Deliverable Phase 1 – Climate risk assessment

Comunidade Intermunicipal da Beira Baixa (CIM-BB)

(CLIMAAX-BeiraBaixa)

Portugal, Região da Beira Baixa

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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Abbreviations and acronyms

Abbreviation / acronym	Description
CLIMAAX	CLIMAte risk and vulnerability Assessment framework and toolbox
PIAAC-BB	Plano Intermunicipal de Adaptação às Alterações Climáticas da Beira Baixa *(Intermunicipal Plan of Adaptation to Climate Change – Beira Baixa)*
CIM-BB	Comunidade Intermunicipal da Beira Baixa *(Intermunicipal Community of Beira Baixa)*
AFLOBEI	Associação de Produtores Florestais da Beira Interior *(Association of Forest Producers of Beira Interior)*
Ovibeira	Associação de Produtores Agropecuários *(Association of Livestock and Agricultural Producers)*
Acripinhal	Associação de Criadores de Ruminantes do Pinhal *(Association of Ruminant Breeders of the Pinhal Region)*
ARBI	Associação de Regantes e Beneficiários de Idanha-a-Nova *(Association of Irrigators and Beneficiaries of Idanha-a-Nova)*
SMPC	Serviço Municipal da Proteção Civil *(Municipal Civil Protection Service)*
CEIF-ADAI	Centro de Estudos sobre Incêndios Florestais - Associação para o Desenvolvimento da Aerodinâmica Industrial *(Forest Fire Research Centre – Association for the Development of Industrial Aerodynamics)*
ANEPC	Autoridade Nacional de Emergência e Proteção Civil *(National Authority for Emergency and Civil Protection)*
AGIF	Agência para a Gestão Integrada de Fogos Rurais *(Agency for the Integrated Management of Rural Fires)*
GNR	Guarda Nacional Republicana *(National Republican Guard)*
CCDR	Comissão de Coordenação e Desenvolvimento Regional *(Commission for Regional Coordination and Development)*
ICNF	Instituto da Conservação da Natureza e Florestas *(Institute for Nature Conservation and Forests)*
ML	Machine Learning
COS-2023	Carta de Ocupação de Solos 2023 *(Land Use and Land Cover Map 2023)*
DGT	Direção Geral do Território *(Directorate-General for Territory)*
LST	Land Surface Temperature
DEM	Digital Elevation Model

Executive summary

This deliverable presents the Phase 1 Climate Risk Assessment for the Beira Baixa region, developed under the CLIMAAX framework, with a focus on wildfire and heatwave hazards. This assessment aims to strengthen regional climate resilience by identifying key climate-related risks and vulnerabilities and proposing pathways for adaptation and risk mitigation. The study aligns with national and European climate governance strategies and builds on the Intermunicipal Plan for Adaptation to Climate Change of Beira Baixa (PIAAC-BB).

The assessment was prompted by the region's exposure to extreme climate events, particularly wildfires and heatwaves. Historical data indicate that approximately 25% of the territory has been affected by wildfires since 2017, while projections suggest a significant increase in heatwave intensity and frequency under both RCP 4.5 and RCP 8.5 scenarios. These climate trends are further compounded by the region's demographic vulnerabilities, including an aging population and widespread rural depopulation.

Two analytical workflows were implemented to assess these risks. The wildfire risk workflow combined satellite data, climate projections, and machine learning techniques to identify areas with the highest hazard potential, particularly in the western and northeastern mountainous zones. The heatwave workflow used regional projections and land surface temperature (LST) mapping to determine urban heat island effects and their impacts on vulnerable populations in urban centers such as Castelo Branco and Sertã.

Stakeholder engagement was a central component of the assessment, with participation from 29 regional stakeholders across sectors including civil protection, forestry, healthcare, energy, and academia. These stakeholders contributed data, validated results, and helped identify future priorities, such as improving model accuracy and integrating new data sources.

Key findings reveal:

- A consistent increase in wildfire-prone days and spatial risk spread under high-emission scenarios.
- High exposure of critical infrastructure — healthcare, transport, and energy systems — to wildfire risks.
- Amplified heatwave risks in urbanized and densely populated areas, exacerbated by urban heat islands.
- Demographic vulnerabilities that heighten sensitivity to heat-related hazards.

This deliverable contributes to the overall CLIMAAX project by offering a replicable methodological approach for regional climate risk analysis and fostering integrated climate governance. It establishes a foundation for Phase 2, which will refine hazard and risk models using higher-resolution and locally sourced data and strengthen stakeholder collaboration to improve regional adaptation capacity.

1 Introduction

1.1 Background

The Beira Baixa region, located in central Portugal, encompasses an area of approximately 5,252.92 km² and comprises eight municipalities: Castelo Branco, Idanha-a-Nova, Oleiros, Penamacor, Proença-a-Nova, Sertã, Vila de Rei, and Vila Velha de Ródão. As of 2021, the region's population stands at approximately 92,459 inhabitants, resulting in a population density of about 17.6 inhabitants per km². The administrative center and largest urban area is Castelo Branco, which houses 70% of the region's population.

The region's recent administrative expansion to include Sertã and Vila de Rei further reinforces its economic significance in forestry and rural development. The landscape is marked by diverse geographical features, from the Gardunha Mountain range in the north to the expansive plains bordering the Alentejo region in the south. This varied topography contributes to the region's rich natural and cultural heritage.

Beira Baixa has some variability in geomorphological terms (plain and mountain), being composed of some mountain landscapes of the mountains of the central mountain range (Serra da Gardunha – 1227m and Serra da Malcata – 1259m), the unit consisting of the Gardunha Mountains, Alveoli and Moradal and the Serra de Penha Garcia, Serra do Perdigão and Serra do Moradal, as well as lowland landscapes, with elevations in the order of 300-500m, with emphasis on the meadows of Idanha.

The territory has clearly Mediterranean climatic characteristics, with some differences between the more mountainous sectors and the lower elevation zones. Summers are warm and dry to oppose cold winters. The month of July is the month that historically presents the highest values of monthly average temperature, minimum average and maximum average. The month of August is the month with the highest maximum absolute temperature (41.6ºC). The humidity of the air it follows the behaviour of the temperature, registering the lowest values in the months of July and August. As far as precipitation is concerned, it varies greatly depending on altitude, with values that are between 600 and 1200mm/year.

Land use is also a distinct element in this markedly rural territory, where it is possible to verify the supremacy of forest landscapes, with a greater predominance of Maritime pine forests (Pinus pinaster Ait.), Eucalyptus forests (Eucalyptus globulus L,), and holm oak (Quercus ilex L,) and cork oak (Quercus suber L.) forests, with some constraints in terms of forest management that hinder the exploitation of their resources, aggravated by forest properties that are characterized by a smallholdings structure, mostly without any management, with forest stands disordered and proliferating invasive plants and spontaneous vegetation, which contributes to the risk of high fire in much of the territory, especially west of the Ocreza River.

In recent decades, Beira Baixa has experienced significant demographic shifts, notably a declining and aging population. Many villages now have as few as 70 to 200 residents, predominantly elderly individuals. This demographic trend has led to the closure of schools and the abandonment of agricultural lands, exacerbating the region's vulnerability to environmental challenges.

Beira Baixa is characterized by a rich natural and landscape heritage, which includes several protected areas of significant environmental and cultural value. Among these are the Natural Park of the International Tagus, the Serra da Malcata Nature Reserve, the Natural Monument of the Ródão Gates, the protected landscape of Serra da Gardunha, and sites designated under the Natura 2000 Network (Habitat Directive), specifically Gardunha and Malcata. Also integral to this heritage is the Naturtejo Geopark, which encompasses the municipalities of Vila Velha de Ródão, Castelo Branco, and Idanha-a-Nova. Recognized as part of the UNESCO Global Geoparks Network since 2006 and included in the Biosphere Reserve Network since 2015.

Beira Baixa faces significant climate risks, particularly from wildfires and heatwaves, due to its dry Mediterranean climate, high summer temperatures, and extensive forested areas dominated by flammable species such as Maritime pine and Eucalyptus. The prevalence of unmanaged lands, smallholdings, and invasive vegetation further amplifies fire susceptibility, especially west of the Ocreza River. Additionally, recurring heatwaves, with temperatures exceeding 41°C, intensify the region's exposure. These risks are compounded by demographic decline and land abandonment, which weaken local capacity for landscape management and adaptation. As such, Beira Baixa requires focused climate risk mitigation and adaptation strategies addressing both fire and heat stress.

1.2 Main objectives of the project

The primary objective of this project is to conduct a high-resolution climate risk assessment for Beira Baixa, focusing on wildfire and extreme heat risks. Through the application of the CLIMAAX framework, the project aims to:

- Improve the understanding of climate-related hazards in the region.
- Enhance data integration for more informed decision-making.
- Develop tailored adaptation strategies to mitigate risks and increase resilience.
- Foster regional collaboration among stakeholders to ensure sustainable climate governance.

By utilizing the CLIMAAX Handbook, the project will provide a structured and harmonized approach to climate risk assessment. This methodology will facilitate the identification of vulnerable sectors, enhance risk monitoring, and support the implementation of adaptation measures, such as contingency plans for extreme temperatures. The findings from this study will contribute to broader national and European climate adaptation efforts, positioning Beira Baixa as a model for other vulnerable regions.

1.3 Project team

The project team comprises two key entities collaborating to conduct the climate risk assessment and implement the CLIMAAX framework (Phase 1 and Phase 2):

Comunidade Intermunicipal da Beira Baixa (CIM-BB)

CIM-BB is the regional coordinating body responsible for fostering intermunicipal collaboration and implementing strategic initiatives in Beira Baixa. As the lead institution, CIM-BB ensures the alignment of the project with regional climate adaptation policies and facilitates stakeholder engagement across municipalities.

greenmetrics.ai

greenmetrics.ai is a technology-driven organization that provides advanced data analytics for environmental and climate risk assessments. Their expertise in climate modeling and risk prediction supports the project's efforts in quantifying vulnerabilities, identifying high-risk areas, and proposing data-driven adaptation strategies.

