Deliverable Phase 2 – Climate risk assessment

Multi – Risk assessment of climate change for Goriska region (MRA - GO)

Goriška region, Slovenia

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

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Document Information

Deliverable Title	Phase 2 – Climate risk assessment
Brief Description	This report presents the refined regional climate risk assessment for the Goriška region conducted in Phase 2 of the MRA-GO project. It focuses on heatwaves and agricultural drought by integrating higher-resolution regional climate data, updated exposure information and locally adapted agricultural parameters, and compares the results with the Phase 1 assessment.
Project name	Multi – Risk assessment of climate change for Goriška region
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Region/Municipality	Goriška region
Leading Institution	PRC, Posoški razvojni center (Soča valley development centre)
Supporting Institutions	GOLEA, Goriška local energy agency
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2.0	…	CLIMAAX's FSTP team	Review completed
3.0	…		Final version to be submitted

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Abbreviations and acronyms

Abbreviation / acronym	Description
ACC	Adaptation to Climate Change
PRC	Soča valley development center (Posoški razvojni center)
GOLEA	Goriška local energy agency
MRA	Multi Risk Assessment
GCM	Global Climate Models
HW	Heatwave
CRA	Climate Risk Assessment
ARSO	Slovenian environment Agency (Agencija Republike Slovenije za okolje)
TNP	Triglav National Park
CDS	Climate Data Store
SECAP	Sustainable Energy and Climate Action Plan
RATF	Regional Adaptation Task Force
EU	European Union
RCP	Representative Concentration Pathway
LST	Land Surface Temperature
UHI	Urban Heat Island
SPI	Standardized Precipitation Index
SPEI	Standardized Precipitation Evapotranspiration Index
GAEZ	Global Agro-Ecological Zones database
RRA	Regional Development Agency (Regionalna razvojna agencija)
ICRA	Regional Development Agency ICRA (Idrija-Cerkno)
KGZS-GO	Institute of agriculture and forestry Nova Gorica
Tas	Daily mean temperature
Tmin	Daily minimum temperature
Tmax	Daily maximum temperature
SURS	Statistical Office of the Republic of Slovenia

Executive summary

This Phase 2 deliverable presents a refined climate risk assessment for the Goriška region, covering all 13 municipalities. It builds on Phase 1, which identified heatwaves and agricultural drought as the region's priority climate risks. The assessment was improved through higher-resolution regional climate data, an ensemble of climate models, updated WorldPop 2025 exposure data, locally adapted crop parameters and information on existing and planned irrigation systems.

The heatwave assessment used the xclim methodology and 1 × 1 km bias-corrected ARSO/EURO-CORDEX temperature data under RCP4.5 and RCP8.5. An ensemble of six climate models was analysed, while selected individual models were also examined. The results show that heatwaves are expected to become more frequent, longer and more intense, particularly after 2030 and under RCP8.5. The highest risk is generally projected in the southern and south-western parts of the region, where greater heat exposure overlaps with higher concentrations of vulnerable population groups.

The agricultural drought assessment used precipitation and reference evapotranspiration data, locally adapted crop coefficients and growing periods, and irrigation-system data. It covered maize, wheat, barley, grapevine (grapes), peaches and nectarines, and grassland. The highest projected losses are generally concentrated in the Vipava Valley and other southern parts of the region. Maize losses may reach approximately 20–25%, grassland losses around 30%, and peach losses up to approximately 36% under RCP4.5 in 2046–2050. The results also show that RCP8.5 does not necessarily produce higher losses in every individual five-year period because of interannual climate variability.

Both heatwaves and agricultural drought were assessed as substantial current risks and critical future risks. Regional resilience capacity was considered medium, as existing strategies, warning systems, technical knowledge and irrigation infrastructure provide a useful basis, but municipalities differ considerably in staffing, funding, data availability and preparedness.

The main limitations concern insufficient data on heat-related health impacts, socio-economic vulnerability, soil moisture, crop varieties, irrigation efficiency and farming practices. Phase 3 will validate the findings with regional stakeholders and support the identification and prioritisation of practical adaptation measures related to heat preparedness, spatial planning, water management, irrigation and agricultural resilience.

The main objective was to provide a reliable basis for planning climate adaptation measures and supporting better decision-making at the local level.

1 Introduction

1.1 Background

The Goriška region, located in the western part of Slovenia, comprises 13 municipalities: Ajdovščina, Bovec, Brda, Cerkno, Idrija, Kanal ob Soči, Kobarid, Miren-Kostanjevica, Renče-Vogrsko, Nova Gorica, Šempeter-Vrtojba, Tolmin, and Vipava. This diverse region, characterized by a range of geographical features, experiences significant climate variability. Some municipalities, including Ajdovščina, Idrija, and Nova Gorica, have developed Sustainable Energy and Climate Action Plans (SECAPs), which represent important milestone in climate change consideration. However, the region lacked a coherent and integrated framework for assessing and managing climate risks, establishing Regional Adaptation Task Force (RATF). The adoption of the Regional Strategy for Climate Change Adaptation of the Goriška Development Region in June 2025 marked the first coordinated effort across all 13 municipalities to systematically assess climate impacts and design joint responses (GOLEA et al., 2025). Nevertheless, the region still faces considerable challenges in addressing climate change at a broader level.

The climate of the Goriška region has experienced noticeable changes in recent decades. Between 1981 and 2005, the average air temperature increased by +0.33°C per decade, with a total rise of +1.0°C over the 30-year period. Precipitation patterns have also been altered, showing a decreasing trend of 2.7% per decade. As a result, the region is experiencing a growing number of heatwaves, rising temperatures, and extended drought periods in the summer, while winter sees more extreme rainfall events, particularly in the form of storms and flooding. These climate impacts, including increasing temperatures, drought, wildfires, and changing precipitation patterns, have profound implications for the region's natural environment, agriculture, public health, and infrastructure. (GOLEA et al., 2021)

Climate change is also altering seasonal dynamics, with longer summers, warmer winters, and shorter snowfall periods. These shifts in climate patterns bring challenges to agriculture, biodiversity, and water resources, creating a need for immediate action to build resilience in the region. Addressing these issues at the regional level is critical, given the interconnectedness of the municipalities, where climate impacts can transcend local borders and affect entire communities. (GOLEA et al., 2021)

1.2 Main objectives of the project

Phase 2 aims to refine and localise the climate risk assessment developed in Phase 1 by integrating high-resolution regional and local data, adapting CLIMAAX workflows to regional conditions, and strengthening the practical relevance of the results for local decision-making.

1. **Deepening and localising climate risk assessments:** Based on Phase 1, Phase 2 enhances the understanding of heatwaves, drought and water scarcity by incorporating detailed local datasets, such as updating population (age), regional crop coefficients, updated irrigation information and high-resolution regional climate projection data.
   In the analysis, official data and climate projections from the Slovenian Environment Agency (ARSO), prepared within the framework of the OPS21 project – Assessment of Climate Change in Slovenia until the End of the 21st Century – were used. We used data with a high spatial resolution of 1 × 1 km. The projections are based on regional climate models from EURO-CORDEX and have been bias-corrected against measurements in Slovenia for the

reference period 1981–2010. We used high resolution bias corrected climate data (daily mean Temperature (Tas), Tmaximum and Tminimum air temperature, precipitation, and reference evapotranspiration) for emission scenarios RCP**4.5 and RCP8.5**, and for 30-year periods up to 2099: **2011–2040; 2041–2070; and 2071–2099**.
When interpreting the results, it is considered that the projections do not represent weather forecasts, but rather possible future climate conditions depending on the selected scenario and model ensemble.

2. **Customising the CLIMAAX methodology to the local context:** Using the CLIMAAX Handbook as the methodological foundation (Phase 1), Phase 2 adapts workflows to regional needs. Key improvements include the use of regional/local high-resolution data, updated WorldPop 2025 Slovenia population data. These updates enhance the spatial accuracy and relevance of the CLIMAAX model by allowing it to better capture current population distribution, local/regional heat exposure and site-specific climate vulnerabilities. As a result, the model outputs become more reliable and useful for local climate risk assessment and adaptation planning.
We also refined agricultural drought modelling by incorporating local irrigation data and updating the crop table with localised data for wheat and maize, while also adding grapevines, peaches/nectarines and grassland. This workflow compares current conditions for the period 2021–2025 with future conditions for the period 2046–2050, and 2066-2070, focusing on irrigation needs and potential yield losses.

3. **Stakeholder engagement:** Several meetings were held with the Regional Working Group for Climate Adaptation Change of the Goriška region to discuss the main directions for localising the CLIMAAX model. The discussions focused on the use of regional and local data, the selection of relevant indicators, and the adaptation of the model to the specific climate risks and territorial characteristics of the Goriška region.

4. **Supporting climate adaptation planning:** It was emphasised that the refined risk maps and indicators produced in Phase 2 could potentially be used to support the future upgrade of the Regional Climate Change Adaptation Strategy for the Goriška region, as well as the preparation of the Action Plan within the P2R-GO project.

1.3 Project team

***Marta Stopar** holds a BSc degree in Environmental Sciences from the University of Nova Gorica (2008). She began her career at the University, working on EU projects as a technical expert in the Laboratory for Environmental Research and as a teaching assistant in Waste Management, Marine Ecology, and Environmental Impact Assessment. Since joining the GOLEA Agency in 2017, she has been led and contributed to several EU projects, both as a project manager and as an expert. Her work also includes the preparation of local energy concepts, SEAPs, and SECAPs, supporting municipalities in sustainable energy and climate planning. She implemented different training courses and capacity building workshops for teachers, public administrators, children, as well as stakeholder workshops to support collaborative climate and energy planning. She actively contributed to the preparation of the Regional Climate Change Adaptation Strategy for Goriška. She is the project manager of the P2R-GO project (Project leader - GOLEA), a subgrant project under Pathways2Resilience (P2R), through which the Goriška region will develope an updated climate adaptation strategy, as well as an action plan and investment plan.*

***Matej Pahor** obtained a Degree in Mechanical Engineering (Energy and Process Engineering) at the University of Ljubljana in 2013. In 2016, he obtained a license as independent expert for energy performance certificate production. He is actively involved in monitoring and targeting as well as in energy accounting activities, elaboration of energy performance certificates, preparation of feasibility studies, technical documentation elaboration, building energy audits, among other. From 2025 on he is a director of GOLEA agency.*

***Žiga Črv** holds a BSc in Computer and Information Science from the University of Ljubljana, Faculty of Computer and Information Science (2023), where he is currently pursuing his Master's degree. During his studies, he gained professional experience as a software developer at Marand d.o.o. in Ljubljana. He is currently employed at Arctur d.o.o. in Nova Gorica, where he works as a backend developer and AI researcher. His expertise lies in backend systems, distributed architectures, and the application of artificial intelligence for practical problem-solving. He has hands-on experience with cloud-based environments, microservices, and database systems, as well as in developing and integrating intelligent solutions into real-world applications. He is also engaged in developing AI models and adapting large language models (LLMs) to specific applications.*

1.4 Outline of the document's structure

This document is structured in accordance with the CLIMAAX Phase 2 Deliverable guidelines and is organized into several key sections. After the Executive Summary and Introduction, the document focuses on the advanced Climate Risk Assessment (CRA) for the selected region, which represents the core of Phase 2. The CRA is divided into the following main sections:

- **Scoping**: This section defines the refined objectives, policy and governance context, stakeholder roles and risk ownership, and explains how key principles and stakeholder engagement processes were applied in this phase.
- **Risk Exploration**: This section presents the updated screening of climate risks, including the selection of the most relevant hazards and the definition of climate scenarios used for further analysis.
- **Regionalized Risk Analysis**: This section provides a detailed, locally adapted analysis of selected hazards, including the refinement of methodologies to local conditions and the integration of additional assessments based on local models, datasets, and knowledge.
- **Key Risk Assessment Findings**: This section summarizes the main results of the risk analysis, including stakeholder engagement outcomes, and evaluates risks based on severity, urgency, resilience capacity, and overall prioritization.
- **Monitoring and Evaluation**: This section outlines the approach for tracking progress, assessing the effectiveness of the analysis, and identifying lessons learned and areas for improvement.
- **Work Plan for Phase 3**: This section defines the next steps of the project, including planned activities, priorities, and the transition from assessment to implementation.
- **Conclusions**: The document concludes with a synthesis of the main findings of Phase 2 and highlights key messages for future climate adaptation planning and decision-making.

