Deliverable Phase 1 – Climate risk assessment

Comunidade Intermunicipal das Beiras e Serra da Estrela (BSE_CLIMAAX)

Portugal, Beiras e Serra da Estrela

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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Author(s)	• João Santos (greenmetrics.ai) • Tiago Marques (greenmetrics.ai) • Joana Faria (CIM BSE)
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Abbreviations and acronyms

Abbreviation / acronym	Description
CIM BSE	Comunidade Intermunicipal das Beiras e Serra da Estrela
PIAAC	Plano Intermunicipal de Adaptação às Alterações Climáticas (Intermunicipal Climate Change Adaptation Plan)
RCP	Representative Concentration Pathway
LST	Land Surface Temperature
DEM	Digital Elevation Model
ICNF	Instituto da Conservação da Natureza e Florestas
ANEPC	Autoridade Nacional de Emergência e Proteção Civil
GNR	Guarda Nacional Republicana
ADERES	Associação de Desenvolvimento Rural Estrela-Sul
AGIF	Agência para a Gestão Integrada de Fogos Rurais
Associação CBPBF	Centro de Biotecnologia de Plantas da Beira Interior
Queiró	Association for Forestry, Hunting and Fishing
Urze	Forestry Association of the Slopes of Serra da Estrela

Executive summary

This deliverable presents the results of the first phase of the Climate Risk Assessment (CRA) conducted for the Comunidade Intermunicipal das Beiras e Serra da Estrela (CIM BSE), a mountainous region in central Portugal. Developed under the CLIMAAX framework, this assessment aims to provide a structured, data-informed understanding of regional climate risks and support evidence-based adaptation planning.

The assessment focused on two climate-related hazards: **heatwaves** and **wildfires**. These risks were selected based on regional climate history, stakeholder priorities, and available modelling capacity. Heatwaves are projected to increase in frequency and intensity, particularly under RCP 8.5 scenarios, with the eastern and southwestern areas showing the most pronounced hazard evolution. Wildfire risk remains a systemic threat, driven by topography, vegetation, and changing climate variables, with extensive exposure expected across much of the region in the 2021–2040 period.

To assess these risks, two workflows from the CLIMAAX toolbox were applied: one for heatwaves and the other for wildfires. Each workflow guided the selection of relevant indicators, scenario parameters, and data layers specific to the nature and dynamics of each hazard. The CRA combined regional data with harmonized European datasets, producing geospatial outputs that highlight spatial patterns of risk across the NUTS3 territory.

Stakeholders, including municipal authorities, national agencies, research institutions, and civil society organizations, were actively involved in a participatory workshop in March 2024. Their feedback informed the hazard selection, model interpretation, and the identification of future analytical needs. Stakeholders were also committed to supporting Phase 2 with local datasets and use cases, enhancing the depth and relevance of future assessments.

Key findings from this phase indicate that both hazards present high severity and urgency. The existing institutional mechanisms for risk governance, including the Intermunicipal Climate Change Adaptation Plan (PIAAC), provide a solid foundation. This project builds on and expands these efforts by enhancing the regional understanding of climate risks through integrated modelling, participatory engagement, and the use of harmonized analytical tools. Future phases will deepen this approach by further incorporating local data and stakeholder insights.

The results of this first phase will support the refinement of adaptation strategies at regional and municipal levels and contribute to the broader goals of the European Strategy for Adaptation to Climate Change. They will also provide information that will facilitate updates to sectoral plans, including civil protection and land-use management instruments.

In conclusion, this assessment marks a step toward a more integrated, locally grounded, and data-informed decision-making process in the Beiras e Serra da Estrela region.

1 Introduction

1.1 Background

The Comunidade Intermunicipal das Beiras e Serra da Estrela (CIM BSE) is a regional public authority located in central Portugal, encompassing 15 municipalities within the NUTS3 Beiras e Serra da Estrela sub-region. This area spans over 6,300 square kilometres and includes a diverse mountainous landscape marked by the Serra da Estrela Natural Park, the largest protected area in mainland Portugal. Characterised by significant ecological and socio-economic value, the region is home to approximately 210,000 residents, many of whom rely on climate-sensitive sectors such as agriculture, forestry, pastoralism, and tourism.

The region's vulnerabilities to climate change have been well documented, including increasing exposure to extreme weather events such as heatwaves, droughts, wildfires, intense precipitation, and cold spells. In recent years, the area has experienced some of the most severe forest fires in Portuguese history, notably the 2022 event that consumed nearly 25% of the Serra da Estrela Natural Park. These events have underscored the urgent need for an integrated and multi-risk climate adaptation strategy tailored to the unique vulnerabilities of this predominantly rural and mountainous territory.

1.2 Main objectives of the project

The BSE_CLIMAAX project aims to deepen the understanding of climate risks in the Beiras e Serra da Estrela region by applying the harmonised framework of the CLIMAAX Handbook. The primary objectives are:

- To conduct a transparent, data-informed multi-risk climate risk assessment (CRA), addressing key hazards including heatwaves and wildfires;
- To enhance regional and intermunicipal capacity for managing climate-related risks through access to the CLIMAAX toolbox and methodological guidance;
- To integrate regional and local data with European datasets to produce robust, actionable outputs that inform planning and adaptation strategies;
- To support the revision and implementation of existing instruments such as the Intermunicipal Climate Change Adaptation Plan (PIAAC), Municipal Emergency and Civil Protection Plans, and the Serra da Estrela Natural Park Management Plan;
- To contribute to improved awareness and preparedness among local stakeholders and communities.

By implementing the CLIMAAX approach, the project supports the alignment of regional adaptation efforts with European frameworks, particularly the EU Strategy on Adaptation to Climate Change and the Civil Protection Mechanism.

1.3 Project team

The project is jointly implemented by CIM BSE and greenmetrics.ai. CIM BSE possesses both the legal mandate and institutional capacity to coordinate climate change adaptation efforts across the NUTS3 territory. Greenmetrics.ai contributes specialised technical expertise in environmental data analysis, geospatial modelling, and the application of advanced risk assessment methodologies.

The combination of CIM BSE's territorial knowledge and institutional authority with greenmetrics.ai's technical expertise ensures a comprehensive and technically sound approach to climate risk assessment in the region.

1.4 Outline of the document’s structure

This deliverable is structured in accordance with the CLIMAAX Phase 1 reporting template:

- **Section 2** details the climate risk assessment process, including scoping, risk exploration, hazard and risk analysis, and preliminary findings.
- **Section 3** presents the key conclusions derived from the Phase 1 assessment.
- **Section 4** discusses progress evaluation and outlines contributions to future project phases.
- **Section 5** provides an inventory of supporting documentation produced during this phase.
- **Section 6** contains all references used throughout the report.

Each section follows the CLIMAAX Handbook's guidance to ensure methodological consistency and facilitate knowledge transfer across participating regions.

2 Climate risk assessment – phase 1

2.1 Scoping

2.1.1 Objectives

The primary objective of this Climate Risk Assessment (CRA) is to identify, analyse, and prioritise climate-related hazards and vulnerabilities affecting the NUTS3 Beiras e Serra da Estrela region. The assessment serves as a strategic tool to inform evidence-based policymaking, regional adaptation planning, and emergency risk management. It seeks to generate region-specific insights through the integration of European and local data, addressing two priority hazards: heatwaves and wildfires.

The CRA aims to support regional governance mechanisms in:

- Enhancing the understanding of climate risk profiles across sectors and geographic areas.
- Supporting updates and implementation of regional adaptation plans such as the Intermunicipal Climate Change Adaptation Plan (PIAAC).
- Improving institutional decision-making processes in the fields of civil protection, land-use planning, and ecosystem management.

Limitations of the assessment include current gaps in vulnerability and exposure data, particularly regarding socio-economic indicators and infrastructure mapping. Additionally, time and resource constraints have influenced the granularity and depth of certain analyses.

