Deliverable Phase 1 – Climate risk assessment

Pernik Climate Risk Assessment for Action (PERNIKCLIMAACT)

Bulgaria, Pernik Municipality

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Document Information

Deliverable Title	Phase 1 – Climate risk assessment
Brief Description	This deliverable provides a climate multi-risk assessment for the municipality of Pernik, developed using the CLIMAAX framework's common methodology for multi-risk assessment – specifically the two workflows of urban heatwaves and extreme precipitation - and analyzing the resulting outputs.
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5.0	…		Final version to be submitted

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Abbreviations and acronyms

Abbreviation / acronym	Description
AR6	Assessment Report 6 from the IPCC
BAS	Bulgaria Academy of Science
CDS	Copernicus Climate Data Store
CoP	Community of Practice
CRA	Climate Risk Assessment
CRM	Climate Risk Management
DRMKC	Disaster Risk Management Knowledge Center
EEA	European Environmental Agency
IFP	Individual Follow-up Plan
IPCC	Intergovernmental Panel on Climate Change
NSI	National Statistical institute
NIMH	National Institute for Meteorology and Hydrology
NUTS	Nomenclature of Territorial Units for Statistics
RCP	Representative Concentration Pathways
PERNIKCLIMAACT	Pernik Climate Risk Assessment for Action

Executive summary

The current report titled “Deliverable Phase 1 – Climate Risk Assessment” under the “Pernik Climate Risk Assessment for Action (PERNIKCLIMAACT)” project outlines the application of the CLIMAAX climate risk assessment framework and toolbox by the municipality of Pernik. As part of this effort, two risk assessment workflows - for urabn heatwaves and extreme precipitation respectively, were successfully implemented using European-level datasets. This initial deliverable is designed to provide an overview of these key climate risks and to lay the groundwork for a more detailed assessment that will incorporate higher-resolution local data in the project’s second phase.

The report begins by presenting the scope of the CRA, detailing its objectives, contextual background, and the nature of stakeholder participation and risk ownership. In essence, the CRA aims to support evidence-based policymaking, inform strategic municipal documents on climate adaptation and risk management, help attract funding for local adaptation initiatives, and strengthen coordination of efforts at the regional level. While the municipality holds primary responsibility for managing these climate risks, it currently lacks the capacity, resources, and knowledge to fully address them. This gap has been a key driver for Pernik’s commitment to the CLIMAAX project, with the goal of empowering the municipality to implement effective risk mitigation and adaptation strategies thorugh data-based evidence.

The focal part of the document looks at the two prioritized climate risks, i.e. urban heatwaves and extreme precipitation, which were selected based on municipal observational knowledge and stakholder validation. The selected workflows were tailored to meet Pernik’s specific assessment needs, with the urban heatwaves risk analyzed using satellite-derived temperature data and the extreme precipitation worflow utilized with local thresholds. The assessments revealed a worsening trend for both risks. In the case of urban heatwaves the assessment highlighted zones where high surface temperatures intersect with areas densely populated by vulnerable groups—namely, children under 5 and elderly residents over 65. These findings provide clear guidance for directing adaptation efforts to the areas most at risk. The accompanying hazard assessment projected a significant increase in heatwave frequency under both RCP4.5 and RCP8.5 scenarios, reinforcing not only the growing severity of this hazard but also offering a timeline that helps structure the municipality’s adaptation planning. In respect to the risk of extreme precipitation, the analysis identified how critical impact thresholds will be affected under the RCP8.5 climate scenario under the pressure of changed magnitute and frequency of extreme precipitation events. The workflow plots that present this information under the form of a map in particular have enabled the municipality to link areas of higher vulnerability and exposure to prioritize in adaptation efforts.

In addition to the analysis of the two selected risks, the report includes early insights into project conclusions, monitoring and evaluation, as well as a progress review of Phase 1, and a work plan for the remainder of the project phases. The municipality evaluates this phase as highly enriching in terms of learning experience and produced outputs that already shed considerable light over the evolution of the risks of urban heatwaves and extreme precipitation. Phase 1 outputs and acquired technical and expert know-how are the staunch foundation for the next phase of the project, particularly in terms of refining the climate risk assessment with local data and building local ownership of future measures through stakeholder engagement.

1 Introduction

1.1 Background

Pernik municipality is a historically industrial and mining municipality, faced with complex climate-related challenges. It is among the most affected by the green transition due to its mining profile. Pernik deals with rising average annual temperature and heavy rainfall. Faced with complex climate challenges, we believe climate resilience requires a comprehensive approach based on strategic planning to optimize the impact of resources. The municipality is a member of the EU Mission: Adaptation to Climate Change and possesses a Municipal Climate Adaptation Strategy that will greatly benefit from a supplementing and upgrading climate risk assessment to be developed under CLIMAAX.

Pernik municipality is located in "South and South-Western Bulgaria" (NUTS1), “South-Western Planning Region” (NUTS2). It spans over an area of 484.2 sq. km, placing it among the medium-sized municipalities in the country, with population size of 81170 as of December 2024 and 24 settlements, including 2 cities - Pernik and Batanovtsi. The Municipality is located in the temperate continental climate zone of Bulgaria, including its mountainous variation on the slopes of the surrounding mountains. The average altitude of the municipal territory ia about 750 m with variations between 600 m and over 1600 m above sea level. Due to local physical and geographical features, temperature inversions are present, which in combination with the predominance of calm weather premise the increase in the concentration of pollutants in the ground air layer.

1.2 Main objectives of the project

PERNIKCLIMAACT is a project designed to deliver a refined climate multi-risk assessment for the Municipality of Pernik and plug it into existing and future strategic climate action documents for evidence-based policy-making and fund-raising for climate change adaptation measures. The project closes the knowledge, skills, and funding gap that has until now stopped the municipality from developing a climate risk assessment. Being able to complete this study is vital for the municipality of Pernik, facing complex risks, e.g. heavy rainfall, urban heatwaves, floods, forest fires, exacerbated by its specific industrial profile.

The overarching objective of the project is to produce a refined climate multi-risk assessment that will be the foundation for upgrading the municipal climate adaptation strategy but also for future policy documents and actions by the municipality in the sector of climate change adaptation. The specific project obectives include the following: Produce a climate multi-risk assessment (Deliverable 1); Produce a refined climate multi-risk assessment (Deliverable 2); Use the refined climate multi-risk assessment to review the municipal climate adaptation strategy (adopted September 2024) and upgrade it by proposing concrete changes to the text of the document (Deliverable 3) and supplement it with an action plan for its implementation; Use the climate multi-risk assessment to initiate reach-out to national authorities to advocate for national funding for climate adaptation measures in the municipality; Use the climate multi-risk assessment process to engage regional authorities for an improved regional approach to planning and prevention in respect to climate change impact and disasters; Share experience, results, and good practices with the other municipalities in Bulgaria (through the National Association of Municipalities); Engage a variety of stakeholders to increase understanding and support for climate risk adaptation.

The climate multi-risk assessment will enable the municipality to upgrade its Municipal Climate Adaptation Strategy. It will inform the municipal action plan in implementation of the strategy, it will enable the municipality to better tailor climate change adaptation measures and combine them in a mutually enhancing way with efforts for the green transition of the region. The risk assessment will serve as the foundation for climate action policies in the municipality and will help it adapt its approach for effective climate change adaptation and disaster prevention. By improving the municipal understanding and evaluation of the climate risks, the study will also equip the municipality with the knowledge and evidence to request and attract public and private funding and investments in climate change adaptation efforts in the municipality. It will also enable the municipality to contribute to regional coordination and planning efforts in disaster prevention and early warning by working jointly with regional authorities and using the study results and methodology. The study will also allow the municipality to better communicate the climate risks to residents to build ownership and support for adaptation measures, as well as to tailor solutions in favor of disproportionally affected segments of the population to ensure climate justice. Thus, the study will enhance multi-stakeholder engagement, which will be carried both directly and through mediators, such as the media and civil society organizations to reach all relevant stakeholders.

1.3 Project team

The project team is composed of two groups: a designated municipal team of three employees appointed by the mayor, and a subcontracted team of supporting experts. These two teams work in close coordination, maintaining continuous communication and adhering to the Work Plan outlined in the Individual Follow-up Plan (IFP). The municipal team is responsible for ensuring that the external experts receive all necessary information and feedback from the municipal administration. They also make sure that the administration fully benefits from the project as a learning opportunity and monitor the quality and timely delivery of project activities and deliverables by the external experts, in line with the Work Plan. The three municipal officials, all in managerial positions, facilitate the exchange of information and promote capacity building among colleagues in their respective departments and sectoral units. The external experts support the municipal team by carrying out assigned tasks and deliverables as specified in the project's IFP. They provide the essential technical and expert input required for the implementation of the PERNIKCLIMAACT - capacities that would not have been available within the municipality without the CLIMAAX support.

1.4 Outline of the document's structure

The main focus of this document is the Phase 1 Climate Risk Assessment (CRA) for the municipality of Pernik, presented in Section 2. This section is structured according to the CLIMAAX framework and begins by outlining the scope of the CRA process, including its objectives, context, stakeholder involvement, and risk ownership. It then proceeds to identify and examine the relevant climate risks, selecting the hazards for analysis and reviewing existing data and knowledge resources. Following this, the section details the chosen workflows and scenarios, and carries out the risk analysis—covering data review, hazard identification, and risk evaluation for each workflow. Initial findings on key risks are also presented, focusing on aspects, such as severity, urgency, and the municipality's adaptive and response capacity. Toward the end of Section 2, the document provides early considerations on monitoring and evaluation, supported by preliminary data. Section 3 presents the main conclusions and highlights the key findings. Section 4 offers an assessment of progress to date, including KPIs and milestones, along with reflections on how this progress will inform and support the upcoming phases. Sections 5 and 6 list the reference materials and supporting documentation, respectively.