1.4 Outline of the document's structure

The document is structured into the following sections:

Section 1- Introduction

Provides a short summary of the region's background, main goals for the implementation of the CLIMAAX framework and project team.

Section 2 – Climate Risk Assessment - Phase 1

Provides a detailed analysis of climate risks affecting Beira Baixa, including hazard screening, scenario selection and risk analysis methodologies.

Section 3 – Key Findings

Summarizes the preliminary results of the assessment, including identified risks, vulnerabilities, and potential issues requiring future adaptation strategies.

Section 4 – Monitoring and Evaluation

Discusses the mechanisms for tracking progress, refining risk assessments, and integrating stakeholder feedback.

Section 5 – Conclusions

Presents the key conclusions from the preliminary climate risk assessment, reflecting on the main results obtained with this methodology and its limitations.

Section 6 – Supporting Documentation

Includes references, datasets, and supplementary materials used in the assessment.

2 Climate risk assessment – phase 1

2.1 Scoping

2.1.1 Objectives

The primary objective of this Climate Risk Assessment (CRA) is to evaluate and quantify the impact of climate hazards, particularly **wildfires** and **heatwaves**, in Beira Baixa. This assessment aims to provide data-driven insights to enhance climate adaptation strategies, improve emergency response mechanisms, and strengthen regional resilience against extreme climate events, with a strong emphasis on stakeholder engagement and risk ownership.

The CRA will contribute to policymaking by integrating scientific data into decision-making processes at municipal and intermunicipal levels. The findings will inform land-use planning, resource allocation, and risk management strategies, ensuring alignment with national climate adaptation policies and European Union directives.

Addressing limitations in data availability and quality is crucial. Many datasets remain fragmented across different agencies, complicating a unified climate risk analysis. Additionally, climate models often lack the granularity required for precise regional predictions. Furthermore, the temporal dimensions of these datasets frequently exclude the worst wildfire years, limiting the accuracy of risk projections and potentially underestimating future vulnerabilities. Strengthening stakeholder collaboration and data-sharing mechanisms will be key to improving risk projections and their applicability.

Ensuring sustained participation from local authorities, research institutions, the private sector, and vulnerable communities is essential to developing inclusive climate adaptation measures. Through continuous collaboration and knowledge-sharing, this project aims to enhance long-term resilience and proactive climate risk management in Beira Baixa.

2.1.2 Context

Climate hazards in Beira Baixa have traditionally been assessed through municipal forest fire defense plans and regional adaptation strategies, such as the Intermunicipal Plan for Adaptation to Climate Change of Beira Baixa (PIAAC-BB). However, these assessments often lack integration, leading to fragmented responses and limited long-term planning.

The primary challenges addressed by this project include the increasing frequency and severity of wildfires and heatwaves, which pose significant threats to the region's economy, environment, and public health. The CLIMAAX project seeks to bridge critical gaps in climate risk assessment by improving data availability, enhancing predictive modeling, and integrating stakeholder-driven adaptation strategies. Additionally, governance frameworks, including regional climate policies and national directives, such as the National Strategy for Integrated Rural Fire Management, play a crucial role in shaping and supporting these adaptation measures.

Furthermore, at both national and local levels, significant efforts are underway to develop heatwave adaptation measures. Portugal's national heatwave contingency plan includes early warning systems, public awareness campaigns, and emergency response protocols, particularly aimed at protecting vulnerable populations. Locally, Beira Baixa municipalities have been working on improving shading in public spaces, increasing access to cooling centers, and integrating heatwave adaptation into urban planning strategies. These measures complement the objectives of the CLIMAAX project by reinforcing community resilience against extreme temperature events.

2.1.3 Participation and risk ownership

Stakeholder participation is a critical component of the climate risk assessment for Beira Baixa, ensuring that risk ownership is distributed across key entities responsible for land management, emergency response, environmental conservation, and public health. Given the complexity of wildfire and heatwave risks, effective collaboration among institutional, municipal, and civil society stakeholders is essential for developing actionable adaptation strategies.

To establish an inclusive and effective engagement process, a diverse set of stakeholders was identified and invited to participate in the project. This initial list includes representatives from governmental agencies, municipalities, research institutions, forestry and agricultural associations, civil protection organizations, and community-based groups. Recognizing that climate adaptation requires ongoing collaboration, this stakeholder network is expected to expand as the project progresses.

Following the identification of relevant stakeholders, a stakeholder workshop was organized to introduce the project, present the work completed so far, and open the analysis to stakeholder-driven feedback. This workshop provided a platform for participants to contribute insights, validate preliminary findings, and highlight critical data gaps. Additionally, it offered an opportunity to align analytical efforts for Phase 2 of the project, ensuring that stakeholder-provided data and objectives are effectively integrated into the next stages of climate risk modeling and decision-support frameworks.

The following stakeholders have been engaged in the project, representing a wide range of expertise and responsibilities:

Agricultural and Forestry Associations: Junta de Agricultores dos Regadios de Ródão, Associação dos Beneficiários da Cova da Beira, AFLOBEI - Associação de Produtores Florestais da Beira Interior, Ovibeira - Associação de Produtores Agropecuários, Acripinhal - Associação de Criadores de Ruminantes do Pinhal, ARBI - Associação de Regantes e Beneficiários de Idanha-a-Nova, Associação Florestal

Municipalities and Civil Protection Authorities: Município de Oleiros - SMPC, Município de Vila Velha de Ródão, Câmara Municipal de Castelo Branco, Município de Castelo Branco, Proteção Civil do Município de Vila de Rei, Câmara Municipal da Sertã, Município de Penamacor, Câmara Municipal de Idanha-a-Nova

Research and Higher Education Institutions: Instituto Politécnico de Portalegre, Instituto Politécnico de Castelo Branco, Centro de Investigação em Ciências da Saúde - Universidade da Beira Interior, ADAI

Governmental and Emergency Response Agencies: ANEPC, AGIF, GNR, CCDR Centro, Instituto da Conservação da Natureza e Florestas, CoLAB ForestWISE, VOST Portugal

Distribution and Transport Utility Companies: E-Redes, REN

These stakeholders play a crucial role in defining risk ownership by contributing data, shaping policy recommendations, and participating in the design of risk mitigation strategies. Their involvement ensures that climate adaptation measures are tailored to regional needs, leveraging local knowledge and institutional expertise.

As the project transitions to Phase 2, stakeholder input will be systematically incorporated into climate risk assessments through structured data-sharing agreements and collaborative analysis sessions. Additional workshops and consultations will be held to refine adaptation strategies and enhance regional preparedness for climate-related hazards. The evolving stakeholder network will continue to support decision-making processes, fostering long-term resilience against wildfires and heatwaves in Beira Baixa.

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

The Beira Baixa region faces increasing risks from **wildfires** and **heatwaves** due to climate change, driven by rising temperatures, decreasing precipitation, and prolonged drought periods. These interrelated climatic variables exacerbate environmental vulnerabilities, making risk assessment essential.

Wildfire risk is primarily influenced by increasing aridity and shifts in seasonal precipitation patterns. The climate risk assessment workflow utilizes climate variables from the ECLIPS2.0 dataset (Zenodo, 2018), which incorporates projections from five regional climate models. Historical wildfire occurrences, sourced from ICNF's geo-catalogue of burnt areas in Portugal (1975–2023) (ICNF, 2023), indicate an upward trend in fire-prone conditions, with projections showing fire-prone days rising to 27% of the year by 2070 under RCP8.5. The analysis integrates wildfire risk indicators such as fire-prone days, fuel moisture index, and vegetation dryness, using Copernicus GLO-30 DEM and CORINE Land Cover datasets, with plans to transition to COS-2023 upon its release.

Heatwaves are intensifying due to rising land surface temperatures, particularly in urbanized areas of Beira Baixa. The Copernicus Data Store provides data from the EURO-CORDEX climate model (Copernicus, 2019), projecting increased heatwave frequency and intensity under both RCP4.5 and RCP8.5. Urban heat island effects have been mapped using Landsat9 historical satellite imagery (USGS, 2021), showing significant temperature amplification in specific neighborhoods of Castelo Branco, such as São Tiago and Senhora da Piedade, as well as in other urban areas like Sertã, Proença-a-Nova, and Vila Velha de Ródão. These areas, characterized by high-density construction and limited vegetation cover, experience sustained elevated temperatures, exacerbating heatwave impacts.

Demographic vulnerability assessments use the WorldPop dataset (WorldPop, 2023), revealing that Beira Baixa's aging population, particularly in urban centers with limited cooling infrastructure, is disproportionately susceptible to heat-related mortality and morbidity. Addressing these risks requires targeted urban planning measures, including the expansion of green infrastructure and increased shading in public spaces.

Despite comprehensive data sources, challenges persist in achieving fine-resolution projections, as European climate models have limitations in long-term forecasts for Beira Baixa. Improving spatial and temporal resolution remains crucial for enhancing machine-learning models and ensuring that risk assessments accurately reflect local climate hazards. Future work will focus on integrating finer-scale datasets and increasing the granularity of climate projections to improve predictive capacity and support targeted adaptation strategies.

2.2.2 Workflow selection

2.2.2.1 Workflow #1

The wildfire risk workflow was selected to address the Beira Baixa region's recurrent and severe wildfire activity, historically concentrated in forested and mountainous municipalities such as Oleiros, Vila de Rei, and parts of the western region impacted by the 2017 Pedrógão Grande fire. This workflow applies hazard modeling based on climate and land-use data to identify zones of increased fire ignition and spread potential. The analysis is critical for informing forest management and civil protection planning. Vulnerable groups identified include elderly residents in dispersed rural settlements, forestry sector workers, and emergency response personnel operating in high-risk, low-access areas.