2.1.2 Context

The Beiras e Serra da Estrela region has historically faced recurring climate hazards, with wildfires and extreme heat events emerging as the most damaging and frequent in recent decades. The devastating wildfire in 2022 and increasing occurrences of heatwaves have highlighted systemic vulnerabilities in emergency preparedness, ecological resilience, and infrastructure robustness.

Climate risk management in the region is guided by national and regional legal frameworks, notably the Basic Climate Law (Law 98/2021), Decree-Law 82/2021 on rural fire management, and the national strategy for adaptation to climate change. CIM BSE plays a pivotal role in coordinating the Sub-Regional Commission for Integrated Rural Fire Management and implementing the PIAAC. The region's governance framework is complemented by civil protection authorities, the Institute for Nature Conservation and Forestry, and local municipalities.

Sectors of high relevance include agriculture, forestry, pastoralism, and tourism. These are not only key economic pillars but are also directly affected by shifts in climate patterns and extremes. External influences, such as national fire prevention programmes, EU adaptation strategies, and funding mechanisms, further shape the adaptation landscape.

Potential adaptation interventions explored through this CRA include land use reclassification, green infrastructure development, fire-resistant landscape design, early warning systems, and strengthening the regional data infrastructure for climate monitoring.

2.1.3 Participation and risk ownership

The stakeholder engagement process was initiated during the preliminary design of the CRA and included the organisation of a participatory workshop involving a wide range of identified stakeholders. The workshop enabled direct dialogue and input from a diverse range of institutional stakeholders, which can be grouped into the following categories:

Municipal authorities and local governance bodies: Município de Almeida, Município de Belmonte, Município de Celorico da Beira, Município da Covilhã, Município do Fundão, Município de Fornos de Algodres, Município de Seia, Município de Figueira de Castelo Rodrigo, Município de Manteigas, Município de Sabugal, Município de Gouveia, Município da Guarda, Município de Mêda, Município de Trancoso, Município de Pinhel.

Civil protection and emergency services: Autoridade Nacional de Emergência e Proteção Civil, Comando Territorial da Guarda, ANEPC, GNR, AGIF.

Academic and research institutions: Universidade da Beira Interior, Instituto Politécnico de Castelo Branco, Instituto Politécnico da Guarda, Associação CBPBI, Beira Interior Plant Biotechnology Centre.

Environmental NGOs and rural development associations: Quercus, ADERES, ADPM (in representation of CCPE), Raia Histórica, Bioeco.

Forestry and agricultural sector organisations: QUEIRÓ, Urze –, Opaflor – Associação de Produtores Florestais da Serra da Opa, Associação Portuguesa de Criadores de Raça Bovina Limousine, Acriguarda.

National and regional agencies for land and biodiversity management: ICNF

Efforts were made to include organizations and entities with responsibilities or interests aligned with vulnerable groups and sectors sensitive to climate change impacts. The participatory workshop served as a platform for these stakeholders to contribute perspectives on climate risks and regional adaptation priorities.

In addition to sharing their views, stakeholders provided valuable feedback and helped define specific analytical needs to be addressed in Phase 2 of the project. They also committed to supporting the provision of local data inputs, which will be instrumental for increasing the resolution and contextual relevance of the next phase of risk analysis. This guidance and collaboration will help ensure that future assessments are aligned with practical priorities and the decision-making context of local actors.

The communication of results is targeted at both technical stakeholders and the general public. Outputs will be disseminated via institutional channels, stakeholder workshops, and regional forums, ensuring transparency and inclusivity in the CRA process.

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

The screening of climate-related risks in the Beiras e Serra da Estrela region was guided by a combination of stakeholder priorities, regional climate history, and the analytical capabilities of the CLIMAAX toolbox. Two primary hazards were selected for in-depth assessment based on their frequency, impact, and relevance to the territory: heatwaves and wildfires.

Heatwaves have become increasingly frequent and intense in the region, with significant implications for human health, particularly among vulnerable populations such as the elderly and young children. The urban heat island effect further amplifies these impacts in more densely built environments.

Wildfires represent a long-standing and escalating threat, with major events, such as the 2022 wildfire, severely affecting natural ecosystems, agricultural land, and protected areas, including the Serra da Estrela Natural Park. The region's mountainous topography and vegetation cover create conditions conducive to fire ignition and rapid propagation.

These hazards were selected due to their alignment with both stakeholder concerns and the availability of relevant historical and projected datasets.

2.2.2 Workflow selection

2.2.2.1 Workflow #1 - Heatwaves

This workflow was selected due to the region’s demographic profile, which includes a high proportion of elderly residents and young children—populations especially susceptible to heat-related health impacts. By combining projected changes in heatwave frequency with spatial population distribution data, the workflow highlights areas of elevated social vulnerability. This approach supports targeted public health planning and adaptation measures.

2.2.2.2 Workflow #2 - Wildfires

Given the historic and projected intensity of wildfires in the region, this workflow evaluates the spatial overlap between wildfire hazard zones and essential infrastructure, with a particular focus on primary roads. These roads are critical for evacuation and emergency response operations. The workflow enables the identification of high-exposure segments, informing priority interventions to increase resilience in the transportation network.

2.2.3 Choose Scenario

The risk assessment incorporated scenario-based projections aligned with IPCC emission pathways RCP 4.5 (moderate emissions) and RCP 8.5 (high emissions), capturing a broad spectrum of plausible future climate conditions for the region.

For the heatwave assessment, two distinct timeframes were considered: a short-term period (2016–2045) and a longer-term horizon (2046–2075), allowing for an evaluation of hazard progression under both emission scenarios. In contrast, wildfire risk modelling focused on the mid-term period of 2021–2040, which aligns with near-future planning needs and the available temporal resolution of relevant datasets.

Modelling wildfire risk for longer-term time horizons was constrained by the limited sensitivity of the machine learning models to evolving climate variables and the coarser resolution of climate inputs relative to detailed topographic and land cover datasets.

The selected timeframes and emission scenarios were strategically aligned with the most robust and regionally relevant climate projections available for the study. Their application ensures consistency with the modelling approaches embedded in the CLIMAAX workflows and facilitates future comparative analyses across time horizons and hazard types.

2.3 Risk Analysis

2.3.1 Workflow #1 - Heatwaves

2.3.1.1 Hazard assessment - Heatwaves

The hazard assessment started with the analysis of historical vs. future hazard data for the number of occurrences of heatwaves according to the EuroHEAT definition of heatwaves – 3 or more consecutive days of temperatures above the 90th percentile for that region. The data encompasses 2 different time periods, a near future (2016-2045) and distant future (2046-2075), and uses EuroCORDEX data for RCP 4.5 and RCP 8.5 emission pathways. The assessment is divided into the administrative Freguesias (Civil parishes) of the Beiras and Serra da Estrela region, which are more than 250.

The hazard data visualization can be seen in Figure 2-1.