2 Climate risk assessment – phase 1

2.1 Scoping

2.1.1 Objectives

This Climate Risk Assessment (CRA) serves multiple key purposes for the municipality. At its core, it seeks to deepen the understanding of the two priority climate risks – urban heatwaaves and extreme precipitation - that currently have a significant impact on the area. By analyzing both the present conditions and future projections, the CRA is intended to act as a foundation for designing adaptation measures that address current vulnerabilities while also anticipating future challenges.

On one level, the CRA clarifies the municipality's existing exposure and sensitivity to these risks, helping to shape immediate adaptation responses. Simultaneously, it aims to highlight how these risks are expected to evolve over time, enabling policy-makers to implement proactive and well-coordinated measures that are timely and consistent. A crucial aspect of the CRA is its commitment to presenting evidence-based, methodologically sound findings in a format accessible to political leaders and local decision-makers, thereby ensuring the outcomes are not only technically reliable but also actionable.

By offering a scientifically grounded framework, the CRA is positioned to support informed political choices and guide the practical selection of technical climate adaptation solutions across various domains, such as prevention, civil protection planning, and emergency response. It will directly inform an update of Pernik Municipality's Strategy for Climate Change Adaptation (2024) and present the foundation for its associated action plan. This includes laying the groundwork for attracting investment and funding to implement adaptation measures. The CRA will also provide the evidentiary basis for justifying selected approaches, helping to secure alignment between strategy, implementation, and long-term policy direction in building local climate resilience.

Beyond its use at the municipal level, the CRA is also intended to support Pernik in advocating for adaptation measures at the regional and national scale. It strengthens the municipality's case for funding by underscoring prevention as a cost-effective and environmentally sound path forward.

Prior to joining the CLIMAAX project, Pernik faced considerable obstacles in producing a CRA. These included a lack of internal expertise, insufficient funding for external support, and the absence of a reliable and standardized methodology that would ensure high-quality analysis comparable across EU municipalities. The CLIMAAX project helped to bridge these gaps—bringing in necessary technical support, providing a robust methodological framework, and offering tools to align scientific depth with policy relevance. In particular, the CLIMAAX workflows addressed a recurring challenge the municipality had struggled with: making use of available European datasets while also identifying, refining, and integrating local data. The framework now enables the team to better evaluate what data is most useful and how it can be applied for clearer insights. This effort will continue and be further developed in the second phase of the project, with a specific focus on enhancing the use of local data sources.

The remaining challenges for the municipality that it will aim to address in the second project phase is the lack of local data and the scarce capacity to interpret and use this data as a policy foundation. The CLIMAAX framework will guide the municipality in selecting and vetting the local data needed for the utilized workflows. If this challenges prove deeper than expected the municipality is ready to consider collecting its own data in the future to service the reiteration of the workflows, which it currently sees as a periodic task.

2.1.2 Context

In September 2024, Pernik Municipality took a major step toward climate resilience by adopting its Municipal Climate Adaptation Strategy. This document—developed by an external team—relies on a combination of European and national data sources, including the IPCC's 2022 Sixth Assessment Report, the DRMKC Risk Data Hub, Copernicus C3S Atlas, Bulgaria's National Institute of Hydrology and Meteorology (NIMH), the Bulgarian Academy of Sciences (BAS), and the Climate-ADAPT platform. It stands as the municipality's primary strategic instrument for adapting to climate change impacts at the local level.

Historically, the municipality's actions in response to climate risks have been reactive - primarily addressing events after they occurred rather than preventing them. Due to a lack of predictive data and strategic direction, adaptation efforts were piecemeal and underfunded. Although the national framework in Bulgaria tasks municipalities with prevention and coordination duties, it does not provide dedicated funding or expert support for the development of local CRAs. This leaves municipalities without the tools needed to implement meaningful, forward-looking climate action, effectively making national strategies difficult to translate into local practice.

To address these long-standing challenges, Pernik turned to the CLIMAAX project. The initiative fills critical gaps in expertise, funding, and methodology, equipping the municipality with a reliable framework for conducting a robust, multi-risk climate assessment. The resulting refined CRA will form the analytical backbone of the adaptation strategy, informing both its update and the creation of a concrete action plan for its implementation.

This pivot toward a more strategic and proactive climate agenda was driven by the mounting urgency of climate-related hazards and the municipality's growing recognition of its leadership role in local adaptation and prevention. In response, Pernik became part of the EU Mission: Adaptation to Climate Change, independently developed its initial adaptation strategy, and sought support through CLIMAAX to produce the in-depth CRA it previously lacked.

With this CRA, the municipality gains more than a technical report - it acquires a powerful tool to influence policy and funding at multiple levels. Locally, it strengthens planning and improves the targeting of adaptation measures. Regionally and nationally, it positions Pernik to advocate for coordinated adaptation efforts and attract investment. Though Bulgaria has a national adaptation strategy (developed with the World Bank in 2019), the absence of local implementation mechanisms severely limits its impact. Pernik's CRA seeks to bridge that gap by grounding adaptation efforts in actual local risks, vulnerabilities, and capacities.

Several economic sectors and systems - such as tourism, healthcare, public infrastructure - face growing threats from climate-related hazards. While the municipal adaptation strategy already proposes actions for the near and medium term, the CRA will strengthen this framework by offering deeper insights into the risks and their projected evolution. It will also enable the municipality to refine, prioritize, and, where necessary, expand its set of adaptation measures to ensure they are both effective and evidence-based.

2.1.3 Participation and risk ownership

Responsibility for managing climate risks rests with the municipal government. Under Bulgaria's Disaster Protection Act (National Gazette, 2016), the municipality - led by the mayor - is legally accountable for drafting and executing action plans for response to disasters. This mandate also extends to preventive and risk reduction planning, including climate change adaptation as a forward-looking form of disaster prevention. While the Ministry of Interior offers some support in civil protection during emergencies, municipalities receive little or no assistance when it comes to long-term prevention and climate adaptation planning. The absence of guidance or resources for proactive adaptation work underscores a significant gap in institutional support.

When disasters, such as extreme precipitation strike, the financial and operational capacity of the municipality is quickly overwhelmed, necessitating assistance from higher levels of government. This reality highlights the importance of adaptation and preventative approaches - not only to protect lives and infrastructure, but also to conserve limited local resources. The municipality intends to use the CRA to identify which adaptation measures would be most effective in decreasing exteme precipitation flood risks over the long term. Likewise, as heatwaves become more frequent and severe - and with an aging population particularly at risk - the CRA will help pinpoint vulnerable zones and timeframes where targeted interventions, such as cooling strategies or healthcare responses, can reduce population exposure and improve resilience.

Once the first phase of the CRA is completed, Pernik plans to actively share the results. The municipality will organize a consultation meeting with local residents and businesses and regional authorities to share the results and request input to granulate the analysis. Simultaneously, public communication will aim to build local awareness and encourage community participation in adaptation initiatives. At the same time, engagement with regional institutions and national agencies, especially after the end of phase 2, will aim to also foster better coordination on climate risk prevention and emergency preparedness. Outreach to national policymakers will focus on advocating for funding and encouraging broader adoption of the CRA methodology across other municipalities in Bulgaria.

During this first project phase, outreach was limited to select stakeholders to gather input on climate-related risks and is therefore not part of the project KPIs and milestones. It was mainly targetting municipal officials and professionals from municipal and regional structures of national agencies and ministries relevant to disaster response, environmental protection, healthcare, and regional development, and representatives of vulnerable communities due to their potential knowledge of risk impacts and exposure. Stakeholder engagement on broader terms based on CRA results is planned purpusofuly by the municipality for Phases 2 and 3 as the CRA results will grant an excellent foundation to generate interest and build understanding in the otherwise difficult-to-communicate topic of climate change.

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

The Municipality of Pernik has been experiencing a multitude of climate-related hazards, including urban heatwaves, extreme precipitation, droughts, and river flooding. Among these, heatwaves and extreme precipitation have been identified by means of institutional knowledge (from historical observations, recent events, and a record of utilized municipal capabilities) and stakeholder validation - as the most pressing risks due to their severity, considerable impact and lack of municipal capabilities to act in adaptation and prevention. These two hazards not only pose direct risks but also act as catalysts for additional hazards, such as droughts and river flooding. Both are further exacerbated by non-climatic factors, particularly inefficient response and prevention efforts management at both state and regional levels, and the health profile and demographic structure of the population in Pernik municipality. Given these considerations, the municipality has prioritized these two hazards and the associated risks for assessment under the current CRA.