In addition to the main sections, the document includes supporting documentation and references, which provide additional context and details to complement the main content.

2 Climate risk assessment – phase 2

This section presents the key steps undertaken in the implementation of the Climate Risk Assessment (CRA), based on the CLIMAAX methodological framework and enhanced through the integration of locally adapted datasets and additional information sources.

2.1 Scoping

In the scoping phase, the key objectives, context and stakeholders were identified and are described in the sections that follow.

2.1.1 Objectives

The objective of Phase 2 of the Climate Risk Assessment (CRA) for the Goriška region is to deepen and refine the preliminary assessment carried out in Phase 1 by integrating high-resolution datasets, improved climate indicators, and enhanced local calibration of the modelling framework. Building on the initial identification of key climate-related risks, Phase 2 focuses on increasing the spatial accuracy and reliability of the assessment, with particular attention to heatwaves and agriculture droughts.

The purpose of this phase is to strengthen the evidence base for regional adaptation planning by incorporating locally relevant datasets (e.g. ARSO high resolution climate data and population density datasets (WorldPOP 2025 Slovenia) and improving the representation of territorial specificities within the CLIMAAX workflow. Emphasis is placed on translating scientific and technical outputs into operational knowledge that can directly support regional and municipal decision-making.

The expected outcome of Phase 2 is a more detailed and locally validated climate risk assessment that supports the preparation and implementation of concrete adaptation measures and investment priorities. The assessment is intended to directly support policy and decision-making processes at municipal levels by helping decision-makers prioritise adaptation actions, allocate resources more effectively, and strengthen cross-sectoral and cross-municipal cooperation.

The project outcomes will contribute to the further development and upgrading of key regional strategic and planning documents, including the Regional Climate Adaptation Strategy, Action Plan, Investment Plan, regional spatial planning processes, and broader regional development policies. In addition, the results are expected to support future investment planning, climate-resilient infrastructure development, and integration of climate adaptation considerations into sectoral planning processes.

Phase 2 also aims to strengthen the operational capacity of regional stakeholders by improving data accessibility, methodological understanding, and inter-municipal cooperation related to climate resilience. Through enhanced modelling approaches and stakeholder engagement, the CRA supports the transition from strategic identification of risks toward practical implementation planning and prioritisation of adaptation pathways.

Heatwaves – benefits of the Phase 2

The Phase 2 model will provide a more locally relevant assessment of heatwave risk using the xclim method and ARSO/EURO-CORDEX 1 km bias-corrected data for Tmin, Tmax and Tas.

- This will allow better alignment with the ARSO heatwave definition for the Goriška climate zone.
- The analysis will use an ensemble of six climate models, while selected individual models will also be assessed separately to better understand differences between model outputs.
- Compared to the basic assessment, the model will provide a clearer picture of expected heatwave frequency, duration and intensity, supporting more reliable local adaptation planning.

Agricultural drought – benefits of the Phase 2

- The Phase 2 model will provide a more realistic assessment of agricultural drought risk using ARSO/EURO-CORDEX 1 km bias-corrected precipitation and reference evapotranspiration data.
- This will improve water balance calculations and better reflect the relation between available water and crop water demand.
- By including local crop coefficients, updated crop data and national irrigation coverage data, the model will better reflect drought impacts on locally relevant crops, including grapevines (grapes), peach trees, grasslands, maize, barley and wheat.
- Compared to the basic assessment, the model will better show where drought impacts and potential yield losses may be most relevant, supporting agricultural adaptation and irrigation planning.

Limitations and boundaries

The CRA is constrained by limited availability of high-resolution local climate and socioeconomic data, gaps in historical hazard records, uncertainties in future climate scenarios, and varying institutional, technical and stakeholder capacities across municipalities. Differences in spatial and temporal resolution, data formats and baseline periods required additional harmonisation and preprocessing and may affect the accuracy or feasibility of some methods. Limited time and human resources also restricted field validation and stakeholder engagement.

To improve regional relevance, Phase 2 integrated additional local datasets, particularly ARSO climate data. However, the lack of harmonised high-resolution datasets limited the integration of data layers within the EuroHeat approach. Therefore, EuroHeat was not further pursued, and the assessment instead developed the xclim-based methodology. The framework still relies on assumptions regarding hazard thresholds, exposure and vulnerability.

For agricultural drought, the assessment uses ARSO/EURO-CORDEX 1 km bias-corrected precipitation and reference evapotranspiration data. Remaining uncertainties relate to climate model assumptions, local rainfall variability and the quality and local relevance of crop coefficients, crop calendars and crop water-demand estimates.

The main limitation of constrained population data is their dependence on the quality of building and settlement mapping. If individual buildings or small rural settlements are not detected, the population may be disproportionately allocated to nearby mapped settlements. Nevertheless, due to improvements in satellite-based building detection, WorldPop considers constrained data to be generally more accurate in most settings.

The analysis was also limited by insufficient harmonised local data on sowing dates, crop rotations, soil conditions, crop varieties, irrigation, farming practices and crop management, particularly for cereals and grasslands. Expert knowledge and local studies were used to adapt model parameters, but further crop-specific validation is needed. Additional details are provided in the supplementary material.

The model primarily assesses water-related crop stress and does not fully represent other yield-influencing factors, such as frost, microclimatic conditions, tillage, windbreaks, irrigation management and farm-level adaptation measures. National irrigation coverage data may not reflect actual local practices, irrigation efficiency, water availability or future irrigation development. Yield-loss results should therefore be interpreted as indicative regional estimates rather than precise field-level predictions.

More systematic and openly accessible data collection, together with continued cooperation with farmers, agricultural experts and other stakeholders, would improve model calibration, validation and practical applicability. Despite these limitations, Phase 2 represents a significant improvement over Phase 1 using more detailed local datasets, higher spatial accuracy and greater relevance for regional climate adaptation planning.

2.1.2 Context

Previous assessment and management of climate risks

Until recently, climate hazards in the Goriška region—such as heatwaves, droughts, floods, wildfires, and landslides—were mostly addressed at the local level, often through ad hoc measures or sector-specific strategies. Some municipalities, including Ajdovščina, Idrija, and Nova Gorica, had already developed Sustainable Energy and Climate Action Plans (SECAPs), which represented an important step towards structured climate action (GOLEA et al., 2021). However, the region lacked a coherent and integrated framework for assessing and managing climate risks.

The adoption of the Regional Strategy for Climate Change Adaptation of the Goriška Development Region in 2025 marked the first coordinated effort across all 13 municipalities to systematically assess climate impacts and design joint responses (GOLEA et al., 2025).

So, In Phase 1 of the CRA Climaax, climate hazards in the Goriška region—such as heatwaves and agricultural droughts—were selected based on existing local and regional adaptation efforts.

Phase 2 builds on this foundation by further refining the climate risk assessment, improving the regional evidence base, and supporting the transition from strategic planning towards more targeted adaptation actions. Nevertheless, the region still faces considerable challenges in addressing climate change at a broader and more operational level.

In addition to strategic and technical activities, the Goriška region has also strengthened awareness and local capacities through the REINFORCING: CLeAR-CLIMATE-CAPA-ORRI project, implemented by Agency GOLEA in cooperation with Stritih d.o.o.. The project focused on improving climate resilience in relation to heat, floods and droughts by connecting pupils, teachers, experts, residents and decision-makers. These activities represent an important previous achievement, as they supported stakeholder engagement and helped translate climate adaptation into locally understandable and community-based actions.

The Goriška region has also been selected to participate in the Pathways2Resilience initiative through the P2R Goriška project, led by GOLEA in cooperation with regional development agencies and expert partners. The project supports the upgrade of the Regional Strategy for Climate Change Adaptation and the preparation of a Climate Resilience Action Plan and Investment Plan. It represents an important step towards stronger cooperation among all 13 municipalities, linking climate risk assessment with concrete adaptation measures, financing and implementation.

Problem definition and broader context

The key problem addressed in Phase 2 remains the fragmented and uneven approach to climate risk management across municipalities. Climate hazards transcend administrative boundaries, and local responses alone are insufficient to address systemic risks to agriculture, forestry, water management, health, infrastructure, tourism, and ecosystems. Phase 2 therefore focuses on strengthening the shared evidence base developed in Phase 1 and supporting a more coordinated regional framework for adaptation planning.

By further developing the climate risk assessment, the project strengthens regional resilience and ensures alignment with national climate adaptation objectives, the European Green Deal, and the objectives of the EU Mission on Adaptation to Climate Change. In this way, Phase 2 not only addresses immediate local vulnerabilities but also supports the integration of climate adaptation into long-term regional development strategies, enabling better access to resources and improved coordination across sectors and municipalities.

Governance context

The governance context of the Goriška region was already defined in Phase 1 and is therefore only briefly summarised here. Slovenia is bound by the EU Climate Law and adaptation frameworks, while the region itself joined the EU Mission on Adaptation to Climate Change in 2023. It is based on EU and national climate adaptation frameworks, the region's participation in the EU Mission on Adaptation to Climate Change, and the Regional Adaptation Strategy for the Goriška region (GOLEA et al., 2025)., adopted in June 2025. Since Slovenia does not have a formal regional governance level, adaptation is coordinated through cooperation between the 13 municipalities, GOLEA, regional development agencies and other relevant stakeholders. As Slovenia lack of regional governance, the 13 municipalities established Regional Adaptation Task Force to tackle climate change issues, which part are energy agency GOLEA and regional development agency PRC (and 3 other regional development agencies) (GOLEA et al., 2025).

Phase 2 builds on this framework by focusing on the operational use of governance structures for a more detailed and locally relevant climate risk assessment. The Regional Adaptation Task Force supports coordination between municipalities and sectors and helps link updated risk evidence with adaptation planning and future investment priorities.

The sectors identified in Phase 1 remain relevant, particularly agriculture and viticulture, forestry and biodiversity, water management, tourism, public health, infrastructure and urban systems, and ecosystems. In Phase 2, the focus is on improving the spatial understanding of key risks, including heatwaves and agricultural drought.

Sectors

The most relevant sectors remain agriculture and viticulture, forestry and biodiversity, water management, public health, infrastructure and urban systems, tourism, and ecosystems. Agriculture and viticulture are particularly exposed to agricultural drought, water deficits and potential yield losses, especially where irrigation availability is limited. Public health is affected by more frequent and intense heatwaves, particularly among vulnerable population groups. Water management is under pressure due to changing precipitation patterns, drought periods and competing water uses. Forestry and ecosystems may be affected by heat stress, drought, wildfire risk and biodiversity loss. Tourism may also be affected by heat stress, reduced summer comfort and impacts on natural assets, while infrastructure and urban systems may face higher heat exposure and increased demand for cooling.

Nearby initiatives/intervetions that may influence the problem

The assessment is also influenced by wider initiatives and data sources, including the EU Mission on Adaptation, MIP4Adapt, the CLIMAAX framework, national climate projections, ARSO data and Pathway2resilience (P2R-GO) and cross-border projects (Programme Interreg Italia -Slovenia).

Possible adaptation interventions are not redefined in Phase 2 but further linked to updated risk evidence. Priority areas include water management, nature-based solutions, heat-health measures, climate-sensitive spatial planning, resilient agriculture and viticulture, wildfire prevention, ecosystem protection and tourism adaptation. Thus, Phase 2 supports the transition from general risk identification towards more targeted adaptation priorities and future planning.

