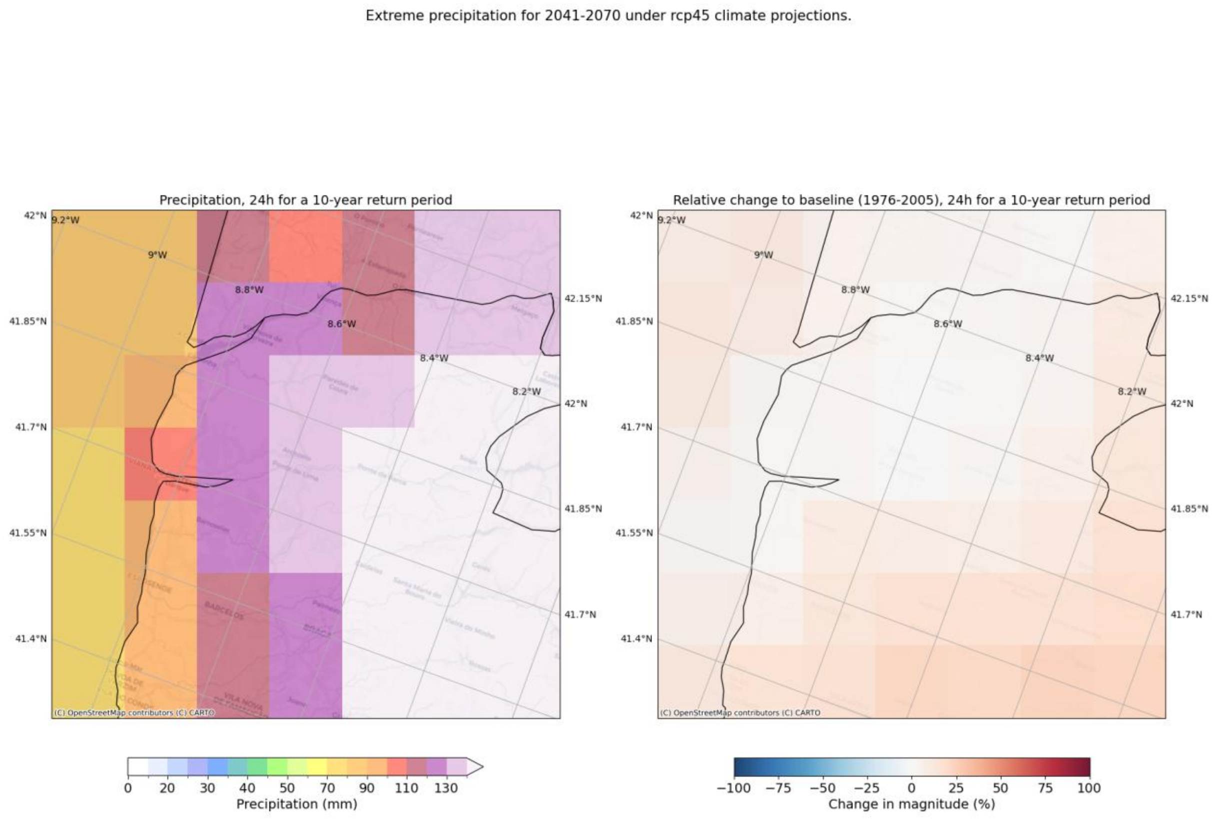

Figure 2-17 – Extreme precipitation 24h (mm) for 2041-2070 period under RCP 4.5 climate projections, in Viana do Castelo.

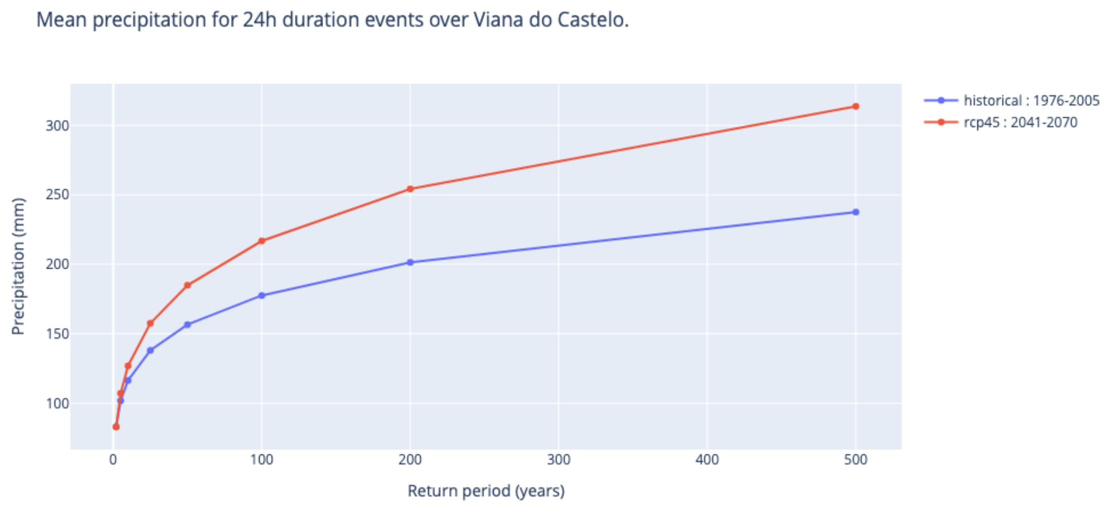

Figure 2-18 – Mean precipitation (mm) for 24h duration events, frequency curves for historical (1976-2005) and RCP 4.5 (2041-2070), in Viana do Castelo.

It should be noted that this workflow includes a step where it is necessary to obtain precipitation data from EURO-CORDEX via the Climate Data Store. During this step, multiple segments exceeding 600 MB are downloaded, a process that can potentially take several hours and, if not completed, will compromise the subsequent steps. An effort should be made to communicate this information to users or, alternatively, although complex, develop code to focus the data download on the area of interest.

2.3.3.2 Risk Assessment

In this risk assessment, we were unable to get the data from the data produced by the Hazard workflow. The region of interest is defined, the point is selected and the domain overlap is compared with Catalonia region, which is the demonstration area. We were unable to understand this logic and it seems that this workflow is still a "work in progress". Even considering that in the portion of the code that forces to use the Hazard produced data, namely "# Define global variable to define the dataset to use (False to use ready-to-go pre-calculated datasets Path A); DATASET_HAZARD_ASSESSMENT = True", the further steps are sticked to Catalonia data and it is impossible to have data for the desired region, in this case Alto Minho – Portugal.

2.3.4 Workflow #4 – Storms

The main datasets used and produced from the Storms workflow are identified in the table below, included hazard, exposure and vulnerability datasets.

Table 2-4 Data overview workflow #2 – Storms

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
• *Copernicus Climate Change Service (C3S) Climate Data Store (CDS) Store: historical storm footprint* • *ERA5 reanalysis: "**Klaus**" windstorm*	• *Vulnerability curves (LUISA damage curves, Curves Feuerstein- for building construction types)*	• *LUISA land cover 2018* • *JRC maximum damage estimates*	• *Structural damages (€/m^2)*

2.3.4.1 Hazard Assessment

In this workflow we were able to simulate data for the Klaus storm (2009) which is the example provided by the workflow. The workflow does not provide any feature to check the available storms for simulate. The forum, which is recommend in the workflow headers, was not a great help also. By using extensive search, we were able to check a few storms that could be available. This should be provided in the workflow. The only storms that produced valid downloads, from almost a dozen tested, were Daria (1990), Martin (1999) and Klaus (2009) which is the example provided. It is recommended the improvement of this part of the workflow.

The simulation for the Klaus Storm Hazard produced the following results:

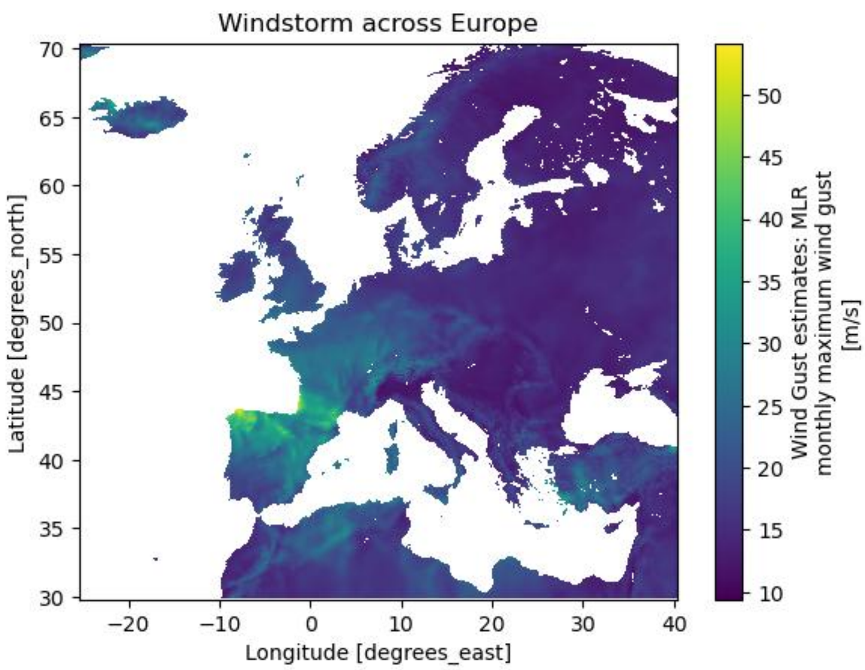

Figure 2-19 – Windstorm across Europe – Windspeeds (m/s).