2.2.2.2 Workflow #2

The heatwave workflow was selected to evaluate the growing risk of extreme heat in urban and peri-urban areas of Beira Baixa, exacerbated by climate change and socio-demographic vulnerabilities. This workflow integrates regional climate projections with satellite-derived land surface temperature data to pinpoint areas affected by urban heat island effects, particularly in Castelo Branco, Sertã, and Proença-a-Nova. The assessment is tailored to guide public health and urban planning responses. Vulnerable groups include elderly residents, individuals with chronic illnesses, and low-income populations in densely built neighborhoods lacking shade and cooling infrastructure.

2.2.3 Choose Scenario

To support a comprehensive climate risk assessment, this project adopts the CLIMAAX framework's guidance on scenario development, incorporating both climate and socio-economic pathways. The selected scenarios are grounded in the Representative Concentration Pathways (RCPs) 4.5 and 8.5, which represent moderate and high-emission trajectories, respectively. These pathways enable a comparison of future risk levels under differing mitigation efforts and global climate outcomes.

The Beira Baixa region has historically experienced extreme climate events, such as the 2017 Pedrógão Grande fire, which severely impacted the western part of the region and emphasized the escalating risks tied to both anthropogenic climate change and landscape characteristics. Thus, scenario selection prioritizes both climate hazards and the socio-economic characteristics that modulate exposure and vulnerability in the region.

Three different time horizons are considered in the scenario analysis to reflect the gradual evolution of climate hazards and to support planning across short-term (2021–2040), mid-term (2041–2060), and long-term (2061–2080) periods. However, due to limitations in climate model resolution and performance (as discussed in Section 2.3.1), the most robust hazard assessments have been produced for the 2021–2040 period.

The scenario analysis considers three main dimensions. First, climate projections based on RCP4.5 and RCP8.5 are applied to wildfire and heatwave risk assessments using datasets such as ECLIPS2.0 and EURO-CORDEX, where RCP4.5 assumes mid-century stabilization of emissions and RCP8.5 reflects continued emission growth and more severe climate impacts. Second, socio-economic factors such as demographic aging, rural depopulation, and growing urbanization—especially in Castelo Branco and Sertã—shape patterns of exposure and adaptive capacity, particularly in areas affected by urban heat island effects and wildfire vulnerability. Finally, data limitations influence the scenario analysis; due to insufficient granularity in some long-term climate model outputs, emphasis is placed on near-future projections (2021–2040), while longer time horizons are referenced more qualitatively to reflect expected trends like increasing aridity and prolonged fire seasons.

Given these considerations, RCP4.5 and RCP8.5 are maintained throughout the risk assessment as bounding cases, representing “moderate” and “worst-case” pathways, respectively. These scenarios provide essential contrasts in hazard severity, which are then linked to exposure and vulnerability data to determine risk levels across infrastructure, population groups, and ecosystems.

2.3 Risk Analysis

2.3.1 Workflow #1 - Wildfires

2.3.1.1 Hazard assessment - Wildfires

The hazard assessment starts with a hazard analysis of the wildfire risk for the period of 2021-2040, considering the RCP 4.5 (Figure 2-1) and RCP 8.5 (Figure 2-2) emissions scenario. The climate variables are projected using the CLMCom_CCLM model, and the changes projected according to this climate model will be later exposed in this document.

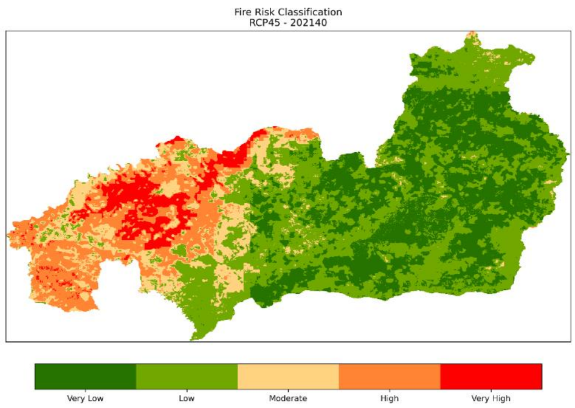

Figure 2--1 Predicted fire risk for the region for the period of 2021-2040 considering RCP4.5, CLMCom_CCLM

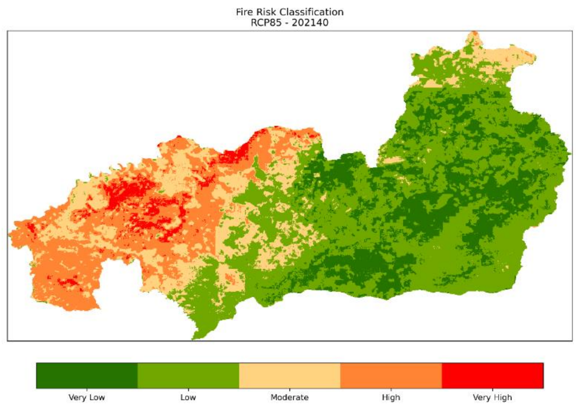

Figure 2--2 Predicted fire risk for the region for the period of 2021-2040, considering RCP 8.5, CLMCom_CCLM

The predicted risk visualization illustrations above confirm the historical pattern of the western part of the region being the most affected by wildfires, with a slightly worrying new-found risk for the northeastern part of the region, which could become a threat as the region’s vegetation poses a big fire hazard in the case of an uncontrolled fire starting in that area.

Considering the RCP 8.5 pathway for emissions, it’s possible to see that the whole region has a considerably larger region of “Moderate” and “High” predicted risk for wildfires, both in the western and northeastern parts.

One of the features of the terrain of the Beira Baixa region contributing to the real hazard and risk of wildfires is the various mountain ranges of the region, which coincide with the zones marked for highest risk of wildfires by the predictive model (and historically), as can be seen in Figure 2-3, depicting a plot of the DEM, sourced from Copernicus GLO-30 data (Copernicus DEM, 2020), of the region.

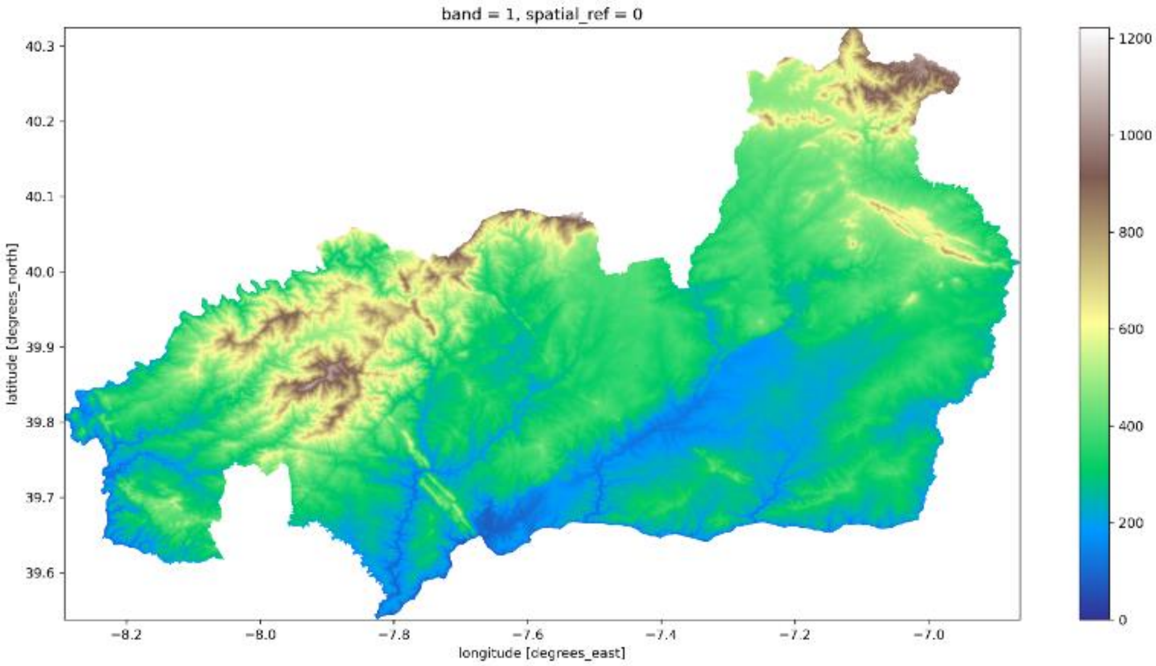

Figure 2--3 Digital Elevation Model for the region of Beira Baixa

This contributes in part to the region's awareness of the need for wildfire prevention measures, as the response capability is harder due to the challenging terrain and the difficulties involving reaching a remote fire occurrence. This also provides a focus of the analysis using more local data collected from the stakeholders involved in this project, as this region's unique geographic challenges regarding wildfires reinforce the need for clear strategizing and data-driven decision making in its climate resilience planning.

The predictive model did not produce the expected results for more distant timeframes (2041-2060 and 2061-2080) for either of the analyzed pathways during the hazard analysis. This could be related to the low number of entry points for the region's extent to train the Machine Learning model used in the workflow, focusing more on the region's geographical characteristics rather than on the climate variables used, as the spatial resolution for the latter is much less fine than the spatial resolution of the elevation/landcover datasets – 12 x 12 km (Debojyoti et al., 2020) vs 0.1 x 0.1 km (**CLMS**, 2019). Further investigation into this will be done as we refine the analyses in Phase 2.

Some of these results can be verified in the following hazard depictions of the Beira Baixa region, depicting less hazardous results, even though most of the climatic variables worsen over the region.