Pernik has experienced a series of urban floods directly linked to the impacts of climate change as manifested in extreme precipitation. Rainfall has increased from 562,7mm to 644,8mm since 1979 and sudden torrential rains cause floods that damage people’s homes, local infrastructure, and local businesses. Thus, for instance, in November 2023 during an extreme precipitation event, the rainfall for 12hours equaled the usual amount for one month. Two other recent examples include torrential rain floodings from the beginning of October 2024 when a rainfall of approximately 40l/sqm flooded parts of the city of Pernik and from April-May 2025 that resulted in power outages, property damages, and infrastructure damages, including a collapsed retaining wall in one of the residential areas that was cause for the mayor to announce partial state of emergency. The damages caused present an existential challenge to the municipality and its residents as these require substantial funds to recover. Heavy rainfall also periodically creates risks of overflow of the Struma river, which runs through a considerable part of the residential areas in the municipality. The city of Pernik is classified in the National Flood Risk Management Plan as a high risk area. Additionally, due to the increasing average annual temperatures the period of snow melting starts earlier and the risks of floods from the river starts as early as December. Floods as a result of heavy rainfall are increasingly common in spring and autumn, and damages caused present an overwhelming challenge to the municipality and its residents as these require substantial funds to recover.

The Municipality of Pernik suffers from increasing average annual temperature, which has risen by 1.5% since 1979. In the summer months there are frequent heatwaves that pose a threat to human health. These are exacerbated by the industrial profile of the municipality as pollution is frequent and the increase in fine particulate matter also enhances the negative impact of heatwaves. Heatwaves in the summer can begin as early as June and continue throughout August, posing risks to the health of the increasingly aging population, as well as creating risks for fires. For example, in July 2024 a large forest fire raged next to the Rasnik village in the municipality causing considerable damage and all settlements in the region were instructed to create disaster response volunteer units. The frequent pollution and increased levels of fine particles in the air from the coal industry also contribute to heatwaves.

Knowledge on the selected climate hazards for this CRA is mainly based on historical observations and pan-European ready-to-use data and instruments, such as the Copernicus Atlas. The municipality, prior to joining CLIMAAX, did not have the capability to identify and operationalize to a sufficient degree available regional or local data and hence use it for decision-making. This is planned to occur in Phase 2 of the project in a targetted manner using the workflow methodology as a guide as to what data to seek to enhance its granularity.

Pernik is also historically a mining region that needs to be transformed and transition from coal mining and coal-based production of electricity to renewable energy sources and a more environmentally sustainable economic profile. Given that climate risks are intertwined with the negative environmental effects of mining and coal electricity production, we believe that the solutions we find to these two clusters of challenges should be mutually enhancing. Climate adaptation solutions should contribute to the green transformation of the region and the green transition should be planned in ways to contribute to climate change adaptation and prevention of climate-induced disasters. The municipality is among those that qualify under the Just Transition Fund for support. A comprehensive climate multi-risk analysis will not only help us plan impactful adaptation measures, adapt our strategy, and prevent disasters and threats to human health and wellbeing, but will enable us to coordinate these solutions with measures related to the green transformation. CLIMAAX has provided us with the methodology, the tools, and the structure to make sure we have a deep understanding of the climate risks that impact the municipality and the region. It has allowed us to contract the needed external help to base the analysis on expert knowledge. Thus, with CLIMAAX, we has been closing the knowledge and funding gap that we previously experienced and which prevented us from conducting a climate risk assessment. Once we have a climate risk assessment, we are confident, this will help us not only to plan concrete climate adaptation measures but also attract the necessary funds to implement them. Being able to learn from CLIMAAX experts and the community of other municipalities that employ the same methodology is particularly important for us. Given the complexity of the climate-related challenges we face due to the specific profile of our municipality, we need and we are eager to learn from the best European practices.

2.2.2 Workflow selection

2.2.2.1 Workflow #1 for Urban Heatwaves based on satellite data

The Municipality of Pernik selected a satellite-based heatwave risk assessment workflow, recognizing its suitability for application at the municipal, i.e. administratively sub-regional, level. This approach not only aligns closely with the municipality's policy objectives, population profile and pollution concerns but also provides valuable support to the local decision-making process. Several contextual factors make this workflow particularly relevant for Pernik: the population is experiencing a steady trend of aging, healthcare services do not consistently meet adequate quality standards, much of the urban infrastructure remains ill-equipped to cope with rising temperatures, air quality is exacerbated by the mining profile of the municipality and the coal-based power plants, and there is an exacerbated health profile of the older population due to the mining history of the region.

These challenges are critical considerations for municipal leadership, particularly for the mayor and local policymakers tasked with shaping future adaptation strategies. The chosen workflow produces a heat risk map that overlays areas of high surface temperature exposure with the spatial distribution of vulnerable population groups—specifically children aged 1 to 5 and adults over the age of 65. This allows the municipality to clearly identify high-risk zones and prioritize targeted, evidence-based adaptation measures.

Moreover, the integration into the analysis of heatwave frequency projections - derived using the EuroHEAT methodology - provides additional insight into the expected increase in extreme heat events over time. This combined analysis offers a clearer understanding of future risks and underscores the urgency of mitigating the impacts of heatwaves, particularly in hotspot areas with high concentrations of vulnerable residents. Together, these tools enhance the municipality's capacity to plan effectively and build long-term resilience to health risks related to urban heatwaves.

2.2.2.2 Workflow #2 for Extreme Precipitation

The extreme precipitation workflow was selected by the Municipality of Pernik as it coincides to the highest degree with the municipal experience of urban floods. The workflow defines extreme precipitation as the occurrence of a large amount of rainfall within a short timeframe – exactly what Pernik has been experiencing as the rootcause of floods in the urban areas, especially whithin the city of Pernik. Since the workflow aims to see how the frequency and intensity of such extreme precipitation events will change under the influence of climate change, it offers the insights that the municipality needs to plan for prevention and more effective response activities as the municipal level. The critical rainfall treshold approach of the workflow is particularly suitable for Pernik, as urban floods are the result of extreme precipitation exceeding the natural and artificial drainage systems capacities.

The municipality hence selected the extreme precipitation workflow as it presents the changes in margnitude and frequency of extreme precipitation for specific durations, return periods, Global-Regional climate model pairs and RPCs (Representation Concentration Pathways) and allows the municipality to identify whether the local critical impact rainfall thresholds for infrastructures, vulnerable locations or areas are to be exceeded (or not) under the influence of climate change scenarios. This alignment with Pernik's local context and needs is the reason the extreme precipitation workflow was ultimately chosen.

2.2.3 Choose Scenario

In the urban heatwaves hazard assessment workflow, two climate change scenarios - RCP4.5 (representing a medium emissions pathway) and RCP8.5 (representing a high emissions pathway) - are used to evaluate how future climate conditions may influence the frequency of heatwave events. The hazard assessment component, aligned with EU-wide health-based thresholds as defined in the EuroHEAT project, provides projections of heatwave frequency for the period 1986-2086 under both climate scenarios for the selected area.

For the Municipality of Pernik, the chosen risk assessment workflow estimates heatwave risk by combining high-resolution surface temperature data with information on the spatial distribution of vulnerable population groups. This approach enables the identification of areas where exposure and vulnerability intersect, offering a robust estimate of both current and future risk levels.

The integration of these hazard and risk assessment workflows provides a comprehensive basis for understanding the evolving heatwave risk landscape. However, it is essential to consider non-climatic contextual factors that may exacerbate future vulnerabilities. Notably, demographic projections indicate a continuing trend toward population aging in the region. In parallel, national healthcare reform strategies, which aim to consolidate services by closing smaller, underperforming municipal health facilities, may further limit local access to care during extreme heat events.

Another non-climatic challenge for the municipality has been the proximity to the capital city, which has been economically tempting for younger generations to relocate for career purposes. However, the municipality has been trying to turn this into an advantage whereby due to good living conditions in Pernik, commute would be a viable and preferable option for people working in the capital. Climate adaptation and green transformation are vital to turn the city and municipality of Pernik into a prefered livigng location by balancing out the consequneces of both climate change and the negatives of the coal-mining profile of the region.

In the extreme precipitation workflow for the hazard we use a baseline and a future scenario to utilize CDS data, i.e. the timespan 1976-2005 represents historical simulations, while the period 2041-2070 is used for climate projections, whereby a specific combination of General Circulation Model (GCM), Regional Climate model (RCM), and a Representative Concentration Pathway (RCP) is selected. In the hazard workflow we look at the historical data scenario and the future projections under RCP8.5. For this later scenario we look at two plots: the precipitation for 24h with a 10-year return period and the relative change to the baseline of the historic period for a 24h precipitation with a 10-year return period. The hazard workflow also gives us mean precipitation for 24h duration events in Pernik municipality for the historical and the RCP8.5 scenarios, which is important in respect to the non-climatic factors related to drainage capacity planning.

In the extreme precipitation risk workflow the municipality again looks at the same historic and RCP8.5 scenarios and seeks to plot the shift in frequency of extreme precipitation events for its defined critical impact-based rainfall threshold for the span 2041-2070 and analyse the juxtaposition between the frequency in the current return period and the expected return period for RCP8.5, as well as plot the relative change in magnitude for the threshold under RCP8.5 with a fixed frequency for period of 2041-2070. The risk workflow takes into consideration non-climatic elements that are incorporated in the critical impact-based rainfall thresholds, namely the capacity of drainage systems and local infrastructure to withstand certain levels of impact from extreme precipitation, which constitute the exposure and vulnerability elements. These scenarios have been applied with the threshold of 35mm in 24 hours with a frequency of 3 years to the municipality of Pernik and the city of Pernik.