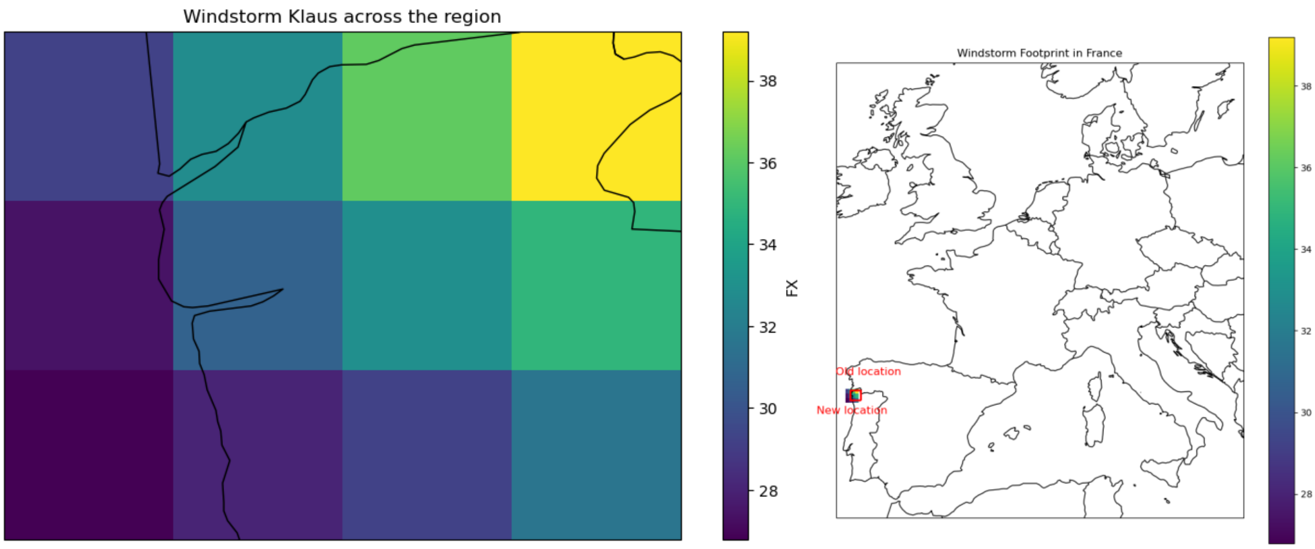

Figure 2-20 – Windstorm Klaus across Alto Minho region – Windspeeds (m/s) [left], and Storm relocation [right].

2.3.4.2 Risk assessment

The risk assessment for the region of Alto Minho related to the Klaus storm were:

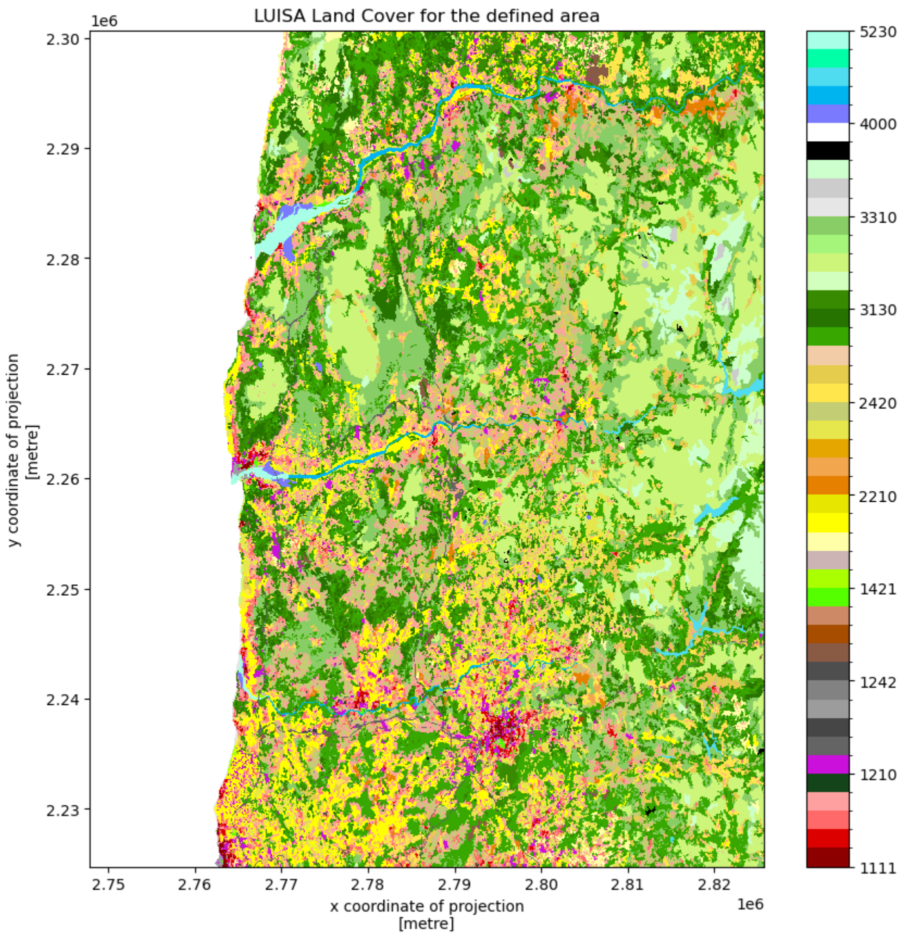

Figure 2-21 – LUISA Land Cover for the defined area.

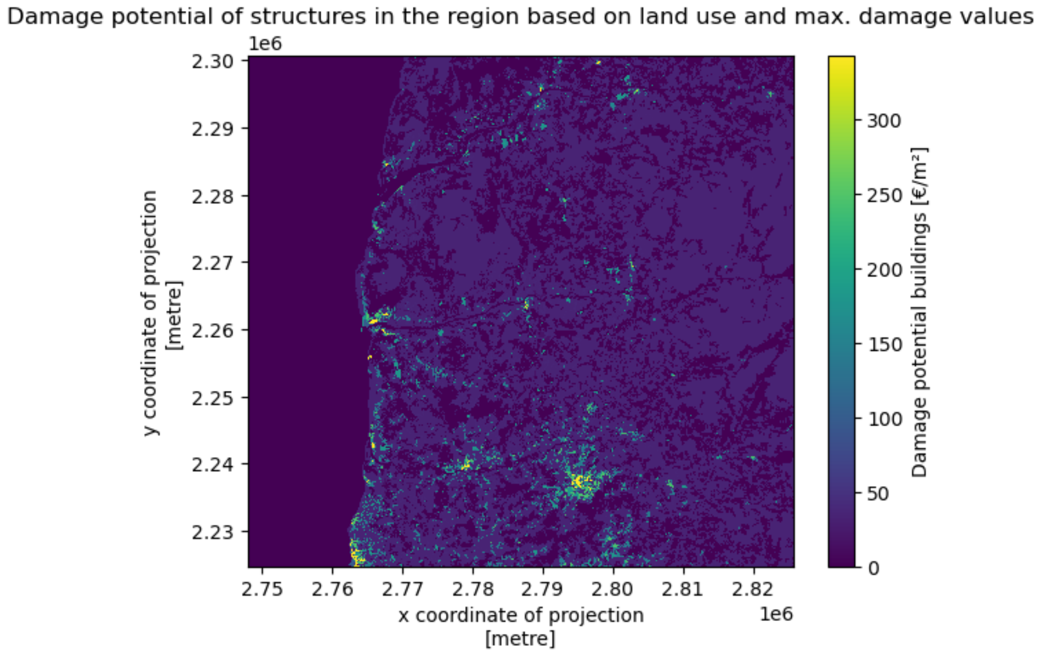

Figure 2-22 – Damage potential of structures (€/m²) in the region based on land use and maximum damage values.

