VALIDATED LOCAL RISK ACTIONABLE DATA FOR ADAPTATION

Deliverable 1.1.

Demonstrator specific climate impact chain analysis

Dr. Cristobal Reveco
Scientist
Helmholtz-Zentrum Hereon
Climate Service Center Germany

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Coordinator – Administrative information	
Project coordinator name	Dr. Jörg Cortekar
Project coordinator organization name	Helmholtz-Zentrum Hereon GmbH
Address	Max-Planck-Straße 1, 21502 Geesthacht
Phone Numbers	+49 (0)40-226 338-445
Email	joerg.cortekar@hereon.de
Project web-site	https://valorada-project.eu/

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1. Executive summary

1.1 Description of the deliverable content and objectives

Deliverable 1.1. aims to generate fundamental knowledge on climate risks faced by the demonstrator participants in Valorada. By conducting participatory workshops in each demonstrator, specific climate impact chains have been formulated. The climate impact chains facilitate the assessments of the impacts of climate change on key community systems, describing how multiple climate hazards cascade and generate risks on society and ecosystems through different causal webs. Based on this assessment, the most relevant factors contributing to climate risks are identified.

A total of 10 climate impact chains have been developed (presented from annex 3 to 11). Each impact chain includes: (1) cause-effect impact sequences; (2) exposure factors; (3) sensitivity factors; and (4) adaptive capacity factors. This deliverable makes a synthesis of the 10 impact chains generated during the project and it presents the key messages emerging from them.

Climate risk factors are analysed from myriad angles: characterised according to territorial characteristics and against different climate hazards, grouped according to topics, and ranked according to priority across demonstrators. Thus, Deliverable 1.1. aims to provide a comprehensive understanding of climate risk by revealing the complex interaction of impact, exposure, and vulnerability factors in relation to climatic, territorial, and human dimensions.

As part of Phase 1 of the VALORADA project, this deliverable contributes to illuminating key climate-risk issues through the collaborative development of climate-impact chains. These chains not only pinpoint areas where climate data can inform local risk management but also serve as foundational elements for other deliverables, including D.2.2. which seeks to characterise barriers and limitations to access, use, customise, and adapt EO and locally produced data. In addition, D.1.1. serves as a starting point for Task 1.3 regarding the selection of climate indicators to be considered in each demonstrator. D.1.1. further informs the development of data catalogues (WP2) and decision tools (WP4).

2. Introduction

2.1 About VALORADA

The effects of climate change vary considerably across regions according to distinct physical, environmental, social, cultural, and economic characteristics, resulting in different sensitivities to climate change. Hence, adaptation measures will have to be implemented at a local level to be efficient at reducing risk and vulnerabilities. Stakeholders such as regional and local authorities are key players in building a climate-neutral, resilient, and adaptive future.

Adaptive action requires considering both, local and global drivers of resilience against compounded risks and potential cascading effects caused by climate change (Westman et al. 2021). In this context, relevant climate information is a prerequisite to (1) anticipate climate changes, reduce uncertainty, and assess the risks for biodiversity, people, and infrastructures at regional and local scales; (2) plan adaptation policies, pilot territorial transition and assess the effectiveness of their measures; and (3) take advantage of the new perspectives offered.

Regions and municipalities produce large sets of non-climate data such as socioeconomic, demographic, or land-use data which can provide meaningful characterisation of climate risk and vulnerability at local scales. Hence, these non-climate datasets contain ***"potential climate value"***. Realising the climate value of non-climate data and enabling its connection with climate data through dedicated data-manipulation services, are promising strategies for boosting the adoption of available climate information and for transforming climate services into user-relevant decision tools. In response to the objectives set in the EU's Adaptation Mission, **VALORADA** will increase the use of available climate information in regional and local administrations by co-designing climate-data services that grant ***"climate-value"*** to locally sourced datasets in regions and communities.

Achieving VALORADA's vision and mission is embedded in a strong co-design process guiding VALORADA's methodology. In this context, VALORADA is structured around the following strategic and operative objectives:

- **Strategic Objective 1:** Assessing the data baseline for climate adaptation and climate resilience needed on a regional and local scale.
- **Strategic objective 2**: Showcasing the added-value of prototype data-manipulation tools through demonstration activities and evaluation.
- **Strategic objective 3:** Maximising the impact of VALORADA tools and applications following the FAIR principles.

2.2. Purpose and scope of Deliverable 1.1.

Deliverable 1.1. attends the **Strategic Objective 1** through the implementation of **Task 1.1,** which seeks to identify pivotal impacts of climate change on key community systems for each demonstrator. This task aims at generating the fundamental knowledge on climate risks faced by the demonstrator participants. Through participatory contextualisation workshops in each demonstrator location, specific climate impact chains have been formulated to characterise local climate risks. The climate impact chains are needed to assess the regional impacts of climate change on key community systems, including multiple hazards through, e.g., complex, and cascading effects. Based on this assessment, the most relevant contributors to local climate risks are identified, thereby enabling:

A. the prioritisation of data needs to support adaptation.

B. to shed light on the necessary climate and non-climate data needs to characterise local climate risk.

In shedding light on key climate risks and on the areas where knowledge about these risks is not clear, Task 1.1. and deliverable 1.1. provide key input to other tasks, including Task 1.3 Allocation of appropriate climate risk indicators for demonstrators; and task 2.2: Value-chain analysis of existing non-climate data. In addition, the climate impact chains represent the first steps towards the development of the data valorisation framework to be presented in deliverable 2.1.

3. Climate Impact Chains: concepts and methodology

3.1. Conceptual framework

Vulnerability assessments are critical for understanding and addressing climate threats to society and ecosystems, and for informing decisions on adaptation to climate change. These assessments rely on both climate and non-climate data to characterise climate-related risks, including hazards, exposure, vulnerability, and adaptive capacity. They require a combination of quantitative and qualitative data to assess how socio-ecological systems may be affected by future climate conditions (Hammill et al. 2013)

Data play a key role in understanding changes and trends in the manifestation of risks and in improving the capacity of systems to adapt to climate change. In the VALORADA project, climate impact chains are used as means to identify critical climate risks at the local level and to shed light on the data needed to characterise these impacts.

The vulnerability and risk analysis in VALORADA follows the conceptual framework established in the IPCC Sixth Assessment Report on Impacts, Adaptation and Vulnerability. (IPCC, 2022). This framework defines risk as the potential for adverse consequences associated with climate change and guides the assessment of climate-related risks and informs adaptation strategies (Pramova et al. 2013).

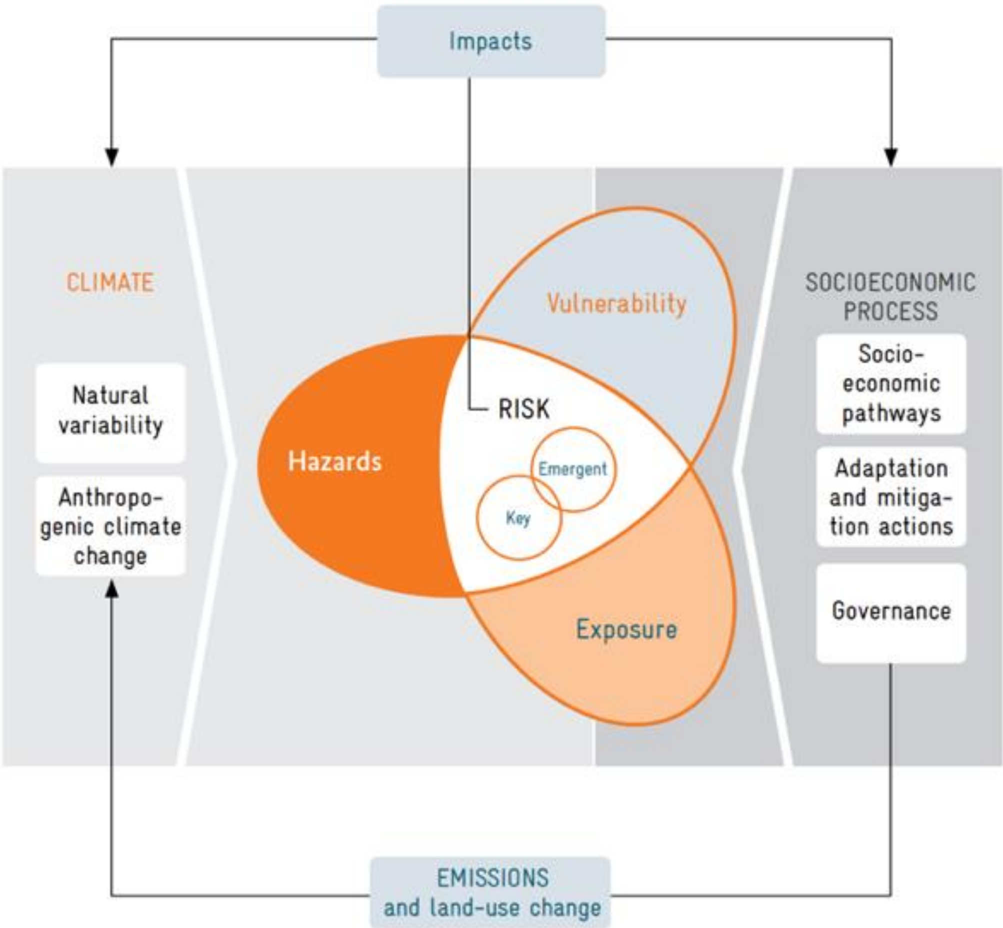


Figure 1: The constituents of climate risk. Source: IPCC 2014, p.1046

Climate-impact chains

Risks associated with climate change are often analysed in isolation, focusing only on specific economic sectors or ecosystems. However, this narrow approach can miss indirect impacts, risks of maladaptation and feedback loops. In contrast, climate impact chains provide a holistic and systemic view of the potential impacts of climate change. These chains illustrate how pressures propagate through a system, capturing both direct and indirect impacts along the way.

A climate-impact chain describes the relationship between a particular climate hazard and its impact on a specific area of influence. These chains aim to identify cause-effect relationships between different components within a system. They describe how a hazard evolves into a risk by considering exposure, potential intermediate impacts and associated sensitivity factors, and response/adaptation capacity (resilience) that reduces vulnerability (GIZ & EURAC, 2017).

An impact chain helps to better understand, systemise, and prioritise the factors that drive risk in the system of concern. The structure of the impact chain developed according to the IPCC AR5 and AR6 approach is based on the understanding of risk and its components.

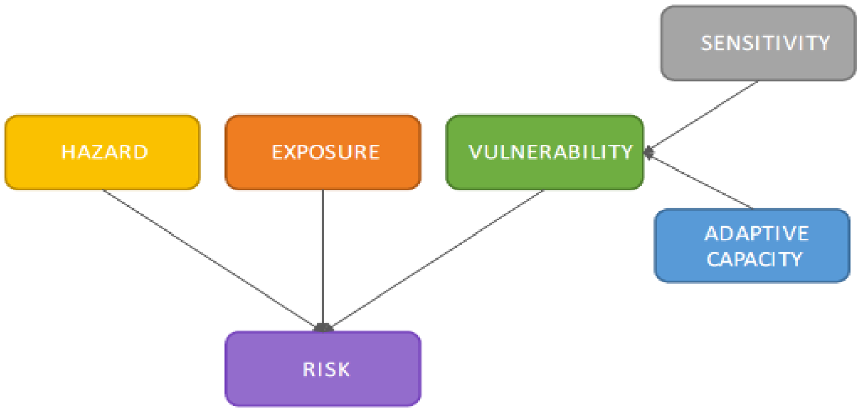


Figure 2: Risk components based on IPCC AR5 and AR 6. Source: ESPON-CLIMATE Update 2022 approach.

Developing climate-impact chains:

In the VALORADA project, we followed the methodology proposed by GIZ (GIZ & EURAC, 2017) for the development of Climate Impact chains. In following this approach, the generation of climate-impact chains were oriented by the following questions:

Overarching question: What is contributing to the risk and which data do we need to characterise such risk?

1. **Step 1: Identify climate impacts and risks.**
   Which major climate impacts and risks do affect your system of concern?
2. **Step 2: Determine hazard and intermediate impacts.**
   Which climate-related hazardous events or trends and their physical impacts pose a risk to the system of concern? Which intermediate impacts link the hazard and the risk?
3. **Step 3: Determine exposure.**

Which factors determine exposure?

4. **Step 4: Determine vulnerability.**
   Which attributes of the system contribute to the risk? We focus particularly on adaptive capacity and sensitivity.