2.1.3 Participation and risk ownership

Stakeholder involvement process in Phase 2

Relevant stakeholders in Phase 2 were identified according to their role in the climate risk assessment process and regional adaptation planning. They include GOLEA, regional development agencies, the 13 municipalities of the Goriška region, ARSO, the University of Ljubljana – Biotechnical Faculty, sectoral stakeholders, and representatives of vulnerable or exposed groups. (see more in chapter 1.2.5)

Stakeholders that participated in CLIMAAX-related meetings included the Regional Working Group for Climate Change Adaptation, GOLEA, regional development agencies, municipalities, ARSO and the Biotechnical Faculty. Their involvement supported the review of results, validation of assumptions, methodological improvement and alignment with the Regional Strategy for Climate Change Adaptation.

Relevant stakeholders

The stakeholders involved in Phase 2 can be grouped according to their roles in the climate risk assessment and adaptation planning process:

- **Regional coordination and technical facilitation:** GOLEA, PRC, ICRA, RRA of Northern Primorska and RRA ROD Ajdovščina. These institutions coordinate the regional adaptation process, support communication with municipalities and stakeholders, and ensure links with the Regional Strategy for Climate Change Adaptation and related projects.
- **Local government:** the 13 municipalities of the Goriška region, which are the primary decision-makers and implementers of local adaptation measures.
- **Technical and scientific experts:** ARSO, Institute of agriculture and forestry Nova Gorica and the Biotechnical Faculty, Department of Agronomy, which provided expert guidance on climate data, indicators, agricultural drought and sector-specific interpretation of results.

- **Sectoral stakeholders:** representatives from agriculture, forestry, water management, tourism, spatial planning, health, infrastructure and civil protection, who are directly affected by climate impacts or responsible for implementing adaptation measures.
- **Vulnerable and exposed groups:** elderly people, people with health conditions, farmers, winegrowers, residents of flood-prone and landslide-prone areas, and communities dependent on tourism and natural heritage.
- **National authorities:** ministries responsible for environment, spatial planning, agriculture and civil protection, which provide regulatory guidance, policy alignment and potential co-financing opportunities.

The most exposed groups include elderly people (over 65) and those with health conditions (heat stress), farmers and winegrowers (drought, storms), residents of flood- or landslide-prone areas, and communities dependent on tourism and natural heritage. They are represented through municipalities, farmers' associations, health institutions and local organisations.

The stakeholders that actively participated in CLIMAAX-related meetings in Phase 2 included the Regional Working Group for Climate Change Adaptation, GOLEA, regional development agencies, ARSO and the Biotechnical Faculty. Municipalities were involved through the regional working group and through the broader regional adaptation process.

Organigram of institutions and responsibilities

The institutional structure is presented in the organigram. The national and EU level provide the strategic and legislative framework. The Regional Council connects the 13 municipalities and provides strategic guidance. Municipalities are the main local risk owners and implementers of adaptation measures. The Regional Working Group for Climate Change Adaptation, composed of GOLEA, PRC, ICRA, RRA of Northern Primorska and RRA ROD Ajdovščina, coordinates the regional process, stakeholder involvement and links with the regional adaptation strategy. Expert institutions support data interpretation and methodological development, while sectoral stakeholders and vulnerable groups contribute local knowledge and help identify needs and priorities.

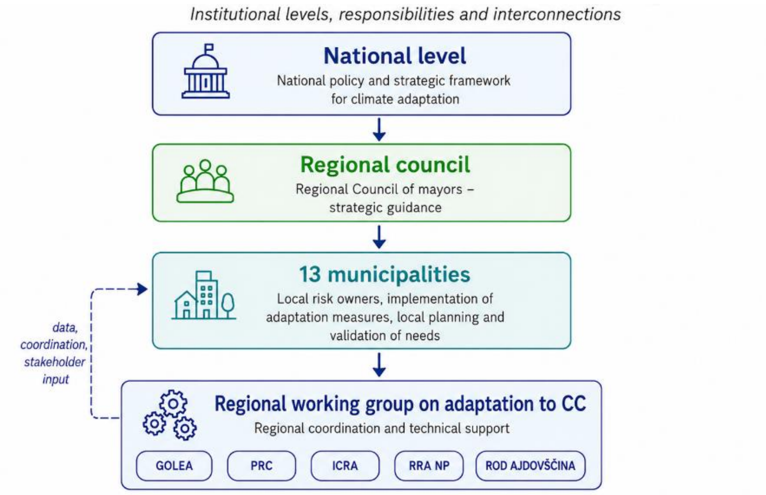

Figure 2-1 Institutional levels, responsibilities and interconnections

Risk ownership and acceptable risk in the region

In the Goriška region, municipalities are the primary owners of local climate risks, as Slovenia does not have a formal regional governance level. They are responsible for planning and implementing adaptation measures related to spatial planning, infrastructure, water management, civil protection, public buildings and communication with residents. National authorities provide the legislative framework and co-financing opportunities.

At the regional level, Working group - GOLEA and regional development agencies support coordination between municipalities, contributes to reviewing results, setting priorities and addressing risks that exceed municipal boundaries.

Risk assessment is carried out through the CLIMAAX process, with support from expert institutions such as municipalities, GOLEA/RWG, ARSO/experts, sectoral institutions, national authorities (ARSO, the Institute of Agriculture and Forestry Nova Gorica (KGZS-GO) and the University of Ljubljana, Biotechnical Faculty, P2R-GO partners). The implementation of measures depends on the type of risk: droughts are linked to agriculture, floods and landslides to municipalities, water management authorities and civil protection, and heat-related risks to health and social care institutions.

A formal regional acceptable risk level has not yet been defined. For high-impact risks such as floods, wildfires, landslides and extreme heat, the acceptable risk level is low, making prevention and protection measures essential. For seasonal droughts, a certain level of residual risk is still present, while adaptation focuses on preparedness, resilience and improved water management.

2.1.4 Application of principles

The principles of the CLIMAAX Framework were applied through the localisation of the heatwave and agricultural drought workflows for the Goriška region. The aim was to improve the local relevance, transparency and practical usability of the results.

Social justice, equity and inclusivity:

The analysis considered groups and areas that are disproportionately exposed to climate risks. In the heatwave workflow, attention was given to children under 5 years of age, elderly people aged 65+, and residents of more exposed urban or densely populated areas by using updated population data with WorldPop 2025 (Slovenia) in combination with the xclim heatwave workflow. In the agricultural drought workflow, the focus was on farmers, winegrowers and rural communities, who are directly affected by drought, heat and water availability.

Quality, rigour and transparency:

The assessment followed the CLIMAAX methodology and used recognised datasets, complemented with more localised data where available. For heatwaves, high resolution bias corrected local climate data (EURO-CORDEX) and updated population data (WORLDPOP 2025 Slovenia) were included. An ensemble of six climate models will be analysed, while selected individual models will partly also be assessed separately to better understand differences between model outputs and the range of possible future heatwave conditions. For agricultural drought, the analysis used climate indicators, agricultural data, crop vulnerability information, an expanded list of crops, and take into account data from the local irrigation network (MKGP, 2025 and internally from Municipality of Ajdovščina). Expert inputs from ARSO, KGZS-GO and the University of Ljubljana, Biotechnical Faculty, supported the preparation and/or interpretation of data and methodological choices. Assumptions, data sources and limitations were documented to ensure transparency and enable review by regional stakeholders.

Precautionary approach:

The precautionary principle was applied by assessing heatwave and agricultural drought risks even where data gaps and uncertainties remain. Both hazards are already relevant for the region and are expected to intensify under climate change. Therefore, the analysis used the best available data to identify potentially exposed areas, vulnerable groups and sectors where early adaptation action is needed. This supports preparedness, prevention and long-term resilience planning, particularly for high-impact risks affecting vulnerable people, agriculture, water management and local communities.

2.1.5 Stakeholder engagement

Stakeholder engagement in Phase 2 built on the participatory process established during Phase 1 and the preparation of the Regional Strategy for Climate Change Adaptation of the Goriška Development Region. While Phase 1 focused on setting up the process, mapping risks and identifying priorities, Phase 2 focused on validating results, improving the methodology and strengthening climate-risk ownership.

In **January 2026**, Phase 1 results were presented to the Regional Working Group for Climate Change Adaptation. Participants generally welcomed the more localised and evidence-based approach. Their feedback highlighted the need for clear, practical and spatially explicit outputs that can support municipal decision-making. They also emphasised the importance of improving local data, especially for agricultural drought, irrigation, crop vulnerability and the translation of technical results into understandable messages for decision-makers and local stakeholders.

On **6 May 2026**, a meeting with municipalities was held to present the impacts of heatwaves, discuss municipal plans and inform participants about ongoing MRA-GO activities.

Several technical and steering meetings were also organised with experts, including ARSO on high-resolution climate data, modelling and indicators, and the University of Ljubljana, Biotechnical Faculty, Department of Agronomy, on agricultural drought, crop vulnerability and irrigation-related data. Continuous communication with the Regional Working Group supported the validation of assumptions and alignment with regional adaptation processes.

Participants included GOLEA, regional development agencies, municipalities, ARSO, the University of Ljubljana, Biotechnical Faculty, and relevant sectoral stakeholders. Priority and vulnerable groups, such as elderly people, farmers, residents of flood- and landslide-prone areas and tourism-dependent communities, were considered mainly through municipal input, but they will be more actively involved in Phase 3.

Project goals and intermediate results were communicated through presentations, working meetings, technical discussions and written materials. The results were well received, as they provided a more localised and evidence-based understanding of climate risks. Feedback focused on the need for practical, understandable and locally relevant outputs for municipal decision-making.

CRA result will support integration into spatial and sectoral planning, alignment with the Regional Strategy for Climate Change Adaptation, connection with national priorities and funding opportunities, and shared responsibility.

The outcomes will be used by municipalities, regional institutions and sectoral stakeholders to identify priorities, prepare adaptation measures, support future projects and inform investment planning. The main difficulties were limited harmonised local data, differences between datasets, varying technical capacities and the challenge of translating technical results into practical messages for decision-makers.

The results of the CRA will be communicated through multiple channels:

- **Municipal and regional councils**, to ensure integration into spatial and sectoral planning.
- **Regional agencies and GOLEA**, to align measures with regional adaptation strategy.
- **National ministries**, to connect with national adaptation priorities and funding opportunities.
- **Stakeholders and the general public**, through workshops, online platforms, and awareness campaigns, emphasizing transparency and shared responsibility.

These future meetings and communication activities will support the use of results in adaptation planning, investment preparation and the implementation of measures under the Regional Strategy for Climate Change Adaptation and the P2R Goriška process.

2.2 Risk Exploration

Risk exploration began with a broad screening of climate-related hazards, exposure and vulnerabilities in the Goriška region. The assessment showed that the region is exposed to several natural hazards, including heatwaves, droughts, floods, wildfires, storms, bora wind and hail. Stakeholders at the 2024 workshop in Nova Gorica highlighted **heatwaves and droughts** as the most urgent and cross-cutting risks, especially due to the increasing likelihood of compound climate extremes.

2.2.1 Screen risks (selection of main hazards)

Heatwaves and agricultural drought remain the main hazards covered by the CRA, as they were already identified as the most urgent and cross-sectoral risks for the Goriška region in Phase 1. The Copernicus Atlas was reviewed as an additional screening source for the region. Its findings support the continued relevance of heat-related hazards and dry-condition indicators for the Goriška region, confirming that heatwaves and agricultural drought remain appropriate hazards.

The main development in Phase 2 is the refinement of the evidence base. In Phase 2, **heatwave** risk will be assessed using ARSO/EURO-CORDEX 1km x1 km bias-corrected data for tasmin, tasmax and tas, enabling better alignment with the ARSO heatwave definition for the Goriška climate zone. **Agricultural drought** risk will be refined using local 1x1 km precipitation and reference evapotranspiration data, supporting improved water balance calculations. Local crop coefficients and irrigation coverage data will be included, enabling more realistic agricultural drought and yield-loss calculations. The crop table will also be updated with grapevines, peach trees and grasslands, while the already included crops, such as corn and wheat, will be refined with relevant local data, including crop coefficients.