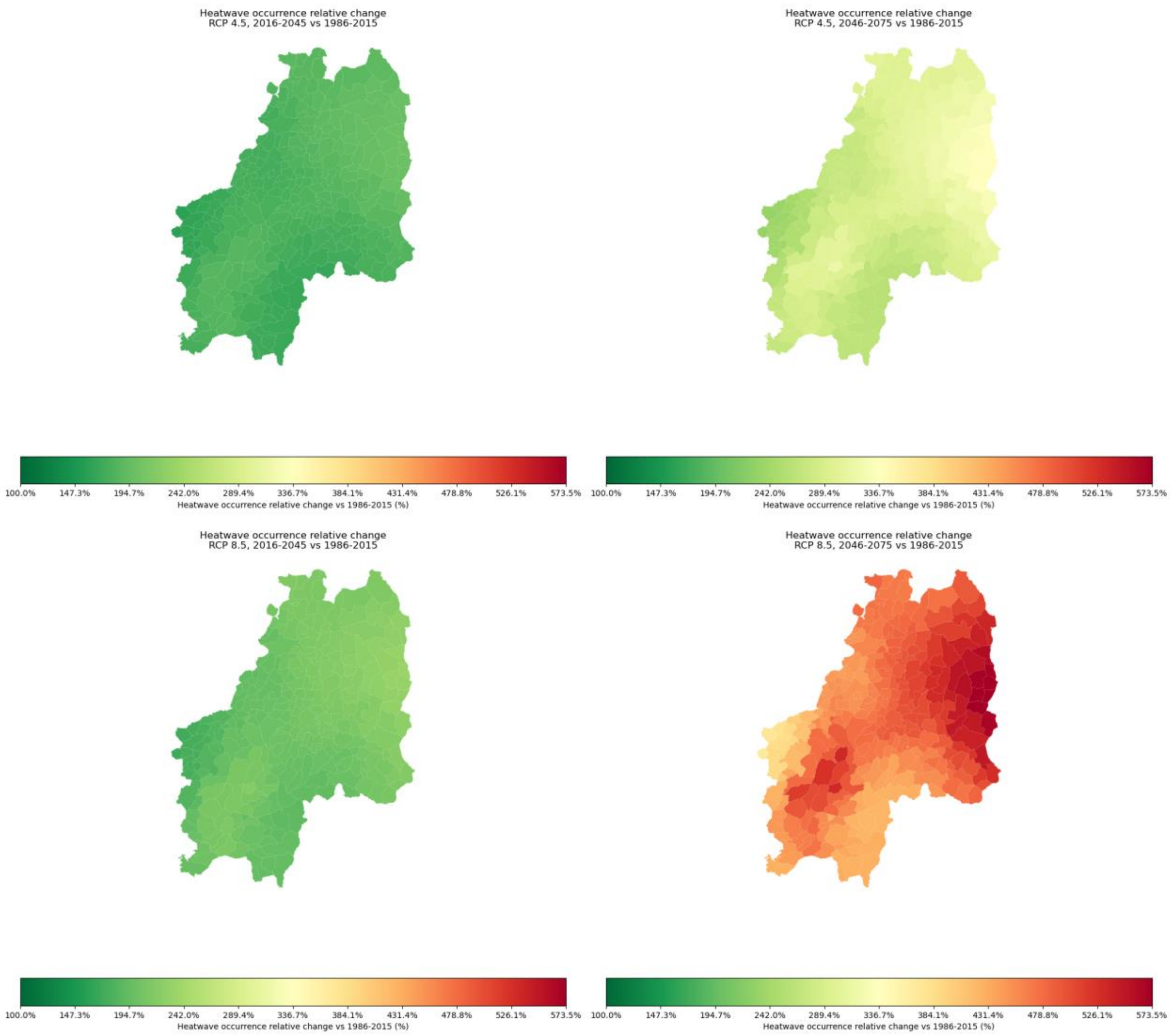

Figure 2-1 Heatwave occurrence evolution when compared to historical values

The eastern part, along with a portion of the southwestern region, is projected to be more severely impacted by extreme heat, with an anticipated increase of approximately 330% under the RCP 4.5 emission scenario and 510% under the RCP 8.5 scenario. The remainder of the region is expected to experience a much lower, though still notable, increase.

This hazard data was also categorized into a 1–10 hazard magnitude scale for use in subsequent risk assessments involving demographic vulnerability data, to be incorporated into the risk assessment matrix outlined in this workflow. This classification into hazard magnitude levels is illustrated in Figure 2-2.

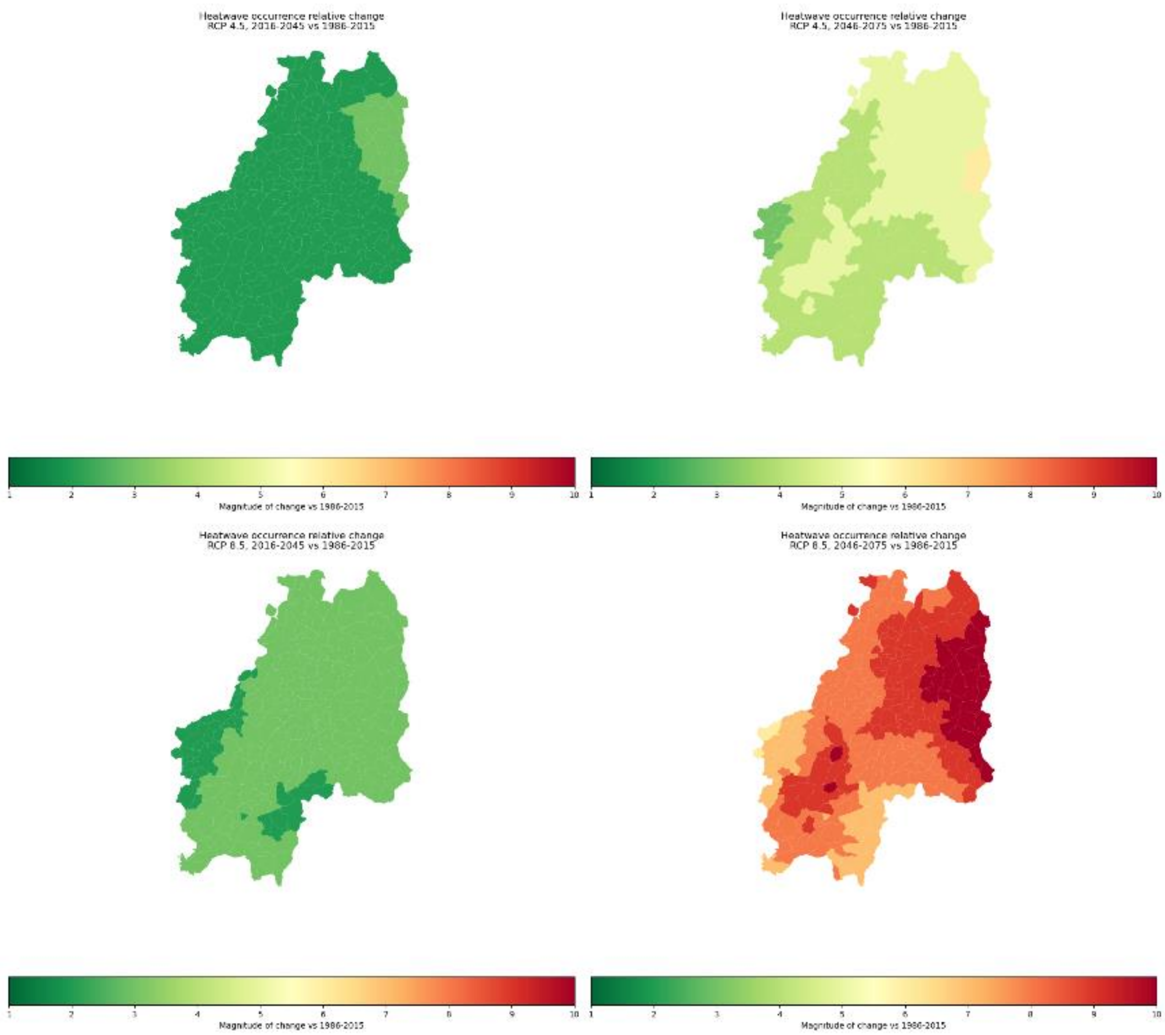

Figure 2-2 Heatwave occurrence evolution when compared to historical values, reclassified to hazard classes

Another component of the hazard assessment involved calculating an LST (Land Surface Temperature) raster for the entire Beiras and Serra da Estrela region. This raster was created using all imagery collected by the Landsat 9 satellite over the four summer months of 2024—June through September. The data was compiled into a single TIF file, which serves as the foundation for analysing the risk associated with the heat island phenomenon, shown in Figure 2-3.