3.2 Methodology

Elaboration of the climate impact chains:

The elaboration of the climate impact chains followed a sequential methodological structure:

Table 1: Methodological process

Development of a Local Climate Information Profile
↓
Workshop 1 design
↓
Data gathering through Workshop 1, implemented on each of the 5 demonstrators
↓
Data analysis, literature revirew, generation of climate impact chains
↓
Delivery of draft 1 of climate impact chains to each demonstrator and local partner for validation
↓
Development of final climate impact chain and report based on stakeholder validation

a. Local Climate Information Profile

The **Local Climate Information Profile (LCIP)** sought to identify key challenges around the management and integration of climate and locally sourced data needed to understand climate risks. The LCIP sought to derive key input needed to run tailor-made workshops in each of the demonstrators within the VALORADA project, as well as to provide insights for the development of data catalogues (WP2) and data management tools (WP4).

The LCIP consists of three parts:

(1) Visualising the climate context (risk and adaptive capacity).
(2) Identify the policies and processes involved in data management, the data stakeholders and the data infrastructure that constitute the data governance to use local data for addressing climate risk in each demonstrator.
(3) Assessment of the maturity level of local data governance schemes.

To comprehensively capture the climate risks relevant to each demonstrator, the data available to characterise these risks and the stakeholders involved in adaptation decisions, before each workshop local partners were requested to complete the LCIP together their respective demonstrators. In preparation for Workshop 1, the LCIP provided the knowledge base needed to understand the climate risks associated with each demonstrator.

b. Workshop series 1

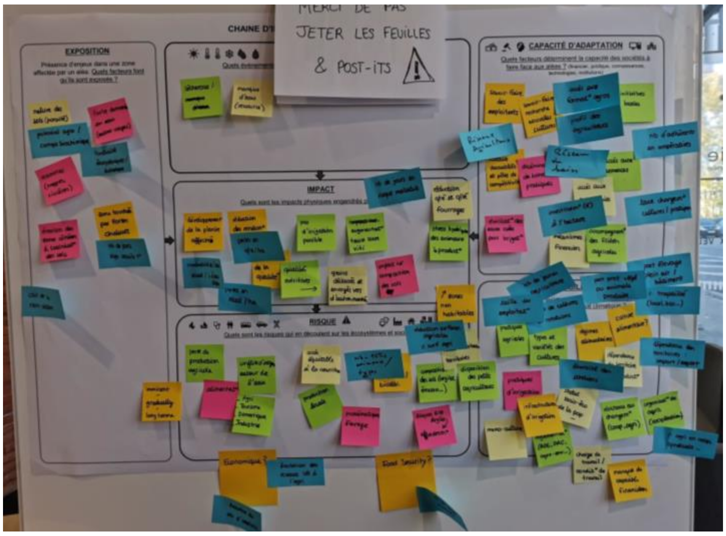
The two-day workshop included a series of activities ranging from an introduction to climate impacts to the identification of climate data sets. During the workshop, a 3-hour session was dedicated to building the foundation of each climate impact chain.

For this activity, stakeholders were given a pre-developed climate impact chain template with basic risk information (risk components and factors). Stakeholders were asked to focus on one risk. Participants were then given a set of questions to guide the identification of the different risk components in the impact chain.

Questions orienting the development of the climate impact chain:

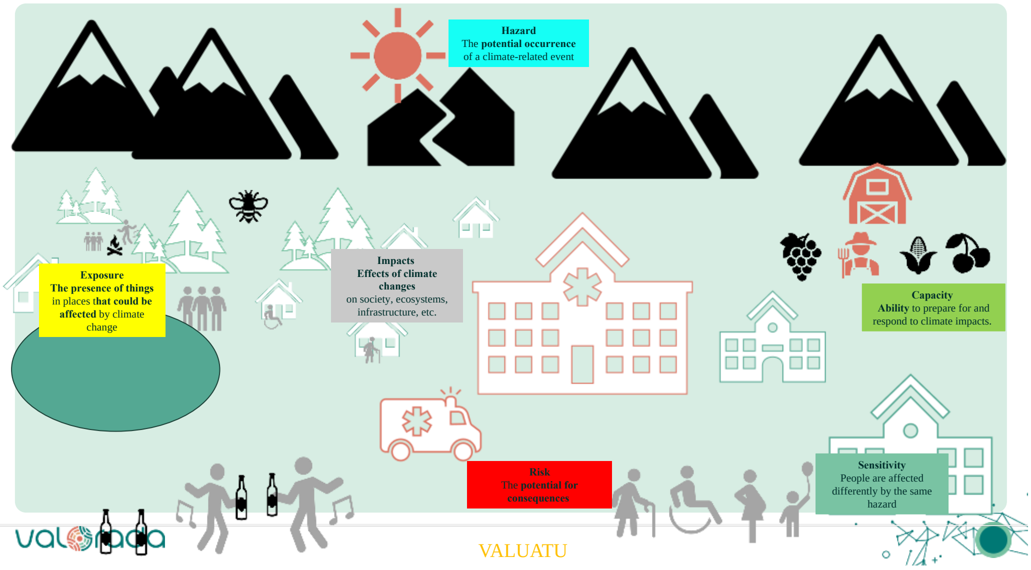
I. Which climate-related hazardous events or trends pose a risk?
II. Which intermediate impacts link the hazard and the risk?
III. Which factors determine exposure?
IV. Which aspects contribute to ecological and societal susceptibility?
V. Which factors determine the social capacities to cope with hazards or to adapt to changing conditions?
VI. What are the key factors identified in the climate impact chain that require attention more urgently? Why?

Picture 1. A template for a climate impact chain after its completion.



For those who may not be familiar with technical terminology, understanding the components of a climate impact chain can be challenging. These components include hazard and climate signal, risk, impact, exposure, and vulnerability. To facilitate comprehension about these concepts, a narrative has been created based on a fictional town called VALUATU, which experiences various climate hazards. This storyline provides a clear and comprehensive account that covers all aspects of risk. The full story of Valuatu can be found in Annex 2.

Picture 2: Valuatu and the different risk factors.



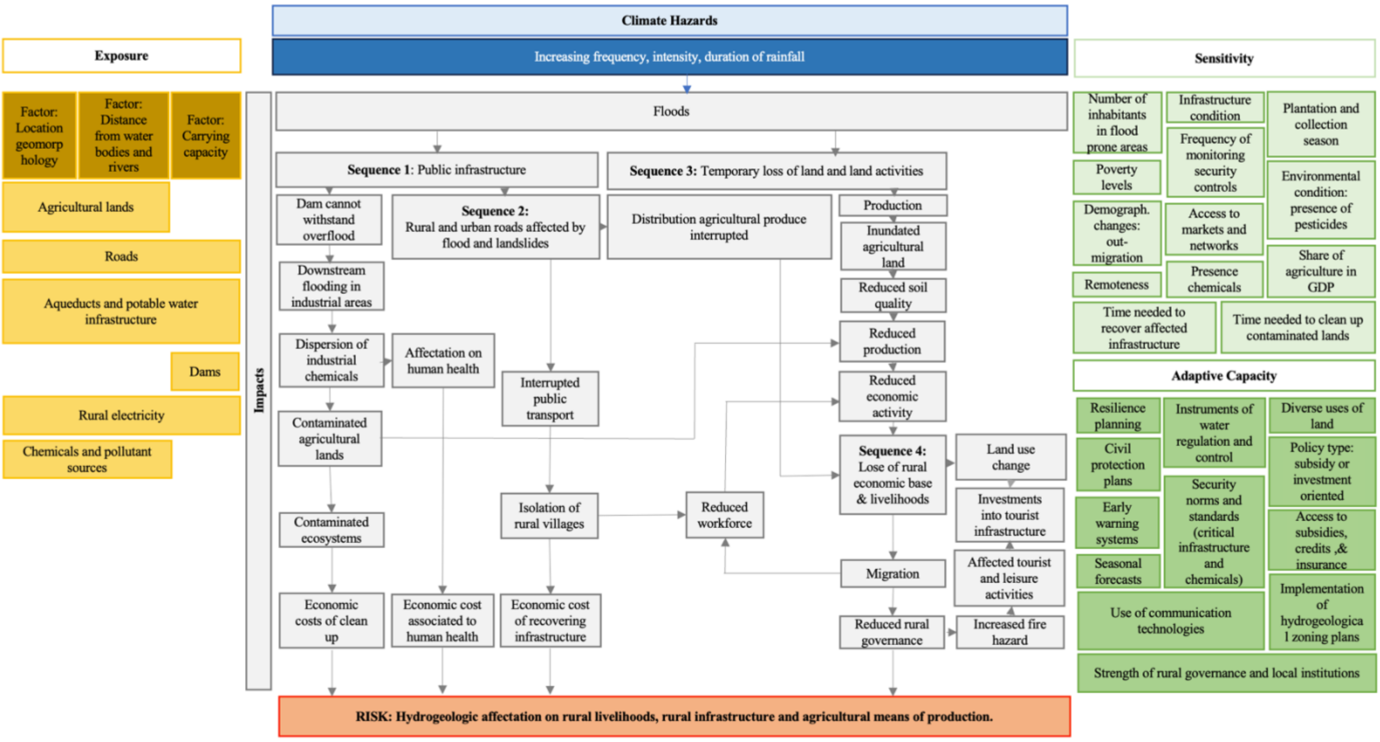
4. Climate Impact Chains: results

Through the development of diagrams or problem trees, in developing a climate impact chain the aim is to contextualize the municipality's or region’s situation regarding already experienced climate events, allowing for the preliminary identification of local impacts and effects resulting from climate change, both negative and positive. These diagrams graphically represent the cause-effect relationships of impacts, vulnerabilities, and exposures in the context of climatic risk on specific sectors or areas, along with the consequences this may have for the demonstrator.
Based on the climate change hazard affecting the municipality/region and on the problem trees, a series of representative impact chains linking each climate hazards to a specific risk were proposed.

The climate impact chain diagram showed below represents through different colours the key factors that require attention more urgently:

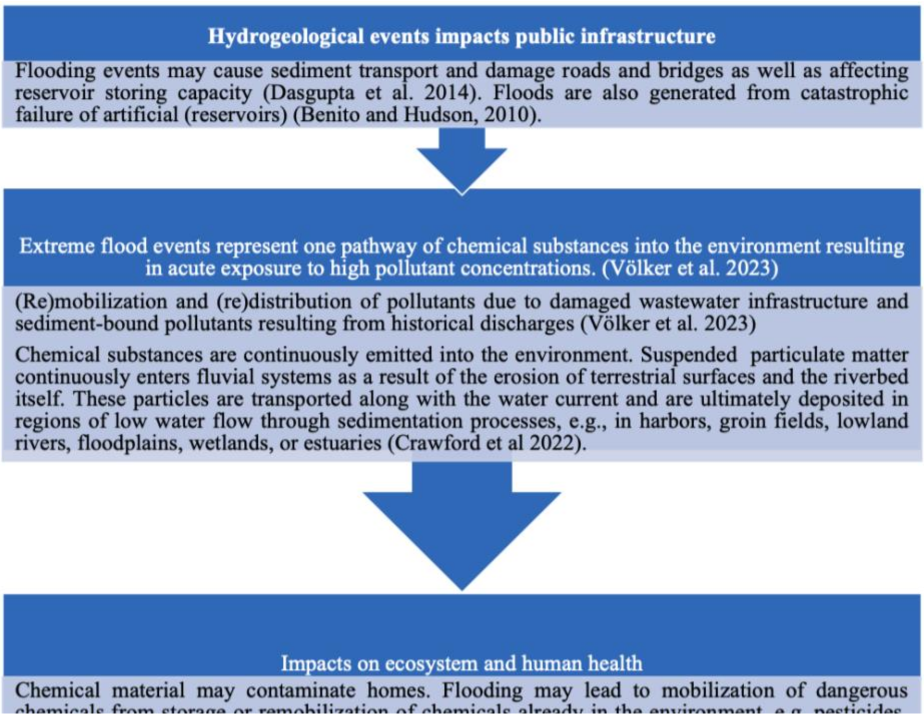
I. Blue: the climate-related hazardous events or trends that pose a risk.
II. Red: the climate risk.
III. Grey: the intermediate impacts linking the hazard and the risk.
IV. Yellow: the factors that determine exposure.
V. Light green: the aspects that contribute to ecological and societal sensitivity.
VI. Dark green: the factors that determine the social capacities to cope with hazards or to adapt to changing conditions.

Figure 3. Example of a climate impact chain diagram:



Once the sequential series were generated, the experience from stakeholders informed each of the different links in the sequential series. Afterwards, a literature review was undertaken to identify documented examples that could help complement stakeholders' perspectives. An example of a single impact sequence supported by literature review is show in figure 4 below.

Figure 4: Example of a single impact sequence supported by literature review.



4.1 Analysis: Shedding light on key risks, impacts, vulnerability, and exposure factors

This section presents the main results of the climate impact chains (abbreviated CIC). While a detailed view of each demonstrator's climate impact can be found in annexes 3 to 11, this section presents the main results and a synthesis of the key elements identified across the demonstrators.