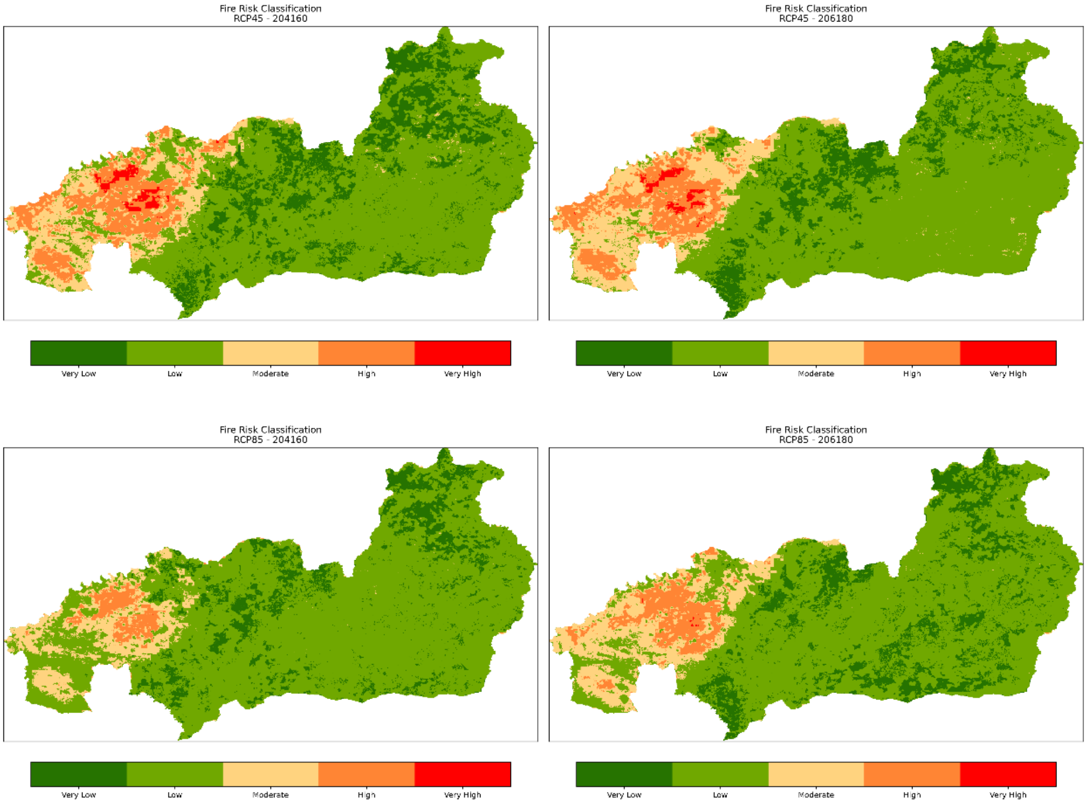

Figure 2--4 Predicted fire risk for the region, periods of 2041-2060, 2061-2080, pathways RCP 4.5 and RCP 8.5, CLMCom_CCLM climate model for variable projection

This, in turn, results in a very geographically aware model (considering the land cover data for 2018 collected in the Corine Land Cover dataset), but not so much a climatic aware model, making the only variables that, in this workflow, evolve with time (the ECLIPS2.0 climatic projections) not so relevant in hazard determination.

Still, an output obtained for these more distant timeframes that is of use to the region's climate resilience efforts, is the differences in expected temperature, aridity, seasonality of temperature, etc. made available in the ECLIPS2.0 dataset (Debojyoti et al., 2020), of which the period of 2021-2040 is visible in Figure 2-5.

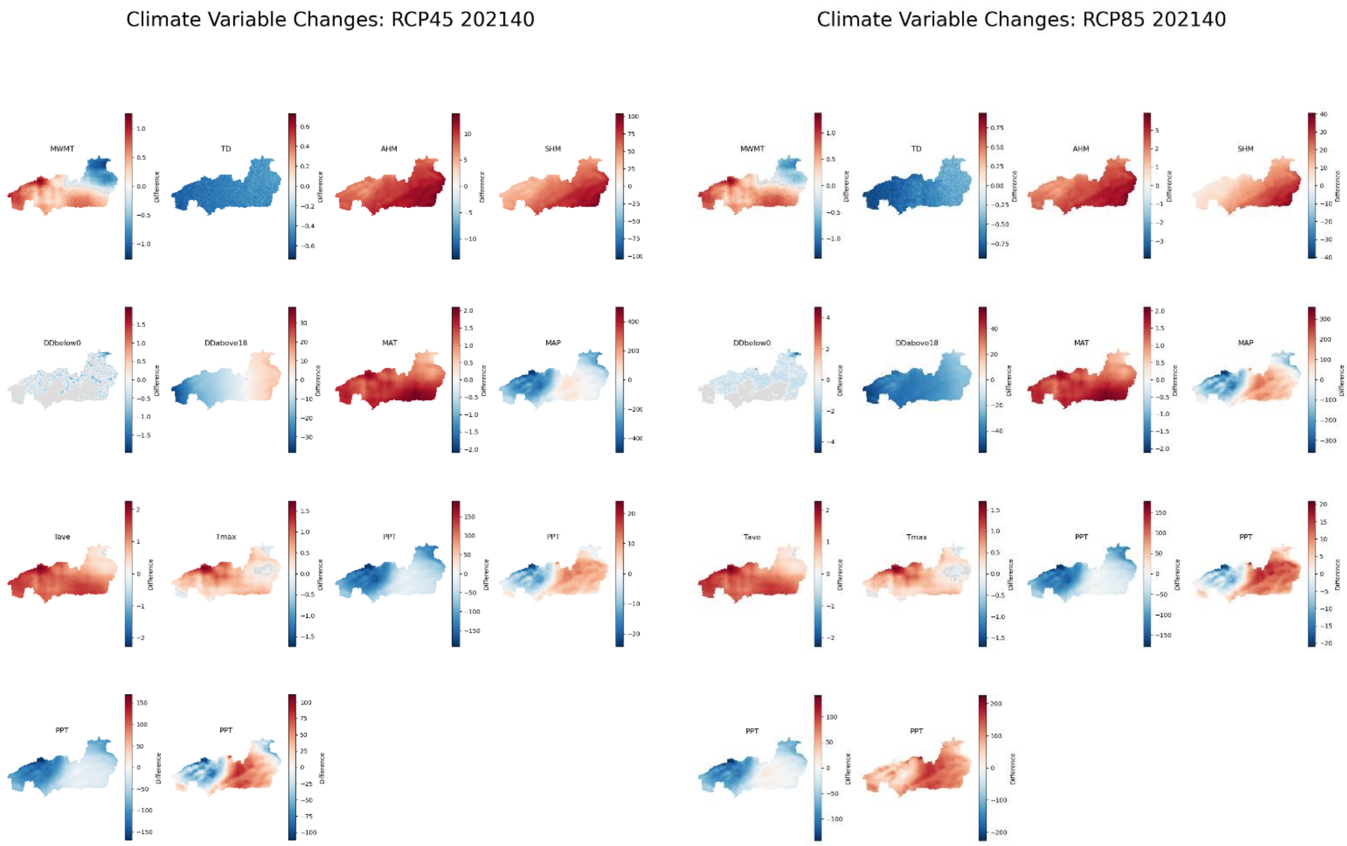

Figure 2--5 Climate variable evolution, according to RCP 4.5 and RCP 8.5, 2021-2040; CLMCom_CCLM

The ECLIPS2.0 variables displayed above are the default ones considered by the open-source CLIMAAX Machine Learning focused workflow, which are the following:

Table 2--1 Climatic variables considered in the training of ML model

Variable Name	*Description*
MWMT	Mean Warmest Month Temperature
AHM	Annual Heat Moisture index
DDbelow0	Degree-days below 0°C
MAT	Mean Annual Temperature
Tave_sm	Mean summer temperature
PPT_at	Mean autumn precipitation
PPT_sp	Mean spring precipitation

Variable Name	*Description*
TD	Continentality (difference between the mean temperature of the warmest and coldest months)
SHM	Summer Heat Moisture index
DDabove18	Degree-days above 18°C
MAP	Total annual precipitation
Tmax_sm	Maximum summer temperature
PPT_sm	Mean summer precipitation
PPT_wt	Mean winter precipitation

Some of these variables have been analyzed and deemed unnecessary for the model's optimal performance. Nevertheless, they were still included during the various training and parameter selection processes for both the regional model and a country-wide model, which was also tested to improve results.

This concludes the hazard assessment for wildfires in the first phase of the CLIMAAX project. It primarily utilized widely available data for the features used to train the prediction model. In the second phase of the project, more local or national alternatives for these data points will be considered, with a focus on finer-resolution data to enhance the model's results.

2.3.1.2 Risk assessment - Wildfires

For the risk assessments conducted in this first phase of the project, we considered only the 2021-2040 hazard assessment, which was performed under both the RCP 4.5 and RCP 8.5 pathways, using all available climate models, which are a part of the ECLIPS2.0 dataset climatic variable projections (Debojyoti et al., 2020). However, the report presents only the risk assessments based on the CLMCom_CCLM model.

Due to the need for locally available vulnerability and exposure data, which were sourced from project stakeholders, and the lengthy processes involved in collecting and identifying this data, most of the vulnerability and exposure data used for the risk assessments in this initial phase were nationally sourced from Portugal's Administrative Data Portal and DGT's data catalogue. Consequently, improving the risk assessment will be a key focus of the second phase of the project and has been one of the main topics discussed with stakeholders thus far and will continue to be in the future.

Exposure and vulnerability analyses are designed to provide stakeholders with more data-driven insights to inform their decision-making processes. They also aim to ensure that the hazard analysis yields results relevant to climate resilience planning, rather than merely offering a general evaluation of future dangers for the region.

The exposure data is either locally sourced (from data points already available to the project team and provided by stakeholders during the first phase of the project) or nationally sourced (from the sources mentioned earlier in this section). These exposure analytics encompass primary roads, the power grid, healthcare buildings and services, and developed areas in the Beira Baixa region, assessing their exposure to wildfire risk and likely future burnt areas.

The analysis begins with the exposure of healthcare units distributed across the region, which is crucial for evaluating the wildfire risk to some of the most essential and critical infrastructure and services for the general population, including clinics, hospitals, and other healthcare facilities.