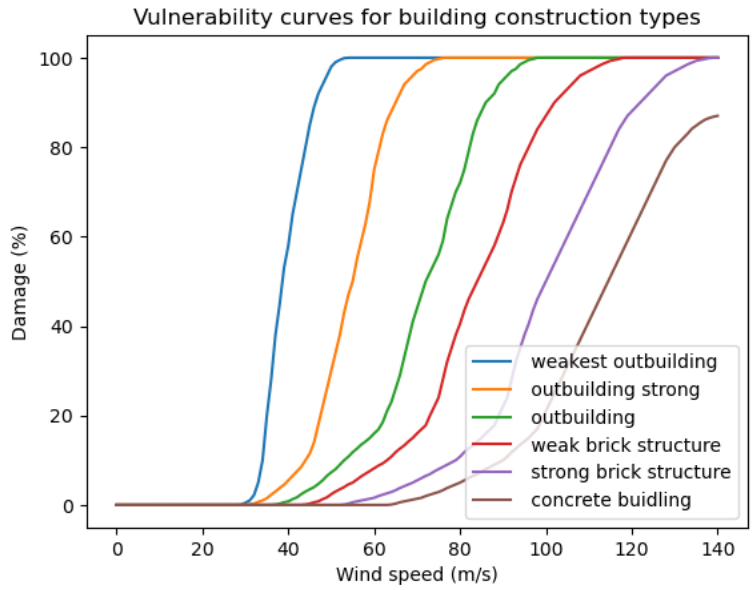

Figure 2-23 – Vulnerability curves for building construction types, relates damage (%) to wind speeds (m/s).

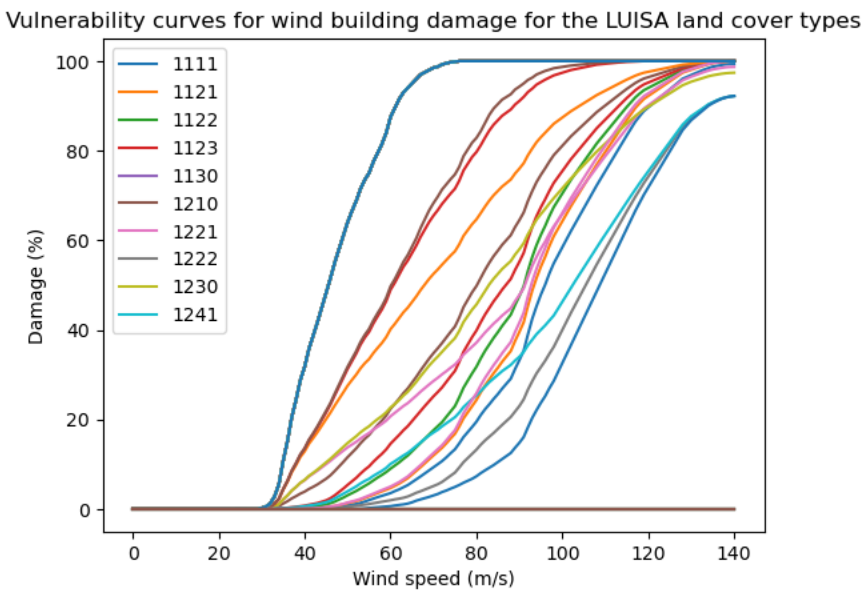

Figure 2-24 – Vulnerability curves for wind building damage for LUISA land cover types.

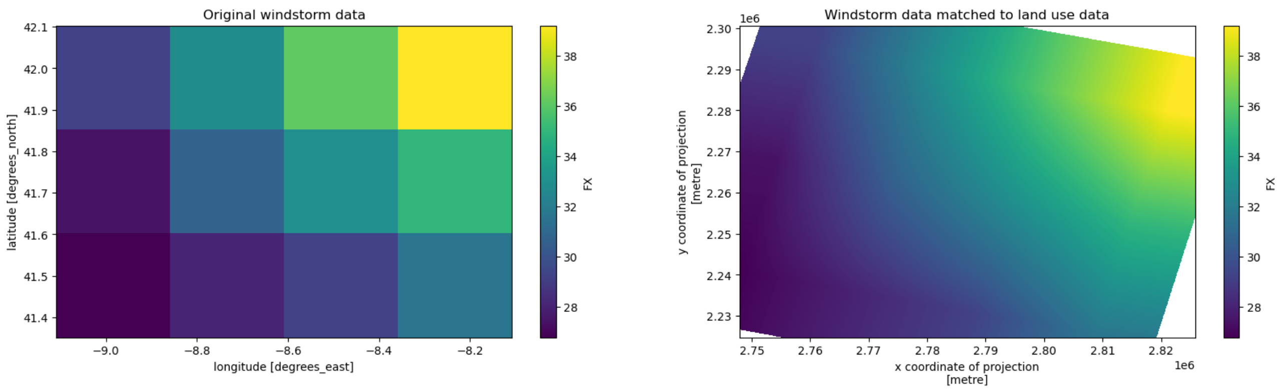

Figure 2-25 – Windstorm map for the defined area.

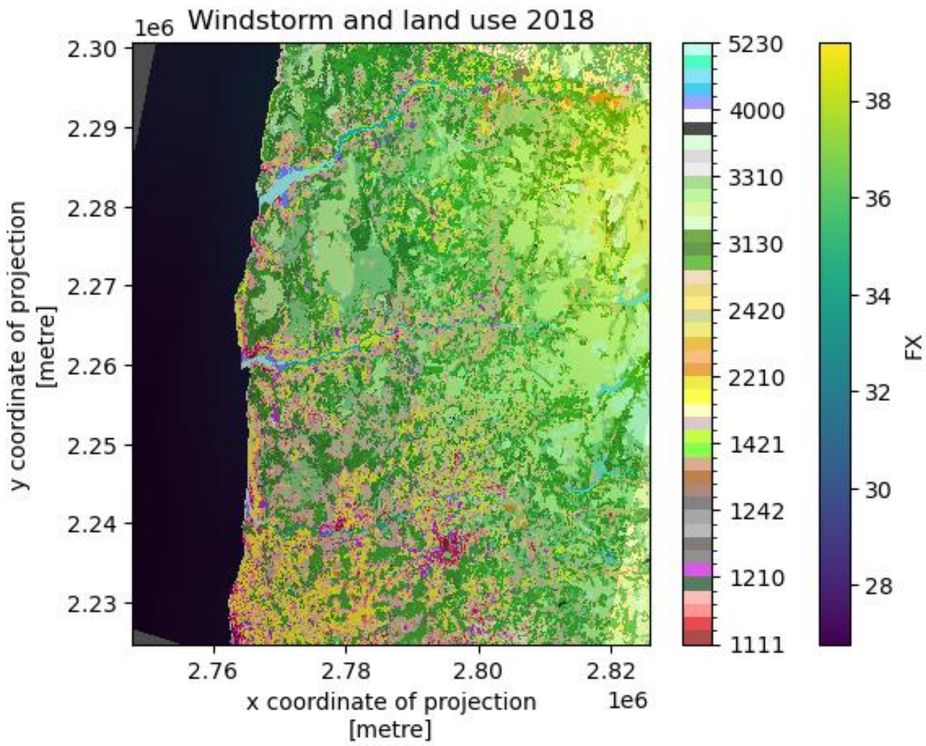

Figure 2-26 – Windstorm and land use 2018.

	Description	Damages [mln €]
3220	Moors and heathland	2.581154e-01
3240	Transitional woodland shrub	1.456713e-01
3330	Sparsely vegetated areas	5.658005e-02
2410	Annual crops associated with permanent crops	5.228622e-02
2430	Land principally occupied by agriculture	3.870046e-02
2420	Complex cultivation patterns	2.416492e-02
2310	Pastures	2.174059e-02
2120	Permanently irrigated land	1.374771e-02
2210	Vineyards	9.345286e-03
3210	Natural grassland	7.602756e-03
3320	Bare rock	4.076586e-03
2110	Non irrigated arable land	2.649741e-03
1210	Industrial or commercial units	2.354768e-03
1123	Isolated or very low density urban fabric	9.396805e-04
1330	Construction sites	8.721526e-04
3340	Burnt areas	7.052819e-04
2220	Fruit trees and berry plantations	3.657954e-04
4000	Wetlands	2.121485e-04
1221	Road and rail networks and associated land	1.704861e-04
1310	Mineral extraction sites	1.300534e-04
1122	Low density urban fabric	8.821026e-05
1421	Sport and leisure green	8.509988e-05
3310	Beaches, dunes and sand plains	6.128540e-06
1241	Airport areas	4.451003e-06
1230	Port areas	2.373347e-06
1121	Medium density urban fabric	1.633600e-07
1111	High density urban fabric	4.190800e-08
1422	Sport and leisure built-up	2.207000e-09
2440	Agro-forestry areas	0.000000e+00
1242	Airport terminals	0.000000e+00

Figure 2-27 – Damages in million € (considered land use 2018).