The overview of key topics across the CIC organised as follows.

- Climate hazards in relation to territorial features
- Risks
- Impacts
- Exposure factors
- Sensitivity factors
- Adaptive capacity factors

4.1.1 Climate hazards in relation to territorial features

Five demonstrators were involved in generating the 10 Climate Impact Chains. Among them, three demonstrators chose to address climate issues within urban areas, two focused on rural dimensions and the remaining five explored climate risks affecting both, urban and the surrounding rural environment.

Table 2: List of demonstrators based on their territorial definition:

Demonstrator	Territorial definition
Prerov (Czech Republic)	Urban
Mlada Boleslav (Czech Republic)	Urban
Toulouse and Montpellier (France)	Urban
Sicoval, Occitanie (France)	Rural
Molise (Italy)	Rural
Central Greece (Eovia) 1	Urban-Rural
Central Greece (Eovia) 2	Urban-Rural
Burgas 1 (Bulgaria)	Urban-Rural
Burgas 2 (Bulgaria)	Urban-Rural
Gabrovo (Bulgaria)	Urban-Rural

Key issues of concern emerging from territorial differences:

- **Urban features vis-à-vis climate hazards**
  - European surface air temperatures have risen almost 1°C higher than the global average since pre-industrial times, with 2022 marking the hottest European summer on record (van Daalen et al., 2022).
  - Urban heat island (temperature difference between inside the city and outside it) can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning, inducing also earlier spring-time flowering in urbanized areas compared to surrounding rural areas (Richter 2015).
  - The impact of climate change on urban biodiversity and ecosystems is already evident, which has led to increased vulnerability, particularly in biodiversity hotspots and essential ecosystem services. It is worth noting that virtually all urban ecosystems are affected by climate change and the urban heat island effect, resulting in changes in temperature, precipitation, evaporation rates, and air quality. These modifications highlight the connection between climate change, urbanisation, human wellbeing, and biodiversity (Ebi et al 2021; Jacobs et al 2014; Rosenzweig et al. 2015; Solecki & Marcotullio, 2013; Luck & Wu, 2002; Frumkin et al., 2008; Keim, 2008).
  - In urban areas, temperatures can be influenced by human-made heat sources, such as vehicle emissions and wasted energy from buildings. Future projections suggest that there may be potential infrastructure damage and increased road maintenance costs. Urban ecosystems are crucial for biodiversity and serve as natural capital for climate adaptation and mitigation, while also contributing to the well-being of residents (Ebi et al 2021; Rosenzweig et al. 2015; Solecki & Marcotullio, 2013; Frumkin et al., 2008).

- **Rural features vis-à-vis climate hazards**
  - The impacts of climate change on rural settlement patterns, livelihoods and incomes are driven by multi-stage causal chains. These chains typically fall into two categories. One involves extreme events such as floods and storms that damage rural infrastructure and directly affect livelihoods. The other type involves impacts on agriculture or ecosystems that are critical to rural populations, resulting from extreme events, altered patterns of extremes due to climate change, or shifts in average conditions (Dasgupta et al., 2014).
  - Underlying conditions such as poverty, remoteness, dependency on agricultural production and patterns of outmigration make rural areas particularly vulnerable to the effects of extreme precipitation, drought, and extreme high and low temperatures.
  - Increasing temperature, droughts and storms generate burnable biomass, which in connection to poor forest management practices, provide a fertile ground for wildfires.

4.1.2. Climate risk

Risk is defined as ‘the potential for consequences [= impacts] where something of value is at stake and where the outcome is uncertain (...). Risk results from the interaction of vulnerability, exposure, and hazard (...).’ (GIZ & EURAC, 2017, p.17).

The identified risks within the climate impact chains encompass a diverse array of topics. These range from the threats of extreme temperatures and droughts to human well-being, as well as urban ecosystem integrity. They extend also to the impacts of floods disrupting infrastructure, logistics, and local economies in both, urban and rural areas.

The information presented in climate impact chains evidences the intricate interplay between climate change and various developmental trajectories, including urbanization, population growth, socioeconomic status, policy formulation, and territorial planning. Additionally, it underscores the influence of human behaviour and institutional characteristics which can either amplify or mitigate climate-related hazards. These are further discussed below along the topics of exposure and sensitivity.

Table 3: Risks attended in each demonstrator.

City / region	**Risk attended**
Prerov	Degradation of urban ecosystems due to urban heat and droughts
Mlada Boleslav	Extreme high temperatures on people’s health in the context of urban transport
Molise	Floods affecting agricultural livelihoods and rural infrastructure
Toulouse	Urban warming affecting people's health
Sicoval, Occitanie	Drought affecting agricultural production and rural livelihoods
Central Greece (Eovia) 1	Wildfire affecting infrastructure
Central Greece (Eovia) 2	Extreme precipitation affecting the agricultural sector
Burgas 1	Urban warming on people and ecosystems
Burgas 2	Flash floods on urban and surrounding rural areas
Gabrovo	Drought and wildfires affecting ecosystems and urban areas

Table 4: Climate signals considered in each climate impact chain:

	Prerov	Mlada Boleslav	Molise	Toulouse	Sicoval, Occitanie	Central Greece 1	Central Greece 2	Burgas 1	Burgas 2	Gabrovo
High temperature	x	x		x		x		x		x
Extreme precipitation			x				x		x	
Drought	x				x	x		x		x

High temperature

Most demonstrators (6) decided to focus on high temperatures (i.e., increase in the average temperature, heatwaves, and urban warming) as the most urgent issue of concern to be attended in relation to the impacts on human health and ecosystems. High temperatures were considered in terms of urban warming (the increase in average urban temperature), heat waves (extreme temperatures in a defined period), and the urban heat island effect (the territorial phenomenon of higher temperatures in parts of the city due to elements of the built environment).

Worldwide, heatwaves have increased in frequency, intensity, duration, and spatial extent due to climate change, with further increases projected (Richter, 2016). In Europe, intense heatwaves are expected to occur more frequently and become more severe due to climate change. Feyen et al. (2020) estimate that with a 1.5°C increase, over 100 million Europeans would be exposed to intense heatwaves annually. Assuming present vulnerability and no additional adaptation, annual fatalities from extreme heat in Europe could rise from 2,700 deaths now to nearly 30,000 with 1.5°C global warming, 50,000 with 2°C and 90,000 with 3°C. The increase in human exposure to and fatalities from extreme heat is most pronounced in southern European countries and the highest number of fatalities will occur in France, Italy and Spain (Feyen et al 2020).

Higher temperatures also became an issue of concern in the context of wildfires in Eovia and Gabrovo. It is expected that the rise in temperature due to climate change may increase fuel dryness and decrease relative humidity, particularly in regions with reduced rainfall. It is widely acknowledged that the increased frequency of extreme climate events may have a significant impact on the susceptibility of forests to fires.

Drought

Five demonstrators representing urban and rural settings expressed concern over the risk of meteorological droughts, broadly defined as low precipitation. In the cases where other types of droughts emerged (agricultural, hydrological, and socio-economic drought), these were treated as phenomena provoking or exacerbating climate impacts; hence, they are discussed within each respective impact sequence. The key issue of concern regarding droughts was the perception of their increase in frequency, extent of occurrence, and duration which affects human livelihoods and ecosystem services. In this context, according to Furtak et al. (2022), in the last century, 45 severe droughts occurred in Europe, affecting millions of people, and causing economic losses of more than $27.8 billion. Currently, on average, 15 % of the European Union's land area and 17 % of its population are affected by drought.

For clarification purposes, the different types of droughts and their connection to each demonstrator is specified below:

Meteorological drought: broadly defined by low precipitation	Sicoval, Eovia, Burgas and Gabrovo
Agricultural drought: deficiency in soil moisture, increased plant water stress	Sicoval
Hydrological drought: reduced streamflow	Prerov and Burgas
Socio-economic drought: balance of supply and demand of water to society	Sicoval, Eovia, Burgas, Gabrovo

Extreme precipitation

In the context of extreme precipitation, three demonstrators (Molise, Eovia and Burgas) expressed concerns regarding the increase of extreme rainfall provoking flash floods in both, urban and rural areas.

Europe has recently experienced a 60 % increase in flood risk, and climate change is expected to intensify storms and floods, including flash floods and urban flooding (Furtak et al. 2022). Future flood losses will depend on climate change, settlement patterns, land use decisions, flood forecasting, warning systems and adaptation measures (Arent et al. 2014). Floods are expected to increase in frequency and severity under all climate scenarios, damaging road and rail infrastructure and causing landslides due to more extreme rainfall events. Landslides -as evidenced in Molise- can lead to long-term disruption and restricted access to certain areas for certain populations. In addition, demonstrators in Molise and Burgas expressed concerns due to the potential dispersion of chemicals from nearby industry due to floods, as well as the potential collapse of critical infrastructure such as dams and roads.

Interaction between extreme precipitation and heat

Demonstrators in different regions expressed concern about the interaction of different climatic conditions throughout the year. This concern was particularly evident in the cases of Eovia and Burgas, where demonstrators recognised the interplay of extreme precipitation, high temperatures and drought as a driver that escalates climate risk.

A notable example of this dynamic is the increase in combustible biomass in forests. For example, in Greece, studies have shown that patterns of a wet season with higher precipitation coupled with prolonged drought are a particularly dangerous combination, as rainfall allows for more plant growth, which then dies and dries out during the drought period, increasing the amount of combustible biomass available to fuel and spread flames (Greenpeace, 2023). Furthermore, storms have caused significant damage to the forested areas of Attica, with several trees broken and felled. This situation greatly influenced the fuel load of the forest and the amount and distribution of downed heavy fuels (Almeida et al. 2023).

Finally, it is worth noting that none of the demonstrators highlighted low temperatures as a primary concern. Although Burgas noted that extreme winds and snowstorms can cause traffic and communication disruptions, local stakeholders chose to prioritise the previously presented climate signals.

4.1.3. Impacts

Impacts are defined as:

'the effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system.' (GIZ & EURAC, 2017, p.17)

A total of 34 impact sequences were developed derived from the 10 climate risks described in the previous section. Impact sequences for each different demonstrator are presented against specific climate hazards, as shown in table 5, below:

Table 5: Impact sequences across demonstrators according to climate hazard.

	Impact sequence	Prerov	Mlada Boleslav	Molise	Toul ouse	Sicoval, Occitanie	Central Greece 1	Central Greece 2	Burgas Heat	Burgas floods	Gabrovo
Heat & drought	Loss of ecosystem services (urban and rural)	x	x	x	x	x	x	x			
	Intrusion of foreign pests	x			x	x	x		x		x
	Changes in species distribution	x			x	x	x		x		x
	Increased species competition	x			x	x	x		x		
	Stress for aquatic life	x				x			x		x
	Reduced institutional capacities for maintenance & monitoring urban ecosystems	x			x		x		x		
	Changing physiological processes	x			x	x					
	Increased air pollution affecting human health				x				x		x
	Modification of ecological interaction	x				x					x
	Soil degradation and desertification					x	x				x
	People’s livelihoods affected					x			x		
	Reduced availability of water	x			x						
	Increased air pollution affecting ecosystems	x									
	Reduced fodder for livestock			x							
	Animal wellbeing					x					
Heat	People’s health	x	x		x				x		x
	Increase risk of traffic accident		x		x				x		
	Physical discomfort and mental stress				x				x		x
	Damaged road infrastructure		x						x		
	Damaged Vehicles due to overheat.		x						x		
	Increased water and food-borne disease								x		x
	Reduced productivity				x				x		
	Risky behaviour while driving		x						x		
	Health of road operators affected		x								
	Impacts on critical urban infrastructure				x						
	Increased transmission of vector-borne diseases										x
Extreme PP	Dissemination chemical pollutants			x				x		x	
	Loss of ecosystem services			x							
	Road interruption			x				x		x	
	Soil degradation			x				x		x	
	Change in land use			x				x		x	
	Out migration			x				x			
	Interruption of public services			x						x	
Combination T & PP	Extreme precipitation, windstorms, plagues followed by drought and extreme temperatures increases tree mortality and burnable biomass/ fuel generation						x	x			x
	Increased risk fire due to abandonment of lands			x			x				
	Wildfires affecting livelihoods.						x	x			

Table 6 presents the impact sequences ordered by commonality (the number of mentions) across the different demonstrators. It is worth noting that ecosystems and human health related impacts are the most represented impact sequences, which suggests the importance of revealing the dynamics, feedbacks and causal relationships that shape human-environment systems.

Table 6: Topics covered in the impact sequences across the demonstrators.