Exposure and vulnerability assessment will also be improved through updated WorldPop 2025 population data and use Landsat 8 land surface temperature data. These datasets will help identify areas where heat exposure, limited vegetation and vulnerable population groups overlap.

Remaining data needs include detailed health impact data, socio-economic vulnerability indicators, crop calendars, upgrade the irrigation data with real data from the field with soil moisture information.

2.2.2 Choose Scenario

For the Goriška region, the scenario selection focuses on the two priority hazards addressed in the refined Phase 2 assessment: heatwaves and agricultural drought. Future climate conditions will be assessed using regional climate projections RCP4.5 and RCP8.5. These scenarios were selected because they are relevant for adaptation planning and stress-testing regional resilience. Socio-economic developments will be considered mainly through locally relevant exposure and vulnerability data. Slovenia is facing with process of population ageing.

For heatwaves, the analysis will consider projected changes in daily maximum, minimum and mean temperatures, with particular attention to the frequency, duration and intensity of heatwave events. The use of high resolution ARSO/EURO-CORDEX 1 km bias-corrected data enables the assessment to better reflect local climatic conditions and the ARSO heatwave definition for the Goriška climate zone. Socio-economic developments for heatwaves, this will primarily include updated population distribution and vulnerable age groups based on WorldPop 2025 Slovenia.

The basic CLIMAAX agricultural drought workflow already calculates water deficit based on precipitation, reference evapotranspiration and crop water requirements. In Phase 2, this calculation will be localised by using more appropriate data on crops, growing seasons, crop coefficients and irrigation. The analysis will focus on potential impacts on locally relevant crops and localised parameters. This will allow the agriculture drought workflow to move beyond a generic drought indicator and better reflect the agricultural structure of the Goriška region. Socio-economic developments will be considered mainly through locally relevant exposure and vulnerability data. The crop table will be updated with local data (maize and wheat) and upgraded with three crops: grapevine, peaches/nectarines and grassland. All consideration crops will include localised data, it will include crop distribution, crop-specific parameters, growing seasons, irrigation-related information of selected crops, depending on data availability. Irrigation network data will be upgraded by using local irrigation data, based on draft grid data available for the Goriška region. This represents an important localisation step, as the vulnerability component of the agricultural drought workflow will better reflect the actual spatial distribution of irrigated and non-irrigated agricultural areas.

Future climate conditions and socio-economic data will be combined by overlaying hazard indicators with exposure and vulnerability layers. In the heatwave workflow, projected heatwave hazard will be combined with updated population exposure. In the agricultural drought workflow, projected water deficit will be combined with crop-specific exposure and vulnerability parameters to estimate potential impacts on selected crops.

The analysis will consider medium- and long-term horizons in line with the availability of local **bias corrected** climate projection data. For **heatwaves**, 30-year climate periods such as **2011–2040,**

2041–2070 and 2071–2099 may be used to ensure consistency with EURO-CORDEX and CLIMAAX approaches. Historical data will be based on years **1981-2010.**

For **agricultural drought**, the analysis may focus more specifically on growing seasons and selected future horizons, because drought risk is strongly linked to crop calendars, water demand and irrigation needs. We followed the basic settings and recommendations for agricultural drought. For vulnerability and exposure, we used **RCP4.5 and RCP8.5** and choose the period **2046–2050 and 2066-2070**.

2.3 Regionalized Risk Analysis

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

Table 2-1 Data overview workflow #1

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Xclim (custom indices: Tmax, Tmin, thresholds Tas, 1981–2099; 1x1km EURO-CORDEX bias correction RCP4.5 & RCP8.5 (ARSO), GCM-RCM: ensamble	*Population age structure (≤5, ≥65; WorldPop 2025 Slovenia)*	*Population density & distribution (WorldPop 2025, Slovenia)*	*Heatwave frequency & duration trends;* *Refined local hazard indicators*
	Vulnerable Population Density dataset from WorldPop (Vulnerable groups: elderly>65; children <5), (*WorldPop 2025 Slovenia)*	*Population density & distribution (WorldPop); Land Surface Temperature (Landsat-8 / RSLab)*	*Heatwave occurrence from 1986–2085;* *Hotspot maps;* *Projected risk to vulnerable groups*

2.3.1.1 Hazard assessment

Not all required input data were available at a compatible spatial resolution; consequently, the EuroHEAT workflow could not be reliably applied and was not pursued further in Phase 2.

Therefore, in Phase 2, the heatwave workflow will be further localised using the Xclim/custom hazard workflow, where temperature and duration thresholds can be adjusted to reflect the ARSO definition (Heatwave) for the Goriška climate zone and to use thresholds based on Tmin and Tmax.

Xclim – Custom Hazard Assessment

The second workflow used in our study applied the Xclim Python package to conduct a tailored hazard analysis based on EURO-CORDEX climate projections. This approach allowed for the creation of custom heatwave indices aligned with Goriška climatic and public health needs.

The xclim approach was applied in Phase 1 as a complementary CLIMAAX method for assessing heatwave hazard in the Goriška region. It enabled a more tailored analysis than the standard EuroHEAT approach, as heatwave indicators were calculated directly from EURO-CORDEX climate variables and could be adjusted to locally relevant thresholds. We prepared hazard assessment based on daily mean temperature (heatwaves index) and another based on daily minimum and maximum temperature, to calculate heatwave frequency and heatwave total length.

The heatwave index is based on daily mean temperature value, where temperature limit is regionalised, based on spatio-temporal analysis of Slovenian temperature time series. In Phase 1, Heatwaves were defined according to the Slovenian Environment Agency (ARSO) definition as periods of at least three consecutive days during which the daily mean air temperature exceeds the climate-type-specific threshold. The Goriška region extends across two relevant temperature regions (*Kozjek in sod. (2016), Figure in supporting material*), so in phase 2, two thresholds are applicable: 25 °C for the ameliorated Mediterranean climate type (temperature region), covering the lower part of region/Vipava Valley area (see Nova Gorica), and 22 °C for the moderate climate of hilly areas, covering the higher and more mountainous parts of the region (see city Bovec). Bovec was selected as an example of a northern, higher-altitude area compared with Nova Gorica. Our focus was on south part of region, where we have biggest cities and more concentrated population (for example city Nova Gorica). These thresholds are used by ARSO for heatwave monitoring and are based on the upper tail of daily mean temperature distributions, approximately corresponding to the 96th percentile for 2006–2015 or the 97th percentile for 1986–2015. The definition of a heatwave is based on the daily mean air temperature because it provides a simple indicator that incorporates the effects of daytime solar radiation, air humidity and wind—key meteorological variables influencing the human energy balance. Using only the daily maximum temperature is less representative, as high humidity and limited night-time cooling may result in a comparable heat load even when the maximum temperature is lower (Ključevšek in sod, 2017).

In Phase 2, the xclim approach will be further refined using higher-resolution ARSO/EURO-CORDEX 1x1 km bias-corrected temperature data (Tmax, Tmin, Tas). This will allow heatwave frequency, duration and intensity to be assessed with improved spatial detail and better alignment with the ARSO heatwave definition. Compared to the 12 km EURO-CORDEX data used in Phase 1, the 1 km bias-corrected data will provide a more locally representative basis for analysing heatwave hazard in the Goriška region. In phase 1 we used model MPI-M-MPI-ESM-LR_CLMcom-CCLM4-8-17, but a model ensemble is preferable because it reduces the influence of biases in individual models and provides a more robust estimate of future heatwave frequency and related uncertainty. In our case we use the **ensemble,** years 1981-2099, build up from six follow global and reginal models combinations: CNRM-CERFACS-CNRM-CM5_CLMcom-CCLM4-8-17, ICHEC-EC-EARTH_DMI-HIRHAM5,IPSL-IPSL-CM5A-MR_IPSL-INERIS-WRF331F, MOHC-HadGEM2-ES_KNMI-RACMO22E, MPI-M-MPI-ESM-LR_CLMcom-CCLM4-8-17 and MPI-M-MPI-ESM-LR_SMHI-RCA4.

The main advantage of the xclim approach is its flexibility, as it allows the selection of temperature thresholds, climate variables, scenarios and time periods. However, it also requires more methodological choices and careful data preparation. In Phase 2, xclim was therefore serve as the main basis for localising the heatwave hazard assessment, while the exposure component will be updated with WorldPop 2025 Slovenia population data.

Overall, the xclim approach provides the most suitable basis for the Phase 2 localisation of the heatwave workflow, as it combines climate scenario analysis with the possibility of using local thresholds and higher-resolution climate data. For the temperature thresholds, the lower threshold was set at **20 °C or above**, corresponding to the criterion for a tropical night, when the daily minimum temperature does not fall below 20 °C. The upper threshold was set at **30 °C or above**, corresponding to the criterion for a hot day, when the daily maximum temperature reaches or exceeds 30 °C (or 35 °C which represent threshold for very hot day). Both thresholds are based on the standard climate indicators used by the Slovenian Environment Agency (ARSO, 2020).

The XCLIM results of model ensemble for the Goriška region up to 2099 (presented on Figure 2 and 3) show a consistent increase in heatwave index. Additional figures for heatwave frequency and heatwave total length are in presented in supporting material for Nova Gorica and Bovec places. We choose two places because national definition is depending also on Temperature regions. Heatwave frequency is projected to rise after 2030, with a stronger increase under RCP8.5. The heatwave index highlights a sharp growth in the number of days within heatwave conditions, with values exceeding 70 days per year by late-century in the pessimistic scenario. Similarly, the total number of heatwave days indicates longer and more persistent events, particularly from 2035 onward. Although the exact values depend on the chosen definition, the overall trend is clear (in both phases): heatwaves will become more frequent, longer, and more severe, significantly raising risks for health, agriculture, infrastructure, and ecosystems in the region. Finally, it appears that despite some variations, the results from both hazard assessments generally follow the same trend if we compare the same model.

Here we used ensemble of 6 GCM-RCM models for both cities (shown below), where similar analyses conclusion was built up (as consequence of the definition based on temperature regions).It is possible also to use each GCM-RCM model separately, but because of transparency (etc.) we used ensemble. For city Nova Gorica, the results indicate an increase of heatwaves under both climate scenarios (figure bellow and in supplementary material), with a more pronounced increase under RCP8.5 than under RCP4.5. When the hot-day threshold of Tmax ≥ 30 °C is applied, a higher number of heatwave events and a longer total duration are identified, whereas the stricter very-hot-day threshold of Tmax ≥ 35 °C captures fewer but more intense episodes of extreme heat. The difference between the two scenarios is particularly pronounced for the very-hot-day threshold, as RCP8.5 projects a substantially greater future increase in the frequency and duration of the most intense heat events. In city Bovec we consider different temperature region as in Nova Gorica for heatwaves index, so consequently we used threshold of daily mean temperature 22 degrees or above (instead of 25 degrees as in Nova Gorica) for three days. As it is shown in Figure 3 the results indicate an increase of heatwaves under both climate scenarios (figure bellow and in supplementary material), with a more pronounced increase under RCP8.5 than under RCP4.5. When the hot-day threshold of Tmax ≥ 30 °C and Tmin ≥ 20 °C (tropical night) are applied, the frequency and duration of heatwaves appear after 2080 in RCP 8.5.

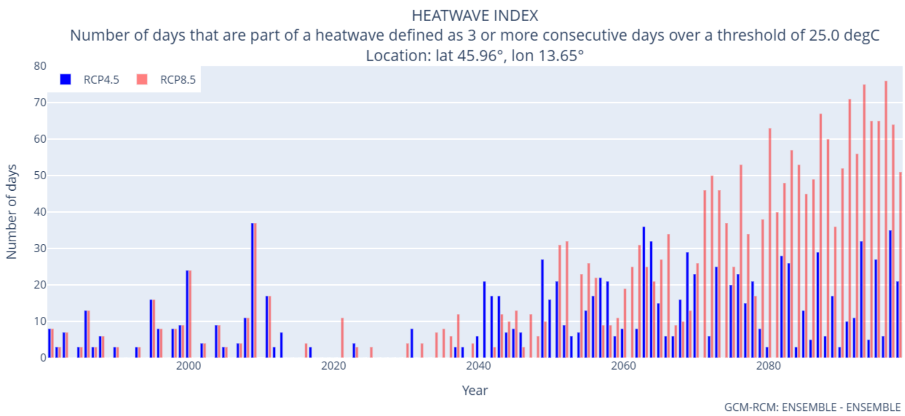

Figure 2-2 Heatwave index of the selected location Nova Gorica city centre – South part of the region (lower area).