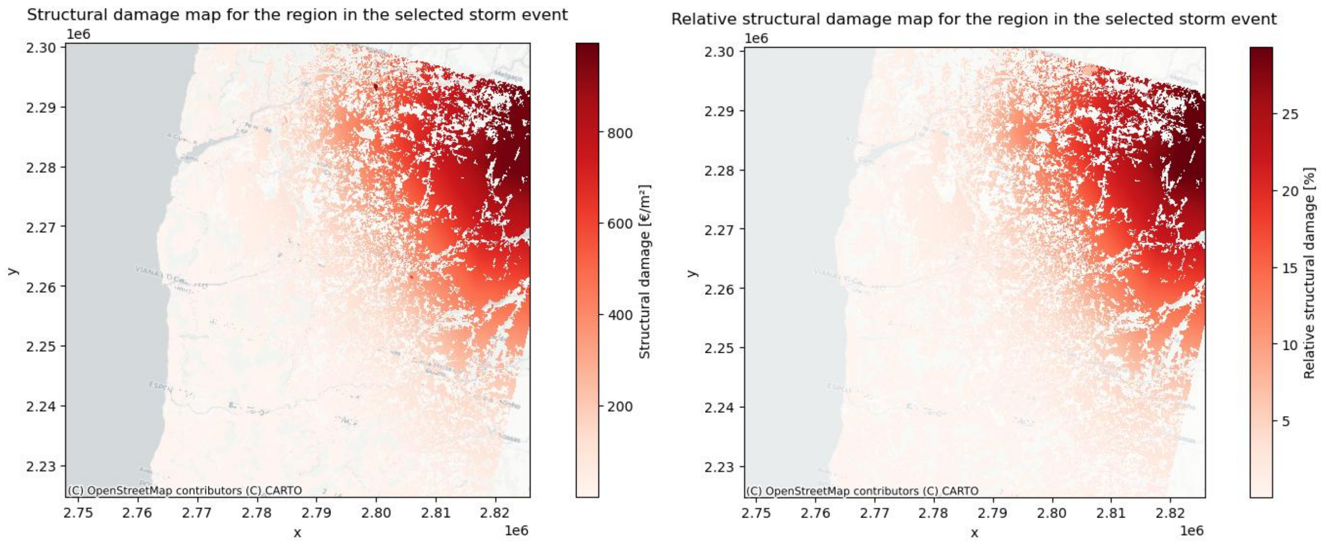

Figure 2-28 – Structural damage (€/m^2) map [left] and Relative structural damage (%) map [right], for the region in the selected storm event.

As an overall comment about the workflows used, the Flood workflow was well streamlined and the flux was logical and easy to use and fine tune for desired conditions. The same could not be said about the previous Fire workflow version. However, the last available version (late April 2025) was a very good improvement and the workflow is now usable. It should be noted that the last cell of the Fire Hazard workflow, which plots the historical and future data (located just after the cell titled "The cell below plots two figures, one for the historical and one for the future period, showing the maps for the best, worst, and mean case scenarios."), fails to generate the images. The images obtained by the Viana do Castelo team for this data were produced using code modified by us to avoid the issues caused by the previous workflow. However, the failure to generate these images did not compromise the use of the Risk Assessment Workflow, as the necessary data generated by the Fire Hazard workflow is correctly produced in the file hierarchy.

Considering the Heavy rainfall workflow, the hazard part is usable and produces very interesting data. Care must be taken, as said before, in warning the users when a huge amount of data must be downloaded. The risk portion is “frozen” in Catalonia data and it’s impossible (at least we did not find a way with the provided code), in the present state, to be used for another region, using the Hazard part of the workflow produced data.

The Storms workflow works well with the provided example storm (Klaus 2009) but must be refined to be able to simulate other storms and information about storm availability should be provided to users.

All workflows provide low to very low-resolution data (even the region’s shapefile limits are very rough) which makes it suitable for a very general analysis for risk assessment. However, to be able to feed local management plans, this data must be densified. The logical step will be to add the possibility to allow users to provide better resolution data, when available, in a simple manner.

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

- **key results from risk analysis**

Considering the Fire risk analysis conducted for the region of Alto Minho, Portugal, using the workflows in the notebooks FWI_Hazard_Assessment.ipynb and FWI_Risk_Assessment.ipynb, reveals significant insights into the increasing wildfire hazard and risk faced by this region. The primary conclusion from the hazard assessment is that the region is experiencing an increasing wildfire hazard, primarily driven by rising values of the Fire Weather Index (FWI). This index, a widely recognized metric, combines critical meteorological variables such as daily noon surface air temperature, rainfall intensity, wind speed, and relative humidity, providing a score that reflects how favorable the climate conditions are for the occurrence and spread of wildfires.

The analysis demonstrates a clear trend towards higher seasonal FWI values in Alto Minho, indicating that the region is becoming progressively more susceptible to wildfire occurrences. These rising FWI values suggest a shift towards warmer and drier conditions, directly increasing the likelihood of wildfires and enhancing their potential intensity. Moreover, the wildfire season in Alto Minho is lengthening, which means that the period of the year during which wildfire conditions are favorable is extending. This extension increases the region's exposure to wildfire risks, making wildfires more likely to occur over a longer period. Spatial analysis within the hazard assessment further identifies specific areas within Alto Minho where the FWI is consistently high, indicating regions that are particularly prone to wildfire hazards.

The risk assessment builds upon this hazard analysis by incorporating a detailed evaluation of vulnerability. In this assessment, wildfire risk is defined as a combination of wildfire danger — determined by FWI and the availability of burnable vegetation — and vulnerability, which is assessed across three critical dimensions: human, economic, and ecological. Human vulnerability considers areas with high population density, where many people are directly exposed to wildfire threats. Economic vulnerability evaluates regions with valuable properties and infrastructure at risk of damage. Ecological vulnerability focuses on zones of high environmental value, including forests, nature reserves, and critical habitats that could suffer severe and potentially irreversible damage. The assessment identifies the highest-risk areas in Alto Minho as those where high wildfire hazard (high FWI and fuel availability) coincides with high vulnerability in one or more of these dimensions.

The flood risk analysis conducted for the region of Alto Minho, Portugal, using the workflows in the notebooks Hazard_assessment_FLOOD_RIVER.ipynb and Risk_assessment_FLOOD_RIVER.ipynb, provides detailed insights into the flood hazard and associated risks that this region faces. The hazard analysis begins by using high-resolution flood maps provided by the Joint Research Centre (JRC), which depict the extent of river flooding under extreme events of varying statistical probabilities, specifically those with return periods of 10, 20, 30, 40, 50, 75, 100, 200, and 500 years. These flood maps allow for a precise spatial analysis of areas within Alto Minho that are most susceptible to river flooding, effectively identifying flood-prone zones along the region's river systems.

The analysis is further enhanced by considering the impact of climate change on flood hazards. This is achieved using the Aqueduct Floods dataset, which provides a qualitative assessment of how flood conditions are expected to change under different climate scenarios. The comparison of current flood maps with those projected under various climate change scenarios reveals that Alto Minho is likely to experience an increase in the frequency and intensity of flood events. In particular, areas that are currently exposed to low or moderate flood risks are expected to experience a higher probability of flooding as climate conditions evolve. This analysis not only highlights the regions most at risk of river flooding but also demonstrates how these risks are likely to increase due to the effects of climate change.

Building on this hazard assessment, the risk analysis integrates information on economic vulnerability to provide a more comprehensive understanding of flood risk in Alto Minho. The economic risk is assessed based on the potential for flood-related damages to built infrastructure, calculated using a combination of flood maps, land use data, and economic vulnerability metrics, specifically damage curves that quantify the expected economic losses under different flood scenarios. The analysis demonstrates that the most significant economic risks are concentrated in areas where high flood hazard coincides with high-value infrastructure and densely populated zones. This means that even a moderate flood event could result in substantial financial losses in these critical areas. The analysis provides a clear picture of the regions within Alto Minho where flood damage is most likely to be severe, and it quantifies the potential economic impacts of flooding under different scenarios.