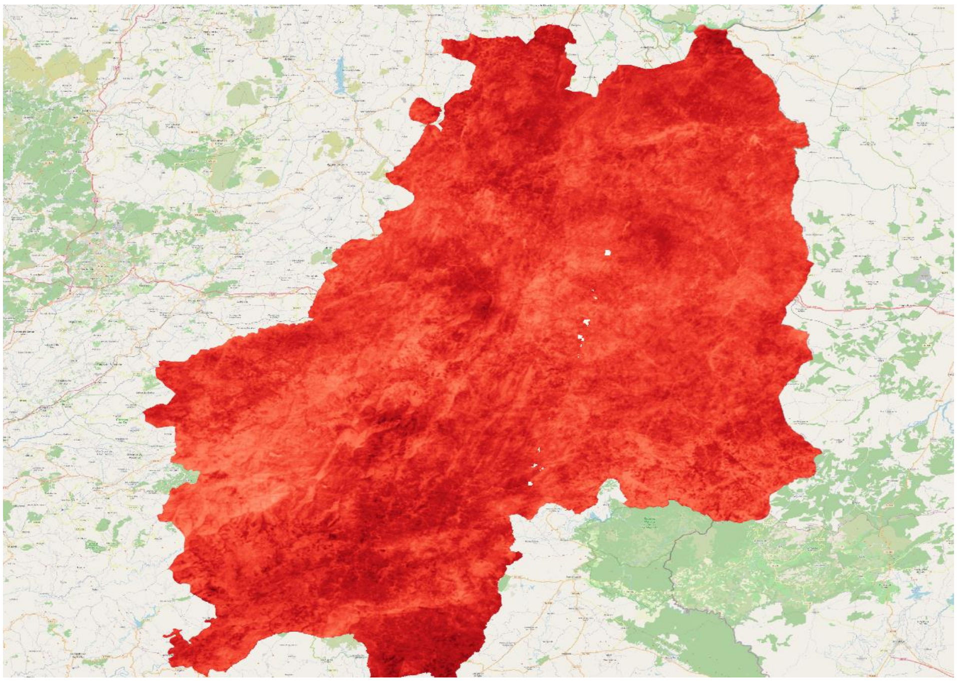

Figure 2-3 Land surface temperature raster for the entirety of the Beiras and Serra da Estrela region

2.3.1.2 Risk assessment - Heatwaves

As the primary focus of the heatwave analysis is the impact on the health of the population, a key 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 into 10 categories, automatically calculated based on the lowest and highest values across the civil parishes of the Beiras and Serra da Estrela region. This approach is suitable because the region features several cities with comparable population sizes (Guarda, Fundão, Seia, and Covilhã), without extreme outliers that would distort the population data, unlike other regions in Portugal.

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

This vulnerable population data is illustrated in the graph presented in Figure 2-4.

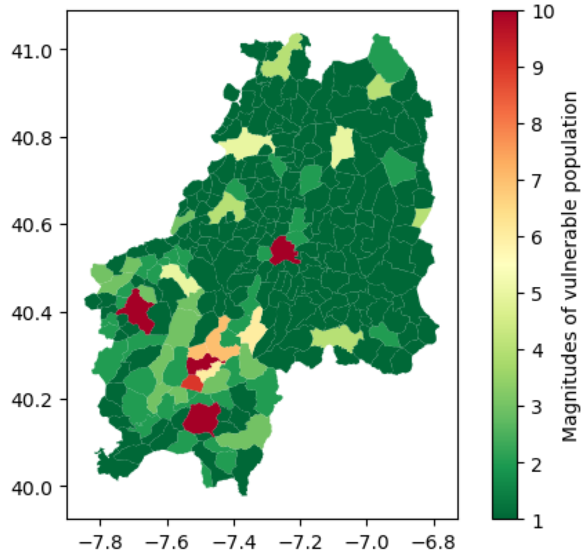

Figure 2-4 Vulnerable population, classified into 10 magnitude levels

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 Figure 2-5, we derive the map presented in Figure 2-6.

In the vulnerability analysis for heatwaves, we can see that the most at-risk civil parishes are the main ones of the 4 cities of the region: Fundão, Guarda, Seia and Covilhã. While the easternmost part of the region is one associated with a high hazard for the evolution of extreme heat days, the low population in the region mitigates the risk associated with those civil parishes.

Risk matrix 10+10

Magnitude of change in heatwave occurence	1	2	3	4	5	6	7	8	9	10
10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17	Very high 18	Very high 19	Very high 20
9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17	Very high 18	Very high 19
8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17	Very high 18
7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17
6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16
5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15
4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14
3	Very low 4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13
2	Very low3	Very low 4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12
1	Very low 2	Very low 3	Very low 4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11

Vulnerable population density

Figure 2-5 Risk matrix between magnitude of change in heatwave occurrence and vulnerable population density

Figure source: CLIMAAX Handbook

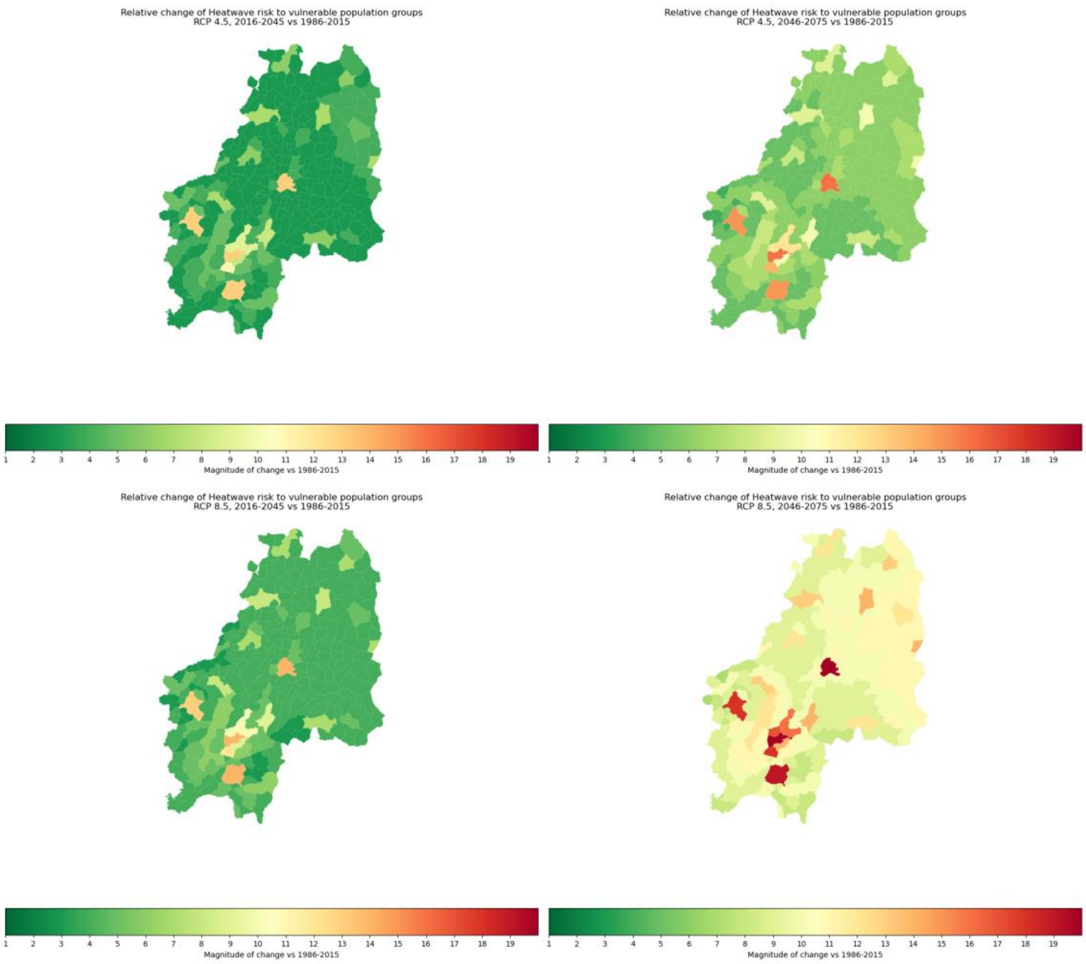

Figure 2-6 Risk magnitude levels

The risk associated with the urban heat island effect—caused by the high reflectance of urban zones 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 the population, particularly if individuals reside or spend time in areas 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 2-7 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 Covilhã, one of the civil parishes at highest risk for vulnerable population groups. Figure 2-8 provides a histogram of the LST values for the same period and city.