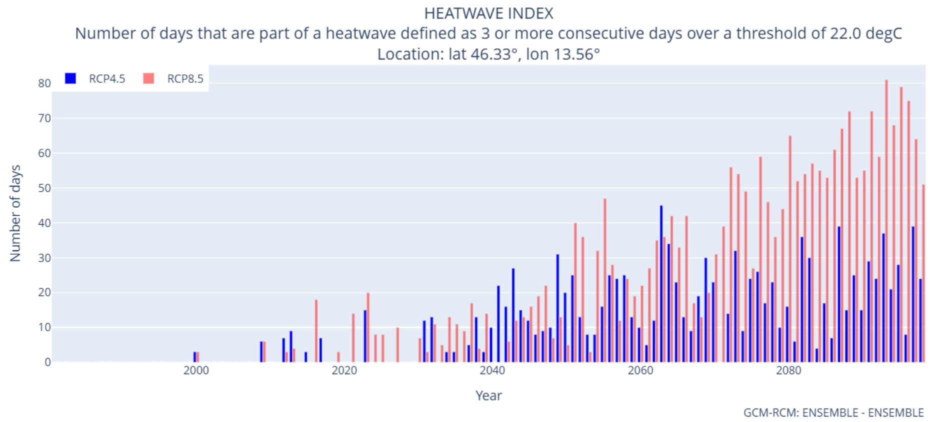

Figure 2-3 Heatwave index of the selected location Bovec city centre - North part of region (hilly area).

2.3.1.2 Risk assessment

<u>Risk assessment for heatwaves based on satellite-derived data</u>

This procedure was developed to assess heatwave hazards at fine spatial resolution by integrating satellite-derived Land Surface Temperature (LST) data with layers representing vulnerable populations. The analysis focused on Nova Gorica, a densely populated and heat-exposed city in Goriška region (figure in supporting material). Unlike climate projections, this method relies on observed, high-resolution thermal data, offering actionable insights for local planning.

LST data were obtained from Landsat 8 via the RSLab Portal (Parastatidis et al., 2017). These surface temperatures were then classified into five major categories—Very Low (<25°C), Low (25–35°C), Medium (35–45°C), High (45–55°C), and Very High (>55°C)—and further refined into 10 sub-classes to better capture urban heat hotspots (figure in supporting material).

In parallel, in phase 2, high-resolution population data was updating from WorldPop 2025 (2025, Slovenia) were used to identify vulnerable groups, focusing on male and female populations aged 5, 65, 70, 75, and 80. The data, representing the year 2025, were processed and classified into 10 vulnerability categories using the same classification method to ensure compatibility and sensitivity in urban settings. In Goriška region, people aged 65 and over represent approximately 25% (SURS, 2025). The oldest age groups bear the greatest burden of heat-related mortality (Ballester, J. et al). The spatially unconstrained population data used previously distribute the population across all land grid cells, including areas that are likely uninhabited. In this 2nd phase, we used unconstrained data to ensure comparability with Phase 1, as well as spatially constrained population data, which allocate the population only to built-up or inhabited areas and therefore provide a more accurate representation of the actual spatial distribution and concentration of the population. A comparison of the two approaches also shows that the constrained method produces a more spatially precise and clearly concentrated representation of populated areas, whereas the unconstrained method results in a more diffuse distribution of population across the landscape.

These two layers—thermal exposure and demographic vulnerability—were then merged into a 10×10 spatial risk matrix to generate a composite heat risk index as in Phase 1. This index highlighted areas where high surface temperatures and vulnerable populations intersect, revealing urban heat risk hotspots (figure in supporting material).

The results were presented in an interactive map (Figure 2-4), enabling stakeholders to easily visualize heat exposure and spatial vulnerability. Although the workflow does not include future projections, it provides a high-resolution baseline that complements model-based assessments by identifying areas most exposed to heat and overlapping them with zones of high density of vulnerable age groups. This satellite-based approach supports the identification of priority intervention areas and informs local adaptation measures, such as cooling centres, green infrastructure, and urban planning.

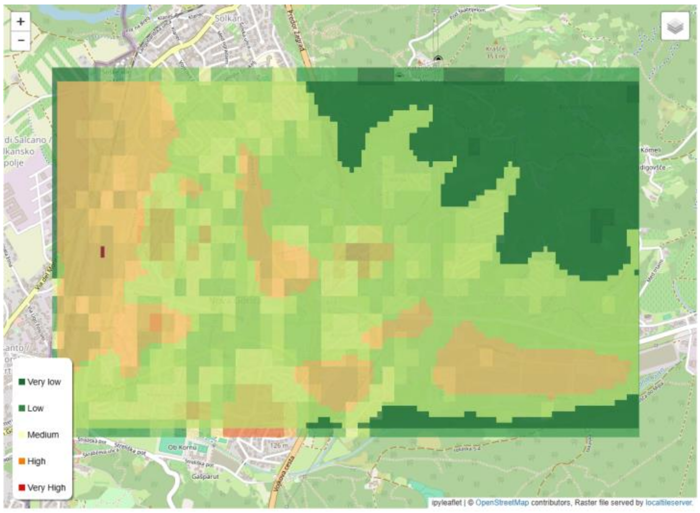

Figure 2-4 Risk data on the interactive map for Nova Gorica with constrain data

Vulnerability, shown in orange and red (Figure above), is concentrated mainly in the western and south-western parts of Nova Gorica, particularly along the border with Gorizia and in densely built-up urban areas. Individual areas of high vulnerability also occur in the north-western part towards Solkan and in several smaller parts of the city centre. Overall, high and very high vulnerability is most strongly associated with railway, commercial, industrial and parking areas, as well as with dense urban development. The central school complex and sports park are predominantly located within areas of medium vulnerability. As the raster cells are relatively large, individual buildings may lie only partly within an orange or red zone.

<u>Risk assessment for heatwaves based on climate projections</u>

The results of the risk workflow help us identify the places that are the most exposed to the effects of heat in combination with the map of areas with high density of vulnerable groups of population (based on age). Risk Analysis aligns with the CLIMAAX structure—combining **hazard**, **exposure**, and **vulnerability** data to produce actionable risk outputs (Risk = Hazard × Exposure × Vulnerability).

Phase 1 provided the methodological basis for the heatwave risk assessment, including the use of EUROHEAT projections, spatial analysis within the Goriška boundaries, age-based vulnerability data, and the combination of hazard and vulnerability layers through a 10x10 risk matrix. These elements were retained as the foundation for further refinement and localization in Phase 2.

The workflow follows a stepwise scheme: hazard quantification (via EuroHEAT data), integration with exposure (updated population distribution based on WorldPop 2025 data) and vulnerability (demographic sensitivity via updated WorldPop data), and final risk visualizations. This process assesses future heatwave risk in Goriška by integrating EUROHEAT hazard projections with demographic vulnerability data through a spatially explicit, matrix-based risk model.

The resulting maps visualize relative change in heatwave occurrence to vulnerable population and the spatial distribution of projected risk (Figure below). These outputs offer critical insights for long-term adaptation planning, particularly in older urban areas, and support localized decision-making for infrastructure, public health interventions, and early warning systems. For the period 2016–2045, very low values prevail, while Phase 2 shows somewhat more pronounced areas of low risk in the central and southern parts of the region, compared with the very low values identified in Phase 1. The period 2046–2075 is characterized by an increase towards low and medium risk levels, with a locally higher value in the south-western part of the region. The differences may result from the use of different temperature thresholds.

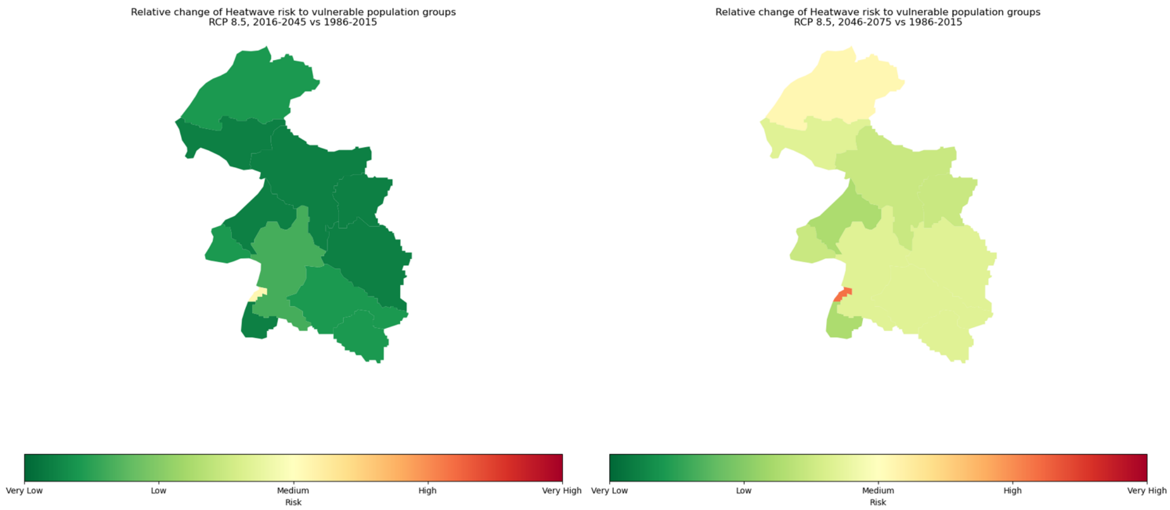

Figure 2-5 The picture above shows the potential projected increase of the heatwave risk for RCP 8.5 to vulnerable population groups for Goriška region. This result is based on the combination of the projected magnitude of change in the heatwave occurrence with the distribution of the vulnerable groups of the population.

2.3.2 Hazard #2 – Agriculture drought - finetuning to local context

Drought hazard and risk assessments were conducted using the Agricultural Drought workflow. **Agricultural drought** is a medium-term phenomenon, characterized by reduced soil moisture content and is caused by a prolonged period of meteorological drought. The lack of soil moisture can have a significant impact on crop growth. Statistical indices, such as the Palmer Drought Severity Index, help assess agricultural drought conditions.

The assessment covered six crop groups: maize, wheat, barley, grapevine, peaches and nectarines, and grassland. Separate model variants were applied for two maize growing calendars and three grassland cutting periods.

The definition of the growing season was an important part of the local adaptation of the workflow. Local research indicates that maize sowing dates in the region may vary considerably and can influence drought sensitivity. Earlier sowing may help rainfed crops make better use of spring soil moisture before peak summer heat. Other practices, including green windbreaks, may also improve yields under dry conditions, while a change in tillage method alone does not necessarily increase plant water availability.