	Impact sequence	Number of mentions across demonstrators
Heat and drought (combined)	Loss of ecosystem services (Urban and rural)	7
	Intrusion of foreign pests	6
	Changes in species distribution	6
	Increased species competition	5
	Stress for aquatic life	4
	Reduced institutional capacities for maintenance & monitoring urban ecosystems	4
	Changing physiological processes in ecosystems	3
	Soil degradation and desertification	3
	Modification of ecological interaction	3
	Reduced availability of water	2
	People's livelihoods affected	2
	Animal wellbeing	1
	Increased air pollution affecting ecosystems	1
	Reduced fodder for livestock	1
Heat	People's health (Includes all related variables: physical discomfort, mental stress; respiratory disease due to air pollution)	12
	Increase risk of traffic accident	3
	Damaged critical infrastructure	3
	Increased water and food-borne disease	2
	Damaged Vehicles due to overheat.	2
	Reduced productivity	2
	Risky behaviour	2
Extreme PP	Road interruption	3
	Soil degradation	3
	Changes in land use	3
	Dissemination chemical pollutants	3
	Migration	2
	Increased transmission of vector-borne diseases	1
Combinatio n T & PP	Increased burnable biomass. (increased tree mortality due to extreme precipitation, windstorms, plagues followed by drought and extreme temperatures)	3
	Increased hazard of wildfire due to abandonment of lands	2
	Wildfires affecting livelihoods.	2

The social and environmental determinants of health approach (WHO 2014) was employed as a conceptual framework to analyse climate risks. This approach recognizes the multifaceted nature of health, which includes not only individual factors but also broader social, economic, and environmental influences. This approach enables the identification of underlying causes of human vulnerability vis-à-vis climate change, such as poverty, education, housing, and environmental conditions.

- Social determinants of health, include “the unequal distribution of power, income, goods, and services, globally and nationally, the consequent unfairness in the immediate, visible circumstances of peoples lives’ – their access to health care, schools, and education, their conditions of work and leisure, their homes, communities, towns, or cities – and their chances of leading a flourishing life” (Commission on Social Determinants of Health, 2008).
- Environmental determinants of health, include “… all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours … targeted towards preventing disease and creating health-supportive environments (including clean air and water, healthy workplaces, safe houses, community spaces and roads and managing climate change) (WHO 2014).

This conceptual approach facilitated interaction of a diverse set of professional disciplines and sectors during the workshops, facilitating meaningful interactions among professionals from social services, urban planning, and environmental management. The collaboration between disciplines and sectors enabled the development of a comprehensive understanding of human well-being in the context of climate change in each of the demonstrators, which is further reflected in each of the climate impact chains presented in the annexes.

A summary of the core aspects revealed by the impact sequences is presented below:

I. Impacts emerging at the interphase of human and ecosystem health.

Owing to the interdependence of ecosystem well-being and ecosystem services, increased ecological stress results in a reduction in both the quality and quantity of ecological services. This, in turn, has a direct impact on the social and environmental determinants of health (Cairns and Pratt, 1995). For instance, it is worth noting that high temperatures have a detrimental effect on the welfare of urban inhabitants by undermining ecosystem services such as urban cooling, air purification, and recreational space provision, as highlighted by Rosenzweig et al. (2015). It is important to recognize that urban ecosystems are particularly susceptible to these impacts. Changes in temperature, precipitation, and other environmental factors can potentially disrupt ecosystem services and green infrastructure, which may lead to a cascade of environmental changes (Solecki & Marcotullio, 2013; Praskievicz & Chang, 2009). These alterations may increase the vulnerability of urban ecosystems, biodiversity, and ecosystem services to geohydrological threats such as groundwater quality reduction, subsidence, and salinity intrusion (Frumkin et al., 2008; Keim, 2008).

The case of Prerov exemplifies the importance of considering the impact on urban ecosystems. City representatives decided to address the risks of urban heat, warming, and droughts in relation to the degradation of urban ecosystems. In Prerov, it is projected that the number of hot days (with temperatures above 30°C) will increase as temperatures rise. It is projected that in the mid-century, there may be an increase in the number of hot days with temperatures exceeding 30°C, including more frequent and longer heat waves. In this context, the urban ecosystem of Prerov may face degradation due to various impacts, such as the introduction of foreign pests and changes in disease patterns, alterations to water conditions that may pose stress to aquatic life, changes in species distribution, and modifications to ecological interaction networks, among others. As urban ecosystems are degraded, important ecosystem services that support urban resident's wellbeing are jeopardised, including the availability of green areas that cool the city or that provide space for recreation.

Moreover, it is important to note that the reduction in social determinants of health has raised concerns regarding social justice, particularly in communities with limited resources who struggle to cope with high temperatures as indicated in the case of Toulouse.

The impact of extreme high temperatures on human health is multifaceted and varies based on factors such as timing of exposure and nature of activity. For example, the urban heat island effect is particularly pronounced at night when stored daytime heat is released (Ebi et al., 2021), making it difficult for the elderly or children to find alternatives to escape the night heat. The urban heat island effect became an issue of concern across all demonstrators discussing high temperatures in urban areas.

In the case of Toulouse, the impact chain draws attention to the potential impact of urban warming on the health of residents, citing the deterioration of social and environmental determinants of health as a key concern. The impact chain notes that increased temperatures in private households can cause physical discomfort, and mental stress, while at work can reduce productivity.

Furthermore, as discussed in Mlada Boleslav, higher temperatures increase the risk on drivers and pedestrians in urban areas, since heat affects road infrastructure, necessitating maintenance work during the summer season and exposing workers to extreme heat conditions, increasing the risk of occupational health issues, and increasing risky behaviour among drivers.

II. Impacts on critical infrastructure

Disruption in the functioning of critical infrastructure (energy systems, water provision, public transport) can have significant impacts on populations reliant on these systems. Such disruptions, stemming from both high temperatures and floods, were considered crucial across most demonstrators. For instance, in the case of heat, it was discussed that energy grids experiencing above-normal demand during peak times may lead to blackouts, which can in turn limit access to air conditioning, exposing vulnerable populations to risky temperatures (this was particularly evidenced in the case of Toulouse). Furthermore, water systems could experience stress due to a variety of factors, including increased demand, reduced capacity, or diminished water quality, increasing the risk of conflicts around water uses (as discussed in Toulouse and Prerov, wher epotentil conflicts could merge from environmental versus hygiene needs).

Additionally, lengthy extreme temperatures can cause surface overheating, which can accelerate road and railway deterioration. This deterioration can result in issues such as deformation and asphalt melting on roads, leading to unsafe conditions, reduced infrastructure lifespan, and increased maintenance costs (Jacobs et al., 2014; Slavich et al., 2022). In addition, it has been observed that higher temperatures can lead to an increase in the occurrence of rail buckling incidents, which may pose a risk to train travel (Jaroszweski et al., 2014). Issues related to road infrastructure were highlighted in Mlada Boleslav and Toulouse.

On the other hand, Molise, Eovia, and Burgas have brought attention to the impacts of floods. Key aspects highlighted in the impact sequences underscore that floods have the potential damage road and rail infrastructure by harming the sub-base layers. Also, the impact sequences shed attention to the issue of landslides causing damage to road, rail infrastructure, and riverbanks. This can lead to long-term interruptions of operation and/or limited access for certain population groups to economic areas. The case of Molise is particularly difficult, since the percentage of regional territory classified as having high hydrogeological criticality is 18.8 %. All 136 municipalities in Molise are affected, although with varying levels of risk and danger (Region Molise-b, 2017). In the case of Molise, a critical issue of concern emerged around the ability of dams to withstand heavy rainfall and the associated risk of chemical contamination, and pollutants from nearby industrial areas being spread during flood events. In addition, the timing required to repair disrupted infrastructure became a critical aspect in the discussion, as reparation times after floods can be long and maintain rural population isolated.

III. Impacts on livelihoods

The impacts on livelihoods, particularly affecting the economic stability of rural household stem from several angles. The impact sequences focused particularly on issues affecting the economic base of households due to problems related to reduced work employability, affected workforce, disrupted communication and mobility infrastructure, and forced migration.

In agricultural regions like Sicoval (Occitanie), concerns emerged due to the potential increase in conflicts over water resources needed for irrigation, energy, industrial, and domestic water access and due to decreased water availability from rivers and groundwater, compounded by rising demand, as discussed in Kovats et al (2014). Concerns also arise Sicoval, Eovia and Molise over declining agricultural productivity due to shifting precipitation patterns, resulting in excessive runoff, soil erosion, and nutrient depletion, affecting crop yields and the populations linked to agricultural production chains, as documented also by Furtak et al, (2023).

Rural communities, heavily reliant on agriculture and natural resources, are especially vulnerable to climate variability and extreme events, as previously shown in Dasgupta et al. (2014). Poverty, isolation, and marginalization exacerbate this vulnerability, limiting their capacity to respond effectively (Gowda et al 2018). Disruptions in infrastructure, like roads and communication networks, severely impact livelihoods by reducing workforce and economic activity, as highlighted in the three rural demonstrators.

Migration trends, particularly in Molise, reflect the impact of climate change on agricultural productivity and local economies, leading to workforce shortages and economic decline. In Molise, Sicoval and Eovia concerns emerged as outmigration can also affect rural governance and local institutions and induce land changes. The phenomenon of abandoning agricultural activities has triggered processes of lack of territorial governance, which increases the risk of both fires (recolonization of these areas begins with the settlement of shrub species) and hydrogeological instability (as documented in Region Molise-b, 2017). When the land is no longer used, fragmentation decreases while fuel connectivity increases and thus the fuel horizontal and vertical continuity, leading to increase fire risk (Chuvieco et al. 2023)

IV. Improving conditions for wildfires.

Wildfires have become a significant concern in Molise, Sicoval, and Eovia, highlighting governance challenges previously discussed. Eovia, Greece, has particularly emphasized concerns regarding wildfires due to due to high temperatures, droughts, and storms, which have led to increased tree mortality and a surge in burnable biomass, exacerbating fire risks

(previously documented by Kovaks et al. 2014). Forest fires are highly sensitive to climate change and are influenced by factors such as fuel moisture, precipitation, humidity, temperature, and wind speed. Projected temperature increases may lead to increased fuel dryness, particularly in regions with reduced rainfall, which could potentially intensify forest vulnerability to fires (Ministry of Environment and Energy, 2022). In Greece, severe drought events have already caused forest decline, and rising temperatures are further promoting the spread of invasive species, which could compound wildfire risks (Gowda et al. 2018).
Particular concerns emerged in Eovia due to the perceived lack of forest management and the surge in dry biomass, due to human activity being abandoned in some rural areas. For example, it was indicated by stakeholders that practices such as reforestation with mixed plantings of conifers (black pine, maritime pine, and Cedrus) are further aggravating the risk of wildfires (this is also documented in Alemeida et al. 2023). Furthermore, the intensive tourist activity in North Evia has also been identified as a cause for concern, as the use of light construction materials and proximity of holiday houses to forests can increase the risk of fire spread during incidents.

4.1.4. Exposure

Definition exposure:
'The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.' (GIZ & EURAC, 2017, p.17).
Importantly, when describing exposure, the focus is on the factors that generate or exacerbate exposure in the context of a specific impact sequence. Hence, we avoid naming stakeholders or places exposed to risk, and instead, we shed light on the issues that determine certain groups of people or assets experiencing higher levels of exposure under a similar hazard. In each impact chain, exposure factors are linked to specific sequences, providing thus an explanation of why specific assets, people, or places have different exposure.
Exposure factors are presented divided according to hazard: (I) urban heat, (II) heat and drought in rural areas, (III) heat and drought increasing exposure to fire hazards, and (IV) extreme precipitation.

I. EXPOSURE IN THE CONTEXT OF URBAN HEAT:

Factor 1: Location

Location refers to the physical space where people stand during periods of extreme temperature. In the context of transport, mobility options (car, bicycle, or walking) and flexibility (choosing when to commute) can determine different levels of exposure to commuters during a heat wave, as shown in Mlada Boleslav. Regarding urban ecosystems, in the case of Prerov, location negatively affects urban trees. Competition for space between trees and the provision of urban services (electricity cables) has provoked trees being taken away from the city centre to provide space for the extension of public luminary.

Factor 2: Physical conditions of built environment

This factor refers to aspects affecting green space and human health by contributing to unfavourable bioclimatic conditions in urban areas. These include building materials, housing density, or anthropogenic heat from transport and buildings that exacerbates urban temperature -as noted by Ebi et al. (2021)-.