2.3 Risk Analysis

2.3.1 Workflow #1: Urban Heatwaves

Table 2-1 Data overview workflow #1 Urban Heatwaves

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
EuroHEAT project CDS dataset	*WorldPop data (DOI: 10.5258/SOTON/WP00646) for most vulnerable groups of the population, age structures of 2020*	*RSLab Landsat8*	*Risk map plotting the possible heat risk level to vulnerable population.*

2.3.1.1 Hazard assessment

The hazard workflow used is the one relying on EuroHEAT CDS data and it evaluates the projected impact of climate change on the frequency of heatwaves in the municipality of Pernik, considering both the RCP4.5 and RCP8.5 climate scenarios. This assessment relies on a CDS dataset provided by the EuroHEAT project, which offers high-resolution data on a 12x12 km grid across the entire European Union, spanning the years 1986 to 2085. Due to the absence of a nationally established definition for heatwaves, the methodology adopts the EU-wide health-related criteria to ensure consistency and comparability.

For the purposes of the current Climate Risk Assessment (CRA), the analysis focuses on the months of June through August, which are recognized as the hottest months of the summer season. Within this framework, heatwaves are characterized as events lasting at least two consecutive days during which both the maximum apparent temperature (Tappmax) and the minimum temperature (Tmin) exceed their respective 90th percentile thresholds for each month. This dual-threshold approach ensures a comprehensive representation of heatwave conditions by accounting for both daytime and nighttime temperature extremes.

The results, presented in Figure 2-1, illustrate the anticipated annual frequency of heatwaves under the two climate change scenarios, highlighting a clear upward trend in heatwave occurrence over time. These projections provide crucial information that enables the municipality to better understand the evolving risks associated with extreme heat events and to develop targeted strategies for climate adaptation and public health protection in response to these emerging challenges.

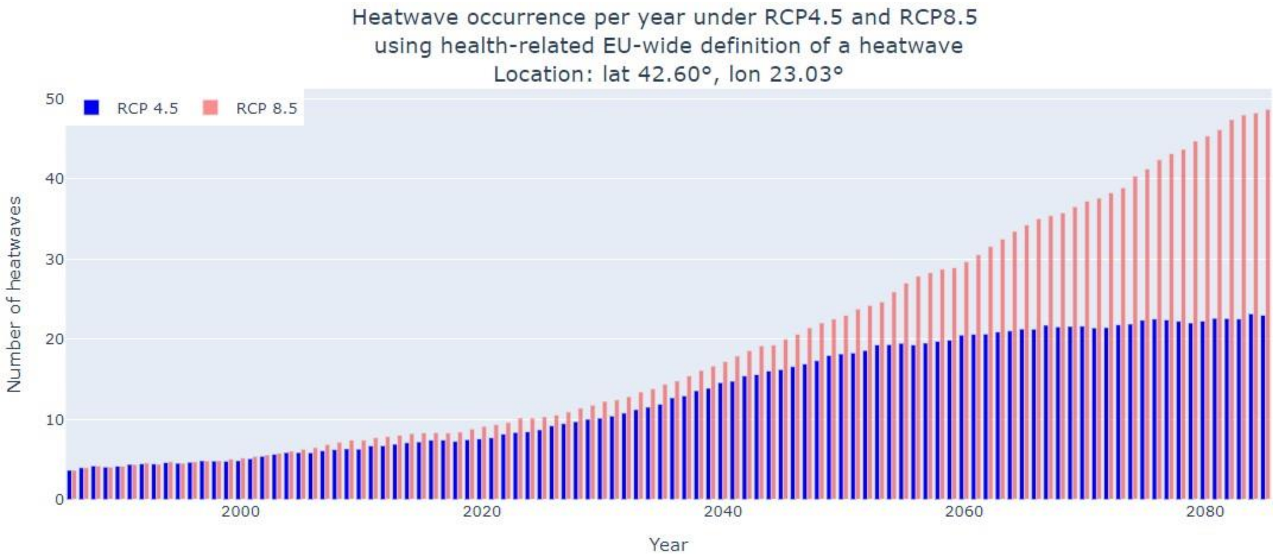


Figure 2-1 Heatwave occurrence per year under RCP4.5 and RCP8.5 using health related EU-wide definition of a heatwave for the location of Pernik

2.3.1.2 Risk assessment

The CLIMAAX risk assessment workflow utilized by the Municipality of Pernik is grounded in historical satellite-derived data. Fundamentally, this approach involves overlaying maps of overheated areas - derived from land surface temperature satellite imagery - with population density maps highlighting vulnerable groups, specifically children under five and elderly individuals over 65 years of age. This integration generates a 10x10 risk matrix that forms the foundation for developing a comprehensive heat risk map, illustrating the level of heat exposure faced by vulnerable populations.

In implementing this workflow, the municipality utilized RSLab Landsat 8 data (incorporating MODIS emissivity) to analyze surface temperatures across a polygon encompassing its territory. The focus was placed on the largest urban areas, deliberately excluding smaller settlements and forested regions that are less susceptible to heatwave impacts. This dataset provided critical exposure information for the risk analysis.

Vulnerability data, reflecting the density of at-risk population groups, was sourced from the WorldPop dataset and incorporated into the risk map generated by the workflow. This combined analysis enabled the Municipality of Pernik to pinpoint locations where heat exposure is most pronounced and where vulnerable populations are most concentrated. Because of the limited spatial resolution of the vulnerable population density data, the interactive risk map proved instrumental in enhancing the municipality’s ability to identify high-risk areas by ptoviding the possiblity to zoom-in. The integration of more localized data in the second phase of the project is expected to further mitigate these challenges.

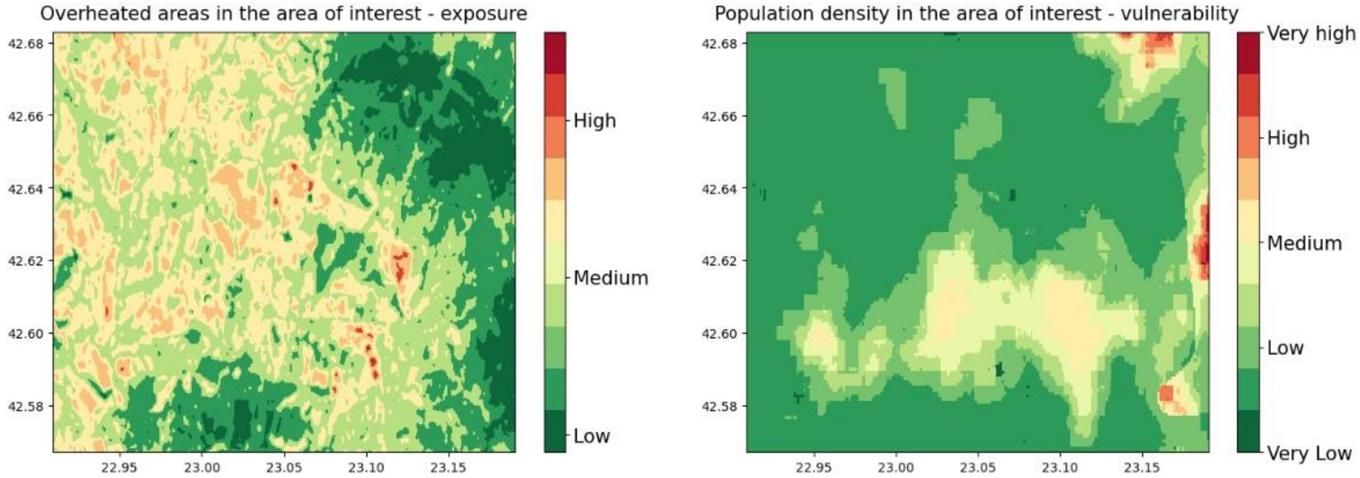
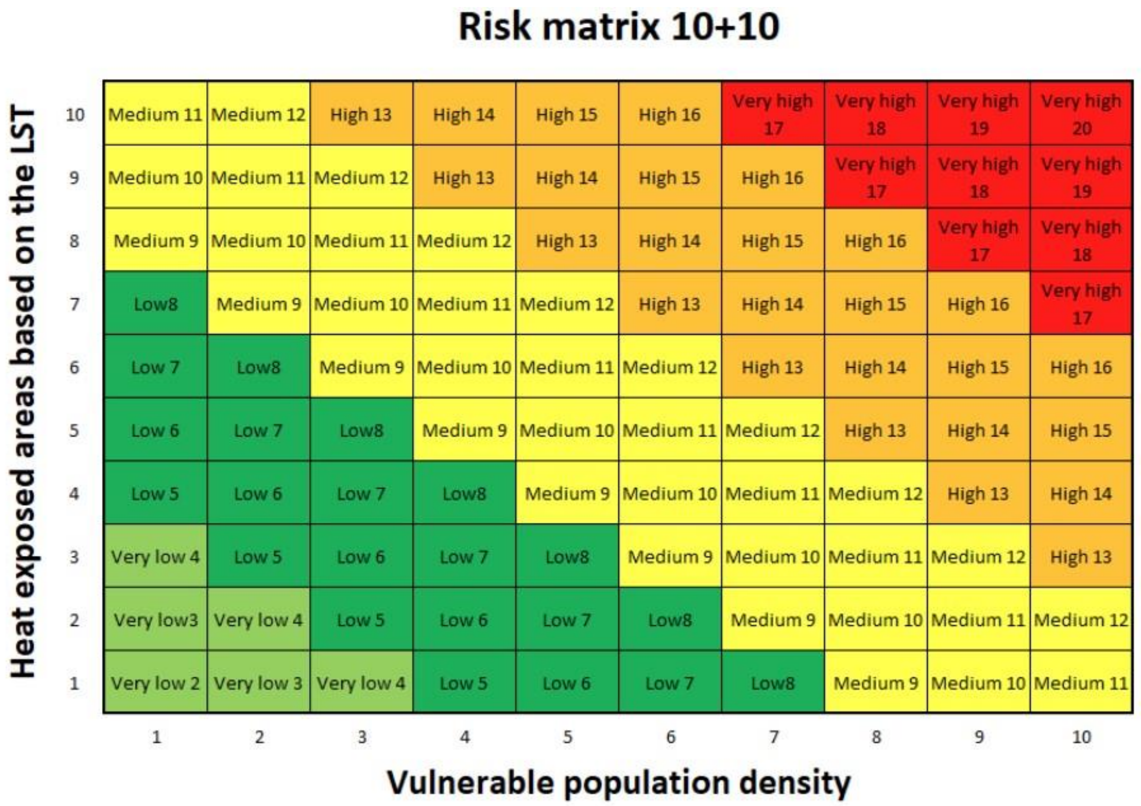