Table 2-2 Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
ARSO/EURO CORDEX RCP4.5 & RCP8.5 with bias correction (precipitation flux, max/min/daily mean T and relative evapotranspiration data), used **mpi_m_mpi_esm_lr** as the GCM and **smhi_rca4** as the RCM and option to used ensemble of 6 models	Crop selection (Climate zones) – vulnerable crops (important crops for the region), distribution of fully irrigated cropland Updated and localized crop table for maize, wheat, barley, peaches and nectarine, grasslands and grapevine (grapes) crops	Irrigation availability from GAEZ v5 (percentage of cropland in each grid-cell equipped with irrigation systems) at 11 km res. from 2015 National irrigation grid - MKGP (2026 – rewieved and harmonized) in .shp file Updated national irrigation grid with planned irrigation grid in municipality of Ajdovščina and municipality of Vipava in .shp file (2026)	Maps of agricultural drought risk zones, Revenue losses

2.3.2.1 Hazard assessment

The Goriška region is a diverse landscape, and therefore the main agricultural crops differ between the northern and southern parts of the region. The northern part is more mountainous, with grasslands and livestock farming playing a more important role, while the southern part of the region, especially the Vipava Valley and Brda, is more strongly oriented towards agriculture, fruit production and viticulture. Vineyards comprise 89.93ha (12.9%) and present the largest single category. Grasslands represent 83.20ha (11.9%), winter barley represents 79.82ha (11.5%) and maize for grain accounts for 79.28ha (11.4%). The remainder of the land is spread across a wide array of crops including potatoes, vegetables, pears, peach, other fruit crops, and winter wheat, together occupying 24% of irrigated area demonstrating high fragmentation in land use.

The region is increasingly exposed to more frequent and prolonged summer droughts, accompanied by declining precipitation and higher evapotranspiration. Past droughts, particularly in 2003, 2012, 2017 and 2022, caused significant agricultural damage, reduced yields and put pressure on local water resources. Farmers, winegrowers, fruit growers, livestock breeders and rural communities dependent on local springs and smaller water supply systems are among the most vulnerable groups.

The crop table in the CLIMAAX model was built up and upgrade to better reflect locally relevant agricultural production in the Goriška region. The selected crops include **grapevine/vineyards (grapes) and peach trees (peaches and nectarines) as characteristic permanent crops (non staple), maize, barley and wheat as representative arable/cereal crops (already presented in phase 1), and grasslands (grasses and fodder crops) as agricultural land-use category.** This selection is supported by official agricultural land-use records and local agricultural analyses, which identify permanent grasslands, vineyards, maize, cereals and fruit production as relevant components of the regional agricultural landscape. Local studies for Nova Gorica, Renče–Vogrsko and the wider Vipava Valley confirm the strong presence of grasslands, vineyards and maize, while peach trees are included as a locally characteristic fruit crop and wheat as a representative cereal crop.

Grapevine, or grapes, is one of the most characteristic and economically important crops in the Goriška region, especially in wine-growing areas such as Goriška Brda and the Vipava Valley.

Vineyards strongly shape agricultural production, the cultural landscape and local value chains. In the assessment, grapevine can be considered both as the crop itself and through grapes as the final product, since drought affects vine development as well as grape quantity and quality. Although grapevine has some capacity to withstand shorter dry periods due to its deeper root system, prolonged drought can reduce shoot growth, berry development, yield and grape quality, especially during flowering, berry growth and ripening. This is particularly relevant for Goriška, where rising summer temperatures and more frequent dry periods may increase drought risk and irrigation needs in vineyard areas.

Peaches and nectarines are also important fruit crops in the Goriška region, particularly in areas with favourable microclimatic conditions. They contribute to local agricultural production and regional identity. In the assessment, they are treated as perennial fruit crops, where drought affects tree growth, fruit development, fruit size and quality. Peaches and nectarines have high water demand during fruit development and ripening and are highly sensitive to water deficit. Drought stress can lead to smaller fruit, lower quality, premature fruit drop and reduced yields, making irrigation planning especially important under more frequent summer drought conditions.

Grasslands, including grasses and fodder crops, are important for fodder production, livestock farming, permanent grassland maintenance and landscape stability in the Goriška region. In the assessment, drought mainly affects biomass production, regrowth after mowing, fodder quality and the number of possible cuts during the season. Although grasslands can use soil water relatively effectively, prolonged drought can reduce growth, sward density and fodder yield. This is particularly important in spring and summer, when most annual biomass is produced and livestock systems depend strongly on stable fodder availability.

We decided to update/establish new localized crop table for maize, wheat, barley, peaches and nectarines, grasslands and grapes (grapvine) crops. To ensure the model accurately reflects local conditions, the phenological development stages and growing seasons were calibrated for the local conditions integrating local agronomical data from KGZS NG (Poženel, 2026), Brence et al. (2021), Černe (2020), and adjusted for local grassland systems and recommendations (Valenčic, 2020). Somewhere we include more options of crop with different start and end seasons where it was relevant.

The input parameters for the CLIMAX model were synthesized from standardized FAO irrigation and drainage guidelines, supplemented by regionally specific agricultural data (FAO, 2026), UNESCO-IHE (2004), Appendix VI – 7, Sub-continental temperate and continental temperate.

We used two 5 years long time periods from 2046 - 2050 (mid-century) and 2066-2070 (end-century) for RCP4.5 and RCP 8.5. Mpi_m_mpi_esm_lr as the GCM and smhi_rca4 as the RCM was used and build up also an option to run ensemble of 6 models as well.

In hazard assessment, the impact of precipitation deficits on yield loss for all six crops: maize, barley, wheat, peaches, grapevine and grasslands which are important crops cultivated in the region. Grassland is represented by three cutting periods, while maize includes two variants with growing seasons from day 100 to 300 (1) and from day 105 to 286 (2). We used two models for the hazard assessment: one for **crops ("staple crops")** and one for **non-staple crops**, namely grapes, peaches, and nectarines, consequently, also risk assessment was adopted. Grapevine, grapes and peaches and nectarines were linked to the SPAM category Temperate Fruit (temf). Grassland is not explicitly represented in the SPAM crop classification and was therefore treated separately; where a SPAM category was technically required, Rest of Crops (rest) was used as a proxy. All other crops were linked to proper SPAM classification.

Projected yield losses vary by crop, period and location, with the Vipava Valley (South part of region) generally being the most exposed area. Under RCP4.5, maize losses reach up to approximately 35% in 2046–2050 and decrease by about 10–15 percentage points in 2066–2070. Grassland losses increase with later mowing/cutting, with Grassland Cut 3 showing losses of approximately 4–36% in 2046–2050, compared with 4–15% in 2066–2070. In contrast, wheat and barley losses increase by approximately 2–6 percentage points towards the late-century period. The results also show that RCP8.5 does not necessarily produce higher losses in every five-year period, as outcomes depend on interannual variability, precipitation distribution and local conditions. Figures are in the supporting material to CRA and present maize, wheat, grasslands 1-3 (three distinct mowing periods – three cutting periods per year) and barley yield loss due to precipitation deficit in the region between period 2046-2050 (mid-century) and 2066-2070 (end century) under the RCP4.5 and RCP8.5 scenarios.

Under RCP8.5, the highest projected yield losses in both 2046–2050 and 2066–2070 are concentrated in the southern part of the region, particularly in the Vipava Valley, while losses generally decrease towards the north-east. For Maize 1, precipitation-deficit-related yield losses are estimated at approximately 20–25% in the most exposed locations and around 15% across most of the remaining region. Maize 2 shows a broadly similar spatial pattern.

Projected losses for wheat and barley are lower, reaching approximately 7%. For grassland, losses in the south-western part of the region increase with each successive cutting period in 2046–2050, ranging from approximately 15% to 30%. In 2066–2070, the highest projected loss occurs during the second cutting period, reaching up to 24%. Compared with the first period, losses associated with the first and third cuttings of grass decrease by approximately 10 percent.

At this point we also need to point out that Observed yield reductions cannot always be attributed solely to drought, as other factors, particularly frost in fruit production, may also have a significant influence.

For non-staple crops (grapes, grapevine, peaches and nectarines), the results indicate yield losses of up to 36% for the 2046–2050 period, particularly for peaches under RCP4.5. Under RCP8.5, the projected losses are, on average, approximately 10% lower than under RCP4.5. Yield losses for grapes/grapevines are projected to be approximately 9–12% during the 2066–2070 period of RCP8.5, primarily in the south and southwest of the region; for peaches and nectarines, losses could reach up to 25% (these are highly dependent on irrigation).

2.3.2.2 Risk assessment

The risk assessment analysis estimates potential revenue losses for selected crops in the region due to irrigation deficits under the RCP 8.5 emission scenario for 2046–2050 and 2066-2070. These revenue losses represent the lost opportunity cost (in thousands of euros) if crops are cultivated without irrigation. The Agricultural Drought Risk Assessment (CLIMAAX handbook, DROUGHTS repository) evaluates this by combining production and revenue data with yield loss projections, producing a “lost opportunity” map that highlights vulnerable areas depending on existing irrigation systems and also marked the irrigation systems planned in near future. The method is based on 2010 data, assumes a linear relationship between yield and revenue, and may be less accurate for high-value crops. In general, farms with minimal irrigation infrastructure, and water-dependent crops are expected to face the greatest risk of reduced productivity.

Under RCP8.5 in 2066–2070, the highest potential losses are generally projected in the southern and western parts of the region for maize (approx. 100.000 EUR), wheat (approx. 15.000 EUR), grassland 1 (less than 1.000 EUR), grassland 2 (approx. 12.000 EUR), grassland 3 (approx. 7.000 EUR)), and barley (approx. up to 40.000 EUR) under RCP8.5 (2066-2070) (figures also in supporting material). Farms with limited irrigation infrastructure and crops with higher water requirements are expected to face the greatest economic risk.

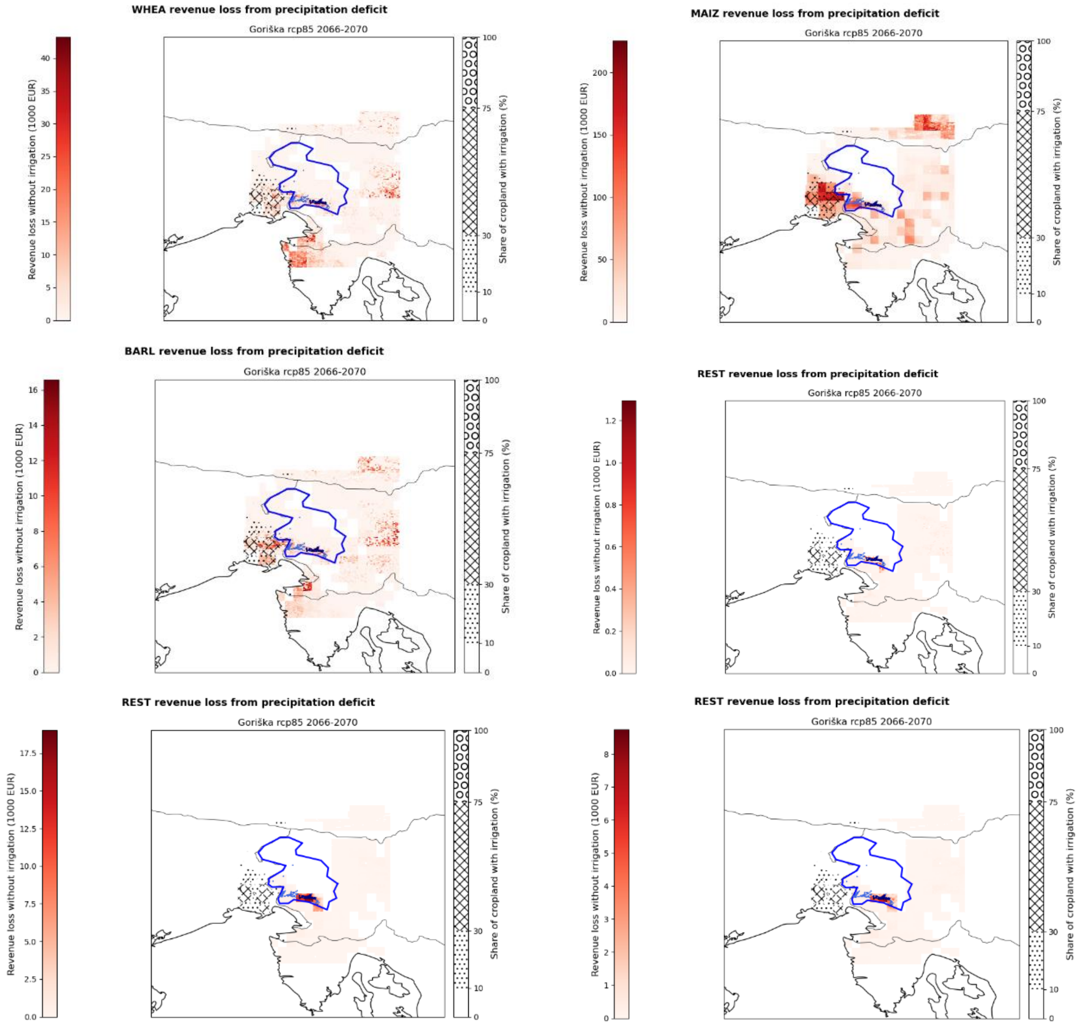

Figure 2-6 Revenue losses for the RCP8.5 scenario 2066-2070 in Goriška Region for concerning staple crops (in the following order: wheat, corn, barley, grassland 1, grassland 2, and grassland 3)

Under RCP8.5 in 2066–2070, the highest potential losses are generally projected in the southern and western parts of the region for grapes (approx. 25.000 EUR), peaches and nectarines (approx. 200.000 EUR) and grapevine with approx. 50.000 EUR) (figures also in supporting material). As irrigation is essential for successful peach production, the lack of irrigation infrastructure is directly reflected in higher expected revenue losses.