Factor 3: Time and timing of exposure

This factor sheds light on how the risks associated with heat exposure can vary depending on the length of exposure (how long people are exposed) and the time when exposure occurs. For example, while some individuals may have access to cooler environments during the day, such as shopping centres or swimming pools, they may lack cooling amenities at night, which is particularly dangerous for vulnerable groups (elderly, children, pregnant women). However, it has also been observed that prolonged exposure to high temperatures can cause significant fatigue among operators of equipment and road builders working in hot weather (as documented by Jacobs et al., 2014). Additionally, individuals waiting at unsheltered transit stations during peak hours may also experience severe heat stress (Slavich et al., 2022).

Factor 4: Nature of activity (indoor – outdoor activity)

This factor focuses mostly on people's activities while at work or during commuting times. For outdoor workers, high metabolic heat production associated with occupational tasks combined with high ambient and radiant heat, low air flow, and sometimes high humidity, add to human heat strain (Ebi et al 2021). Furthermore, cyclists and pedestrians an be exposed to dehydration and heat strokes, and might also suffer from heat stress and health problems, potentially shifting to public transit or avoiding travel if they can't use a private vehicle (Jaroszweski et al. 2014).

II. EXPOSURE IN THE CONTEXT OF HEAT AND DROUGHT IN RURAL AREAS

Factor 1: Level of erosion and salinisation

It refers to soil erosion and salinization leading to negative impacts on soil properties and plant physiology, therefore significantly reducing agricultural production.

Factor 2: Water demand and availability

A region whose water level in aquifers and rivers is currently relatively low will be more exposed to the effects of climate change. Regarding demand, some areas are more exposed to risk if they have high water demands. Demand is linked to the nature of agricultural activities, but also to tourism or industry, and potential conflicts around water in some regions may be higher according to economic activities.

Factor 3: Human intervention in agroecosystem:

It refers to human intervention impacting agroecosystem and provoking erosion of natural habitats, or through processes of urbanization, pollution, and use of chemicals in agroecosystem.

III. EXPOSURE FACTORS IN THE CONTEXT OF WILDFIRES

Factor 1: Topography

It refers to terrain shape and morphology which greatly influence fire ignition and behaviour. Wind regimes, solar exposure, rainfall and air temperature and humidity distribution, all impact vegetation distribution and moisture contents (Chuvieco et al 2023).

Factor 2: Presence of fuel

It refers to the factors increasing the amount of burnable biomass, including fuel composition and weather conditions (including windstorms that increase dead tree which becomes burnable biomass). Vegetation load, structure, composition, and moisture status influence wildfire ignition and spread (Chuvieco et al. 2023).

Factor 3: Location

It refers to distance, which makes areas be exposed directly through contact with the fire front or via flaming embers; or indirectly through the dispersion of smoke, or by fire-caused changes in hydrological cycles or soil erosion (Chuvieco et al. 2023).

IV. EXPOSURE IN THE CONTEXT OF EXTREME PRECIPITATION

Factor 1: Location

It refers to instances where geomorphology amplifies exposure (physical extent of floodplains and catchment hydrology) (Thomson and Clayton, 2022).

Factor 2: Distance from water bodies and rivers

It refers to the proximity of streams, lakes, rivers that can overflow and affect populated areas.

Factor 3: Carrying capacity of specific infrastructure

Floods are also generated from catastrophic failure of artificial (reservoirs). Examples from Molise region highlights the exposure of dams under the risk of overflowing and the consequent impacts on towns, agricultural and industrial areas, which can further increase risk through the spread of chemicals.

In summary, the exposure factors identified across the demonstrators can be classified into four main groups. These categories highlight the significance of the space-time dimension as a determinant of exposure factors. Time factors are evident in the human activity category, where temporal dynamics such as the timing and duration of exposure are particularly relevant, especially concerning impacts related to heatwaves and the Heat Island Effect. The spatial dimension underscores the influence of underlying physical features of infrastructure, soils, and ecosystems in shaping exposure levels.

Table 7. Categories representing exposure:

Physical conditions of the built environment	Infrastructure	Physical conditions of the non-built environment	Human activity
It refers to urban features that increase the exposure of urban ecosystems and human health in the context of high temperatures, including building materials, housing density and the need for space to provide public infrastructure which competes against space for green areas.	It refers to how different location factors increase exposure of physical assets (distance to water bodies or to fire-risk areas). It refers also to the carrying capacity of specific infrastructure and the risk of failure of water reservoirs, roads, or water collection systems.	It refers to the factors increasing the amount of burnable biomass, including fuel composition and weather conditions. Also, it looks at the role of geomorphology in amplifying exposure to floods and of topography in amplifying fire risk. Finally, it refers to the original conditions of ecosystems (levels of erosion, salinisation, level of aquifers).	It refers to aspects that limit people's choices to avoid positioning themselves in areas of exposure to heat at specific time and for long periods of time: nature of activity (indoor/outdoor) that determines a higher number of exposure hours.

Table 8: Exposure factors	Prerov	Mlada Boleslav	Molise	Toulouse	Sicoval, Occitanie	Central Greece 1	Central Greece 2	Burgas	Burgas	Gabrovo
	Degradation of urban ecosystems due to urban heat and droughts.	Extreme high temperatures on people’s health in the context of urban transport.	Floods affecting agricultural livelihoods	Urban warming affecting people's health	Drought affecting agricultural production and rural livelihoods	Wildfire affecting infrastructure	Extreme precipitation affecting the agricultural sector	Urban warming on people and ecosystems	Flash floods on peri-urban areas (urban-rural interphase)	Drought and wildfires affecting ecosystems and urban areas.
Physical conditions of built environment										
Urban heat island affecting human thermal comfort	x	x		x				x		x
Urban heat island increasing air pollution	x	x		x				x		x
Urban heat island increasing energy use	x	x		x				x		x
High building density and a lack of urban green	x	x		x				x		x
Competition of green spaces with other urban needs (traffic/energy)	x									
Infrastructure										
Location of assets (dams, roads, factories)			x						x	
Infrastructure carrying capacity (Dams)			x				x		x	
Physical conditions of non-built environment										
Geomorphology			x				x		x	
Distance to water bodies			x				x		x	
Presence of fuel						x		x		x
Topography						x				x
Wind speed and direction						x				x
Distance between settlements and wildfire-prone areas						x				x
Smoke dispersion						x				x
Soil conditions: Level of erosion and salinisation					x					
Original condition of aquifers and water bodies					x					
Erosion of natural habitats					x					
Behavioural aspects and human activity										
Number of hours of exposure per person		x		x				x		x
Nature of activity (outdoor vs indoor)		x		x				x		x
Human intervention in agroecosystem					x					
Tourism and touristic activities exposed to fire risk						x				x

4.1.5. Vulnerability

Definition of vulnerability:

'The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.' (GIZ & EURAC, 2017, p.17).

VULNERABILITY COMPONENT 1: SENSITIVITY

Sensitivity is determined by factors that directly affect the consequences of a climate hazard. Sensitivity may include physical attributes of a system (e.g., building material of houses, type of soil on agriculture fields), social, economic, and cultural attributes (e.g. age structure, income structure), etc. (ibid).

I. Social factors mediating sensitivity to climate risk:

Factor 1: Demography

As urban population steadily increase, larger numbers of people are at risk of heat stress in the built-up environment of cities (Richter 2015).

Factor 2: Human physical attributes

The impact of extreme high temperatures primarily revolves around two key factors: aging and pre-existing health conditions. With aging emerging as a significant demographic trend (Feyen et al., 2020), a larger portion of society is vulnerable to extreme heat events. Research by Ebi et al. (2021) indicates that adults over 65 years and infants under 1 year, who are particularly susceptible to life-threatening effects of extreme heat, now face twice as many heatwave days compared to previous decades. Moreover, individuals with pre-existing health conditions, especially those with cardiovascular, respiratory, and renal diseases, are at heightened risk of heat-related mortality and morbidity (Hajat et al., 2010).

Factor 3: Economic status and social capital

It refers to the fact that under a similar climate hazard, people's susceptibility to harm differs according to factors such as poverty, unemployment, social isolation and little mobility, social cohesion, household structure, gender, education attainment, language proficiency, race, house-ownership and more (Puntub et al 2022). For example, social isolation, little mobility, being confined to bed, living alone, being unable to care for oneself are key risk factors during heatwaves (Ebi et al 2021; Hajat et al, 2010). Furthermore, the risk of water-borne illness is greater among the poor, infants, elderly, pregnant women, and immune-compromised individuals (Barata et al 2018).

Factor 5: Behavioural factors

The use of alcohol, medications, and illegal narcotics is associated with increased mortality during heat extremes (Ebi et al 2021). Some drugs, notably diuretic, psychotropic, and anticholinergic drugs, have been implicated in increasing the risk of heat-related death or illness (Hajat et al 2010).

In a second vein, regarding the risk of wildfires, human action (due to negligence) is a key determinant of fire ignition (Greenpeace, 2023). Some factors such as population density and aging, proximity to roads and urbanized areas, and social conflicts can increase the risk of fire ignitions (Knorr et al 2016 in Chuvieco et al. 2023).

In a third vein, resistance to change was identified as a central factor increasing sensitivity in rural areas. Climate change has many consequences that require the agricultural world to adapt. Adapting involves changing practices and habits. However, it is sometimes difficult for farmers to take ownership of these innovation processes, these new practices, or ways of doing things (as contended in Sicoval).

II. Factors mediating sensitivity of livelihoods

Factor 1: Production and distribution means

In the rural settings of Molise and Sicoval, factors such as crop choices, reliance on agricultural production, access to markets and networks were identified as significant contributors.

Factor 2: Remoteness

Remoteness plays a crucial role, as rural areas often lack alternatives in the event of road blockages, as evidenced in Molise and as previously documented by Dasgupta et al. (2014).

Factor 3: Outmigration

The phenomenon of abandoning agricultural activities due to reduced economic opportunities, was also highlighted as a sensitivity factor. In cases such as Molise and Sicoval, this trend has been observed to diminish territorial governance, thereby increasing the risk of fires and hydrogeological instability.

Factor 4: Institutional inertia

This factor accounts for concerns about the neglect by policymakers and underinvestment in infrastructure and services in rural areas, discussed in Dasgupta et al., (2014) and highlighted by Molise and Sicoval.

III. Factors mediating the sensitivity of ecosystems

In urban areas, demonstrators highlighted concerns about changes in tree species composition, with 'urban-adapted' species often replacing indigenous species and dominating urban landscapes. Additionally, urban ecosystems may be at risk of degradation due to overuse and population pressures. Furthermore, urban ecosystems face unique stressors, leading to heightened exposure to hazards such as high population density, the influence of non-climate-related stressors, and the urban heat island (UHI) phenomenon (Farrell et al., 2015).

In rural areas, the selection of crops is of great importance, particularly in regions such as Central Greece and Sicoval, which show that different crops present different degrees of sensitivity to high temperatures and drought. As Kovats et al. (2014) suggest, crop breeding aimed at increasing yield potential while also improving drought resistance, along with adjusted agronomic practices, may help to reduce the risks of yield shortfalls due to projected temperature changes.

In the context of forests, the risk of wildfires can be influenced by the composition and homogeneity of forest species. For instance, pine trees and evergreen shrubs can provide ample fuel for wildfires. Furthermore, in forestry areas, reduced open spaces between trees can create continuous and unmanaged masses that are highly flammable, thereby facilitating the spread of large forest fires (Greenpeace, 2023). Moreover, it has been observed by Chuvieco et al. (2023) that human settlements and infrastructure, such as roads, power lines, and railroad tracks, may lead to ecosystem fragmentation, which can exacerbate the spread of fires.

III. Factors mediating sensitivity of urban areas

Factor 1: Rate of urban growth:

Increasing urbanisation could amplify the urban heat island effect, which causes urban and metropolitan areas to be significantly warmer than their surrounding rural areas (Feyen et al 2020). In addition, the combined effects of heatwaves and air pollution might further exacerbate human stress in densely populated areas (Feyen et al 2020).

Factor 2: Expansion of impermeable surfaces:

One of the most significant alterations impacting urban streams is the proliferation of impervious surfaces. This transformation modifies the hydrological dynamics and channels pollutants that accumulate from buildings, roadways, and parking lots into the streams (Grimm, et al. 2008).

Factor 3: Interruption of infrastructure

Numerous health hazards linked to extreme climate events in urban settings stem from disruptions in critical infrastructure. Blackouts, for instance, amplify heat exposure, consequently heightening health risks (Barata et al., 2018). Furthermore, aging infrastructure, maintenance expenses, and the anticipated rise in urban population leading to heightened demand for infrastructure utilization are all factors that influence the uninterrupted operation of critical infrastructure.

In sum, the approach of social-environmental determinants of health orients the grouping of sensitivity factors into four categories. An environmental approach shows how the conditions of the built and non-built environment as well as decisions regarding their management mediate susceptibility to harm and human wellbeing. A social approach (physical attributes, behaviour, decision options, and socio-economic variables) sheds light on individual and social factors shaping human wellbeing.