Figure 2-2 Maps of overheated areas (exposure) and population density (vulnerability) in the Municipality of Pernik



Risk matrix 10+10

Heat exposed areas based on the LST (rows) / Vulnerable population density (columns)

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

Figure 2-3 Risk matrix combining overheated areas and vulnerable population density for the Municipality of Pernik

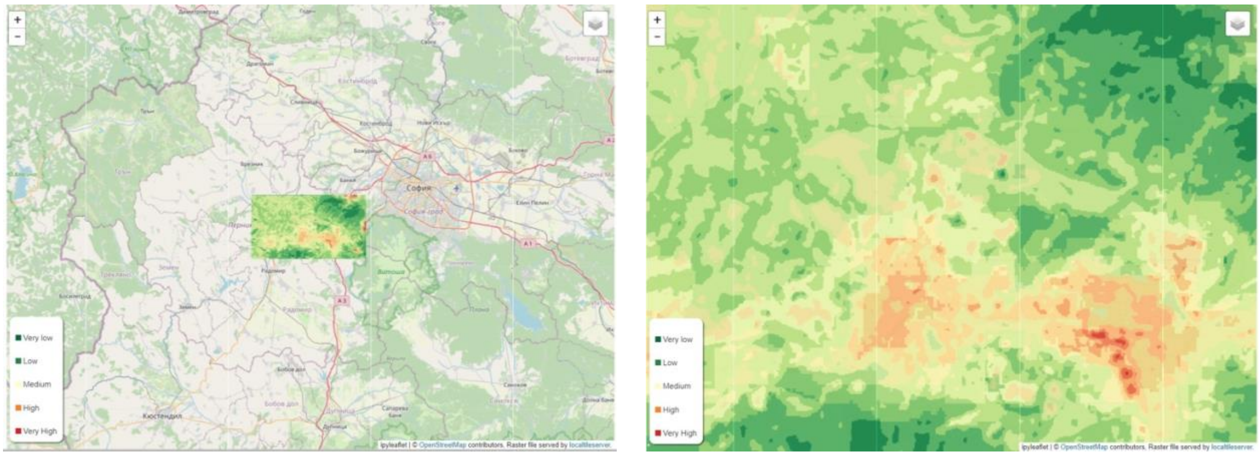


Figure 2-4 Heatwave risk to vulnerable population in the Municipality of Pernik to the left, zoomed version to the right.

A detailed analysis of the results obtained through the heatwave hazard and risk assessments is provided in Section 2.4.

2.3.2 Workflow #2: Heavy Rainfall / Extreme Precipitation

Table 2-2 Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
CDS EURO-CORDEX climate projections for precipitation flux at a 12km spatial resolution: timeframes - 1976-2005 (baseline or historic simulations) and 2041-2070 (climate projections)	*Critical impact rainfall threshold incorporating data on what impacts are no longer sustainable or acceptable for local conditions*	*Critical impact rainfall threshold incorporating data on what impacts are no longer sustainable or acceptable for local conditions*	*Maps plotting shifts in magnitude and frequency of extreme precipitation events as defined by the threshold for two scenarios – historic and RCP8.5*

2.3.2.1 Hazard assessment

The hazard workflow was applied to generate rainfall datasets corresponding to both current and future climate scenarios. The process involves several key steps, including the extraction of annual maximum precipitation values, the fitting of multiple statistical distributions, and the calculation of return periods for specific rainfall durations and climate scenarios. CDS EURO-CORDEX climate projections for precipitation flux at a 12km spatial resolution are used to assess future climate hazards. Historical simulations are derived from the timeframe from 1976-2005, while climate projections are based on the period from 2041-2070 for RCP8.5. The data is cropped for the studied region of Pernik municipality, and a combination of General Circulation Model (GCM), Regional Climate model (RCM), and a Representative Concentration Pathway (RCP) is used for plotting. The workflow plots the temporal series of annual maximum precipitation for a selected location - in this case the city of Pernik and the entire region - in this case the municipality of Pernik. It is also used to plot the expected precipitation for a 3-hour event for a certain period for these two locations, as well as to compute precipitation changes in percentages for a particular year period. All these intermediary steps are then used to plot the results under the form of extreme precipitation maps that show the expected precipitation and the relative change for the period 2041-2070 under the RCP8.5, i.e. precipitation for 24 hours for a 10-year return period and the relative change compared to the baseline of 1976-2005 for a 10-year return period (See Figure 2-5). The plot results also compute mean values of expected precipitation versus return period for the historical and the future time-frames (See Figure 2-6). The workflow thus allows to see how critical impact rainfall thresholds are affected under different climate change scenarios, in the case of Pernik municipality and the RCP8.5 in specific.

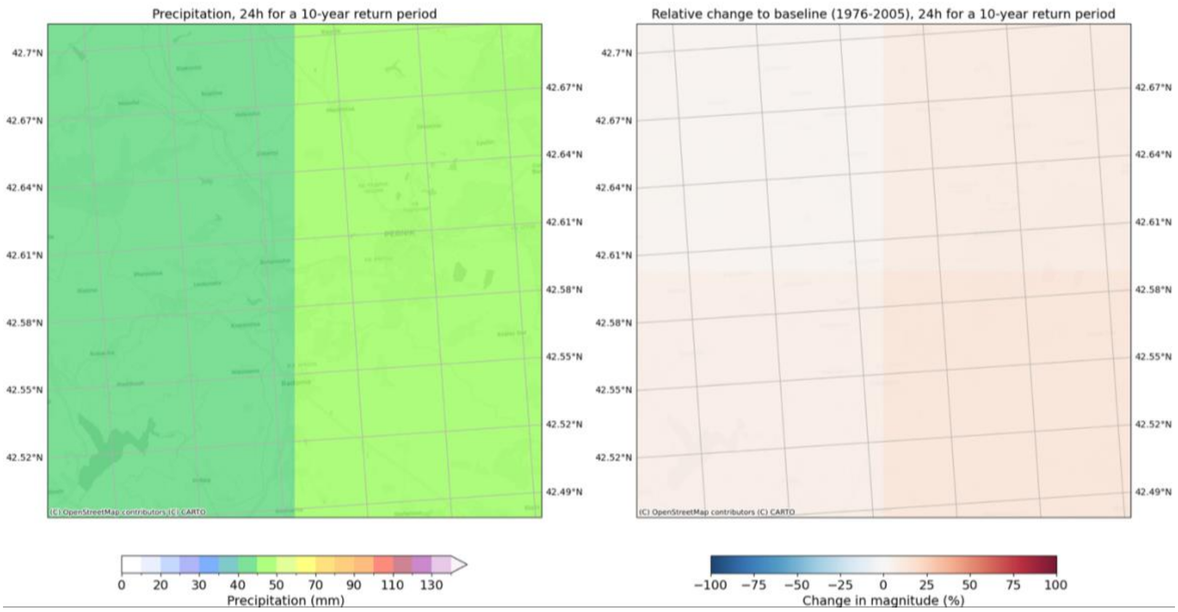


Figure 2-5 Extreme precipitation for 2041-2070 under RCP8.5 climate projections for the municipality of Pernik.

Figure 2-6 Mean precipitation for 24h duration events for historical and RCP8.5 scenarios for the municipality of Pernik.

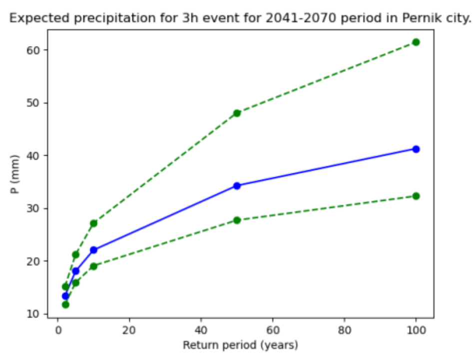


Figure 2-7 Expected precipitation for 3h event for 2041-2070 period for the city of Pernik.