The hazard analysis for extreme precipitation in the region of Alto Minho, Portugal, using the workflow in the notebook EXTREME_PRECIPITATION_Hazard_Assessment.ipynb, provides a detailed understanding of the changing risk associated with extreme rainfall events. This analysis is based on high-resolution climate datasets derived from EURO-CORDEX climate projections, which offer insights into the intensity and frequency of extreme precipitation under both historical and future climate scenarios. Specifically, the analysis focuses on the annual maximum precipitation values for the region, using historical data (1976-2005) as a baseline and climate projections (2041-2070) to assess future conditions.

The primary finding of this hazard assessment is that extreme precipitation events in Alto Minho are expected to become more intense and more frequent under future climate scenarios. The analysis begins by extracting annual maximum precipitation values, which are then used to model different return periods. This allows for a detailed understanding of the probability of extreme rainfall events of various intensities occurring in any given year. These return periods are calculated for multiple scenarios, providing a clear view of how the risk of extreme precipitation is likely to evolve.

One of the most critical aspects of this analysis is the comparison between the historical and projected climate data. The analysis reveals a clear trend towards higher maximum precipitation values under future climate conditions. This means that rainstorms that are currently considered rare, such as those with a 100-year return period, are expected to become more common. Additionally, the intensity of rainfall during these extreme events is projected to increase, meaning that the region will experience heavier rainfall in shorter periods, which significantly heightens the risk of flooding, soil erosion, and other related hazards.

Although the hazard analysis provides a comprehensive understanding of the potential for extreme precipitation events, it is important to note that this analysis does not include a direct assessment of risk, as the risk workflow was not completed. This means that the analysis does not quantify the potential impacts of these extreme rainfall events on people, property, or infrastructure in Alto Minho. However, the hazard analysis itself is a critical first step, as it clearly demonstrates that the region is likely to face increasingly severe and frequent extreme precipitation events in the future due to climate change.

- **Major risks**

The major wildfire related risks that Alto Minho is experiencing, and is likely to continue experiencing, are primarily related to the increasing wildfire hazard driven by rising Fire Weather Index (FWI) values. One of the most critical risks is the growing frequency and intensity of wildfires. The rising FWI values reflect a trend towards warmer and drier climatic conditions, making wildfire conditions more likely and severe. As FWI values increase, the region is at greater risk of experiencing wildfires that ignite more easily, spread faster, and burn more intensely. This situation poses a direct threat to human safety, property, and the natural environment.

Another significant risk is the lengthening of the wildfire season in Alto Minho. The analysis demonstrates that the period of the year during which wildfire conditions are favourable is extending, meaning that the region is exposed to wildfire risks for a longer duration each year. This prolonged exposure increases the likelihood of wildfires occurring and makes it more difficult for local authorities and firefighting units to maintain readiness throughout the entire season.

In addition to the general hazard posed by higher FWI values and a longer wildfire season, the spatial analysis in the risk assessment identifies specific high-risk areas within Alto Minho. These are regions where high wildfire hazard overlaps with high vulnerability. Areas with dense populations face a higher risk of human casualties and injuries during a wildfire event. Economically valuable regions, including those with expensive properties and critical infrastructure, are at significant risk of severe financial losses. Ecologically sensitive areas, such as forests, nature reserves, and critical habitats, are also at risk of suffering irreversible environmental damage. The combination of these factors means that Alto Minho is facing a multifaceted wildfire risk, with different areas exposed to different types of severe impacts.

The major risks associated with river flooding in Alto Minho are directly linked to the region's extensive river network and its exposure to extreme flood events, which are expected to become more frequent and severe due to climate change. The first and most critical risk is the direct impact of river flooding on residential, commercial, and industrial areas located within flood-prone zones. The high-resolution flood maps reveal that several areas along the main rivers in Alto Minho, including the Minho River and its tributaries, are particularly susceptible to flooding, with extensive floodplains exposed to inundation under extreme events with return periods as short as 10 or 20 years. As the return period increases to 50, 100, or 200 years, the flood extent expands significantly, affecting a larger area and putting more assets at risk.

Another significant risk is the economic damage resulting from these flood events. The analysis highlights that Alto Minho is exposed to substantial economic risks due to its combination of high flood hazard and the presence of valuable infrastructure, including residential buildings, commercial establishments, and industrial facilities. The economic vulnerability analysis uses damage curves to quantify the expected losses under different flood scenarios, revealing that even moderate floods can result in considerable financial losses. The presence of critical infrastructure, such as roads, bridges, and utilities, within flood-prone areas further increases the potential for economic disruption during and after flood events.

In addition to the direct damage to infrastructure, the analysis also points to the significant risk posed by the disruption of essential services, including transportation and utilities, which are often concentrated along river corridors. Flooding in these areas can lead to widespread disruptions, affecting not only the directly impacted zones but also neighbouring areas that depend on these critical services. Moreover, the expected increase in flood hazard due to climate change means that regions that are currently at moderate risk could become high-risk areas in the future, with more frequent and intense flood events leading to greater damages and higher economic losses.

The major risks associated with extreme precipitation in Alto Minho are directly related to the increasing intensity and frequency of these events under future climate scenarios. The most immediate risk is the potential for flooding, both from rivers and from surface water, as extreme rainfall can overwhelm natural and man-made drainage systems. The analysis shows that even relatively moderate rainfall events are expected to become more intense, increasing the likelihood of flash floods in urban areas and river floods in rural and low-lying regions.

In addition to flooding, the region faces the risk of soil erosion and landslides, particularly in steep or mountainous areas where intense rainfall can destabilize soil and cause slope failures. These landslides can pose a direct threat to infrastructure, such as roads and buildings, and can also result in the loss of valuable agricultural land. The hazard analysis indicates that the expected increase in extreme rainfall will exacerbate these risks, making landslides and erosion more frequent and severe.

Another significant risk is the damage to critical infrastructure, including roads, bridges, and utilities, which may be directly impacted by intense rainfall and subsequent flooding. The increased frequency and intensity of extreme rainfall events mean that existing infrastructure may be insufficiently resilient, leading to higher repair costs and greater disruption during extreme weather events.

Finally, the region is also at risk of disruption to essential services, including water supply, electricity, and transportation, as extreme precipitation can damage utility networks and block major transportation routes. This type of disruption can have far-reaching consequences, affect not only the directly impacted areas but also neighbor regions that depend on these services.

- **Severity of the risk**

The severity of the wildfire risk in Alto Minho is assessed as high and increasing. This conclusion is supported by clear evidence of a continuous upward trend in Fire Weather Index (FWI) values, which reflect a shift towards warmer and drier conditions that are highly favorable for wildfire development. These rising FWI values directly increase the likelihood of wildfires occurring and make them more intense when they do. The extension of the wildfire season further exacerbates this risk, as it means that Alto Minho is exposed to wildfire hazards for a longer period each year, making it more difficult to maintain preparedness and response capacity.

The severity of the risk is not only a function of the increasing FWI values but is also heavily influenced by the region's high vulnerability in critical areas. Densely populated zones face the most severe human risks, where many lives could be lost in the event of a fast-spreading wildfire. Economically valuable regions are at risk of suffering substantial financial losses, with homes, businesses, and infrastructure at risk of being damaged or destroyed. Ecologically important areas are threatened by irreversible environmental damage, as wildfires can devastate forests, destroy habitats, and significantly alter local ecosystems.

The combined hazard and risk analysis clearly indicates that these impacts are not only likely but are also expected to worsen in the future if current climatic trends continue. The convergence of high wildfire hazard with high vulnerability in key areas of Alto Minho means that the region is facing a scenario where wildfires could cause catastrophic damage in multiple dimensions. This situation highlights the urgent need for comprehensive wildfire prevention, preparedness, and response strategies to mitigate the potential impacts and protect the region's people, property, and natural heritage.

The severity of flood risk in Alto Minho is assessed as high, and this risk is expected to increase significantly in the coming decades due to the effects of climate change. The hazard analysis demonstrates that the region is already experiencing significant flood risks, with extensive areas exposed to river flooding under extreme events with short to moderate return periods (10, 20, 50, and 100 years). The inclusion of future climate scenarios further reveals that the frequency and intensity of flood events are likely to increase, expanding the areas at risk and heightening the severity of flood impacts.