Table 9. categories representing sensitivity.

Urban dynamics	Infrastructure	Ecological properties	Human-social dynamics
It refers to physical aspects that contribute to the urban heat island and its effects on urban ecosystems and human health. E.g., the expansion of impermeable surfaces that reduce the rate of water infiltration and increase the urban albedo. It also refers to the use of 'urban-adapted' foreign species replacing indigenous species in urban landscapes.	It refers to variables that affect the condition and functioning of infrastructure: aging, cost of maintenance and monitoring infrastructure (dams, roads, electric grid). It also refers to the robustness of critical infrastructure to continue functioning without interruption (energy grid). Finally, it considers recovery time of damaged infrastructure after an extreme event, such as roads after a flooding event.	In urban environments, it refers to tree species composition, age, location, and access to water, which determines harm. It also refers to human activities that increase the exposure of ecosystems, such as urbanization, pollution, use of chemicals in agroecosystem, or ecological fragmentation. In non-urban ecosystems, it refers to forest homogeneity (mediates fire risk). Climatic variables such as duration of heat wave and drought.	Human physical attributes and health status, (risk) behaviour (use of drugs and alcohol); human activity, (variables affecting mobility modes in the city in the context of high temperatures: Distance to be covered, flexible routes & Mobility options). It also refers to demographic variables (concentration, presence in risk areas, and migration); and Socioeconomic variables (Poverty, remoteness, access to markets, social networks); farming practices.

Table 10: Sensitivity factors	**Prerov** Drought & heat degrading urban ecosystems	**Mlada Boleslav** High temperatures on people's health in the context of urban transport.	**Molise** Floods affecting agricultural livelihoods	**Toulouse** Urban warming on people's health	**Sicoval, Occitanie** Drought affecting agricultural production and rural livelihoods	**Central Greece 1** Wildfire affecting infrastructure	**Central Greece 2** Extreme precipitation on agriculture	**Burgas** Urban warming on people and ecosystems	**Burgas** Flash floods on peri-urban areas (urban-rural interphase)	**Gabrovo** Drought and wildfires on ecosystems and urban areas.
Urban dynamics										
Rate of growth	x	x		x				x		x
Expansion of impermeable surfaces	x	x		x				x		x
Reduced rate of water infiltration	x			x						x
Ecological properties										
Tree species composition	x			x				x		x
Tree age composition	x									
Tree location	x									
Forest homogeneity						x				
Type of crop					x					
Climatic: Duration of heat wave / drought						x				x
Ecosystem/landscape fragmentation level						x				x
Increasing demand vs lower availability	x				x					
Reduced water available for ecosystems	x			x	x	x		x		x
Infrastructure										
Infrastructure aging		x	x						x	
Time/cost needed to recover infrastructure/			x				x		x	
Cost of maintenance and monitoring		x	x				x		x	
Continuity service of critical infrastructure				x				x		
Human dimensions										
Behaviour		x				x				x
Distance to be covered		x								
Flexible routes & Mobility options		x								
Use of drugs and alcohol		x		x				x		
Human physical attributes (Age) & health status		x		x			x	x		x
Demographic concentration				x				x		x
Demographic changes (out-migration)			x						x	
Number of inhabitants in flood risk areas			x				x		x	
Socioeconomic: Poverty levels			x	x	x	x	x	x	x	x
Share of agriculture in GDP			x		x		x		x	
Remoteness and isolation			x	x			x		x	
Access to markets and density of social networks			x		x		x		x	
Presence of industry close to agricultural lands			x		x		x		x	
Farming practices			x		x		x		x	

VULNERABILITY COMPONENT 2: ADAPTIVE CAPACITY

Adaptive capacity is normally determined in terms of knowledge, financial resources, social and institutional factors, technologies, legislations, and infrastructures that enable people to adjust to the effects of climate change (Dasgupta et al. 2014).

I. Factors determining adaptive capacity in the context of urban heat and drought.

Factor 1. Availability, access, and distribution of financial resources

Economic resources needed for the provision of public services such as urban vegetation and heat refuges, or private resources to access medical services and insurance, or air conditioning are identified as crucial to increase adaptive capacity (Puntub 2022).

Factor 2. Spatial planning

Spatial planning influences the spatial configuration, type, and degree of development of buildings and land use, as well as landscapes and green spaces (Richter 2015). Examples of sound spatial planning consider improved design and insulation of houses, schools, and hospitals, increasing tree and vegetative cover, installing green or reflecting roofs, or using cool pavements (Feyen et al 2020). Also, the Implementation of thermal regulations and building codes are relevant in this sense.

Factor 3. Integrating resilience into public policy in the health sector

Factors related to health policy emphasize the importance of implementing effective and cost-efficient public health interventions to address climate change impacts and reduce health burdens and inequities. This includes monitoring interventions, involving young people and marginalized groups in solution identification, and providing timely home-based prevention advice. Heat health warning systems are crucial for triggering community alerts and emergency actions, with a focus on prevention strategies for vulnerable individuals. Additionally, upgrading health infrastructure, enhancing workforce capacity, conducting vulnerability assessments, and promoting multisectoral cooperation are essential components of comprehensive public health and climate change adaptation efforts (Ebi et al 2021).

Factor 4: Integrating resilience into public policy in transport sector

The integration of resilience factors into public transport policy underscores the importance of adaptive organizations in operating transport systems, which entails embedding adaptation across all functions and developing strategies to address current and future weather conditions. Improving adaptive capacity involves assessing design, financial, and organizational capabilities to respond to climate change risks, ensuring that transport planners and operators adhere to design standards that consider specific climate parameters. However, the longevity of infrastructure investments challenges the applicability of these standards, especially for durable structures like bridges and roads, highlighting the need for comprehensive asset lifecycle planning in climate adaptation efforts. Additionally, allowing time flexibility for commuting emerged as a key consideration during workshops.

Factor 5: Integrating resilience into public policy of urban ecosystem.

Factors related to public policy in urban ecosystems emphasize the critical need for conserving, restoring, and expanding urban ecosystems to bolster climate resilience and address the growing pressures of urbanization and development. Achieving these goals necessitates improved urban and regional planning, policy, and governance, along with enhanced multi-sectorial cooperation. Additionally, fostering greater coordination among governance structures managing local ecosystems and urban biodiversity, including various green spaces, is essential for strengthening ecosystem functioning and promoting social-ecological engagement. Furthermore, adaptive capacity in urban landscapes depends on ecological, physiological, and genetic diversity, highlighting the importance of considering both human-induced and nonhuman-derived factors, such as species interactions and natural processes, in enhancing adaptive capacity.

Factor 6. Education, awareness, and stakeholder engagement

Education, awareness, and engagement were proposed as central factors increasing adaptation. These factors underscore the significance of education and awareness initiatives regarding risk factors and appropriate responses, alongside the necessity for training public officials and to increase collaboration across sectors in addressing specific health issues:

- Vector-borne and infectious diseases entail cooperation among epidemiologists, hospitals, social workers, and community members to monitor and respond to infection rates.
- Heat-related illnesses require engagement from local authorities, media outlets, and utility providers to implement heat-health warning systems and provide support during extreme heat events.
- Water quality concerns demand joint efforts from emergency responders, urban planners, and water management agencies to address flooding and enhance infrastructure.
- Air quality, asthma, and allergies call for collaboration between meteorology services, public health institutions, NGOs, and the private sector to conduct research, regulate emissions, and develop relevant products.

II. Factors determining adaptative capacity in the rural world in the context of heat and drought:

Factor 1: Capacity to adapt agricultural and livestock-management practices.

The capacity to adapt practices in the rural world, including adjusting sowing and harvesting dates, utilizing longer cycle crop varieties, implementing adaptive land use management, preserving upland vegetation, and maintaining soil water retention capacity, reducing erosion, soil carbon loss, and flood risks, pest, and disease management, adjusting planting, and harvesting dates, and managing resources are recommended to address climate change impacts on agriculture.

In the context of livestock, improved management for reducing heat stress considers the use of heat-tolerant livestock, and improved design of confined animal housing, altering diets, providing adequate shade and clean drinking water supplies, monitoring stock rates continuously to match forage availability, altering the timing of feeding/ grazing and reproduction, and selecting the species/breeds that match climatic conditions (Gowda et al 2018).

In the context of water management, aspects such as adoption of more water-efficient technologies and of water-saving strategies, implementation of governance instruments in river basin management plans and integrated water management, robust water management, pricing, and recycling policies to secure adequate future water supply and prevent tensions among users, are all highlighted by Kovats et al (2014).

Factor 2. Integration of best practices in forestry management and prevention measures

Various strategies and challenges related to forest resilience were proposed. Mostly, response approaches to climate change impacts on forestry should focus on enhancing ecosystem resistance and resilience while addressing potential limitations to burnable biomass accumulation. These include:

- Landscape planning and fuel load management are crucial for reducing wildfire risk.
- Practices related to revitalizing rural areas with agroforestry landscapes to create a more resilient environment against forest fires, increased monitoring, and controlled burning.
- Preference for species adapted to warmer conditions and the selection of tolerant genetic varieties to reduce forest mortality and damage by pests and diseases.
- Increase forest management financing to control biomass accumulation, balancing fire prevention and suppression efforts.

Factor 3: Knowledge

The knowledge factor encompasses the ability to conduct knowledge generation activities, including ecosystem, forest, and soil monitoring, as well as epidemiological surveillance of vector-borne animal diseases. It also involves building capacities based on this information.

Factor 4. Coordination across institutions

Coordination across institutions was highlighted as a cross-cutting factor. Coordination is needed for reducing the risk of wildfires (firefighting in the wildland-urban interface is a complicated issue since it involves citizens/people safety and management); and to integrate the activities of actors involved in public policy in urban areas, transport, ecosystem management and the rural world.

III. Factors affecting adaptive capacity against floods in the rural world:

Several aspects affect the adaptive capacity of rural communities to extreme precipitation. Overall, across the demonstrators, these aspects highlight the complex interplay between socio-economic factors, institutional frameworks, and environmental pressures shaping adaptive responses in rural communities. These include access to land and resources, access to technologies, markets, and infrastructure; access to water, credit, extension services, off-farm employment opportunities, tenure security, asset base, and farming experience. But also, policies emphasizing collaboration among stakeholders and investment-based approaches over subsidies. Institutions and networks, access to information and the behavioural factors that lead to utilization.

Table 11: Adaptive capacity factors	**Prerov**	**Mlada Boleslav**	**Molise**	**Toulouse**	**Sicoval, Occitanie**	**Central Greece 1**	**Central Greece 2**	**Burgas**	**Burgas**	**Gabrovo**
	Drought & heat degrading urban ecosystems	High temperatures on people's health in the context of urban transport.	Floods affecting agricultural livelihoods	Urban warming on people's health	Drought affecting agricultural production and rural livelihoods	Wildfire affecting infrastructure	Extreme precipitation on agriculture	Urban warming on people and ecosystems	Flash floods on peri-urban areas (urban-rural interphase)	Drought and wildfires on ecosystems and urban areas.
Landscape resilient Planning	x	x		x	x	x		x	x	x
Multi-sectorial cooperation	x		x	x					x	x
Financial resources				x		x		x	x	x
Frequency of ecosystem monitoring	x	x				x			x	
Urban resilient planning & env. building standards		x		x				x		x
Local Institutions (flexibility, strength, cooperation)			x				x		x	x
Education, awareness, and stakeholder engagement						x		x	x	x
Funds to fix damaged infrastructure	x			x				x		
Resilient forest management						x			x	x
Knowledge on the state of ecosystems		x							x	x
Health Policy (public health protection measures)				x				x		x
Water management and access to water				x	x		x			
Agricultural regulation (reduced subsidies)					x		x		x	
Public policy urban ecosystem				x				x		
Early-warning systems	x		x			x				
Enforcement of regulation on infrastructure		x	x							
Frequency of infrastructure inspections		x	x							
Agricultural subsidies and credits			x						x	
Knowledge and access to research on agriculture					x		x			
Access to technologies and infrastructure							x		x	
Information about invasive species	x									
Tree and ecosystem inventory	x									
Funds to upgrade road infrastructure		x								
Air conditioning		x								
Preparedness of emergency services		x								
Diversity of mobility options		x								
Access to land and natural resources			x							
Socioeconomic safety nets			x							
Environmental protection, and landscape preservation			x							
Public policy in transport sector								x		
Agricultural practices (land use management, water conservation & erosion control)					x					
Livestock management practices					x					

4.2 Discussion and key takeaways

A critical goal of the climate impact chains in the VALORADA project is to provide a better understanding about adaptive capacity factors. In this section, we focus on the limitations and possibilities emerging from different approaches to explore adaptive capacity, and how in turn these approaches provide different perspectives on risk and on the use of locally produced data and climate data. We explore four approaches: storylines, prioritisation, contextualisation, and the adaptation challenge approach.