2.3.2.2 Risk assessment

The extreme precipitation risk assessment methodology allows to analyze the risk associated with the extreme precipitation hazard by plotting how the current local critical impact-based rainfall thresholds will shift under climate change scenarios by taking into account two main elements – the magnitude and the frequency, i.e. a rainfall of what magnitude will occur with what frequency. The risk workflow has been applied to the specific location of the city of Pernik and the regional assessment of the municipality of Pernik (for clarity of terms please note that the word region is used liberally here to indicate a larger territory whereas in respect to administrative division, "region" under the Bulgarian national administrative division nomenclature is a unit above the municipal level and encompasses several municipalities). Hazard data has been used as generated by the hazard workflow and the CDS data has been plugged in its non-bias-corrected version. The historical timeframe refers to the period 1976-2005 and the future projections are based on the period 2041-2070. The projections are computed for the RCP 8.5 for the duration of 3 and 24 hours with the ichec-ec-earth/knmi_racmo22e as Global/Regional Climate Model Chain. Both the site specific and the regional assessment are carried out for the impact threshold of 35mm magnitude/24hr duration/3year frequency. The test of domain overlap between the historical dataset and threshold dataset verified the validity of the results. Due to lack of local data a dummy dataset was used for the code, where a tiff file with the local data had to be inserted, and the thresholds were fixed for all pixels at one value. This risk workflow was technologically more difficult to use as it generated a number of code errors but with the assistance of the CLIMAAX Service Desk the municipality was able to resolve them and compute the results. The generated plots for shifts in magnitude and frequency (See Figure 2-8 and Figure 2-9 respectively) are a valuable asset in planning adaptation and prevention measures that we have planned to enhance with more local data during Phase 2 of the project.

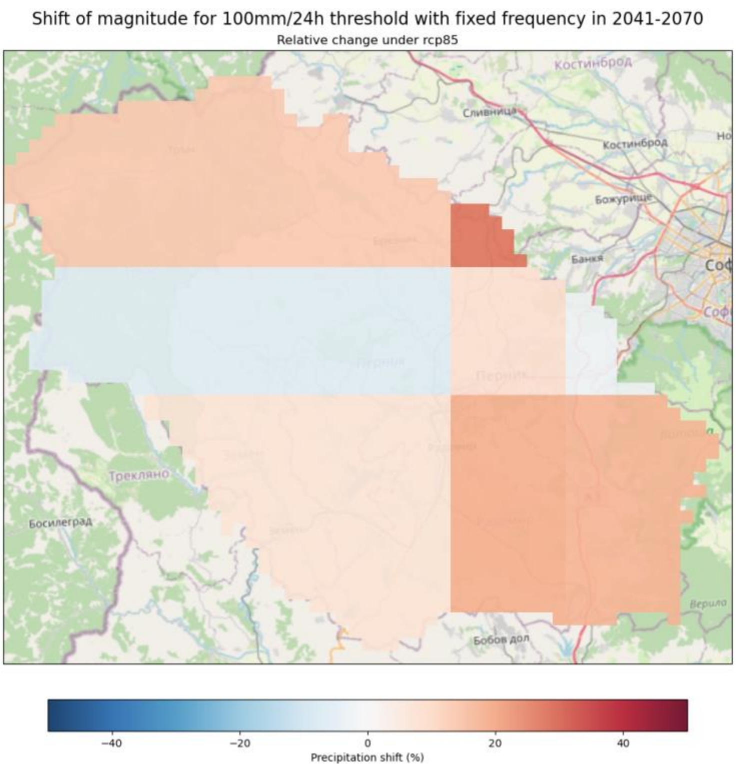


Figure 2-8 Shift in magnitude for 100mm/24h threshold with fixed frequency in 2041-2070 under RCP8.5 for the Municipality of Pernik.

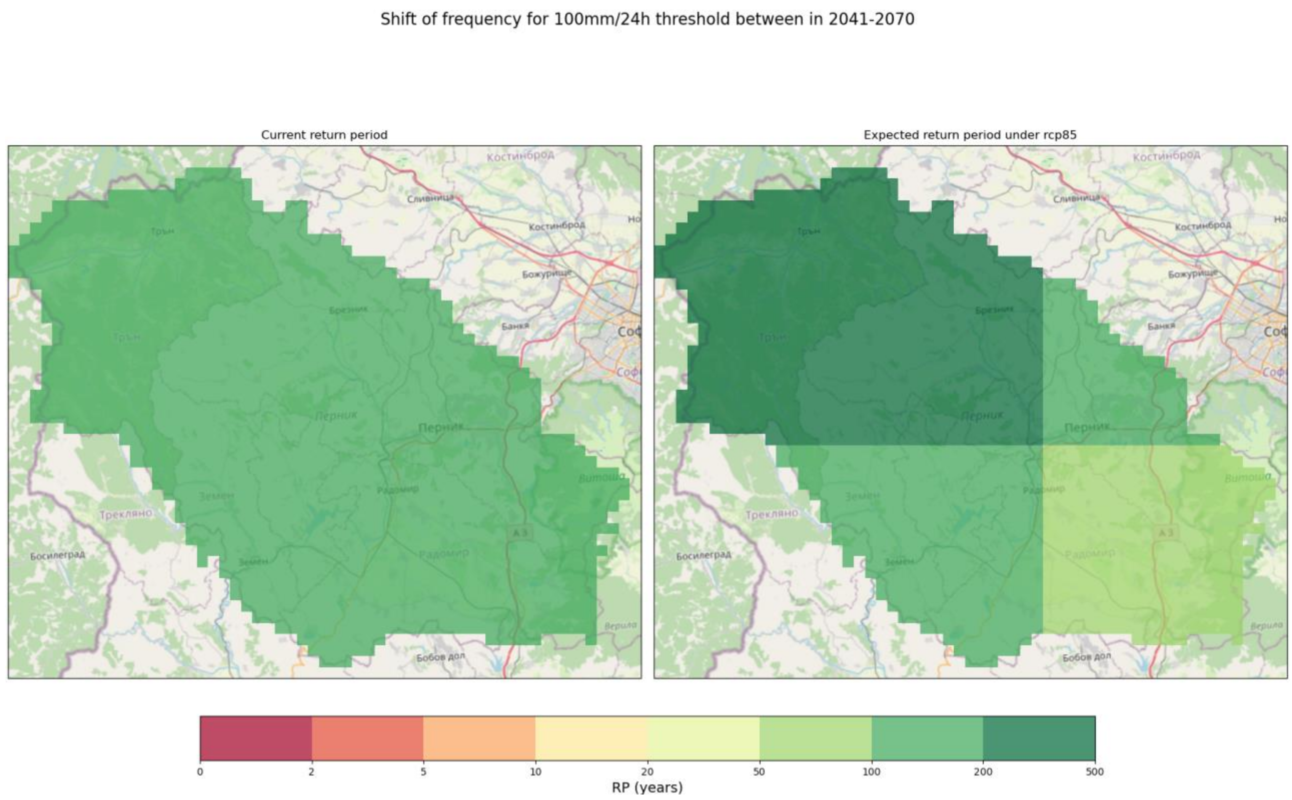


Figure 2-9 Shift in frequency for 100mm/24h threshold between 2041-2070 for the Municipality of Pernik.

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

The heatwave hazard assessment reveals a marked rise in the frequency of heatwave events under both future climate scenarios—RCP4.5 and RCP8.5. Notably, under the RCP8.5 scenario, the number of heatwaves is projected to double over the next two decades. Figure 2-1 illustrates this trend for the municipality of Pernik, showing a consistent increase in heatwave occurrence across both scenarios. This upward trajectory signals a pressing need for Pernik to adopt adaptive measures aimed at protecting its residents and economy from the escalating threats and cascading effects associated with heatwaves.

In complementarity, the heatwave risk assessment identifies priority areas within the municipality that require immediate attention. These include zones with both high heat exposure and dense populations—particularly in and around the settlements of Pernik, Batanovtsi, Bosnek, Kladnitsa, and Rudartsi. When considered alongside projections of rising heatwave frequency under both climate models, this spatial analysis provides a clear direction for targeted interventions aimed at reducing the overall impact of this growing hazard.

Heatwaves are known to trigger a chain of negative effects across various systems, including public health, energy infrastructure, water supply networks, and sectors like cultural tourism—a field that Pernik has been actively developing through festivals in recent years. Among these, the most immediate and critical risks are to human health, especially in densely populated urban areas. Vulnerable groups, such as the elderly and young children, face the highest risk. This challenge is particularly acute in Pernik, a municipality experiencing demographic aging, where many buildings lack modern insulation or air-conditioning systems, and where lower-income older and retired from the workforce residents are disproportionately affected by extreme heat.

The health-related consequences of heatwaves include increased mortality rates, heatstroke, dehydration, heat exhaustion, and the exacerbation of chronic or pre-existing medical conditions. Furthermore, issues related to access and quality of healthcare services compound these risks, highlighting the urgent need for targeted strategies to protect vulnerable segments of the population from prolonged heat exposure.

Extreme precipitation severity is poised to increase as well for future projections. Under RCP8.5 for the future projection for 2041-2070 the entire territory of the municipality will be subject to precipitation for 24h (10 year return period) that exceeds the current threshold of 35mm. Spatially the Eastern part of the municipal territory seems at higher risk of extreme precipitation and settlements in this region should be prioritized in adaptation and disaster response measures and plans. The return period for 24h precipitation events of mean volume above 35mm is also projected to become shorter for the territory of the municipality under RCP8.5 and above 40mm the shift in intensity widens compared to the historical baseline data. In respect to the city of Pernik the volume for 3h precipitation events under the future projection is also seen to rise. The analysis clearly points to the need to organize adaptation measures around proofing infrastructure, educating the population, and preparing for response actions in urban areas with a relatively mid-term time horizon.

The plots from the risk workflow point to the areas where the shifts in magnitude and frequency will be most dramatic and therefore should be prioritized. The urban center of Pernik is located in such an area on the map that sees an increase in both and should therefore be among the locations to act first. The East and East-South territory of the municipality is again poised to have a rise in magnitude and a higher rate of a frequency shift compared to the baseline year and therefore should be considered with more attention and with priority. These identified areas prone to more severe impact from extreme precipitation also coincide with the path of the Struma river which indicated the potential for conflating risks, whereby extreme precipitation events could be conducive to river flooding. This is yet another argument to look at those areas with priority when planning adaptation and response measures.