The severity of flood risk is not only a function of the hazard itself but is also heavily influenced by the region's economic vulnerability. The risk assessment clearly shows that the most severe impacts are likely to occur in areas where high flood hazard coincides with high-value infrastructure. These areas, which include densely populated zones and economically important regions, are at risk of suffering substantial financial losses during flood events. The damage curves used in the analysis quantify these potential losses, revealing that even a moderate flood could cause millions of euros in damages, while a severe flood could lead to catastrophic economic impacts.

The combination of high flood hazard, increasing risk due to climate change, and the presence of vulnerable infrastructure means that the flood risk in Alto Minho is not only severe but is also likely to worsen in the future. This situation calls for urgent action in the form of flood mitigation measures, including improved flood defenses, better land use planning, and enhanced early warning systems, to protect the region's people, property, and economic assets.

The severity of the hazard associated with extreme precipitation in Alto Minho is assessed as high and increasing. The hazard analysis clearly shows that the region is already experiencing significant rainfall events under historical climate conditions, but that these events are expected to become even more frequent and intense in the future. This shift is directly linked to the effects of climate change, which is driving a trend towards more extreme weather patterns across the region.

The increasing intensity of extreme rainfall events means that the region is more likely to experience severe flooding, with the potential for significant damage to homes, businesses, infrastructure, and agricultural land. The projected rise in rainfall intensity also means that the risk of landslides and soil erosion is likely to increase, particularly in steep or mountainous areas. Moreover, the expected increase in rainfall extremes will place greater pressure on local drainage systems, which may be insufficient to cope with the higher volumes of water, leading to surface water flooding in urban areas.

While the hazard analysis provides a clear picture of the increasing severity of extreme precipitation in Alto Minho, it is important to note that this assessment does not include a direct evaluation of risk, as the risk workflow was not completed. This means that the analysis does not quantify the potential economic, social, or environmental impacts of extreme precipitation in the region. However, the evidence of increasing rainfall intensity and frequency strongly suggests that the potential impacts could be severe, particularly in areas that are already vulnerable to flooding, landslides, or infrastructure damage.

This situation underscores the urgent need for targeted mitigation measures, including improved flood defenses, enhanced early warning systems, and the implementation of sustainable land management practices to reduce soil erosion and increase the resilience of local infrastructure.

2.4.2 Urgency

- **Wildfire Risk in Alto Minho**

The risks associated with wildfires in Alto Minho are expected to have a major impact in the near future, with their severity continuing to increase over the coming decades if current climatic trends persist. The analysis demonstrates that the Fire Weather Index (FWI), a key indicator of wildfire hazard, is already rising, reflecting a shift towards warmer and drier conditions. These climatic changes mean that the region is becoming more susceptible to wildfires, with a longer and more intense wildfire season. The most critical period for these risks is during the hottest and driest months of the year, typically from late spring to early autumn. This is when the region is most vulnerable to wildfire ignition and spread.

Action to minimize damages must be taken immediately. Local authorities, emergency response teams, and land management agencies should prioritize wildfire prevention measures as soon as possible. This includes creating and maintaining firebreaks, improving forest management practices to reduce fuel loads, strengthening early warning systems, and enhancing the capacity of firefighting units. Public awareness campaigns should also be launched to educate residents about wildfire prevention and response, particularly in high-risk areas where FWI values are highest. Taking these actions now is crucial because delaying them will make it increasingly difficult to prevent and control wildfires as conditions continue to deteriorate.

The modelled wildfire risk in Alto Minho is primarily based on a slow-onset hazard, driven by gradual climatic changes that increase the frequency and intensity of wildfire conditions over time. Rising temperatures, decreasing rainfall, and longer dry periods slowly create an environment more prone to wildfires. However, while the hazard itself develops gradually, its manifestation can be sudden and catastrophic. A wildfire can ignite within minutes and spread rapidly, causing widespread destruction. This combination of a slow-building hazard that can result in sudden, devastating events makes the risk particularly dangerous. The urgency of taking action is extremely high because, while the underlying hazard builds gradually, the resulting wildfire can occur suddenly and cause immediate and severe damage.

- **Flood Risk in Alto Minho**

The flood risks in Alto Minho are expected to have a major impact during the wettest months of the year, typically from late autumn to early spring, when the region is most susceptible to heavy rainfall and river flooding. The analysis shows that flood hazard is already significant in many areas along the region's river systems, and these risks are expected to worsen as climate change leads to more frequent and severe rainfall events. Specifically, areas currently exposed to flooding under a 50-year or 100-year return period could experience such floods far more frequently, posing a major threat to homes, businesses, and critical infrastructure.

Immediate action is essential to minimize flood damages. Local governments must enhance flood defences, including the construction or reinforcement of levees, floodwalls, and natural flood buffers. Urban planning should be adjusted to restrict development in high-risk flood zones, and drainage systems must be upgraded to handle the increased runoff expected during extreme rainfall events.

Emergency response plans should also be revised to ensure that communities are prepared for rapid evacuations and that critical infrastructure is protected. Taking these measures now is crucial because delaying them could lead to catastrophic flood impacts in the future.

The modelled flood risk in Alto Minho is a combination of both slow-onset and sudden-onset hazards. The slow-onset component is driven by gradual climatic changes, which increase the frequency and intensity of extreme rainfall events, making floods more likely over time. However, the actual flood events themselves are sudden-onset hazards, occurring rapidly during or immediately after intense rainfall. This dual nature of the risk means that the urgency of taking action is extremely high. Although the long-term trend is a slow build-up of risk due to climate change, the damage can occur suddenly, with little warning, during a single severe flood event. This reality emphasizes the need for both long-term planning to address the slow-onset aspects of the hazard and immediate preparedness to respond to sudden flood events when they occur.

- **Extreme Precipitation Hazard in Alto Minho**

The risks associated with extreme precipitation in Alto Minho are expected to have a major impact primarily during the wettest months of the year, when the region is most exposed to intense rainfall. The hazard analysis clearly shows that extreme precipitation events are expected to become more frequent and more intense under future climate scenarios, with historical rainfall extremes being surpassed by even heavier rainstorms. The most severe impacts are likely to occur during periods of prolonged heavy rainfall, which can lead to widespread flooding, soil erosion, and landslides.

Action to minimize the damages caused by extreme precipitation must be taken immediately. Local authorities should prioritize natural flood management measures, such as restoring wetlands and reforesting steep slopes to reduce runoff. Urban planning should ensure that new developments are designed with sufficient drainage capacity, and existing drainage systems should be upgraded to handle more intense rainfall. Public awareness campaigns should educate residents about the risks associated with extreme rainfall and prepare them to respond during severe storms. Proactive measures are essential because waiting until the impacts become severe will make it much harder to prevent damage.

The modelled extreme precipitation hazard in Alto Minho is primarily a slow-onset hazard, driven by gradual climatic changes that increase the frequency and intensity of heavy rainfall events over time. These changes develop over years, as rising temperatures and shifting weather patterns create conditions for more extreme rainfall. However, the impacts of this hazard can manifest suddenly during an extreme rainfall event, which can occur with little warning. This combination of a slow-onset hazard that can produce sudden and severe impacts makes the risk particularly dangerous. Although the increasing intensity of rainfall is a gradual process, the resulting floods, landslides, or erosion can occur in a matter of hours, causing widespread damage. This dual nature means that the urgency of taking action is extremely high. Long-term mitigation measures must be implemented now to reduce the hazard, while short-term preparedness measures are needed to ensure that communities are ready to respond when extreme rainfall occurs.

2.4.3 Capacity

- **Wildfire Risk in Viana do Castelo**

Viana do Castelo has established a comprehensive set of climate risk management measures to mitigate wildfire risks, in alignment with the Municipal Climate Action Plan (PMAC) and the National Integrated Management Plan for Rural Fires (PNGIFR). These measures encompass a range of preventive, preparedness, and response strategies designed to reduce the likelihood and impact of wildfires.

One of the primary measures is proactive forest management, which includes the maintenance of extensive fuel management areas designed to break the continuity of vegetation and reduce the intensity of any potential wildfire. These fuel management areas are strategically located near urban areas, along critical infrastructure, and within forested regions that are particularly vulnerable to fire. The municipality also maintains a network of firebreaks, which are regularly cleared to ensure they remain effective barriers to fire spread. Reforestation efforts prioritize fire-resistant species, such as cork oak (*Quercus suber),* which are less prone to ignition and can naturally slow the spread of flames.

Monitoring and early warning systems are another critical aspect of wildfire management in Viana do Castelo. The municipality collaborates with national agencies to maintain a network of meteorological stations that provide real-time data on temperature, humidity, wind speed, and other key factors influencing fire risk. This data is used to calculate and monitor the Fire Weather Index (FWI), allowing for the rapid detection of periods of high fire risk. Fire patrols are also deployed during peak fire seasons to ensure early detection of any ignitions.