A. Storylines:

In general terms, our definition of adaptive capacity has followed the commonly used definition provided by the IPCC, where adaptive capacity is determined by the categories knowledge, financial resources, technologies, legislations, and infrastructures (Dasgupta et al 2014). However, trying to distribute the adaptive capacity factors identified across the climate impact chains according to the IPCC categories posed a challenge, as each factor of the CIC could be characterised by multiple IPCC categories. For instance, table 12 below, shows that the factor "Frequency of monitoring ecosystems" can be characterised from an economic, an institutional and a technological perspective, each providing a unique storyline. An early-warning system, for instance, does not only rely on institutional design or a single technology. For an early-warning system to be successfully implemented, it demands knowledge about climatic, non-climatic and social dynamics that shape risk to a specific threat. Success demands implementation, and for that, systems require technologies, infrastructures, but also a pedagogy that makes those affected by a threat to understand how to act and to have the means to act. Hence, an early warning system is constituted by multiple storylines. In this case, characterising the factor "frequency of ecosystem monitoring" from -let us say- an economic storyline only, other storylines that account for the institutional and technological dimensions of monitoring become excluded. Hence, attempting to assign an adaptive capacity factor exclusively to a single category—be it knowledge, institutions, social, economic, legal, technological, or infrastructural—overlooks the interconnected dynamics among these factors.

Table 12. The multiple storylines of each adaptive factor

Factor	Knowledge	Economic	Social	Institutional	Infrastructure	Technologies
Landscape resilient Planning	x	x		x	x	x
Multi-sectorial cooperation	x		x	x		
Financial resources		x		x		
Frequency of ecosystem monitoring		x		x		x
Urban resilient planning & env. building standards	x	x	x	x	x	x
Local Institutions (flexibility, strength, cooperation)	x		x	x		
Education, awareness, and stakeholder engagement	x	x	x	x	x	x
Funds to fix damaged infrastructure	x	x		x	x	x
Resilient forest management	x	x	x	x	x	x
Knowledge on the state of ecosystems	x			x		x
Health Policy (public health protection measures)	x	x		x		

Water management and access to water		x	x	x	x	
Agricultural regulation (reduced subsidies)	x	x		x	x	
Public policy urban ecosystem	x			x		
Early-warning systems	x	x	x	x	x	x
Enforcement of regulation on infrastructure		x		x		
Frequency of infrastructure inspections		x		x		
Agricultural subsidies and credits		x	x	x		
Knowledge and access to research on agriculture	x	x		x		
Access to technologies and infrastructure	x	x	x	x	x	x
Information about invasive species	x			x		
Tree and ecosystem inventory					x	
Funds to upgrade road infrastructure		x		x	x	
Air conditioning		x				
Preparedness of emergency services	x	x	x	x	x	x
Diversity of mobility options		x	x		x	x
Access to land and natural resources		x		x		
Socioeconomic safety nets	x	x	x			
Environmental protection, and landscape preservation	x	x	x	x	x	x
Public policy in transport sector	x	x	x	x	x	x
Agricultural practices (land use management, water conservation & erosion control)	x	x	x	x	x	x
Livestock management practices	x	x			x	x

In highlighting the multiple storylines structuring each of the adaptive capacity factors of the climate impact chains, we seek to shed light on two aspects. First, by acknowledging that each adaptive capacity factor can be described, explained an understood from different storylines, we underscore the complexity of each single adaptive factor. A storyline approach highlights that the determinants of adaptive capacity (knowledge, institutions, etc.) are intimately connected between one another, each shaping a unique story, and together, constituting an interconnected and integral storyline. We argue that adaptive capacity factors require multiple storylines in order to be characterised, communicated, and implemented.

Secondly, a storyline approach sheds light on the multiple sources of data, information and knowledge needed to generate comprehensive storylines. Given the constitution of each adaptive factor, data, information, and knowledge is needed from diverse sources, and their integration requires collaboration from a diverse set of actors.

B. Prioritisation:

A second perspective pertaining to adaptation factors emerges from their prioritisation. Here, we aim to shed light on the most relevant adaptive capacity factors. Table 13 below shows adaptive capacity factors structured according to the number of repetitions that each factor appears across demonstrators. Hence, we use the repetition as a proxy for priority.

Table 13. Priorities regarding adaptive capacity factors

High priority	Mid priority	Lower priority
High priority includes factors that repeat between 8 and 4 times. The adaptative capacity factor with the highest priority across demonstrators is (resilient) territorial planning (urban and rural) with 8 repetitions. High priority factors also include multi-sectorial cooperation, and financial resources (5 repetitions), local Institutions (flexibility, strength, cooperation), education, awareness, and stakeholder engagement, as well as frequency of ecosystem monitoring (4 repetitions).	Middle priority considers factors with 2 and 3 repetitions. These include funds to fix damaged infrastructure, resilient forest management, knowledge on the state of ecosystems, health Policy (public health protection measures), water management and access to water, agricultural regulation (reduced subsidies) (all with 3 repetitions). Public policy on urban ecosystems, Enforcement of regulation on infrastructure, Early-warning systems, Frequency of infrastructure inspections, Agricultural subsidies and credits, Knowledge, and access to research on agriculture, Access to technologies and infrastructure (all with 2 repetitions).	The category of lower priority includes factors with only 1 repetition: Socioeconomic safety nets, Environmental protection, and landscape preservation, Access to land and natural resources, Information about invasive species, Tree and ecosystem inventory, Agricultural practices (land use management, water conservation & erosion control), Livestock management practices, Public policy in transport sector, Funds to upgrade road infrastructure, Diversity of mobility options, Access to air conditioning, Preparedness of emergency services.

When examining the adaptive capacity factors across the three priority levels, a key topic within high-level priority factors is the role assigned to the social dimension of adaptation to climate change. High-priority factors highlight the role of people's interaction, cooperation, coordination, and engagement in contexts of building resilient institutions, capacity building and education, and in the context of multi-sectorial cooperation. It is well documented that silo approaches limit adaptive capacity due to lack of coordination, competition, and lack of policy integration. However, collaboration spaces can overcome such barriers. Central to collaboration is the quality of social interactions. In this context, it is worth mentioning that local stakeholders highlighted the value of implementing participatory workshops to discuss the risk factors highlighted in this report.

Furthermore, territorial planning emerged as a consistently high-priority factor across almost all demonstrators. Across demonstrators, territorial planning tends to be discussed in terms of project implementation (to reduce UHI, or reduce flood risk, or to secure critical infrastructures).

Only a mid-priority was granted to policy dimension of health and environmental issues across the demonstrators (only 3 and 2 repetitions respectively), which contrasts with the role of social-environmental determinants of health discussed in the impacts, exposure and sensitivity sections. Our impression is that the division between municipal competencies, particularly between planning/project implementation versus policymaking, could influence perceptions of how municipal and regional actors can deal with health and environmental concerns. Hence, while they may perceive this connection as a problem to be addressed, they may lack to competencies to act upon them. One option is that since many policies related to health, building regulations and codes, and water management are typically governed by higher-level institutions, the direct influence of municipal authorities in these areas (beyond enforcement and project implementation) is rather limited. this is made evident in the adaptation plans pertaining to each demonstrator, and where adaptation strategies are structured around three modes: (1) the development of specific projects, (2) the integration of national adaptation policies into a local scale, or (3) seek to enforce national legislation. Only in some cases they embark on policy development.

- For example, while Molise has developed a municipal adaptation plan, coordination is being sought with the national Hydrogeological Zoning Plan (PAI) (identifies risk scenarios related to landslide) and the National Rural Development Program (PSRN) in order to further strengthen Molise's rural policy and regulations.
- In the case of Mladá Boleslav, the administration has developed a Sustainable Urban Mobility Plan, which emphasizes the promotion of urban public transport and cycling (attractive and reliable transportation for all residents, adequate capacity roads and spaces for motorized transport where desired), and it includes activities such as renewal of the public transport fleet to provide better thermal comfort in the summer, a system for the rapid reconstruction of transportation infrastructure sections affected by natural disasters, and restrict parking areas.
- In the case of Prerov, their adaptation plan aims to increasing the ecological stability of the territory (revitalisation of ponds, etc); reduce the risks associated with high temperatures during heat waves (implementation of extensive and intensive green roofs, etc); development of a network of cycle paths, install shades above sidewalks and in other public spaces, create a system of financial micrograntsfor associations and a participatory budget. Also, to implement energy saving measures and install renewable energy sources in buildings.
- In the case of Montpelier, an adaptation plan is oriented by 10 objectives. While these do not yet specify policies, they establish policy objectives and several projects. These include seeking to renovate buildings against energy poverty, make public transport accessible to all through free access of the network and free use of bicycle, develop renewable energies (energy master plan); protect the population and activities from climate risks and make the coastline resilient to climate change; preserve biodiversity, preserve water resources, build the region's sustainable and equitable food system and to develop an economy with a positive impact.
- In Sicoval, stakeholders engaged in the ecological transition, the Territorial Food Project (PAT) aims to develop actions in response to economic, environmental, and social issues through policies and projects. These include fight against food waste, organic production, food education, and financial accessibility.
- In central Greece, and in the context of floods, actors seek to integrate the National Strategy for Adaptation to Climate Change (ESPKA), together with the Regional Plan for Adaptation to Climate Change and the Water Basins Management Plans. In synthesis, such policy integration provides a framework for the implementation of the projects seeking to revitalise cities through regeneration of areas and public buildings, the implementation of erosion Protection Interventions – Soil Desertification, as well as Flood Risk Prevention and Management Measures.

- In central Greece and in the context of wildfire, specific initiatives were suggested as ways to increase adaptive capacity. These include enforcing and funding the National Forestry Strategy, ensure reforestation with a logical biodiversity plan; promote a balanced relationship between fire prevention and suppression, not only in terms of financing but also in terms of perceived interest, and forest management and status monitoring across the entire year and enhancing ecosystem resistance and resilience; improve fuel load management, reduce forest mortality through species better adapted to warm, selection of tolerant or resistant species, include Fire-prevention in public education, devolve political power from centralized bureaucracies to local organizations, increase participation; improve real-time mass communication; promote disciplinary, sectoral, social and gender diversity among fire scientists, policymakers and wildfire managers, ensure coordination across institutions, among others.

C. Contextualisation

It is important to notice that while the number of repetitions can shed light on the most identified adaptation factors, such categorisation does not provide clarity regarding the importance of such factors in terms of increasing adaptive capacity. For instance, factors within the lower priority can play critical roles where climate risk is considered from a sectorial basis. For example, the factor "preparedness of emergency services" was identified as a key lever for adaptation against wildfires in Eovia. In the same vein, public policy in the public transport sector was a central topic of discussion in Mlada Boleslav. In addition, since most of demonstrators focused primarily on urban or peri-urban areas, there is a bias for urban issues in detriment of rural-related adaptive capacity factors. Practices in the rural world are less represented, but not less important for rural demonstrators. With this in mind, we underscore the need to understand adaptive capacity factors in context. Contextualisation demands a profound understanding of the local setting; about who and what is affected by a climate hazard, about thresholds of risk acceptance and about the metrics involved in prioritizing adaptive action. Each single climate impact chain (presented in the annexes) facilitates such an understanding.

D. Observing adaptation as an adaptive challenge

In order to address the issue of contextuality, in this final part we focus on considering climate change as a cross-cutting issue affecting local development. We build on the work developed by O'Brian & Selboe (2015) to articulate our findings within the concept of the "adaptation challenge". In their work, O'Brian and Selboe express that there tends to be a mismatch between adaptive strategies considered or implemented to adapt to climate change and the full scope of the climate change problem: "*The full scope of the problem is not limited to changes in climate parameters. It is about multiple, interacting processes that can amplify or dampen the social and biophysical impacts of climate change at different spatial and temporal scales and influence the capacity to perceive and respond to change"* (p.1). The scholars argue that so far climate change has been considered mostly as a technical challenge to be solved through expertise, innovation, know-how, skills, and resources. As a result, they contend that this approach has ended up in a "to-do list" composed of management approaches and numerous projects. Against this, their proposal is to consider adaptation not only as an effort to minimize climate impacts, but to consider climate change as a challenge, where attention is devoted towards understanding *change itself* as part of a social, cultural, and human process.

Stemming from this perspective, they argue that adaptation has to do with:

(1) addressing the social structural causes of vulnerability (adaptation as a problem of development) (Erisken et al 2015);

(2) identifying the endogenous limits to adaptation rather than external forces (Adger et al 2009);

(3) developing collective strategies to adaptation (Butzer and Enfield 2012);

(4) responding to multiple processes (changing economic conditions, health threats and social change);

(5) considering the interaction between values, beliefs, knowledge, cultures, and institutions where adaptive challenges are grounded -since they influence how systems and change are perceived and approached-. In essence, the understanding of the problem not as a technical, but as a systemic social construct.