2.4.2 Urgency

Heatwave risk stems from a slow-onset hazard, which may not demand immediate crisis response but still calls for proactive and timely planning. Although the urgency might seem lower compared to sudden disasters, the current, tangible effects already justify the need for targeted adaptation measures. These actions can be initiated now and expanded incrementally over the next 10 to 20 years—particularly important under the more severe RCP8.5 scenario, where the frequency of heatwaves is expected to double.

Demographic trends, such as the aging population, act as non-climatic risk multipliers that could intensify the impacts if left unaddressed. This makes long-term planning even more crucial. Another key consideration is the scale and timeframe required for adaptation efforts. Many of these interventions - such as improving housing, greening urban areas, or upgrading public infrastructure—involve significant financial investment and extended implementation periods. Therefore, early initiation of planning and mitigation strategies is essential to ensure that the municipality is prepared to cope with increasing heat-related risks in the years to come.

Extreme precipitation arises from a sudden onset event, which is also harder to predict with climatic models and scenarios. Since the severity also is projected to increase, the municipality should take timely action to prevent floods by improving drainage infrastructure and to mitigate disturbances to the local population by organizing response plans and strategies for when extreme precipitation events occur. Under the RCP8.5 hazard plot for the future projection for 2041-2070 the entire territory of the municipality (Figure 2-5) will be subject to precipitation for 24h (10 year return period) that exceeds the current threshold of 35mm. Spatially, the Eastern part of the municipal territory seems at higher risk of extreme precipitation and settlements in this region should be priorities in adaptation and disaster response measures and plans. The precipitation magnitude and frequency shift, however, indicates the municipality could prioritize adjusting to current impact levels first and then upgrade to higher impacts as the shift in magnitude seems to be below 20% for at least 2/3 of the municipal territory and can focus resources in preparation for more disruptive impacts in the 1/3 of the territory that is shown as prone to a higher percentage change in magnitude (Figure 2-8) and that coincides with the area of a shorter return period under RCP8.5 from the frequency shift risk workflow plot (Figure 2-9).

2.4.3 Capacity

Regarding urban heatwave risks, no formal management measures have been implemented at present and lack of understanding about the risk and its impacts prevented the municipality from taking such actions or developing any relevant capabilities to act. The municipality issues warnings in advance of anticipated extreme heat, but no specific interventions have been introduced to mitigate associated impacts. The analysis conducted within the CRA framework has, therefore, provided valuable insights and a deeper understanding of this risk and the underlying hazard. These findings will guide the development of targeted adaptation strategies, facilitating more effective planning and improving the municipality's capacity to plan for concrete measures and afterwards seek to obtain the necessary funding from both national and EU sources to implement those.

The Municipality of Pernik currently faces significant limitations in addressing the impacts of extreme precipitation events. Due to the rapid onset and often unexpected nature of these occurrences, preventive actions have been largely limited to the routine maintenance of relevant drainage infrastructure. In terms of disaster response, the municipality has established a disaster response and civil protection plan (Pernik Municipality, 2023). However, the scale of extreme precipitation events often requires the municipality to request regional support through coordination with regional authorities and the activation of the regional disaster response framework. Post-event recovery also presents considerable challenges, as restoration relies on support from national funding. The current state of risk management and disaster response capabilities underscores the urgent need for enhanced measures in prevention of floods from extreme precipitation, adaptation to other heavy rain impacts, and capacity building in risk governance.

By incorporating this risk into the Climate Risk Assessment (CRA), the municipality is laying the groundwork to improve its prospects for securing national funding aimed at risk mitigation. Furthermore, this effort enhances its ability to pursue European Union funding and attract private investment to support risk management initiatives.

2.5 Preliminary Monitoring and Evaluation

During phase 1 of the project, the municipality tested and applied two workflows from the CLIMAAX common methodological framework. To this end the project team familiarized themselves with the CLIMAAX methodology, established the technical infrastructure, and acquired the expert knowledge required to implement the workflows locally. Challenges were met during the workflow testing stage, where certain technical issues led to errors, especially in regards to the extreme precipitation workflow. Nonetheless, these were resolved with prompt support from the CLIMAAX Service Desk that offered advise and practical guidance on how to cope with particular errors. During this stage the municipality gained a solid understanding of workflow complexities, benefits, and potential limitations. The technical challenges to a certain extent contributed to delving further into the methodology and deepening the municipal undertanding about the workflow logic. These insights into the methodology itself are vital to be able to operate with local data in the second project phase.

The application of the two workflows enabled a realistic interpretation of the outcomes, factoring in possible constraints and assessing their influence on the overall results. Additionally, contentwise this phase laid the groundwork for identifying and gathering locally relevant data to improve the Climate Risk Assessment (CRA) in the project's second phase. The applied workflows will guide the project team during the second phase as to what additional local data will benefit the analysis and will help the municipality target its policies in a more cost-effective manner. The later is particularly important given the financial contraints on the municipal capacity to act in climate adaptation and disaster prevention.

During Phase 1 stakeholder engagement was limited to ad hoc consultations with individual experts, local officials, and select representatives of affected groups. Feedback from them was utilized to validate risk selection and confirm most pressing needs and expextations. The validation outreach was important for the municipality in light of its plans to use the CRA for policy design that needs to meet citizen support. These stakeholder outreach efforts are not a formal part of the Work Plan, KPIs, or Milestones. This was planned intentionally as the municipality, from experience, believes that climate adaptation is a difficult and not-too-familiar topic and both public and institutional discourse will be easier to establish and maintain on the CRA results. Therefore the main stakeholder outreach work is planned for Phases 2 and 3 and will be based on the content of the two deliverables respectively, whereby Phase 3 will particularly link it to policy, implementation of concrete measures, and local ownership of joint municipal and regional efforts. These stages, apart from citizen outreach, insitutional dialogue, and expert engagement on the results, will also include media outreach and communication efforts to raise project awareness and disseminate information on attained results, and on how and why the approach can be replicated, and how it can lead to better policy decisions.Targetted communication actions will also serve both to advocate for funding for the implementation of specific adaptation measures in the municipality and to gear up regional efforts towards climate adaptation based on risk assessment.

Following the conclusion of Phase 1, we have developed a solid grasp of local climate risks through the standardized CLIMAAX framework. While certain methodological limitations exist, they did not significantly affect our outcomes and we anticipate that further refinement using local data will offer deeper insights into the identified risks. This will help understand the risks and their local impact even better. It is the municipalities' realistic expectation that some data might not exist or might not be readily available and contentwise accessible, which could require data collection in the future to make up for this omission.

2.6 Work plan

For the subsequent phase 2, the municipality will study how local data can improve the analysis we conducted with European data during phase 1. The initial CRA of this first deliverable gives us the foundation to explore what data we could further accumulate locally and refine to insert into the workflows. This targeted approach should make it easier for the municipality to identify and vet existing data, as well as to see how it contributes to the desired level of quality of the refined CRA. This will assist the municipality in overcoming two obstacles at the local level: absence or difficult accessibility of local data and quality vetting of local data.

In phase 3, the focus will be to study how the obtained results – i.e. the refined CRA – can be translated into policy decisions by upgrading the municipal climate adaptation strategy and designing an action plan for its implementation. Another focus would be to study how it can improve regional and national planning and strategic approach to climate adaptation and disaster readiness in respect to the two risks. Last but certainly not least in importance will be the quest to improve local ownership of the policy decisions by affected groups to ensure public support that will translate into sustainability of the efforts.

For additional clarity it should be noted that the work plan of the municipality for the remaining two phases includes five distinct activities that have been distributed in time as follows:

- Phase 2 – 10 months:

Activity 2.1 – 1 months: organizing a consultation meeting with local residents and businesses and regional authorities to share the CRA results and request input to granulate the analysis.

Activity 2.2 – 2 months: conducting research and compiling a database of available and relevant to the workflows regional and local data.

Activity 2.3 – 7 months: inserting the local data of higher resolution into the study to improve its granularity and produce a refined municipal multi-risk assessment.

- Phase 3 – 6 months:

Activity 3.1: reviewing the municipal climate adaptation strategy in light of the results from the study and upgrading it by proposing concrete changes to the text of the document and supplementing it with an action plan for its implementation.

Activity 3.2: sharing the study results with the relevant regional and national authorities to contribute to the regional efforts for disaster prevention and early warning and organizing a meeting with local residents and the business to share the refined results and to explain what they mean for practical measures.

3 Conclusions Phase 1- Climate risk assessment

Overall, Phase 1 has delivered substantial value to the municipality of Pernik. The hazard and risk assessment conducted during this phase has yielded important insights for managing the municipality's two priority climate risks: urban heatwaves and extreme precipitation. Thanks to the CLIMAAX financial support, the municipality was able to secure external expertise, which enabled the analysis. Useful resources were the thematic CoP webinars and the Service desk, the later particularly vital in respect to the technical application of the workflows.