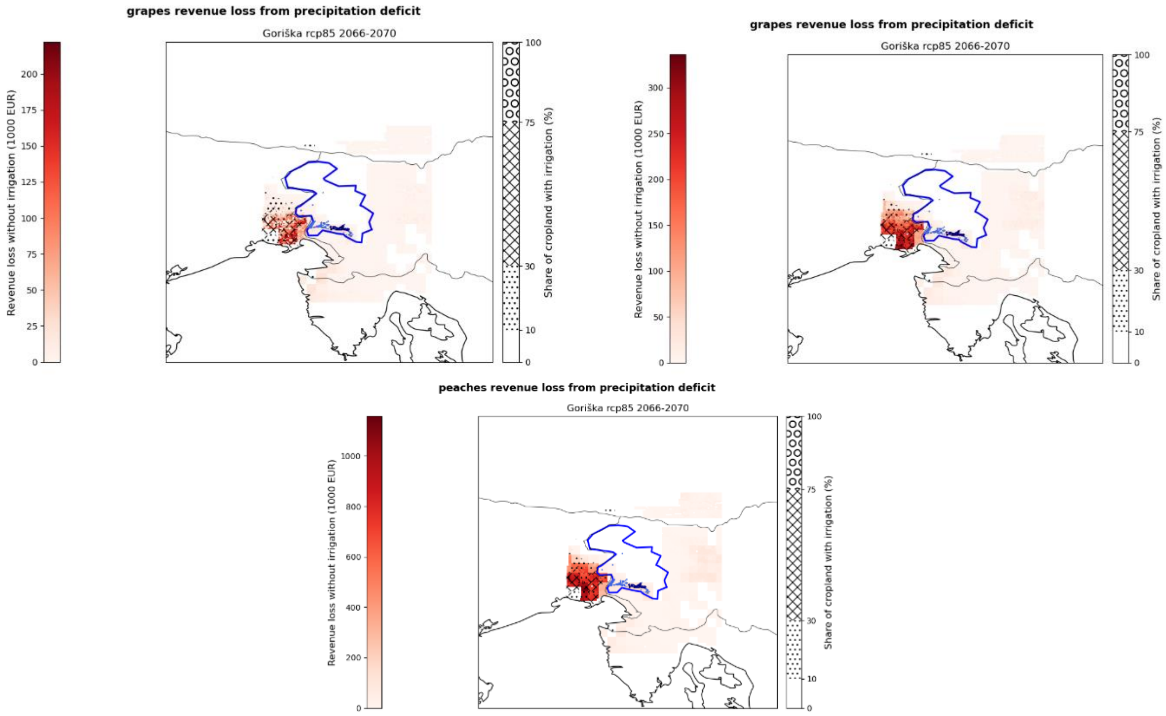

Figure 2-7 Revenue losses for the RCP8.5 scenario 2066-2070 in Goriška Region for concerning non staple crops (grapes on left, grapevine on right, peaches and nectarine in the middle)

The spatial comparison shows that the planned irrigation system in the municipalities of Ajdovščina and Vipava is primarily located in areas with the highest sensitivity to agricultural drought in the absence of irrigation. The light blue polygons represent existing irrigation systems, while the dark blue polygons indicate planned irrigation systems. Existing irrigation systems in the Goriška region are also predominantly located in areas identified as having higher drought vulnerability.

2.3.3 Additional assessments based on local models and data

The additional work mainly focused on integrating locally relevant and spatially more detailed datasets directly into the two selected CLIMAAX workflows: heatwaves and agricultural drought. For the heatwave assessment, the analysis was improved by using ARSO/EURO-CORDEX 1 km bias-corrected temperature data (Tmin, Tmax and Tas, as the national heatwave definition is based on Tas), by aligning the assessment with the ARSO heatwave definition, and by including temperature regions, which enable a more appropriate application of the relevant temperature thresholds for the Goriška area. In addition, updated WorldPop 2025 data for vulnerable population groups were used, improving the spatial understanding of population exposure to heatwaves.

For agricultural drought, the workflow was upgraded by using bias-corrected high-resolution local data (1 × 1 km) on precipitation and reference evapotranspiration (instead of relative humidity, wind speed and solar downward radiation at 12 km spatial resolution and daily temporal resolution) as input data for the model, together with locally relevant crop parameters, an updated crop selection and improved irrigation data. The existing national irrigation network was included in the analysis as a spatial layer (.shp), together with the planned irrigation network in the municipalities of Ajdovščina and Vipava as a spatial representation of irrigation. This planned irrigation infrastructure was considered as an already foreseen response to climate change, particularly to increasingly frequent and intense drought conditions.

These additions did not represent a third standalone assessment, but they significantly improved the local relevance of the two main risk analyses. Remaining needs include further validation of irrigation data, more detailed socio-economic vulnerability indicators and interpretation of the results together with local stakeholders in Phase 3.

2.4 Key Risk Assessment Findings

The preliminary assessment confirms that **heatwaves and agricultural droughts** represent **severe and pressing climate risks for the Goriška region**. Both hazards have already produced substantial impacts and are projected to intensify under future climate scenarios, with consequences that span public health, agriculture, water management, forestry, and regional development.

The Key Risk Assessment was carried out in accordance with the CLIMAAX Risk Evaluation Protocol, which evaluates each selected risk according to current and future severity, urgency, resilience capacity and overall risk priority.

The assessment presented below considered a preliminary expert-based evaluation derived from the findings of Phase 1, the refined risk-analysis outputs produced in Phase 2, the wider regional adaptation process and stakeholder engagement. The proposed scores will require discussion and validation with municipalities, sectoral institutions, agricultural stakeholders and representatives of vulnerable groups during Phase 3.

The preliminary evaluation indicates the following:

Risk Workflow	Severity		Urgency	Capacity	Risk Priority
	C	F		Resilience/ CRM	
River flooding					
Coastal flooding					
Heavy rainfall					
Heatwaves	3	4	4	2	very high
Agricultural Drought	3	4	4	2	very high
Fire					
Snow					
Wind					

Severity	Urgency	Resilience Capacity	Risk Ranking
Critical	Immediate action needed	High	Very high
Substantial	More action needed	Substantial	High
Moderate	Watching brief	Medium	Moderate
Limited	No action needed	Low	Low

Figure 2-8 Key risk assessment Dashboard (evaluation dashboard)

2.4.1 Mode of engagement for participation

The stakeholder engagement process is described in Section 2.1.5. For risk evaluation, feedback from the Regional Working Group, municipalities and technical experts was used to support the interpretation of the Risk Analysis results.

The feedback confirmed heatwaves and agricultural drought as priority risks and highlighted the need for clear, locally relevant and spatially explicit outputs. Stakeholders also pointed to remaining data gaps, particularly regarding health impacts, socio-economic vulnerability, local crop and soil conditions, and irrigation efficiency.

The assessment presented below is therefore preliminary and will be further discussed and validated with municipalities, sectoral institutions and representatives of priority groups during Phase 3.

2.4.2 Gather output from Risk Analysis step

The risk evaluation uses the principal outputs generated in the Regionalized Risk Analysis described in Section 2.3. For heatwaves, the following outputs were taken forward:

- heatwave index, frequency and total heatwave length derived from the xclim assessment;
- comparison of the ensemble of six climate-model combinations and selected individual models;
- comparison of RCP4.5 and RCP8.5 for the selected future periods and representative locations;
- spatial risk maps combining projected changes in heatwave occurrence with WorldPop 2025 data for vulnerable population groups;
- Landsat 8-derived Land Surface Temperature results for Nova Gorica; and
- the satellite-based composite heat risk index and interactive map showing where elevated surface temperatures overlap with concentrations of vulnerable population groups.

The xclim outputs provide evidence on the projected development of the heatwave hazard, while the Landsat 8 analysis and composite index provide a high-resolution representation of current local heat-risk hotspots.

For agricultural drought, the evaluation uses:

- crop-specific water-deficit results;
- indicative crop-yield losses;
- estimated revenue losses where suitable data were available;
- spatial comparisons under RCP4.5 and RCP8.5 for the selected future periods; and
- the interpretation of drought exposure in relation to existing and planned irrigation networks.

These outputs were used jointly to assess the current and future severity of both risks, the urgency of action, the available resilience capacity and their overall priority for the Goriška region. Detailed descriptions of the datasets, calculations and methodological adjustments remain in Section 2.3.

2.4.3 Assess Severity

Severity was rated as limited, moderate, substantial or critical based on observed and projected impacts, exposure, affected sectors, potential cascading effects and stakeholder feedback.

The current severity of heatwaves was assessed as substantial. Heatwaves already affect public health, especially older people and young children, as well as agriculture, ecosystems, energy demand and urban areas. They may also increase ozone pollution, wildfire risk and pressure on health services. However, limited regional health-impact data do not justify a critical current rating. Future severity was assessed as critical, as projections indicate more frequent and longer heatwaves, particularly under RCP8.5. Expected impacts include increased heat-related mortality, ecosystem damage, higher electricity and water demand, reduced labour productivity and greater wildfire risk.

The current severity of agricultural drought was assessed as substantial. Recurring droughts already cause crop and fodder losses, economic damage and pressure on water resources, particularly affecting viticulture, fruit production, field crops and livestock farming. Future severity was assessed as critical due to projected increases in crop water deficits, irrigation demand, and potential yield and revenue losses. These impacts may reduce farm income, intensify competition for water and contribute to soil degradation and agricultural land abandonment. However, the results remain indicative, as local soil conditions, crop varieties, irrigation efficiency and adaptation measures are not fully represented.

Stakeholder feedback confirmed both risks as major regional priorities. Nevertheless, available data, technical knowledge and institutional capacity still vary between municipalities. Further validation with vulnerable groups and agricultural stakeholders is planned for Phase 3.

2.4.4 Assess Urgency

Urgency was assessed based on changes in severity, the timing and persistence of impacts, and stakeholder feedback.
Heatwaves – Immediate action needed: Heatwave severity is expected to increase from substantial to critical. Events already occur regularly and are projected to become more frequent and longer. As they can develop rapidly and cause immediate health impacts, particularly among vulnerable groups, adaptation measures should be strengthened without delay.
Agricultural drought – Immediate action needed: Agricultural drought severity is also expected to increase from substantial to critical. Although drought is a slow-onset hazard, its impact may persist across several seasons and affect agriculture, water availability and ecosystems. Immediate action is needed because improvements to irrigation, water management and agricultural practices require long planning and implementation periods.
Stakeholder and expert feedback confirmed the need for immediate and coordinated action for both risks.