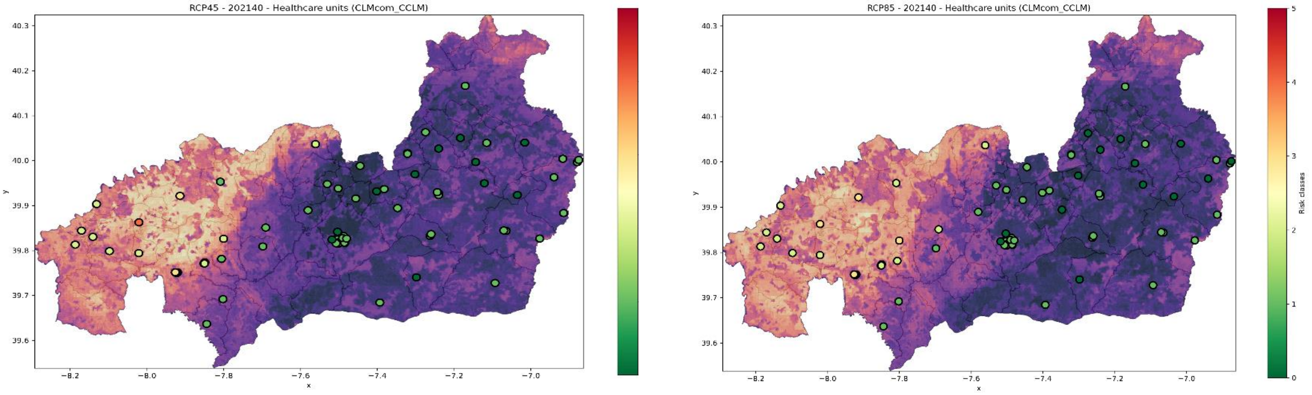

Figure 2--6 Healthcare services exposure to wildfires, RCP 4.5 and RCP 8.5, period of 2021-2040

The risk to primary roads (national roads, highways, etc.) in the region was also analyzed. This analysis contributes to an assessment of risk to critical infrastructure and, in the specific case of roads, can identify which roads are most likely to be impassable during a wildfire in the hazardous region. This, in turn, supports a more informed process for planning resilient infrastructure and developing mitigation strategies to manage infrastructure shutdowns.

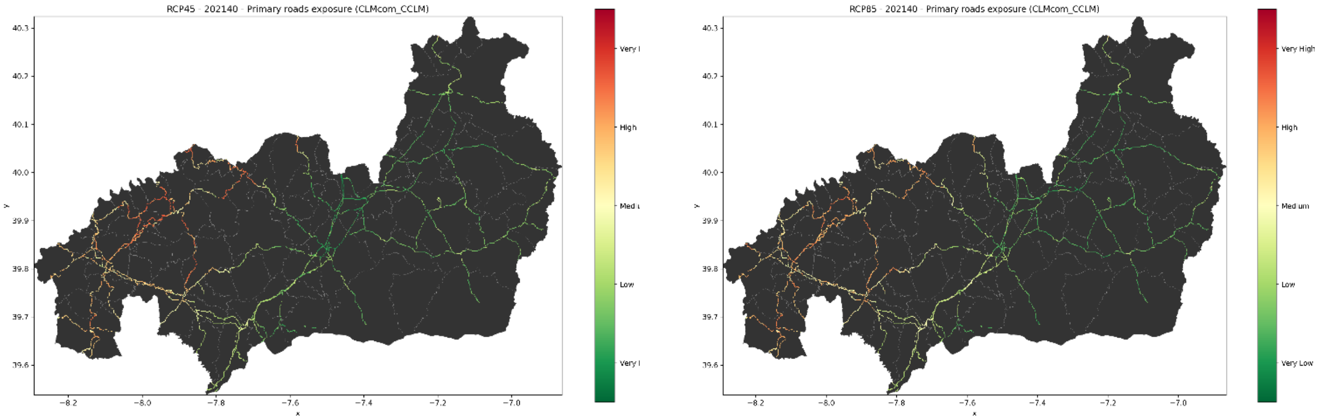

Figure 2--7 Primary roads exposure to wildfires, RCP 4.5 and RCP 8.5, period of 2021-204

Another aspect of infrastructure exposure risk studied and analyzed in this first phase of the project is the distribution and transmission power grid in the region. This analysis aids in strategizing ways to minimize the impact of wildfires on the population's access to electricity. Additionally, it highlights the presence of power lines, which could potentially ignite fires in areas with high combustible material, particularly in already hazardous regions.

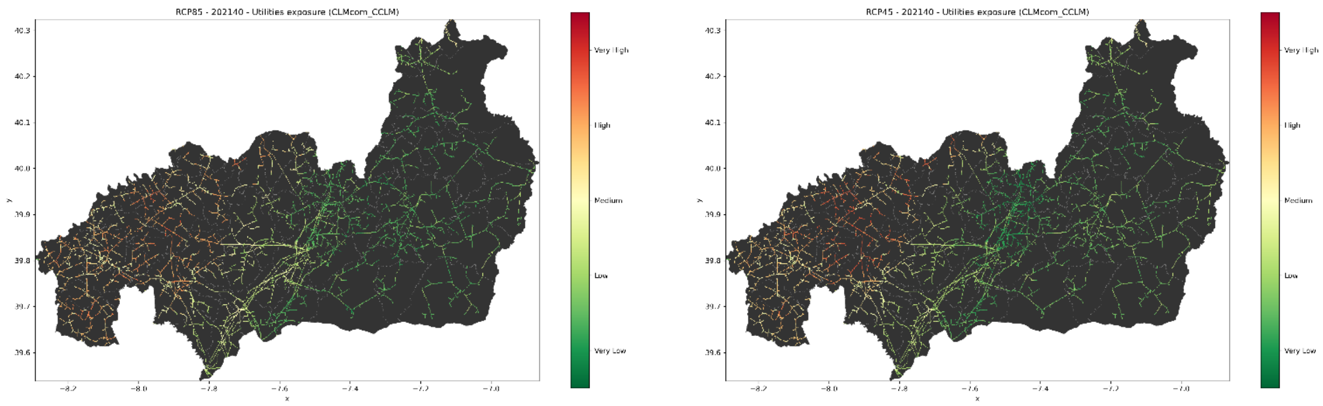

Figure 2--8 Distribution and transport power grid exposure to wildfires, RCP 4.5 and RCP 8.5, time period of 2021-2040

The western region, identified as the primary hazardous area within the Beira Baixa region, encompasses various smaller settlements and urbanized zones, along with the essential supporting infrastructure. This results in elevated risk and exposure metrics and, historically, has posed a threat to the lives and livelihoods of the region's residents, as evidenced by the devastating June 2017 Portugal wildfires that severely impacted the area.

This concludes the risk assessments conducted during the first phase, based on the currently available exposure and vulnerability data. In the next phase, a key focus will be on assessments that project stakeholders have expressed interest in exploring further, such as the average distance and response time for wildfire response teams to reach and begin combating a wildfire outbreak. To achieve this, extensive data collection will be required from CIM-BB or other relevant project stakeholders.

2.3.2 Workflow #2 - Heatwaves

2.3.2.1 Hazard assessment - Heatwaves

The hazard assessment began with an analysis comparing historical and future hazard data regarding the frequency of heatwaves, as defined by the EuroHEAT criterion—three or more consecutive days with temperatures exceeding the 90th percentile for the region. The data covers two distinct time periods: the near future (2016–2045) and the distant future (2046–2075), utilizing EuroCORDEX data for the RCP 4.5 and RCP 8.5 emission pathways. The assessment is organized according to the administrative Freguesias (civil parishes) of the Beira Baixa region.

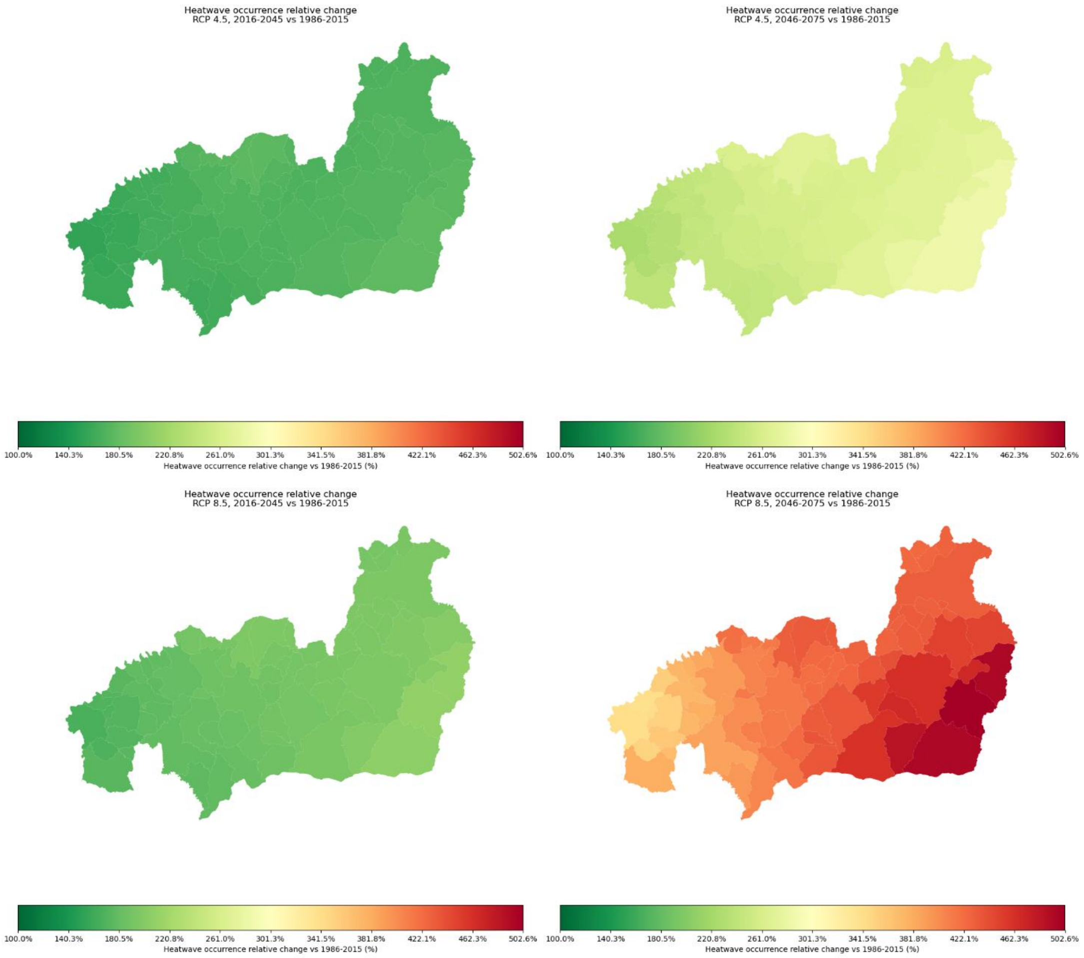

Figure 2--9 Heatwave occurrence evolution when compared to historical values (1986-2015), projected for the emission pathways of RCP 4.5 and 8.5, for two different time periods 2016-2045 and 2046-2075

The southeastern part of the region is projected to experience a more severe impact from extreme heat, with an expected increase of approximately 300% under the RCP 4.5 emission scenario and 500% under the RCP 8.5 scenario. The eastern part of the region, while still showing a noticeable increase, is anticipated to have a significantly lower rise in heatwave frequency. Ecologically, this is beneficial for reducing wildfire hazards; however, it remains detrimental to the population, as this area is densely populated with vulnerable residents living in small villages and settlements.