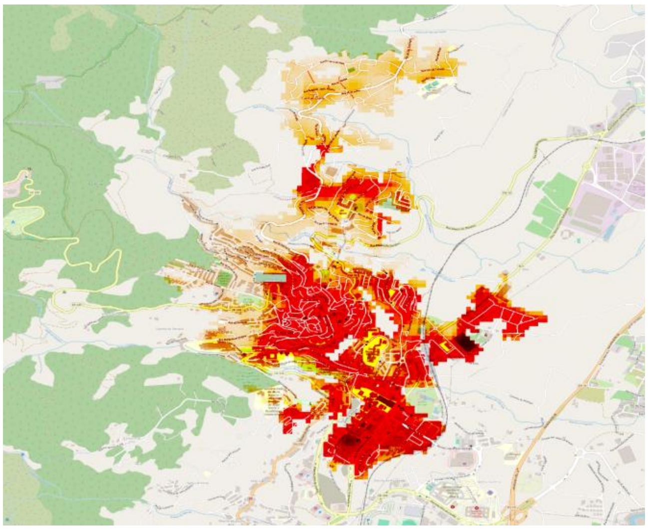

Figure 2-7 LST mean values for the summer of 2024, residential zones of the city of Covilhã

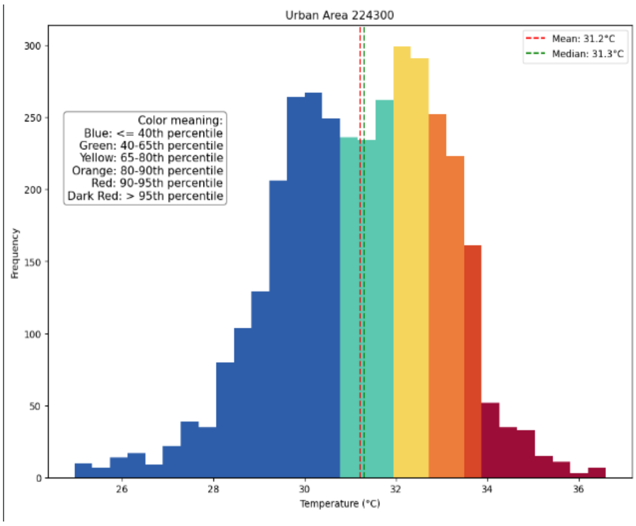

Figure 2-8 Histogram of the LST values depicted in Figure 2-7

As shown in Figure 2-7, the eastern, central, and southern parts of the city are the most affected by high Land Surface Temperature (LST) values. These areas are characterized by narrow streets with little to no shade, some zones featuring densely packed vertical residential buildings, and others with open storage areas. The southern 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.

2.3.2 Workflow #2 - Wildfires

2.3.2.1 Hazard assessment - Wildfires

The hazard assessment began with an analysis of wildfire risk in the Beiras and Serra da Estrela Region for the 2021–2040 period, based on projections under the RCP 4.5 (Figure 2-9) and RCP 8.5 (Figure 2-10) emission scenarios. Climate variables were simulated using the CLMCom_CCLM regional climate model. The projected changes derived from this model are detailed throughout this section.

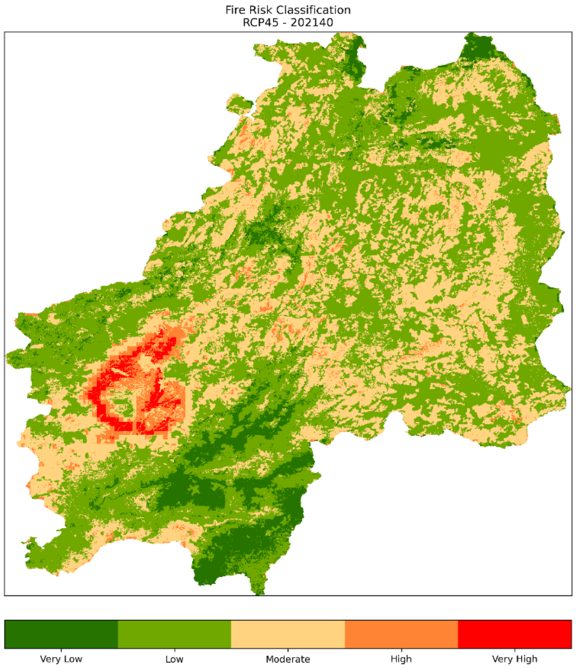

Figure 2-9 Predicted fire risk for the region for the period of 2021–2040, considering RCP 4.5

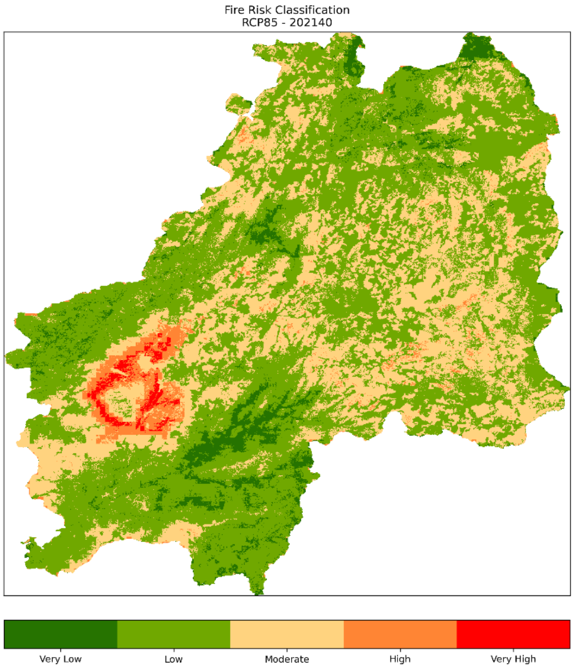

Figure 2-10 Predicted fire risk for the region for the period of 2021–2040, considering RCP 8.5

The outputs confirm the historically observed trend of elevated wildfire risk in the eastern part of the region, particularly around the Serra da Estrela mountain range. However, the projections indicate a significantly uniform risk across the entire region, with the exception of certain areas in the southern subregion where the risk is reduced—more notably under RCP 4.5 than RCP 8.5.

The RCP 8.5 pathway suggests a broader, though not necessarily more intense, wildfire hazard footprint across the region, extending the risk into areas previously deemed less vulnerable, particularly along the western flanks of the Serra da Estrela and certain parts of the southern subregion. This shift highlights the amplifying effect of higher-emission scenarios on hazard distribution.

Topography plays a critical role in this context. As shown in Figure 2-11, the Digital Elevation Model (DEM) demonstrates that the mountainous terrain prevalent in this region aligns with areas of heightened fire risk. The complex relief not only facilitates fuel accumulation but also hampers fire suppression efforts due to limited accessibility and prolonged response times.

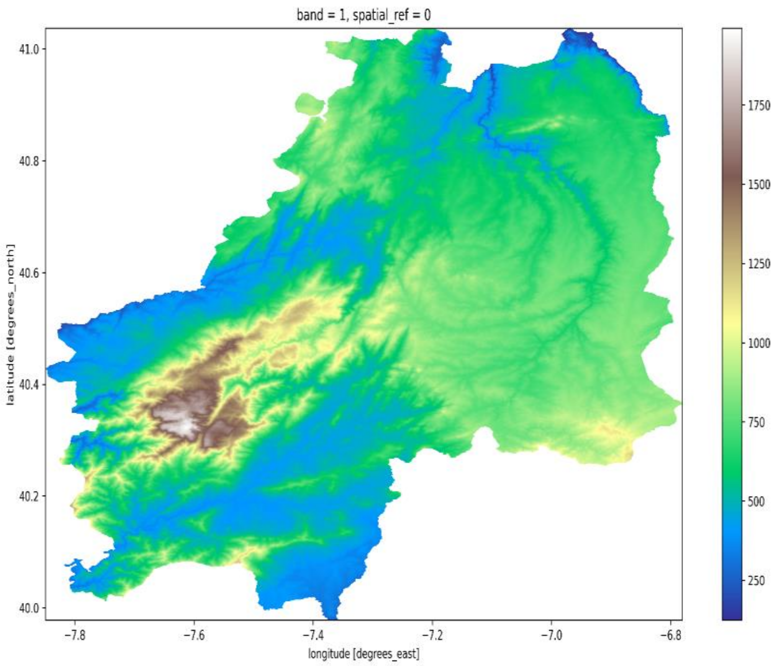

Figure 2-11 Elevation map of the Beiras and Serra da Estrela Region

Given these geographic constraints, wildfire risk management in the region requires targeted strategies. The assessment has therefore integrated stakeholder-supplied local data to enhance the granularity of analysis. The region's complex orography necessitates adaptive fire prevention and response planning, backed by spatially resolved and data-driven resilience frameworks.