During Phase 1 the municipality experienced a number of challenges that can be clustered into two broader groups:

- Technical challenges: related to the municipality's limited technical readiness for conducting complex risk assessments and the general lack of in-house expertise in CRA processes. Therefore, Phase 1 proved instrumental in establishing both the necessary technological infrastructure and procedural framework to apply the CLIMAAX methodology - an approach that can be replicated and sustained even beyond the project's timeline. Given the limited experience with CRA methodologies in the municipality - and across most Bulgarian municipalities – the availability of a structured and repeatable process is especially valuable. The technical assistance provided by CLIMAAX was a critical support in this context and highly appreciated by the local team.
- Data-related challenges:
  - Related to the esolution of available pan-European data, for instance in the heatwave workflow, which complicated the analysis. Nevertheless, the results - especially those visualized through the interactive map - provided a sufficiently informative basis for guiding early risk management efforts, even before the CRA is refined with local datasets. In Phase 2, the municipality plans to incorporate more detailed local data to strengthen and streamline the analysis.
  - Related to the lack of local data: a remaining challenge to be addressed in the next project phase. In Phase 2, the project team will prioritize identifying, collecting, and integrating such data - not only for climate indicators but also for non-climatic risk factors, such as social and economic vulnerabilities, which are key to understanding exposure and sensitivity more comprehensively.

To ensure that the assessment aligns with local priorities, expectations, and practical realities during Phase 1 ad-hoc stakeholder engagement took part and the engagement confirmed that the subject is difficult and local ownership will be challenging to build. Therefore, for Phase 2 and 3, the municipality will simplify CRA outputs for broader audiences and emphasize actionable insights during policy discussion both in respect to citizen outreach and involving other institutional decision-makers at the regional and national level.

The initial CRA findings signalled to the municipality the need to prioritize buidling an actionable implementation plan for its climate adaptation strategy, which will be updated upon the completion of the refined CRA. Since both risks included in this current initial CRA are projected to exacerbate and are of considerable impact, the municipality needs to act strategically to make the most of its limited resources under the available time horizon. The initial findings also point to extreme precipitation being a risk to prioritize due to its rapid onset and more unpredictable nature but also due to the lack of capacity at present to respond to current and potential levels of the hazard. The urban heatwaves risk provides a longer window of opportunity to introduce adaptation measures but this would not justify a delayed start of actions as vulnerable groups suffer under the current state of hazard impacts considerably as well. To ensure the effectiveness of its efforts, the municipality will seek ways to have measures for both risks enhancing one another when possible and/or foreseeing how those can also assist with adaptation, prevention, or response to other compound hazards and cascading effects of the priority risks analyzed in this CRA.

4 Progress evaluation and contribution to future phases

The initial project output, generated through the application of the two workflows, marked the development of the first Climate Risk Assessment (CRA) for Pernik Municipality. The subsequent phase of the project will expand on this foundation by identifying existing datasets - or those that can feasibly be gathered and organized - to create a resource repository aimed at increasing both the detail and reliability of the assessment. These datasets will be integrated into the workflows to produce an enhanced version of the CRA, which will serve as the second deliverable.

As the methodology for the refined CRA remains consistent with that of Phase 1, the knowledge, experience, and outputs developed so far will play a critical role in shaping the next steps. Phase 3 will then build upon the outcomes of the first two phases to revise the municipality's climate adaptation strategy, outline a detailed action plan for its implementation, and initiate outreach to regional and national decision-makers. The objective will be to secure support for specific adaptation measures and foster better coordination of regional preventive efforts.

In addition, this initial CRA from Deliverable 1 will serve as a cornerstone for outreach and stakeholder engagement during Phases 2 and 3. The focus of municipal communication in these phases will fall on conveying key findings and much less so on explaining technical processes as experience has proven thah effective communication of climate-related risks to the broader public and stakeholders that amounts to addressing non-specialist audiences benefits from this approach. By prioritizing results over methodology, the goal is to present complex, multi-hazard climate assessments in an accessible and relatable way that can foster greater understanding and encourage active involvement.

In this spirit, once Phase 2 is underway, the municipality intends to carry out a consultation meeting with local residents and businesses and regional authorities to share the results and request input to granulate the analysis. These outreach efforts will aim to engage a diverse range of stakeholders and residents. These activities will be grounded in the findings from the first CRA (Deliverable 1), serving both to raise public awareness and to gather feedback that will inform the CRA's refinement.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
Successfully apply 2 workflows ("Heatwaves" and "Heavy Rainfall") for Deliverable 1;	Completed during Phase 1.
Hold 1 consultation meeting with local and regional stakeholders to: (1) present the PERNIKCLIMAACT project and the initial climate risk assessment (CRA) results (from Deliverable 1), (2) announce communication channels for stakeholders to share available data, input, and experiences that would support the refinement of the CRA, as well as (3) to collect any feedback and input on climate risks that the stakeholders can readily share at the meeting (meeting to be held after Deliverable 1 is completed so as to feed into the data for Deliverable 2);	To be completed in Phase 2 after completion of Deliverable 1 and before completion of Deliverable 2.

Key performance indicators	*Progress*
Take 3 communication actions to share results/progress with stakeholders (e.g. media publications, social media posts, in-person and online events, dissemination and delivery of presentations), whereby the following aims will be achieved respectively: ○ announcement of the results from Deliverable 1 and raising awareness on how the CRA will benefit local residents by improving municipal and regional climate change adaptation policy and efforts; ○ announcement of results from Deliverable 2 and raising awareness on how the refined CRA will benefit local residents by improving municipal and regional climate change adaptation policy and efforts; ○ announcement of results from Deliverable 3 and raising awareness on how the refined CRA has been used to improve the municipal climate change adaptation strategy.	To be completed in phases 2 and 3.
Successfully apply 2 workflows for Deliverable 2 (Phase 2);	To be completed in Phase 2.
Hold 1 discussion meeting with local and regional stakeholders on the PERNIKCLIMAACT refined climate risk assessment and its impact on the municipal adaptation strategy (Phase 3);	To be completed in Phase 3.
Update the Climate change adaptation strategy for the municipality of Pernik based on the CRA and supplement it with an action plan (Phase 3);	To be completed in Phase 3.
Carry out 1 outreach initiative to regional authorities to promote prevention based on the produced CRA and contribute to improved regional coordination (Phase 3);	To be completed in Phase 3.
Carry out 1 outreach initiative to national level policy-makers to promote prevention based on the produced CRA and to advocate for funds for the municipality to implement adaptation measures based on the CRA and its Climate Adaptation Strategy (Phase 3).	To be completed in Phase 3.

Table 4-2 Overview milestones

Milestones	*Progress*
M1: Test of workflow 1 conducted (Phase 1);	Completed during Phase 1.
M2: Workflow 1 successfully applied (Phase 1);	Completed during Phase 1.
M3: Test of workflow 2 conducted (Phase 1);	Completed during Phase 1.
M4: Workflow 2 successfully applied (Phase 1);	Completed during Phase 1.
M5: Climate Multi-Risk Assessment (Deliverable 1) completed and submitted (Phase 1);	Completed and Deliverable 1 submitted during Phase 1.
M6: Attend the CLIMAAX workshop in Barcelona (Phase 1 tentatively as indicated by the CLIMAAX coordinator);	Completed during Phase 1.
M7: Consultation meeting with local and regional stakeholders to discuss the CRA under Deliverable 1 and announce a channel for collecting input on climate risks completed (Phase 2);	To be completed in Phase 2.
M8: A database of available and relevant to the workflows regional and local data created (Phase 2);	To be completed in Phase 2.
M9: Refined multi-risk assessment (Deliverable 2) completed and submitted (Phase 2);	To be completed in Phase 2.
M10: Climate Change Adaptation Strategy of the Municipality of Pernik reviewed and upgraded based on the refined climate multi-risk assessment (Deliverable 3) and supplemented with an action plan for its implementation (Phase 3).	To be completed in Phase 3.
M11: A discussion meeting on the refined multi-risk assessment with local and regional stakeholders and its impact on the municipal climate change adaptation strategy held (Phase 3).	To be completed in Phase 3.
M12: An out-reach effort to national authorities to advocate for funding for climate adaptation measures in the municipality on the basis of the multi-risk assessment initiated (Phase 3).	To be completed in Phase 3.
M13: An out-reach effort to regional authorities advocating for an improved regional approach to planning and	To be completed in Phase 3.

Milestones	*Progress*
prevention in respect to climate change impact and disasters, based on the multi-risk assessment initiated (Phase 3).	
M14: Attend the CLIMAAX workshop held in Brussels (Phase 3 tentatively as indicated by the CLIMAAX coordinator).	To be completed in Phase 3.
M15: Subcontracting support completed (Phase 3).	To be completed in Phase 3.

5 Supporting documentation

- Deliverable 1 CRA Report in PDF - current document, submitted on the CLIMAAX Deliverable Platform.
- Zip file with plots, results, and workflow notebooks for hazard and risk for Workflow 1: Urban Heatwaves - Zenodo DOI: 10.5281/zenodo.17232462
- Zip file with plots, results, and workflow notebooks for hazard and risk for Workflow 2: Extreme Precipitation - Zenodo DOI: 10.5281/zenodo.17232462

6 References

Pernik Municipality: Strategy for adaptation to climate change of the Municipality of Pernik, September 2024.

Pernik Municipality: Plan for Disatster Protection of Pernik Municipality, 2023.

National Statistical Institute: Population as of 31.12.2023 categorized in regions, municipalities, residence and sex, https://shorturl.at/Lzj6H, 2023.

State Gazette: Disaster Protection Act, 5 July 2016.

World Bank, National Strategy for Adaptation to Climate Change of the Republic of Bulgaria, commissioned by the Ministry of Environment and Water, 2019.

National Statistical Institute: GDP and GVA per economic sectors and regions with 2023 data, https://shorturl.at/p5KF7, 11 February 2025.