This hazard data was also categorized into a 1–10 hazard magnitude scale for subsequent risk assessments involving demographic vulnerability data, to be integrated into the risk assessment matrix outlined in this workflow.

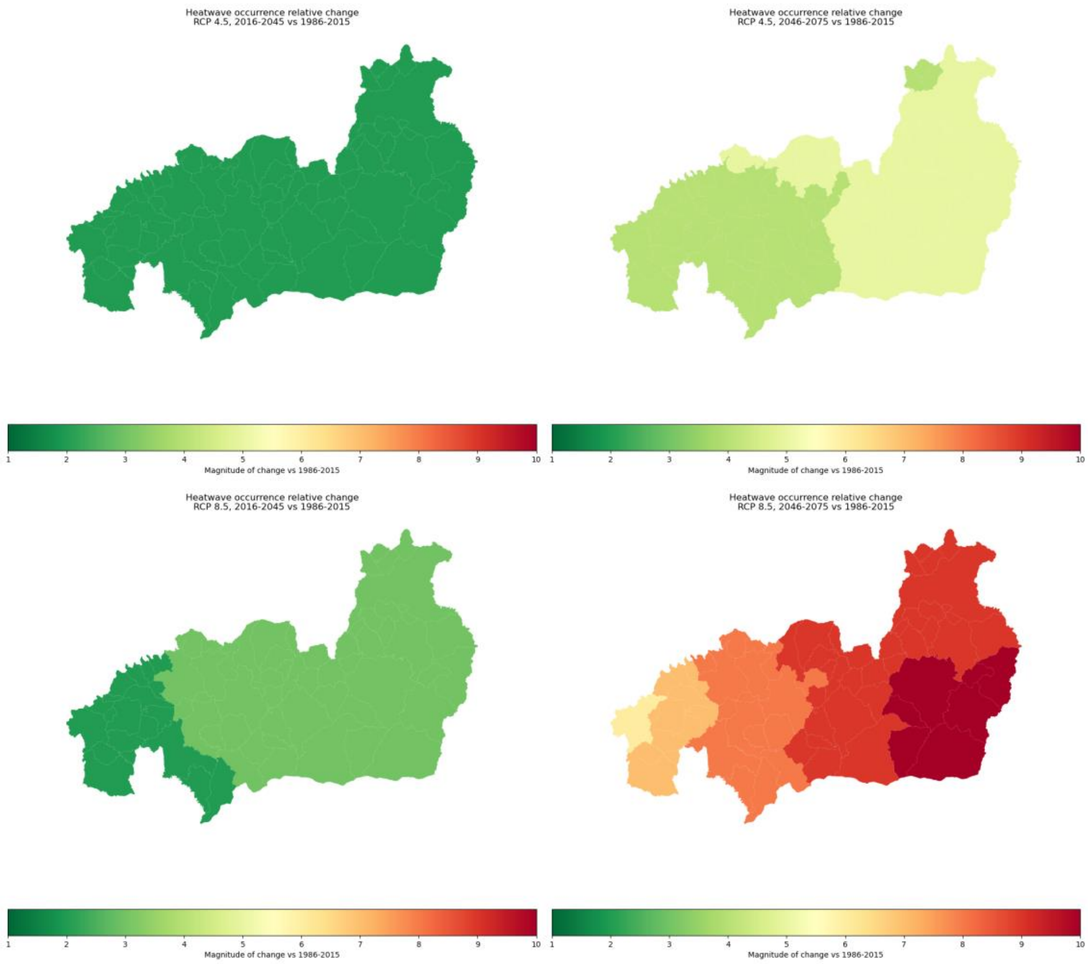

Figure 2--10 Heatwave occurrence evolution when compared to historical values (1986-2015), projected for the emission pathways of RCP 4.5 and 8.5, for two different time periods 2016-2045 and 2046-2075; reclassified to hazard classes

Another component of the hazard assessment involved calculating an LST (Land Surface Temperature) raster for the entire Beira Baixa region. This raster was generated using all imagery collected by the Landsat 9 satellite during the four summer months of 2024—June through September. The data was compiled into a single TIF file, serving as the foundation for analyzing the risk of heat island phenomena.

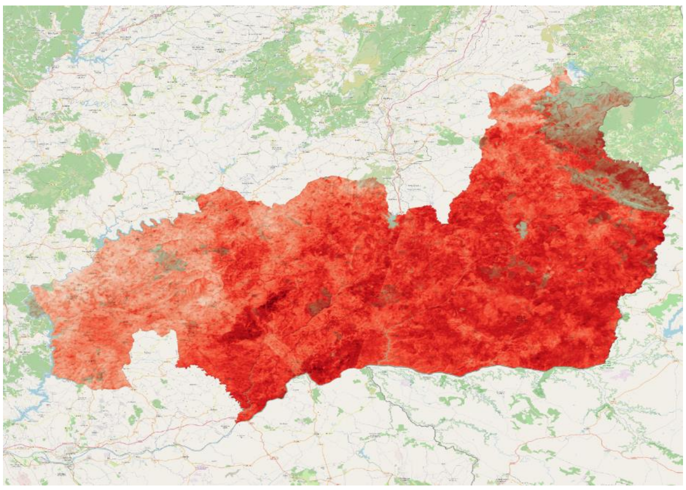

Figure 2--11 Land surface temperature raster for the entirety of the Beira Baixa region for the months of June 2024 through September 2024, calculated using Landsat 9 imagery.

2.3.2.2 Risk assessment - Heatwaves

As the primary focus of the heatwaves analysis workflow is the health of the population, part of the risk calculation involves assessing the distribution of vulnerable groups (infants under 5 years and seniors over 65 years of age). This distribution is classified on a 1–10 magnitude scale to accurately determine the 2–20 risk magnitude by combining it with the heatwave magnitude calculated in the hazard assessment section of this workflow.

The magnitude levels are divided linearly based on a range of 0 to 1,000 vulnerable individuals per civil parish in the region. While this represents a relatively low total population range, it is appropriate given the region's population density—Castelo Branco city has thousands of inhabitants, whereas the rest of the region is sparsely populated.

By using this classification range, we achieve a more comprehensive representation of vulnerable population distribution, rather than a linear classification based solely on the least and most populated civil parishes. The latter approach would disproportionately assign a significant magnitude level to the Castelo Branco civil parish, while relegating all other parishes in the region to magnitude levels between 1 and 3, thus yielding a more relevant risk output for the entire region.

The population distribution data was obtained from the WorldPop database (Bondarenko et al., 2020), which provides age and sex structure estimates derived from automated projections of the latest census data. Although not 100% precise, it offers a reasonably accurate estimate of the geographical distribution of the region's population.

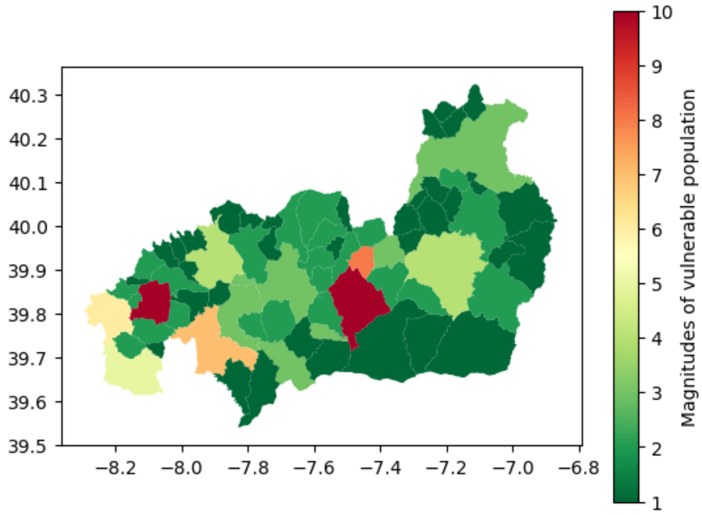

Figure 2--12 Vulnerable population, classified into 10 magnitude levels

By combining the vulnerability magnitude associated with the vulnerable population with the previously calculated heatwave evolution hazard magnitude, as outlined in the risk matrix shown in the CLIMAAX Handbook (5 different risk classifications for 19 different risk levels: Very Low 2-4, Low 5-8, Medium 9-12, High 13-16 and Very High 17-20), we derive the plot presented in Figure 2-13.

This analysis reveals that the civil parishes of Castelo Branco and Sertã are the most at risk across all scenarios. Their risk levels range from Medium in the near-future RCP 4.5 projection—primarily due to the high number of vulnerable individuals and overall population density in these areas—to Very High in the far-future RCP 8.5 projection, accurately reflecting both the presence of a vulnerable population and the 500% relative increase in heatwave occurrences. Other civil parishes in the region, such as Alcains, União das Freguesias de Proença-a-Nova e Peral, and União das Freguesias de Idanha-a-Nova e Alcafozes, follow closely behind in terms of risk, though they present slightly lesser but still significant challenges for the region.