Model performance for longer-term periods (2041–2060 and 2061–2080) was suboptimal in this iteration of the hazard analysis. The likely cause is the relatively sparse spatial representation of the region within the training dataset used by the Machine Learning-based CLIMAAX workflow. Specifically, the coarser spatial resolution of the climatic projection inputs (12 × 12 km; Debojyoti et al., 2020) compared to finer-scale topographic and land cover datasets (0.1 × 0.1 km; CMLS, 2020) may have limited the model's capacity to capture temporal evolution of wildfire risk with sufficient detail.

This discrepancy is illustrated in **Figure 2-4**, where lower hazard levels are projected for mid- and late-century scenarios, despite the overall worsening of underlying climate variables across the region. This can also be seen in the differences between higher emissions worst-case scenario projections following RCP8.5 and mid-case scenario projections following RCP4.5 not being very accentuated or even non-existent.

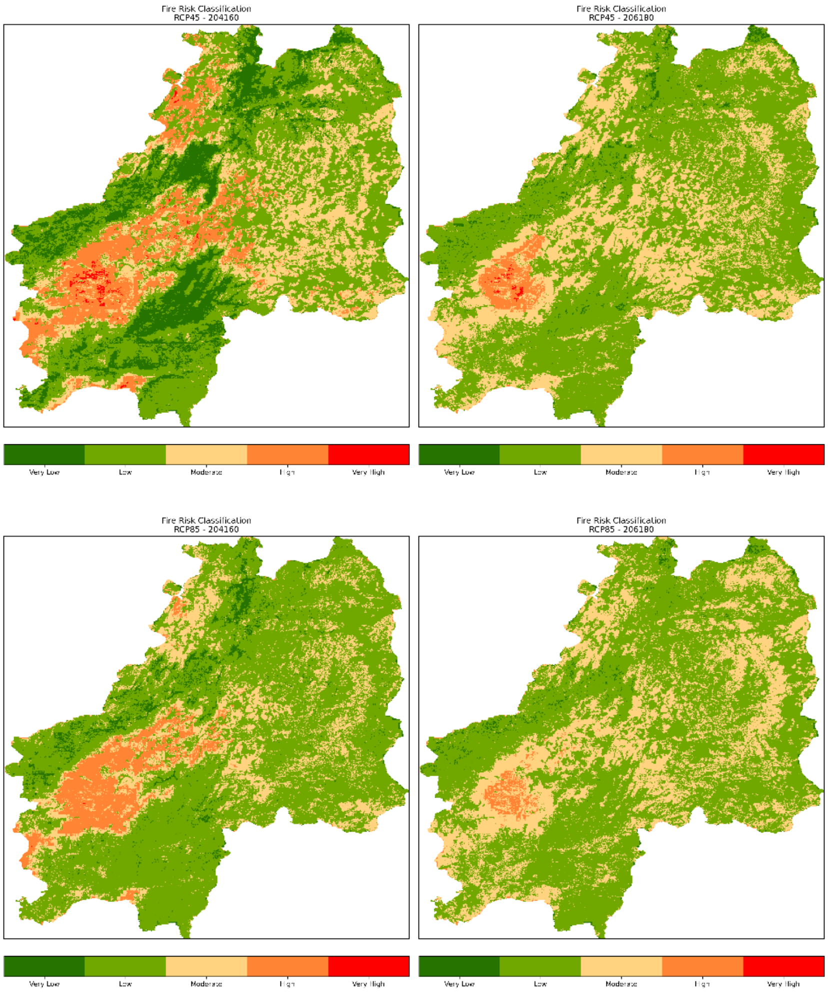

Figure 2-12 Predicted fire risk for the region, periods 2041–2060 and 2061–2080; pathways RCP 4.5 and RCP 8.5, CLMCom_CCLM climate model

Consequently, while the model shows a high degree of geographical awareness—primarily driven by the 2018 Corine Land Cover data—it demonstrates less responsiveness to climate dynamics, as the ECLIPS2.0-projected variables do not significantly influence risk evolution over time within the current framework.

Nonetheless, the ECLIPS2.0 dataset remains instrumental in regional resilience planning. Variables such as temperature extremes, moisture indices, and precipitation seasonality provide important contextual insights for future hazard characterization.

The CLIMAAX workflow incorporates the following default ECLIPS2.0 climate variables during ML model training:

Table 2-1 Climate variables used in model training

Variable Name	*Description*
MWMT	Mean Warmest Month Temperature
AHM	Annual Heat Moisture Index

Variable Name	*Description*
DDbelow0	Degree-Days Below 0°C
MAT	Mean Annual Temperature
Tave_sm	Mean Summer Temperature

Variable Name	*Description*
PPT_at	Mean Autumn Precipitation
PPT_sp	Mean Spring Precipitation
TD	Continentality (temperature range between warmest and coldest months)
SHM	Summer Heat Moisture Index

Variable Name	*Description*
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

The temporal evolution of these climate variables can be visualized in Figure 2-13, for the short-term future, according to RCP 4.5 and RCP 8.5, CLMCom_CCLM climate model.