2.4.5 Understand Resilience Capacity

The resilience capacity for both heatwaves and agricultural drought was assessed as **medium**. Existing capacities include ARSO forecasting and warning systems, municipal communication, SECAP measures, the Regional Climate Adaptation Strategy, technical expertise, and existing and planned irrigation infrastructure. However, capacities differ between municipalities, while gaps remain in funding, staff, local data, health preparedness, support for vulnerable groups, irrigation efficiency and water availability. The region therefore has a basis for managing both risks, but further investment, coordination and targeted adaptation measures are required.
Existing capacity (further in supported material) is also supported by the availability of daily irrigation recommendations and by planned investments in irrigation infrastructure, although their accessibility, uptake and long-term effectiveness vary across the region.

2.4.6 Decide on Risk Priority

Risk priority was assigned using the evaluation dashboard (Figure in chapter 2.4), which combines current and future severity, urgency and resilience capacity. Both heatwaves and agricultural drought were assessed as substantial at present and critical in the future, with immediate action needed and medium resilience capacity. Consequently, both risks were classified as **very high priority** and should be addressed as key priorities in Phase 3 and in regional adaptation planning.

2.5 Monitoring and Evaluation

The main lessons and findings from Phase 2 are summarised below:

- **Main learning:** Higher-resolution regional data and locally adapted parameters significantly improved the relevance of the CRA. For agricultural drought, the definition of the growing season and sowing dates proved particularly important, as these parameters can substantially influence modelled drought sensitivity. Local stakeholder and expert knowledge were therefore essential for adapting the model to regional conditions.
- **Main difficulties:** The greatest challenges were the integration of datasets with different spatial and temporal resolutions and the fragmented availability of information on crop

management, sowing dates, crop rotations and local agronomic practices, particularly for cereals and grasslands. This limited model parameterisation, calibration and validation.

- **Data still needed:** Further information is required on heat-related health impacts, socio-economic vulnerability, soil moisture, crop varieties, irrigation efficiency, local water availability and additional bias-corrected and localised climate data. More systematic and openly accessible regional or national data on crops and agricultural practices would also improve future assessments.
- **Interpretation of results:** Crop yields are influenced not only by drought and soil-moisture deficits but also by management practices and other hazards, including frost, particularly in fruit production. Some simulated crop responses may therefore require further investigation, and the results should be interpreted with caution.
- **Stakeholder role and feedback:** The Regional Working Group, municipalities, ARSO and agricultural experts supported the interpretation and localisation of the results. Local input on crop calendars, sowing dates and agricultural practices increased the practical relevance and credibility of the assessment.
- **Learning process:** Learning was supported through technical consultations, stakeholder meetings, comparison of model results and documentation of assumptions, uncertainties and methodological choices. Further validation with local stakeholders is planned in Phase 3.
- **Monitoring system:** A fully integrated regional monitoring system for heatwaves and agricultural drought is not yet in place. Existing data sources provide a basis, but indicators, responsibilities, data sources and review intervals should be further defined.
- **Communication of results:** Final outcomes will be communicated through maps, concise summaries, presentations and workshops with municipalities, sectoral institutions and priority groups. The results will also support the preparation of the Regional Adaptation Action Plan.
- **Use of resources:** Resources were used efficiently by focusing on the two priority risks and adapting established CLIMAAX workflows and official datasets. However, data harmonisation, local parameterisation and methodological adjustments required considerable additional work.
- **Overall impact:** The CRA improved the regional evidence base and institutional understanding of climate risks. Its wider impact on public awareness, investment and policy implementation will become clearer once the results are applied in Phase 3 and in regional adaptation planning.

2.6 Work plan Phase 3

The final phase will focus on translating the results of the refined climate risk assessment into practical adaptation options and improved risk management planning for the Goriška Region. It will build on the key findings from Phase 1 and Phase 2, particularly the priority risks related to heatwaves and agricultural drought.

The main activities will include reviewing the assessment results, engaging local stakeholders, discussing possible adaptation options and identifying the most relevant measures. Stakeholders, municipalities, decision-makers and regional experts will be involved to ensure that the proposed measures are realistic, locally relevant and aligned with regional needs.

For heatwaves, the work will focus on measures that reduce exposure and vulnerability, improve preparedness, support spatial planning and raise public awareness. For agricultural drought, the focus will be on water management, irrigation planning, crop resilience and support for the agricultural sector.

The phase 3 will provide a strategic basis for future adaptation planning and possible follow-up investments. The main output will be a contribution to local adaptation strategies and improved risk management plans, helping to transform the assessment findings into actionable adaptation measures for the Goriška Region.

3 Conclusions Phase 2- Climate risk assessment

Phase 2 substantially improved the climate risk assessment developed in Phase 1 by providing a more detailed and locally relevant analysis of heatwaves and agricultural drought in the Goriška region. The use of high-resolution ARSO/EURO-CORDEX climate data, updated population data with WorldPop 2025, locally adapted crop parameters and information on existing and planned irrigation systems increased the spatial accuracy and practical relevance of the results. The assessment therefore provides a stronger evidence base for regional and municipal adaptation planning.

For heatwaves, the application of the xclim methodology, based on a bias corrected ensemble of six climate-model combinations and selected individual models, enabled a more reliable assessment of future changes and model uncertainty. The results indicate that heatwaves will become more frequent, longer and more intense under both RCP4.5 and RCP8.5, with substantially greater changes under RCP8.5. The increase is expected to become more pronounced after 2030 and to intensify further during the second half of the century. The south-western part of the region is generally expected to experience higher heatwave risk, particularly where stronger changes in heatwave occurrence overlap with concentrations of vulnerable population groups, including older people and children under five. These changes may have consequences beyond direct heat exposure. Increasing heatwave frequency and duration may place additional pressure on public health services, water and electricity demand, agriculture, ecosystems, urban infrastructure and labour productivity. The analysis confirms that heatwaves are already a substantial regional risk and may become critical in the future. Immediate action is therefore required to strengthen heat-health preparedness, protect vulnerable groups, improve public communication and integrate heat risk into spatial and sectoral planning.

The agricultural drought assessment was improved by incorporating high-resolution precipitation and reference evapotranspiration data, locally adapted growing periods and crop coefficients, and existing and planned irrigation infrastructure. The analysis was extended beyond maize, wheat and barley to include grapevines and grapes, peaches and nectarines, and grasslands with different cutting periods. This provided a broader understanding of the potential effects of water deficits on crops that are important for the regional agricultural economy.

The highest projected yield losses are generally concentrated in the southern and south-western parts of the region, particularly in the Vipava Valley. Under RCP8.5, maize losses may reach approximately 20–25% in the most exposed areas, while projected losses for wheat and barley are generally lower. Grassland losses vary considerably between cutting periods and may reach approximately 30%. For permanent crops, losses may reach up to 36%, particularly for peaches. The results also indicate potentially significant revenue losses where irrigation is unavailable or insufficient, with peaches and nectarines showing particularly high economic exposure.

The agricultural drought results confirm the importance of irrigation and water management for maintaining agricultural production. The spatial overlap between planned irrigation systems in Ajdovščina and Vipava and areas identified as particularly drought-sensitive supports the relevance of these investments. However, infrastructure development should be accompanied by efficient water use, reliable water availability, improved agricultural practices and crop-specific adaptation measures. Agricultural drought is therefore assessed as a substantial current risk and a potentially critical future risk requiring immediate and coordinated action.

The assessment classified both heatwaves and agricultural drought as very high adaptation priorities. Regional resilience capacity was assessed as medium. Existing forecasting and warning systems, municipal communication channels, technical expertise, strategic documents, irrigation recommendations and existing or planned irrigation infrastructure provide an important foundation. Nevertheless, the capacity to manage climate risks differs considerably between municipalities due to differences in staffing, funding, technical knowledge, data availability, health preparedness and water-management capacity. Stronger regional coordination is therefore necessary to prevent unequal adaptation capacity across the 13 municipalities.

Several methodological and data-related challenges were addressed during Phase 2. These included the integration of datasets with different spatial and temporal resolutions, the adaptation of climate-risk workflows to regional conditions, the localisation of crop coefficients and calendars, and the use of stakeholder and expert knowledge to improve model assumptions. Cooperation with municipalities, regional development agencies, ARSO and agricultural experts strengthened the interpretation and practical relevance of the results.

Overall, Phase 2 confirms that heatwaves and agricultural drought already affect the Goriška region and are expected to intensify under future climate conditions. The results provide a clear basis for moving from risk assessment towards adaptation planning. Phase 3 should therefore focus on validating the results with regional stakeholders and translating them into realistic measures related to heat preparedness, protection of vulnerable groups, spatial planning, water and irrigation management, crop resilience and future adaptation investments.

Some limitations remain due to insufficient regional data on health impacts, socio-economic vulnerability, soil conditions, crop characteristics, farming practices, irrigation efficiency and future water availability. The agricultural model mainly assesses water-related stress and does not fully capture other yield-influencing factors; therefore, yield and revenue-loss estimates should be treated as indicative regional results.

A fully integrated regional monitoring system has not yet been established. Common indicators, responsibilities and review procedures still need to be defined, and further stakeholder validation is required.

4 Progress evaluation

Progress in Phase 2 is aligned with the Individual Follow-Up Plan, where this phase is defined as a **refined regional/local high-resolution analysis and risk assessment, including comparison of results** between Phase 1 and Phase 2.

In Phase 1, the CLIMAAX common methodology and supporting Toolbox were used to establish a baseline climate risk assessment for the Goriška Region. In Phase 2, this assessment was upgraded by using more locally relevant data, higher-resolution datasets, climate indicators and improved methodological approaches.

The main result of this phase is the preparation of **D2 – Refined regional/local multi-risk assessment**, including local data and comparison with the results of Phase 1. This marks the transition from a general climate risk assessment towards a more detailed and applicable evidence base for future adaptation planning.

The activities carried out directly support Phase 3 of the project, which will focus on stakeholder engagement, the identification of adaptation options and the preparation of relevant measures to reduce climate risks. The results of Phase 2 will therefore serve as a technical basis for discussions with local stakeholders, municipalities, decision-makers and other relevant regional actors.

Overall, Phase 2 represents an important transition from the initial application of the CLIMAAX methodology towards a more localised, high-resolution and practically applicable climate risk assessment for the Goriška Region.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
External experts selection: Successful selection of 1 external expert (consortium) through a transparent public procurement process (according to Slovenian public procurement legislation). Phase 1	Completed
Successfully applied 1 workflow for assessment using the supporting Toolbox. Phase 1.	Completed
Successfully applied 1 workflow for regional/local high-resolution analysis and risk assessment. Phase 2	Completed
Successfully applied 1 workflow for comparison of results between Phase 1 and Phase 2. Phase 2.	Completed
Dissemination activities: Completion of at least 5 publications and dissemination actions, including updates on our website. Phase 1, 2 and 3.	2 actions from Phase 1 2 dissemination actions from Phase 2: • FB post: https://www.facebook.com/share/p/18qkPUgA3z/ • Webpage post: https://www.prc.si/novice-in-dogodki/novice/druga-faza-projekta-climaax-nadgradnja-ocene-podnebnih-tveganj-za-gorisko-regijo

Key performance indicators	*Progress*
Media coverage: Securing at least 2 media publications featuring the project. Phase 2 and 3.	In progress

Table 4-2 Overview milestones

Milestones	*Progress*
M1: Test of the CLIMAAX supporting tool (D1). Phase 1.	Done in Phase 1
M2: Regional/local high-resolution analysis and risk assessment (D2) successfully applied. Phase 2.	Done
M3: Comparison of results between D1 and D2 done (D2). Phase 2.	Done
M4: Attend the CLIMAAX workshop held in Barcelona. Phase 2.	It was already done in Phase 1.

5 Supporting documentation

The additional documents and datasets have been uploaded to the Zenodo platform. The contents of the folder are as follows:

- Phase 2 Deliverable:
  - Main report
  - Supporting material – document includes charts, figures and dissemination outputs
- Workflows Outputs:
  - Heatwaves Workflow:
    - Hazard Assessment (XCLim)
    - Risk Assessment (climate projections and satellite derived data)
  - Droughts Workflow
    - Agricultural drought Workflow (Staple and non-staple)
    - Irrigation and crops

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