Another key finding illustrated in Figure 2-14 is that the southeastern part of the region, despite being the most impacted by temperature changes according to EuroCORDEX data, does not exhibit a high-risk level due to its low overall population density. However, the settlements in this area are characterized by a notably aged populace, despite their small size, being, in their majority part of the Tejo International Natural Park.

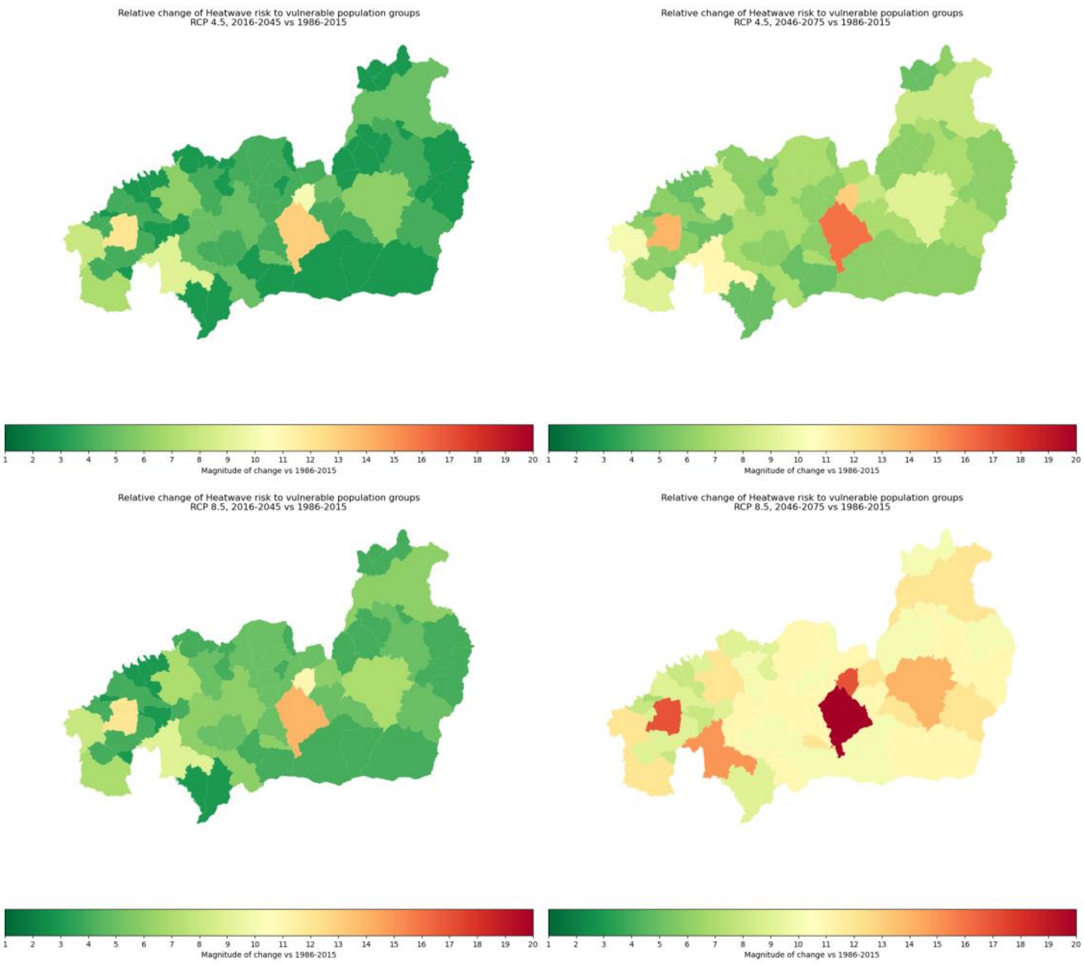

Figure 2--13 Risk magnitude levels, calculated by the sum of the vulnerability magnitude levels and the heatwave hazard levels, separated by civil parish of the Beira Baixa region, RCP 4.5 and RCP 8.5, for 2 time periods 2016-2045 and 2046-2075

The risk associated with the urban heat island effect—caused by the high reflectance of urban areas due to building materials that reflect electromagnetic radiation, resulting in elevated land surface temperatures in more urbanized parts of cities—can exacerbate the adverse health impacts of heatwaves on populations. This is particularly true if people reside or spend time in areas of the city with high land surface temperatures.

Several strategies can mitigate the urban heat island effect, such as incorporating green spaces and trees into the urban landscape, which reduce the effect and provide shade. To support planning and strategizing efforts to minimize this phenomenon, Figure 2-14 presents a mapping of the historical mean Land Surface Temperature (LST) values for the summer of 2024 in the residential zones of the city of Castelo Branco, which is part of the civil parish identified as having the highest risk to vulnerable population groups. Additionally, Figure 2-15 provides a histogram of the LST values for the same period.

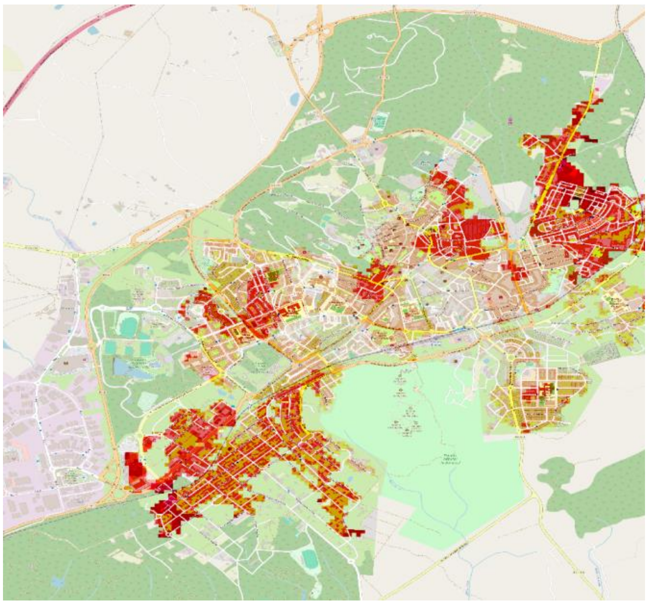

Figure 2--14 LST mean values for the summer of 2024, residential zones of the city of Castelo Branco, part of the Castelo Branco civil parish.

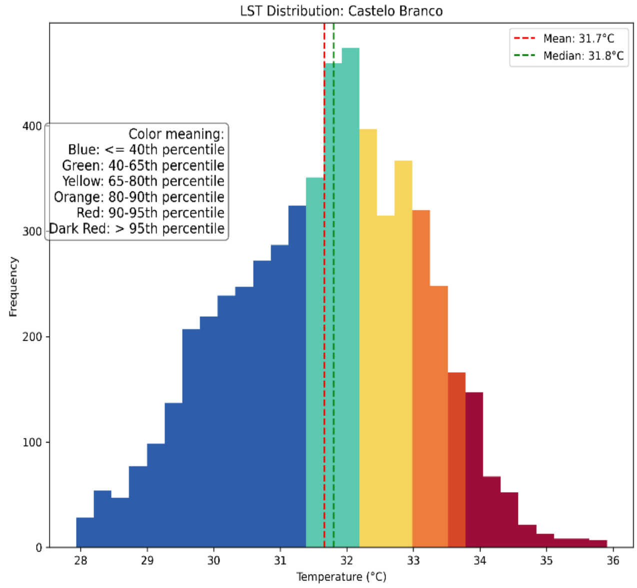

Figure 2--15 Histogram of the LST values depicted in Figure 2-14

As illustrated in Figure 2-15, the northeastern and southwestern parts of the city experience the highest Land Surface Temperature (LST) values. These areas are characterized by tall residential buildings with minimal to no shade available at street level. The southwestern part also includes the city's largest mall, which exhibits an unusually high LST value on its rooftop, though this does not pose an immediate threat to the population.

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

The Beira Baixa region is highly vulnerable to wildfires due to its geographical and climatic conditions. A significant portion of its landscape is covered by forests and shrublands, which serve as abundant fuel sources. Historically, wildfires have been a recurrent hazard, with catastrophic events such as the 2017 Portugal wildfires severely impacting Beira Baixa and surrounding areas. These wildfires resulted in extensive environmental degradation, loss of human lives, and destruction of infrastructure, underscoring the severity of wildfire risk in the region.

According to the climate risk assessment, the frequency and intensity of wildfires are projected to increase significantly due to rising temperatures and prolonged dry periods. Since 2017, approximately 25% of the region has been affected by wildfires, making it one of the most fire-prone areas in Portugal. Climate projections further suggest that by 2070, extreme wildfire risk days will constitute up to 27% of the year under high-emission scenarios (RCP 8.5). The hazard analysis for the 2021-2040 period confirms that wildfire risk is particularly concentrated in the eastern part of the region, especially in areas containing the various mountain ranges of the region.

The exposure analysis highlights the severe risk posed to critical infrastructure, including healthcare facilities, transportation networks, and the power grid. Under both RCP 4.5 and RCP 8.5 scenarios, primary roads and power distribution networks are at considerable risk, potentially disrupting emergency response operations and exacerbating the socioeconomic impact of wildfire events. Additionally, healthcare services, essential for treating wildfire-related injuries and respiratory conditions, face heightened exposure, further complicating disaster response efforts.

In addition to wildfires, Beira Baixa is increasingly affected by extreme heat events. Climate models predict an escalation in both the frequency and intensity of heatwaves, particularly in urban areas such as Castelo Branco, Sertã, Alcains, Proença-a-Nova, etc. The urban heat island effect amplifies these conditions, leading to prolonged high temperatures that disproportionately impact vulnerable populations, especially the elderly.

The demographic vulnerability assessment highlights the growing risks to Beira Baixa's aging population, which is particularly susceptible to heat-related morbidity and mortality. The mean summer temperature and the maximum summer temperature are projected to rise significantly, increasing the risk of heat stress and related health conditions. Furthermore, the increased occurrence of heatwaves is expected to exacerbate drought conditions, reducing soil moisture and further heightening wildfire risk.