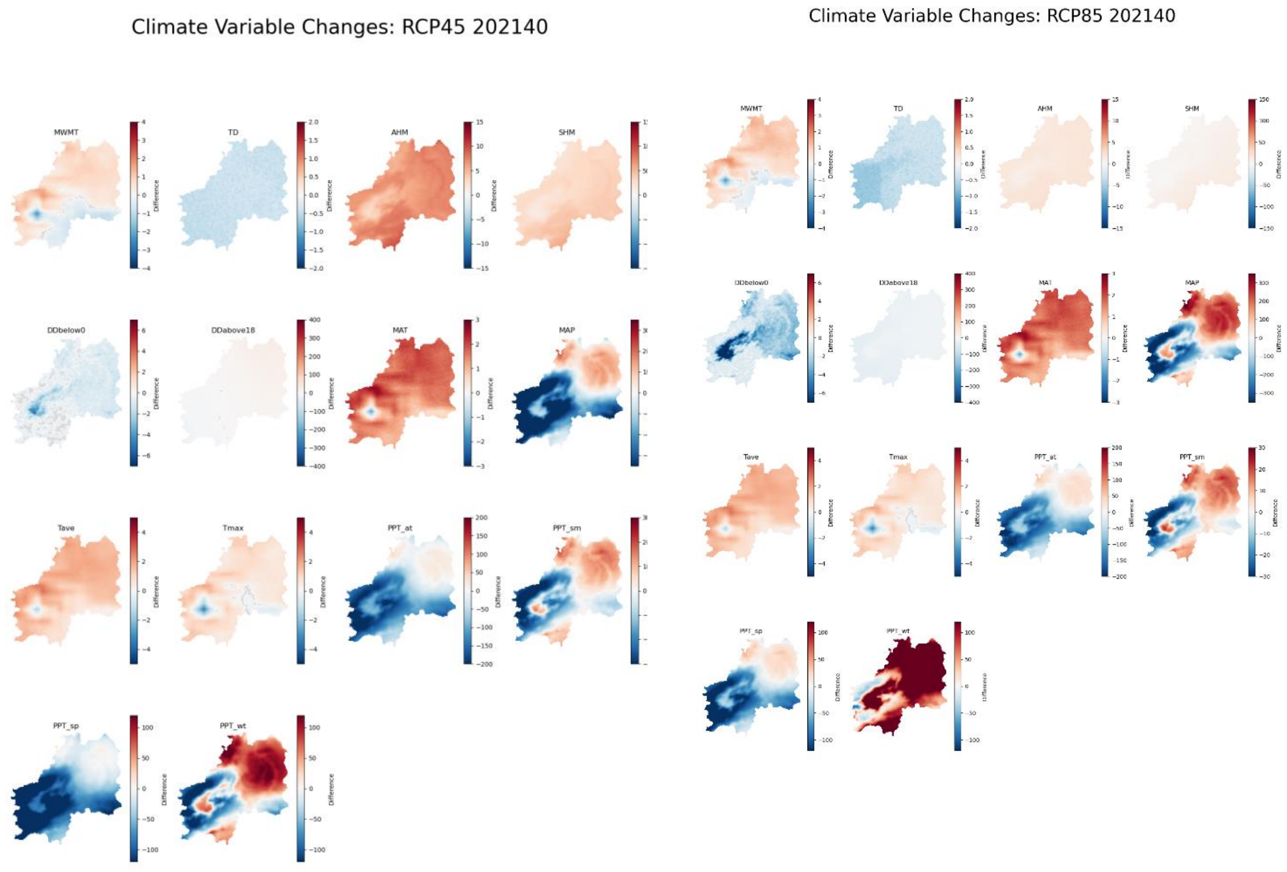

Figure 2-13 Projected climate variable evolution

While not all variables were found essential for optimal model performance, they were retained during various stages of model selection and validation, including the testing of both regional and national-scale configurations.

This completes the wildfire hazard assessment for the Beiras and Serra da Estrela Region under Phase 1 of the CLIMAAX initiative. The analysis leveraged primarily open-access datasets and predictive modelling, with subsequent project phases expected to refine the model using higher-resolution local and national data sources to enhance forecasting precision.

2.3.2.2 Risk assessment - Wildfires

Due to current data limitations, the exposure analysis was limited to the region's primary road infrastructure. Roads were selected as critical assets due to their importance in evacuation, emergency response, and economic connectivity. The analysis identified road segments with elevated exposure to wildfire-prone areas, particularly in municipalities with dense forest cover and steep topography, as evidenced in Figures 2-13 and 2-14

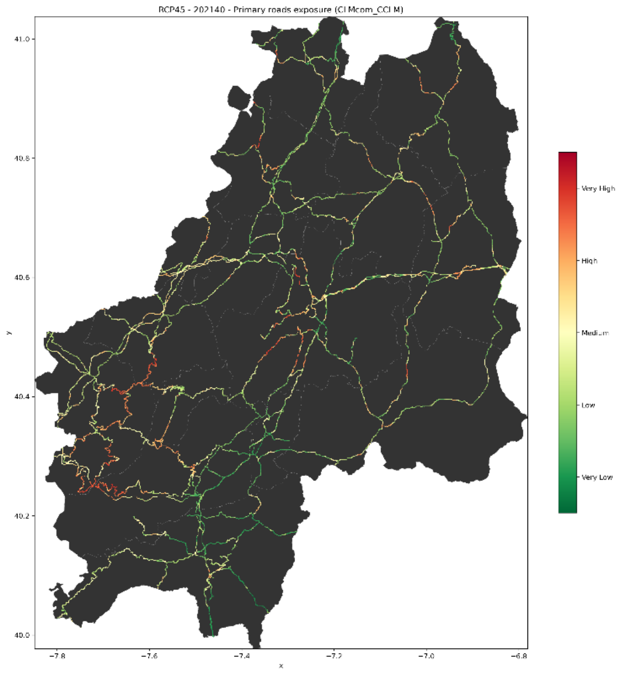

Figure 2-14 Predicted fire risk exposure for primary road, RCP 4.5

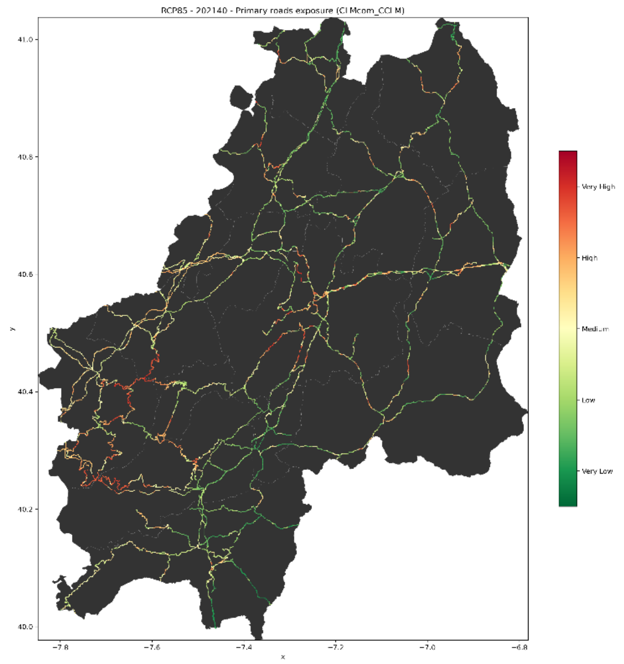

Figure 2-15 Predicted fire risk exposure for primary roads, RCP 8.5

Although vulnerability data (e.g., population density, housing characteristics, accessibility constraints) were not available for this phase, stakeholder consultations have prioritized the collection and integration of such data in the next project phase. The limitations of this analysis are acknowledged, and the findings are considered preliminary until complemented by additional datasets.

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

The assessment revealed two primary climate risks of significant severity: heatwaves and wildfires. The severity of heatwaves is especially high in urbanised and demographically vulnerable areas, where both the frequency and intensity of heat events are projected to increase substantially under RCP 4.5 and 8.5 scenarios. The eastern and southwestern subregions demonstrated the highest hazard evolution, reaching up to a 510% increase in heatwave occurrence under RCP 8.5 for the 2046–2075 period.

Wildfire severity remains a critical concern for the region, particularly in the eastern and mountainous zones. The 2021–2040 modelling based on RCP 4.5 and RCP 8.5 scenarios indicates that large portions of the region—including high-altitude forested areas—will continue to face extensive exposure to fire hazards. While some attenuation of risk appears in later model projections, this is attributed to model limitations rather than real-world trends.

2.4.2 Urgency

Both hazards exhibit high urgency for intervention. Heatwaves, as a gradually intensifying hazard, demand immediate planning responses in health systems, civil protection, and urban design. Short-term projections already show a steep trajectory in frequency and intensity, underlining the need for rapid policy alignment and adaptive infrastructure.

Wildfires present a more acute, sudden-onset hazard. Their urgency lies in the immediate threat they pose to life, ecosystems, and infrastructure, particularly during the peak summer months. Given the increasing spatial footprint of risk zones, urgent investment in prevention, early warning, and suppression capacity remains a priority.

1. Capacity

From a financial perspective, local governments and regional authorities allocate resources for climate adaptation initiatives through national and European Union funding instruments, including the EU Cohesion Fund and the European Green Deal. These mechanisms support projects related to infrastructure enhancement, sustainable agriculture, and disaster risk management. Additionally, they serve to incentivize private sector investments in green infrastructure, renewable energy, and sustainable land use practices, thereby contributing to the reduction of regional vulnerability to climate-related hazards.

From a social and human capital perspective, local and regional authorities have implemented training initiatives aimed at strengthening community preparedness and response. Programs such as "Safe Village, Safe People" educate residents—including vulnerable populations—on evacuation protocols and emergency procedures, thereby reducing the human and social impacts of climate risks. Concurrently, training activities targeting local officials, community leaders, and residents address climate risk management, sustainable agricultural practices, and emergency preparedness. These include professional capacity-building efforts for firefighters, agricultural extension agents, and climate risk planners. Furthermore, regional universities and research institutions are encouraged to conduct research on climate impacts and to develop tailored adaptation strategies for the Beiras and Serra da Estrela region, thus enhancing the region's scientific and strategic capacity to address climate challenges.