Education and awareness campaigns are regularly conducted, targeting both the general public and specific groups such as rural landowners, farmers, and tourists. These campaigns emphasize the importance of responsible behavior in fire-prone areas, such as avoiding the use of open flames, properly disposing of cigarette butts, and maintaining clear zones around homes. Fire response capacity has been strengthened through the training of local firefighting teams, the acquisition of specialized firefighting vehicles, and the establishment of coordination protocols between municipal, regional, and national emergency services.

Proactively managing wildfire risks in Viana do Castelo can generate several significant opportunities. Economically, the sustainable management of forest areas can foster the development of a local bioeconomy. Forest residues collected during fuel management operations can be converted into biomass energy, providing a renewable energy source that reduces carbon emissions while creating local jobs. Reforestation with fire-resistant species can enhance biodiversity and increase the region's carbon sequestration capacity, supporting climate mitigation efforts.

Socially, enhanced community awareness and engagement in wildfire prevention can strengthen social cohesion, as local residents become active participants in safeguarding their environment. The knowledge gained through wildfire prevention and response can also position Viana do Castelo as a leader in climate resilience, attracting investment in green technologies and innovative monitoring systems. The municipality's experience in managing wildfire risks can be shared with other regions facing similar challenges, creating opportunities for knowledge exchange and collaborative projects.

From a natural perspective, the use of fire-resistant species in reforestation projects can enhance the resilience of local ecosystems, while the maintenance of fuel management areas can create ecological corridors that benefit native wildlife. The integration of smart monitoring systems, including satellite imagery and drones, can enhance the municipality's ability to detect and respond to wildfires quickly, reducing environmental damage.

- **Flood Risk in Viana do Castelo**

Flood risk management in Viana do Castelo is guided by a combination of structural and non-structural measures that are designed to prevent and mitigate the impact of river and surface water flooding. These measures are detailed in the Municipal Climate Action Plan (PMAC) and include specific interventions targeting areas with a history of flooding.

Structurally, Viana do Castelo has invested in the reinforcement of riverbanks along major waterways, including the Lima River, where embankments have been strengthened and extended to prevent overflow during extreme rainfall events. Retention basins have been constructed in strategic locations to temporarily store excess rainwater, reducing the pressure on urban drainage systems. These retention areas are complemented by the expansion and maintenance of drainage networks, ensuring that heavy rainfall can be effectively channeled away from populated areas.

In urban areas, the municipality has adopted sustainable urban drainage systems (SUDS) to improve water management. These systems include permeable pavements, green roofs, and rain gardens, which increase the natural infiltration of rainwater and reduce surface runoff. In addition, the municipal stormwater system has been upgraded with larger drainage pipes and the installation of backflow prevention devices to protect low-lying areas from flooding.

Non-structural measures include a robust early warning system that integrates meteorological forecasts with local monitoring stations, providing residents with advance notice of impending flood risks. This system is supported by a network of automated rainfall and river level monitoring stations, which are linked to a centralized control center. In the event of a flood alert, municipal emergency services are mobilized, and residents in high-risk areas are notified via a combination of text messages, social media, and local radio broadcasts.

Land-use planning regulations strictly control development in flood-prone areas, with construction permits requiring detailed hydrological studies to ensure that new buildings do not exacerbate flood risks. Public awareness campaigns are regularly conducted to educate residents on the importance of keeping drainage channels clear and on how to respond in the event of a flood.

Effectively managing flood risks in Viana do Castelo can lead to a range of benefits. Economically, the adoption of sustainable urban drainage systems (SUDS) can reduce flood damage costs, enhance the aesthetic appeal of urban areas, and increase property values. Green roofs and rain gardens can also provide recreational and ecological benefits, improving the quality of life for residents. The expertise gained in managing flood risks can position Viana do Castelo as a leader in climate adaptation, attracting funding for further resilience initiatives.

Socially, the community's increased awareness of flood risks and preparedness can strengthen social resilience, fostering a culture of solidarity and mutual support. Improved flood management can also reduce the disruption of essential services, including transportation, water supply, and electricity, enhancing the quality of life for residents.

Environmentally, the restoration of wetlands and natural floodplains can enhance biodiversity and improve water quality. These green areas act as natural buffers, absorbing excess rainwater and reducing the impact of flooding. The knowledge gained through these initiatives can be shared with other municipalities, promoting sustainable flood management practices across the region.

- **Extreme Precipitation Risk in Viana do Castelo**

Viana do Castelo has developed specific measures to address the risks associated with extreme precipitation, as outlined in the PMAC. These include the enhancement of urban drainage systems to accommodate higher volumes of water, with recent upgrades focusing on the installation of larger drainage pipes, the construction of additional retention basins, and the use of backflow prevention devices. The municipality has also adopted sustainable urban drainage systems (SUDS), including permeable pavements, green roofs, and rain gardens.

Monitoring systems are in place to provide early warnings, integrating real-time data from rainfall and river level sensors. The emergency response plan is regularly updated, and public education campaigns ensure that residents know how to protect themselves and their property during extreme rainfall events.

Mitigating extreme precipitation risks can enhance urban resilience and create economic opportunities. Investing in SUDS can reduce damage costs, enhance urban aesthetics, and attract tourism. Socially, increased community awareness can foster resilience, while the development of expertise in sustainable drainage can position Viana do Castelo as a regional leader in climate adaptation. Environmentally, green infrastructure enhances biodiversity, improves water quality, and contributes to climate mitigation.

2.5 Preliminary Monitoring and Evaluation

- **First-phase: lessons and most difficulties**

The first phase of the climate risk assessment for Viana do Castelo, conducted under the CLIMAAX project, provided valuable insights into both the strengths and limitations of the current climate risk assessment approach. One of the most significant lessons learned was the importance of maintaining a clear and structured workflow for each risk type, including floods, wildfires, heavy rainfall, and storms. The structured nature of the CLIMAAX workflows ensured that data was consistently processed and analyzed, leading to a standardized approach that enhanced comparability across different risk types.

However, the process also highlighted several key difficulties. One of the main challenges encountered was related to data availability and quality. While the workflows were designed to use global datasets by default, these datasets often lacked the resolution and local specificity needed for effective decision-making in Viana do Castelo. For instance, the flood hazard maps produced by the workflow were of very low resolution, which made them unsuitable for detailed local planning and management. Similarly, the heavy rainfall risk workflow was constrained by data limitations, with the risk analysis being stuck on Catalonia data, making it impossible to produce risk maps for Viana do Castelo.

Technical difficulties also played a significant role, particularly in the case of the fire hazard workflow. The initial version of this workflow was not functioning correctly, and extensive edits were required to produce meaningful results. Although the CLIMAAX team eventually provided an improved version, the initial technical issues delayed progress. Additionally, the heavy rainfall workflow was affected by a significant challenge in data download, where the process required downloading multiple large segments, creating a high risk of incomplete data acquisition.

Stakeholder engagement was another area of difficulty, as the project team needed to balance the technical aspects of the assessment with the need to communicate findings in an accessible manner. This required continuous adjustments to ensure that the results were understandable and relevant to the local context.

- **Stakeholders' engagement**

Stakeholder feedback is a critical part of the first-phase climate risk assessment. The stakeholders, which included members of the Municipal Civil Protection Commission, local emergency services, environmental organizations, and municipal departments, provided several important observations. They emphasized the need for higher-resolution data in the hazard maps, as the low-resolution outputs from the default workflow were considered insufficient for local planning and decision-making. This feedback reinforced the importance of integrating local data sources wherever possible.

The stakeholders also highlighted the need for a more user-friendly interface for the workflows, as some technical aspects of the workflows were difficult for non-experts to navigate. In response, the project team recognized the importance of providing clear user guidance and potentially simplifying the workflow interfaces for future phases.

There was also feedback on the importance of involving a broader range of stakeholders in the next phase, particularly those directly affected by the identified risks, such as local farmers (for wildfire risks), residents of flood-prone areas, and tourism operators (who may be affected by storms and extreme rainfall). These groups can provide local knowledge that is crucial for understanding vulnerabilities and refining the risk assessment.

Considering the next steps of project, it will be important to involve stakeholders from the private sector, such as insurance companies, which can offer insights into economic vulnerability and risk mitigation costs. Collaboration with local universities and research institutions can also enhance the scientific quality of the analysis.

In this sense, the communication plan includes the following actions: Three meetings with stakeholders (July and November 2025, and March or April 2026); two practical workshops with stakeholders (July 2025 and April 2026); one workshop with citizens (October 2025); one presentation to the general public (October/November); several sectoral working sessions; and one final presentation of the VC_Climaax project (June 2026).