The severity of climate-related hazards in Beira Baixa is substantial, with wildfires and heatwaves posing an escalating threat to both human and ecological systems. The historical context, particularly the devastating 2017 wildfires, illustrates the region's vulnerability and underscores the urgent need for comprehensive climate adaptation strategies. The projected increase in extreme wildfire risk days and intensified heatwaves necessitate proactive mitigation measures to safeguard infrastructure, natural resources, and public health.

2.4.2 Urgency

The impact of wildfires and heatwaves in Beira Baixa is already severe, with the region experiencing major wildfires annually. The devastating 2017 wildfires marked a turning point for policymakers, prompting a shift towards more proactive climate resilience strategies. Despite these efforts, the risks continue to escalate, and urgent action is required to prevent further loss of life, environmental degradation, and economic disruption.

Wildfires, driven by rising temperatures and prolonged droughts, pose an immediate and ongoing threat. The frequency of extreme fire events is increasing, and the projected expansion of extreme wildfire risk days will further strain emergency response capacities. Given the already high frequency of fire outbreaks, adaptation and mitigation measures must be reinforced immediately to protect critical infrastructure and vulnerable communities.

Heatwaves, though less studied compared to wildfires, are becoming more intense each year. The steady increase in summer temperatures exacerbates the vulnerability of elderly populations and urban centers. Current heat mitigation strategies lack sufficient data-driven support, highlighting the urgent need for improved monitoring, urban planning adjustments, and enhanced public health interventions.

Both hazards exhibit slow-onset characteristics, as they are primarily driven by seasonal and long-term climatic trends. However, the steady intensification of these risks necessitates immediate interventions. Policy changes implemented in recent years have focused on reducing wildfire damage, but continued refinements and investments in adaptation strategies are critical to addressing future challenges.

Short-term actions should focus on reinforcing emergency preparedness, expanding fire prevention programs, and improving heatwave monitoring. Long-term strategies must prioritize ecosystem resilience, infrastructure adaptation, and data-driven policy development to ensure Beira Baixa remains resilient in the face of escalating climate risks.

2.4.3 Capacity

The Beira Baixa region demonstrates a multi-layered approach to climate risk management, particularly concerning wildfires, through a combination of structural prevention measures, land-use initiatives, and surveillance systems. A key component of this strategy is the establishment of fuel management strips within the primary and secondary fuel management networks. The primary network, with a standard width of 126 meters, is designed to limit the spread of large-scale fires and facilitate direct firefighting operations. In parallel, the secondary network focuses on reducing fire intensity and impacts, offering passive protection to critical infrastructure, transportation corridors, populated areas, and high-value forest and agricultural land.

Complementing these measures is the implementation of the "Condomínio das Aldeias" (Village Condominium) Program, which promotes fuel management and land-use transformation around villages identified as highly vulnerable to rural fires. This initiative engages landowners in proactive land maintenance, encourages income-generating uses, and establishes protective buffer zones around settlements and strategic infrastructure. It is a pivotal structural measure enhancing protection at the wildland-urban interface.

Additionally, nine Integrated Landscape Management Areas (Áreas Integradas de Gestão da Paisagem – AIGP) have been established across the region. These aim to consolidate fragmented agricultural and forest lands, particularly in areas characterized by smallholdings and high fire risk. By promoting cooperative land management, the AIGP framework strengthens ecological resilience, improves ecosystem services, and supports climate change adaptation in fire-prone territories.

Fire surveillance and early detection capacity in Beira Baixa is supported by a robust, multi-modal system. This includes fifteen fixed observation towers within the National Network of Lookout Posts (RNPV), nineteen strategically placed video surveillance cameras with automated fire detection capabilities, and dynamic land and aerial mobile patrols. These surveillance mechanisms provide comprehensive territorial coverage and enhance early response, particularly in zones of limited visibility or accessibility. Together, these systems significantly reinforce the region's operational readiness and capacity to manage and mitigate wildfire risks.

2.5 Preliminary Monitoring and Evaluation

The first phase of the climate risk assessment provided key insights into the differences in climatic projections associated with different emission pathways (RCP 4.5 and RCP 8.5) and their impact on wildfire and heatwave risks. A significant finding was that under high-emission scenarios, the northern, less populated areas of Beira Baixa could become high-risk zones for wildfires due to their highly combustible vegetation. Additionally, the western part of the region remains the most vulnerable to wildfires, with increasing risk levels as major wildfire occurrences in the past are no longer recent, necessitating short-term planning and prevention strategies.

One of the primary challenges encountered was the performance of the wildfire hazard prediction machine learning model, which did not scale effectively for distant future timeframes (2041-2060, 2061-2080). Future assessments will require model refinement with more localized data and improved projections, incorporating the newly released 2023 national land cover dataset instead of Corine for better accuracy.

Stakeholder engagement has played a crucial role in ensuring the relevance and applicability of the project. All analyses and planned future work were presented to mapped stakeholders, who provided positive feedback and recommendations. Their input has been instrumental in refining the scope of future assessments, such as correlating energy certificates and building quality in areas expected to experience extreme heatwaves. Furthermore, stakeholders have been actively involved in data provision, helping improve the assessment's analytical domains and ensuring more comprehensive regional insights.

To enhance the accuracy and practical applicability of the climate risk assessment, further exploration of local data sources is necessary. Refining the wildfire risk model, leveraging national datasets, and incorporating real regional resilience indicators will be essential steps moving forward. The second phase of the project will focus on integrating these new data points, improving model accuracy, and ensuring that future assessments reflect the region's evolving climate risks and adaptive capacity.

3 Conclusions Phase 1- Climate risk assessment

The Phase 1 Climate Risk Assessment for the Beira Baixa region underscores the escalating threat posed by wildfires and heatwaves, exacerbated by climate change and demographic vulnerabilities. The analysis demonstrates that under future climate scenarios, particularly RCP 8.5, both the frequency and severity of these hazards will increase substantially. The wildfire-prone western and northeastern mountainous areas, along with heat-vulnerable urban centers like Castelo Branco and Sertã, have been identified as key areas of concern.

The implementation of two tailored analytical workflows has enabled a systematic evaluation of hazard, exposure, and vulnerability using climate models, satellite imagery, and demographic datasets. These workflows provided insights into infrastructure exposure—such as the vulnerability of primary roads, power lines, and healthcare services to wildfires—and mapped urban heat island effects at the neighborhood level using Landsat imagery, particularly in Castelo Branco. However, the study also identified critical limitations, including the coarse spatial resolution of long-term climate projections and the scarcity of fine-scale demographic and building-level data, which will be addressed in future phases.

Stakeholder engagement proved essential for contextualizing the analysis and validating the risk scenarios. During the stakeholder workshop, participants highlighted the need for more localized assessments, such as identifying heatwave risks in elderly care facilities or evaluating fire service response times in mountainous and isolated areas. This feedback will shape Phase 2 activities, ensuring alignment with regional planning and operational needs.

Although the region benefits from several structural adaptation measures—including fire surveillance systems, fuel break networks, and the Condomínio das Aldeias programme—the overall governance framework remains fragmented. There is a clear need for enhanced coordination among municipalities and sectors to translate existing measures into a cohesive and effective climate adaptation strategy.

As the project progresses to Phase 2, several priorities have been established. These include refining the wildfire risk model with newly available high-resolution land use data (e.g., COS-2023), integrating local emergency infrastructure datasets, and expanding spatial analyses of heat vulnerability. Notably, one of the central focuses will be conducting detailed risk and vulnerability assessments scoped by stakeholder interests. For example, analyses will be developed to support civil protection services in planning evacuation routes and to inform municipalities' urban planning departments on heat-mitigation strategies such as green infrastructure placement.

By addressing data gaps and incorporating stakeholder-driven priorities, the project will support more effective and targeted adaptation measures. The insights and methodologies developed through this assessment offer a foundation for climate-resilient planning in Beira Baixa and serve as a model for other vulnerable European regions seeking to implement integrated, science-based risk governance frameworks.

4 Progress evaluation and contribution to future phases

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
Delivery of all 5 deliverables	1/5 (20%)
2 successfully applied workflows in Phase 1	2/2 (100%)
2 successfully applied workflows in Phase 2	0/2 (0%)
At least 5 sources of information consulted in Phase 2	0/5 (0%)
Involvement of at least 15 Stakeholders in the project's communication activities	29/15 (> 100%), of which 19 attended the presential workshop on 30/01/2025
Organization of at least 5 dissemination actions	1/5 (20%), Workshop on 30/01/2025

Table 4-2 Overview milestones

Milestones	*Progress*
Organization of a public session in the Pinhal Interior region in Phase 3	0/1 (0%)
Updated version of PIAAC-BB, including guidelines for policymakers in Phase 3	0/1 (0%)

5 Supporting documentation

5.1 Workflow Result Archives

Workflow #1 – Wildfires
Filename: wildfire-result.zip
Includes maps, raster images and visualizations related to the wildfire workflow, under RCP 4.5 and 8.5 for three time periods, a short-term, a medium-term and a long-term future periods.

Filename: wildfire-exposure-result.zip
Includes maps, raster images and visualizations for the exposure data related to the wildfire workflow, under RCP 4.5 and 8.5 for a single, short-term time period

Workflow #2 – Heatwaves
Filename: heatwaves-result.zip
Includes hazard and vulnerability maps produced in the heatwave workflow, under RCP 4.5 and RCP 8.5 for two time periods, one short-term and another long-term future periods.

5.2 Model and Feature Dataset

Wildfire Model and Feature Data
Filename: wildfire-training-features.gpkg
Includes the training data for the wildfire hazard prediction model for the wildfire workflow

5.3 Repository Access

All outputs listed above have been uploaded to the Zenodo repository under the CLIMAAX entry for Beira Baixa:
Zenodo Repository Link: https://doi.org/10.5281/zenodo.15113029
DOI: 10.5281/zenodo.15113029

6 References

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