From a physical infrastructure standpoint, authorities have adopted measures such as the implementation of firebreaks, controlled burns, and other fire-prevention strategies to mitigate the risk of large-scale wildfires. Civil protection services have been equipped with enhanced resources and training to improve their response capabilities to fire-related threats.

From an environmental and ecological standpoint, reforestation efforts have been undertaken to restore biodiversity and reduce the incidence of erosion, flooding, and landslides. The region hosts several protected areas—including Serra da Estrela Nature Park, Serra da Malcata Nature Reserve, and Douro International Nature Park—which contribute to ecological preservation. Furthermore, ecological corridors have been established, and many ongoing environmental initiatives are focused on ecosystem services as a means of conserving the region's extensive biodiversity.

Most of these actions were identified and prioritised within the Intermunicipal Climate Change Adaptation Plan.

The region also presents significant opportunities for innovation, resilience-building, and sustainable development. From a financial standpoint, it holds potential to attract investment in green infrastructure and renewable energy—particularly in solar, wind, and hydropower sectors. These investments can catalyse the development of new markets for sustainable goods and services, thereby contributing to regional economic growth. Emphasising sustainability may also enable Beiras and Serra da Estrela to cultivate niche markets in eco-tourism, organic agriculture, and sustainable forestry. These sectors can generate revenue while preserving the natural environment and enhancing local economies. Moreover, the region can leverage funding from EU climate action programs, national adaptation strategies, and international climate resilience initiatives.

From a social and human capital perspective, Beiras and Serra da Estrela has the potential to position itself as a model region for climate adaptation, attracting regional and international recognition. Local leadership and civil society actors could emerge as reference points in climate resilience, fostering knowledge exchange through conferences, innovation hubs, and collaborative networks. Addressing climate risks can also foster cross-sectoral collaboration among government entities, the private sector, non-governmental organizations, and local communities. Such partnerships facilitate the development of innovative solutions and the dissemination of best practices for climate adaptation.

From a physical perspective, climate adaptation offers an opportunity to design and retrofit infrastructure to be both climate-resilient and energy-efficient. This includes constructing flood protection systems, installing drought-resilient irrigation technologies, developing green buildings, and promoting sustainable transport solutions. Furthermore, there is scope to advance climate-resilient agricultural practices, such as crop diversification, agroforestry, and water-efficient irrigation techniques, which support long-term food security and agricultural productivity.

From a natural capital perspective, the adoption of sustainable land management practices—including reforestation, agroforestry, and regenerative agriculture—can contribute to climate mitigation through carbon sequestration. These approaches also enhance soil health and reduce erosion. Additionally, there is an opportunity to strengthen wildlife conservation and landscape protection efforts, thereby promoting eco-tourism. Responsible eco-tourism can stimulate local economies, support biodiversity conservation, and raise public awareness about environmental issues.

2.5 Preliminary Monitoring and Evaluation

The first phase of the climate risk assessment yielded several insights into both the technical and institutional dimensions of regional climate risk analysis. One of the key lessons learned was the importance of combining local knowledge with standardised analytical workflows. While the CLIMAAX toolbox provided a harmonised framework and facilitated access to consistent data, the integration of local datasets—especially spatial and demographic information—greatly improved the contextual relevance of the results.

Several challenges emerged during this phase. Technical constraints included the limited resolution of available climate projection datasets for long-term wildfire modelling, and gaps in vulnerability data for infrastructure and socio-economic systems. On the institutional side, disparities in technical capacity among municipalities and coordination hurdles occasionally slowed the data collection and validation process. These aspects were partially mitigated through stakeholder engagement, which provided critical feedback and identified additional data sources for future use.

Stakeholder contributions were instrumental in prioritising risks and identifying key areas for further analysis. Their input helped define which indicators and spatial layers would be most useful for regional decision-making, particularly concerning civil protection, land use planning, and ecosystem management. Feedback from the participatory workshop highlighted the need for enhanced support in data interpretation, integration of monitoring systems, and use of risk outputs in operational planning.

Looking ahead, Phase 2 will prioritise the incorporation of stakeholder-provided local data, refinement of modelling assumptions, and improvements in cross-municipal coordination. Specific needs identified include higher-resolution exposure mapping and incorporation of socio-economic vulnerability indices. Continued engagement with local actors will be essential to ensure that the CRA process remains participatory, adaptive, and policy relevant.

3 Conclusions Phase 1- Climate risk assessment

The first phase of the climate risk assessment for the Beiras e Serra da Estrela region, conducted under the CLIMAAX framework, has provided a robust foundation for understanding and addressing key climate-related hazards in the territory. Through a structured application of harmonised workflows and participatory methodologies, the assessment successfully identified and analysed two priority risks—heatwaves and wildfires—based on their historical impact, projected intensification, and regional relevance.

The heatwave analysis revealed a sharp projected increase in hazard occurrence, particularly in the eastern and southwestern subregions, with estimated rises of up to 510% under the RCP 8.5 scenario for the 2046–2075 period. Vulnerability mapping further underscored the risks to demographically sensitive populations in urban centres such as Covilhã, Fundão, Guarda, and Seia, where land surface temperature hotspots and population density converge. These findings point to the urgent need for targeted urban adaptation strategies, public health interventions, and mitigation of the urban heat island effect.

The wildfire risk assessment highlighted systemic exposure across much of the territory, with elevated risk concentrated in forested and mountainous zones. Short- to mid-term projections under both RCP 4.5 and RCP 8.5 suggest a widespread and persistent hazard footprint, exacerbated by topographical complexity and vegetation cover. Although longer-term model outputs displayed attenuated risk, these results are considered artifacts of model limitations rather than indicative of decreasing hazard trends.

Stakeholder engagement was a critical component of this phase, facilitating risk prioritisation, data validation, and future planning alignment. The participatory workshop enabled diverse institutional actors to contribute local insights and helped define future data needs, particularly concerning socio-economic vulnerability and infrastructure exposure. Their commitment to providing local datasets in subsequent phases will enhance the granularity and contextual relevance of future analyses.

The project also identified several methodological and institutional challenges. Technically, constraints included limited access to high-resolution vulnerability data and the moderate sensitivity of long-term wildfire modelling. Institutionally, disparities in technical capacity and coordination among municipalities posed occasional delays, though these were mitigated through collaborative engagement.

In conclusion, Phase 1 has successfully demonstrated the applicability and value of the CLIMAAX framework for regional-scale climate risk assessments. It has produced spatially explicit, data-driven outputs that are both policy-relevant and operationally actionable. The results lay the groundwork for targeted adaptation measures and support the ongoing implementation of the Intermunicipal Climate Change Adaptation Plan (PIAAC) and related regional instruments. Future phases will build upon these achievements by integrating refined local data, enhancing cross-sectoral coordination, and expanding the scope of risk and vulnerability analyses to support resilient development pathways in Beiras e Serra da Estrela.

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%)*
At least 2 workflows ran correctly during Phase 1	*2/2 (100%)*
At least 2 workflows ran correctly during Phase 2	*0/2 (0%)*
At least 15 plans of climate action and resilience updated	*0/15 (0%)*
At least 15 plans of emergency and risk management updated	*0/15 (0%)*
At least 25 stakeholders involved in the project	*28/15 (> 100%)*
At least 2 public dissemination events regarding the project organized	*0/2 (0%)*
At least 3 notes given to local governments and administrations	*0/3 (0%)*
At least 3 articles published in local newspapers	*0/3 (0%)*

Table 4-2 Overview milestones

Milestones	*Progress*
Publication of an article when the project is finished	*Not done*

5 Supporting documentation

5.1 Workflow Result Archives

Workflow #1 – 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.

Workflow #2 – 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

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 Beiras e Serra da Estrela:

Zenodo Repository Link: https://doi.org/10.5281/zenodo.15115155

DOI: 10.5281/zenodo.15115155

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