- **Data availability and requirements**

As of the end of the first phase, new data has become available, particularly improved climate projection datasets from the EURO-CORDEX initiative, which offer higher-resolution information for extreme rainfall and temperature scenarios. The availability of these datasets presents an opportunity to enhance the resolution of the hazard maps produced in the next phase of the project.

However, to fully understand the risks, several additional data types and resources are needed. These include high-resolution topographic data, which is essential for accurate flood modelling, particularly for river floods in urban areas. Enhanced land cover data, including updated vegetation maps, is needed to improve wildfire hazard modelling, ensuring that the analysis reflects current fuel conditions.

From a resource perspective, the project team requires more advanced computational capabilities to process high-resolution data efficiently. This is particularly important for workflows that involve extensive data downloads or complex calculations, such as the heavy rainfall workflow.

In terms of competencies, the team would benefit from further training in advanced climate risk modelling techniques, particularly in the use of machine learning for risk analysis and the integration of local knowledge into the models. Collaborative research with local universities, mainly the University of Minho, was made and is being important to support this capacity building.

Finally, it would be beneficial to expand the monitoring network for climate variables in Viana do Castelo. This could include additional weather stations, river level sensors, and soil moisture sensors, which would provide real-time data to support both hazard detection and risk assessment.

3 Conclusions Phase 1- Climate risk assessment

The first phase of the climate risk assessment for Viana do Castelo district, conducted within the framework of the CLIMAAX project, has provided essential insights into the region's vulnerability to climate-related hazards, including floods, wildfires, extreme precipitation, and storms. This phase has demonstrated the value of adopting a structured, workflow-based approach for climate risk assessment, which has enabled a consistent and systematic evaluation of the main hazards affecting the region. However, it has also highlighted several challenges that must be addressed to enhance the accuracy and usability of the assessment.

One of the most significant achievements of this phase was the successful application of the CLIMAAX workflows to the four primary hazards of interest. The flood hazard assessment produced maps illustrating the extent of river flooding under various return periods, while the wildfire workflow generated Fire Weather Index (FWI) maps that provided a clear view of how fire risk is expected to evolve under different climate scenarios. The extreme precipitation workflow demonstrated the increasing intensity of rainfall events under future climate scenarios, and the storms workflow provided a simulated analysis of the impacts of a major historical storm (Klaus 2009). These analyses have established a solid foundation for understanding the key climate risks facing Viana do Castelo district.

Despite these achievements, the first phase also revealed several important challenges. The most significant challenge was related to data quality and resolution. The flood hazard maps, for instance, were of very low resolution, making them unsuitable for detailed local planning. Similarly, the heavy rainfall risk workflow was limited by its dependence on data for Catalonia, which prevented the generation of locally accurate risk maps for Viana do Castelo district. These limitations underscore the need to integrate higher-resolution local data into the workflows in the next phase of the project. Technical difficulties were another obstacle, particularly in the initial versions of the wildfire workflow, which required extensive edits to function correctly. Although the CLIMAAX team later provided an improved version, the initial delays impacted the overall workflow efficiency.

Stakeholder engagement was another area where valuable lessons were learned. Feedback from stakeholders, including members of the Municipal Civil Protection Commission, emphasized the importance of producing hazard maps with higher spatial resolution and ensuring that the results were communicated in an accessible manner. This feedback has reinforced the need for a more user-friendly interface in the workflows and for the involvement of a broader range of stakeholders, including local farmers, tourism operators, and insurance companies, who can offer critical insights into vulnerability and risk management.

The analysis also highlighted a number of key findings that are critical for Viana do Castelo district. The region is highly vulnerable to river flooding, with extensive areas exposed under even moderate return periods. Wildfires are becoming an increasing concern due to rising FWI values, indicating a longer and more intense fire season. Extreme precipitation is expected to become more frequent and intense, leading to a greater risk of flash floods and landslides. Finally, the analysis of storm hazards confirmed the potential for severe wind damage, particularly in coastal areas.

In conclusion, this first phase of the climate risk assessment has established a solid foundation for understanding the climate risks facing the region but has also highlighted the need for further improvements in data quality, stakeholder engagement, and workflow usability. The next phase must focus on integrating higher-resolution local data, refining the workflows to enhance their accuracy, and expanding stakeholder participation to ensure that the assessment is both scientifically robust and locally relevant. These improvements will be critical for providing decision-makers with the information they need to develop effective adaptation and resilience strategies for Viana do Castelo district.

4 Progress evaluation and contribution to future phases

Phase 1 were focused on the comprehensive application of the CLIMAAX Climate Risk Assessment (CRA) methodology in Viana do Castelo Municipality. In this sense, this deliverable demonstrates the achieved of milestones M1- “Test the CLIMAAX workflows for the different risks”, M2 – “Workflows for the different risks successfully applied” and M3- “CLIMAAX common methodology for multi-risk climate assessment applied”, corresponding to the first phase of VC_Climaax project implementation.

Table 4-1 VC_Climaax overview of milestones (M).

Milestones	Progress
M1: Test the CLIMAAX workflows for the different risks	Achieved, • Floods- 100% completed • Fire- 100% completed • Heavy Rainfall – 100% completed (Hazard; Risk does not work, only for Catalonia) • Storms- completed for Klaus Storm
M2: Workflows for the different risks successfully applied	Achieved, • Floods (river)- 100% applied • Fire- 100% applied • Heavy Rainfall- Hazard 100% applied, Risk does not work for local data, only for Catalonia). • Storms- Applied for Klaus Storm.
M3: CLIMAAX common methodology for multi-risk climate assessment applied	Achieved, • Floods- completed • Fire- completed • Heavy Rainfall- Hazard completed. Risk assessment does not work • Storms used for Klaus storm simulation.
M4: High-resolution local data collected and compiled	
M5: Workflows for the different risks refined and improved	
M6: Potential local adaptation options identified	
M7: Stakeholders participatory processes carried out	Prepare the communication strategy and next actions.
M8: Local adaptation options evaluated and prioritized	
M9: Recommendations for improve risk management plans formulated	
M10: Presentation of the results to policy and decision makers in Viana do Castelo	
M11: Attend the CLIMAAX workshop held in Barcelona	Prepare the poster and identify the relevant technical questions for VC_Climaax's participation in the upcoming workshop in Barcelona.
M12: Attend the CLIMAAX workshop held in Brussels	

Likewise, compliance with the KPI - "At least 2 risk workflows will be successful applied on Deliverable 1 (multi-risk climate assessment)" corresponding to the first phase of the VC_Climaax project has also been identified.

Table 4-2 VC_Climaax overview of key performance indicators (KPIs).

Key performance indicators	Progress
At least 2 risk workflows will be successful applied on Deliverable 1 (multi-risk climate assessment)	• Floods (river)- 100% applied • Fire- 100% applied • Heavy Rainfall- Hazard 100% applied, Risk does not work for local data, only for Catalonia). • Storms- Applied for Klaus Storm.
At least 2 risk assessment will be refined and improved using local data of higher resolution on Deliverable 2 (refined regional/local multi-risk assessment)	
At least 1 local adaptation strategy will be explored and improved	
2 emergency and risk management plans will be improved with the results of the risk and vulnerability assessment	
More than 20 stakeholders will be involved in the project's activities	
At least 5 communication actions will be developed to share the start of the project, the results of each of the 3 phases and the final results of the project	A communication strategy and Plan has designed. - One communication action (social media) was made about the start of the project (Communication outputs IDs: VC_Climaax_01 (Facebook) and VC_Climaax_02 (Instagram)
A final publication will be produced with the actions and results obtained from participation in the project	
3 notes will be drawn up for political decision-makers based on the results of each of the 3 phases of the project	
3 articles in regional media mentioning the project	

However, work has begun on various activities planned for the next phases of the project, in particular: i) local datasets identified and organized; and ii) definition of communication Plan and actions (according strategy and objectives).

5 Supporting documentation

All outputs produced were shared in the Zenodo repository, following this structured

- Main Report (PDF)
- Supplementary Material
    - Floods (SM_Floods.zip)
    - Fire (SM_Fire.zip)
    - Heavy Rainfall (SM_HeavyRainfall.zip)
    - Storms (SM_Storms.zip)
- Communication Outputs (PDF)
- Zenodo link(s)
    - Version 1.0 (https://doi.org/10.5281/zenodo.15116547)
    - Version 2.0 (https://doi.org/10.5281/zenodo.15426297)