Against this, we propose a new organisation of the adaptive factors identified in the climate impact chains following a typology of adaptation as a challenge. With this in mind, we seek to provide a deeper understanding of how adaptation factors further help to characterise climate adaptation in terms of human development.

In table 14 below we exposed each adaptation factor to each of the 5 typologies identified in O'Brian and Selvoe. For each adaptive factor, we posed the question: how does the adaptive factor relate to the adaptation challenge?

Table 14 below highlights that each adaptive factor can contribute to 1 or more features to understand adaptation as a challenge.

Table 14: Adaptive factors as part of the adaptation challenge

Factor	Does it inform about structural causes of vulnerability	Does it consider endogenous limits to adaptation	Does it aim to enhance collective strategies	Does it respond to multiple processes	Does it contribute to the understanding of the problem
Landscape resilient Planning			x	x	x
Multi-sectorial cooperation		x	x		x
Financial resources	x	x			
Frequency of ecosystem monitoring		x		x	
Urban resilient planning & env. building standards			x		x
Local Institutions (flexibility, strength, cooperation)		x	x	x	x
Education, awareness, and stakeholder engagement	x	x	x	x	x
Funds to fix damaged infrastructure		x			
Resilient forest management			x	x	x
Knowledge on the state of ecosystems				x	x
Health Policy (public health protection measures)			x		x
Water management and access to water	x	x	x	x	x
Agricultural regulation (reduced subsidies)		x			
Public policy urban ecosystem	x	x			x
Early-warning systems					x

Enforcement of regulation on infrastructure		x			
Frequency of infrastructure inspections		x			
Agricultural subsidies and credits	x	x			
Knowledge and access to research on agriculture		x			
Access to technologies and infrastructure	x	x			
Information about invasive species					x
Tree and ecosystem inventory		x			x
Funds to upgrade road infrastructure		x			
Air conditioning		x			
Preparedness of emergency services		x	x		
Diversity of mobility options				x	
Access to land and natural resources	x	x			
Socioeconomic safety nets	x	x			
Environmental protection, and landscape preservation			x	x	
Public policy in transport sector			x	x	
Agricultural practices (land use management, water conservation & erosion control)		x		x	
Livestock management practices				x	

We conclude this discussion by arguing that adaptive capacity factors identified through the climate impact chains do not only point to specific areas of policy and implementation to reduce climate risks. They also have the potential to contextualise climate risk as an adaptation challenge by shedding light on the characteristics that make adaptation a development problem which requires a coordinated and multi-sectorial perspective. In the context of the VALORADA project, this is a critical aspect to take into consideration, since as we strive for improved collaboration regarding climate and non-climate data integration and use, we also shed light on the role of locally sourced datasets to provide an enhance understanding of climate risk as a local development challenge. With this in mind, we acknowledge the importance of improving data-management practices locally, including collaboration in problem definition, in data exchange and integration, as well as on access and quality.

Main takeaways

The climate impact chains sought to shed light on the critical factors generating or exacerbating climate risks. Our approach aimed to identify the key issues of concern that generate risk across demonstrators. In this vein, this deliverable has proposed several risk factors and has presented them from different angles: ordered as territorial categories, ordered against different climate hazards, grouped according to topics, and ranked according to repetition. This diversity of lenses aims to provide a comprehensive understanding of the complexities of risk factors according to different dimensions (climatic, territorial, and human risk perception).

This deliverable has integrated the experience of five demonstrators in the generation of 10 climate impact chains. Across the demonstrators, three climate hazards have been considered, namely, heat, drought, and precipitation. The contextualisation of these hazards according to territorial characteristics of each demonstrator (namely, urban, rural, or urban-rural combined) has helped distinguished how territorial features (i.e., geography, geomorphology, topography, and physical layout) lead climate hazards to generate different types of risk.

Our conceptualisation of risk follows the social-environmental determinants of health approach, which seeks to integrate a perspective on health beyond the qualities of individuals and to consider their embedding social and ecological context as determinants of health. Emerging from this, the climate impact chains have highlighted key avenues whereby a climate hazard can impact individuals and society by affecting ecosystem services.

Exposure and sensitivity factors are synthesised following the approach of social-environmental determinants of health, which orient the categorisation of exposure and sensitivity factors into four categories: Physical conditions of the built environment and Urban dynamics, Infrastructure, Ecological properties, human-social dynamics and human activity. In essence, these categories underline an intimate relationship where environmental integrity is intimately connected to human wellbeing.

A critical goal of the climate impact chains in the VALORADA project was to provide a better understanding about adaptive capacity factors. The discussion has integrated aspects such as the importance of context and the identification of storylines that characterise these contexts. Furthermore, it has provided a perspective on adaptation beyond a technical approach, and it has shed light on how an adaptive challenge approach can facilitate characterising climate risk as an endogenous development problem. In characterising hazards, impacts, exposure and sensitivity factors, a deep understanding about the implications of risks to local development is provided.

In relation to impacts, the impact sequences are sometimes intimately connected to one another. For example, the effects of extreme precipitation contaminating agricultural lands bring also negative effects to the production of agricultural produce. In addition, impact sequences do not only relate to one another, but also can experience reinforcing (positive) feed-back loops. In essence, complex processes generating risks are intimately intertwined. In this case, the loss of livelihoods provokes a chain reaction of outmigration, reduced governance, increased fire hazards which affects tourist activity, hence further affecting the livelihood base.

A critical aspect of the development of climate impact chains is to avoid double counting of factors. Most of the times, this was a difficult exercise, since depending on problem definition and the emphasis given to the factor, a factor can be considered within the realm of exposure as much as under sensitivity or adaptive capacity. For instance, factors considered as linked to human activity can be expressed as both, adaptive capacity, or sensitivity. However, we have adopted a careful wording to ensure factors are defined strictly within the definitions provided by the IPCC (2022). When confusions emerged, the only way to ensure consistent definition was through feedback with local stakeholders.

5. Annexes

Annex 1. The Local Climate Information Profile (LCIP)

Rationale:

The **Local Climate Information Profile (LCIP)** seeks to identify key challenges around the management and integration of climate and locally sourced data needed to understand climate risks.

The LCIP seeks to derive key input needed to run tailor-made workshops in each of the demonstrators within the VALORADA project, as well as to provide insights for the development of data catalogues (WP2) and data management tools (WP4).

The LCIP consists of three parts:

(1) Visualising the climate context (risk and adaptive capacity).
(2) Identify the policies and processes involved in data management, the data stakeholders and the data infrastructure that constitute the data governance to use local data for addressing climate risk in each demonstrator.
(3) Assessment of the maturity level of local data governance schemes.

Instructions

To complete the LCIP, information from various forms of documentation existing in local government records, as well as information collected from interviews, newspaper records, etc. may be needed. Given the strategic nature of this document, short answers should be provided. Answers should guide the location of documents, the stakeholders involved (whenever possible or applicable) and brief additional comments needed as background information whenever applicable.

Demonstrator: ____

Demonstrator's focal point (name and institution): ______________________________

Local partner: ____

Person filling out the profile: ____

Date profile is handed in: ____

Comments: ____

____

Part 1. Visualising the climate adaptation context: Experience of local actors regarding the impacts and consequences of climate-extreme events and the responses developed by local actors.

Part 1 aims to derive input needed to develop the climate-impact chains (Workshop activity 1)

Demo's climate challenge	

In relation to the local climate challenge specified above, refer to the impacts caused by climate change over the last 5 years	
Event type (add lines in case more than 1 event is considered) (Extreme T°, excessive/lack rainfall)	
Consequence (Summary of what happened)	
Additional impacts (More than one consequence may occur)	
Responses from actors over the short and medium term (are responses institutionalised or ad-hoc?).	

Institutional aspects	
Work teams linked to adaptation to climate change (roles and influence level -H, M, L-)	
Existence of Local Climate Plans (Mention 3 key goals, 3 key measures)	
Indicators associated with adaptation to climate change (up to 5)	
Availability of climate-risk maps against the local climate challenge (specify format and way to access the maps)	
Guidelines and Policies for extreme temperatures and water availability (Y/N specify which)	
Digitalisation agenda / Modernization Agenda (Y/N, mention 3 key measures)	
Participation in European projects relevant to VALORADA goals (Y/N, which ones)	

Part 2. Exploring the data governance in place to address climate risk.

Part 2 aims to derive input needed to develop the narratives of valorisation, the data-value chains (Workshop activities 2 and 3), and input needed for deliverables Catalogues (WP2) and Data tools (WP4).

Input data	
Data considered in this section refers to the specific locally sourced data as well as climate data that contributes to understand climate risks vis-à-vis the local climate challenge in each demonstrator. Examples of locally sourced data can include: socio-economic data, demographic data, environmental data, territorial data, etc. Local partners are encouraged to decide which types of data to focus on. We recommend focusing on 1-3 datasets, centring efforts on the *low-hanging fruits*.	
Key data (Climate and non-climate) used for the Local Adaptation Plan	
Specific datasets (Climate and non-climate) used for understanding, communicating and tackling the local climate challenge (If different from the above).	
Are there climate datasets used directly by the local stakeholders? (Y/N, for which purpose?)	
Who provide these climate datasets?	
Does the use of climate data/information require support from external expertise?	

Data governance	
This section refers to the management of data specified in the previous section. ***Stakeholders are encouraged to also refer to data management in general, since valuable examples can shed light on effective data-management practices.	
Are there key data-strategic objectives? (Yes/No, specify)	
Are there data quality rules in place? (Yes/No, specify)	
Are there key data quality indicators? (Yes/No, specify)	
Have key data challenges been identified? (Yes/No)	
Are there data quality management practices in place? (Yes/No, specify)	

Is there a budget allocated to improve data governance? (Yes/No)	

Policies and processes	
Are there data management policies or procedures currently in place? (Yes/No, specify)	
Is there a data certification scheme in place? (Yes/No)	
Are there Data risk and privacy metrics in place? (Yes/No)	
What are the key gaps in data management?	

Key data infrastructure	
Is there a defined process for data classification? (Yes/No)	
Is there a defined process for data collection? (Yes/No)	
Is there a defined process for data storage? (Yes/No)	
Is there a defined process for data processing? (Yes/No)	
Is there a defined process for data usage? (Yes/No)	
Are there data catalogues in place (reference data and master data) (Yes/No)	
Are there workflows in place to make it easier to find and understand relevant data? (Yes/No)	
Are there smart-metadata tools in place? (Yes/No)	
Are there tools for automate and scale in place? (Yes/No)	

Data stakeholders	
Which stakeholders are involved in data management (collection, storage, analysis)?	
Who are the data owners? (Provide examples)	
Are there IT architects? (Yes/No, provide example)	
Are there Data analysts? (Yes/No, provide example)	
Are there systems experts? (Yes/No, provide example)	

Are there third-party data providers? (Yes/No, provide examples)	
Are there (local) data-observatory networks? (Yes/No)	
Are there channels to collaborate with citizens and other stakeholders in data collection? (Yes/No)	

Part 3. Based on the Capability Maturity Model Integration -which explores the maturity level of local data governance schemes-, which of the following five maturity levels better describe the data-governance state in each demonstrator?

Part 3 aims to provide input for the narratives of valorisation (workshop activity 2)

Level	Description
Level 1: Initial (ad hoc and chaotic processes)	
Level 2: Managed (basic project management in place)	
Level 3: Defined (standardized processes across the organization)	
Level 4: Quantitatively Managed (quantitative performance measurements in place)	
Level 5: Optimizing (focus on continuous process improvement)	

Local Climate Information Profile

- UK LCLIP: Local Climate Impacts Profile: Spreadsheet notes. Available at https://www.ukcip.org.uk/wizard/current-climate-vulnerability/lclip/ (checked 29th June 2023)
- https://atlan.com/data-governance-readiness-assessment/ (checked 29th June 2023)
- https://atlan.com/data-governance-maturity/?ref=/data-governance-readiness-assessment/ (checked 29th June 2023)
- https://www.informatica.com/resources/articles/what-is-a-data-catalog-benefits-and-use-cases.html (checked 29th June 2023)

Annex 2. The story of Valuatu

In the quiet town of Valuatu, nestled between rolling hills and a winding river, life had always been predictable and serene. However, as the years passed, Valuatu faced a new and growing threat: climate change.

(HAZARD) The first signs of trouble appeared as the seasons grew more erratic. Summers became blistering hot, (IMPACTS) scorching the fields and causing droughts that withered the crops. (HAZARD) The threat of fire increased. (RISK) Winters brought heavy rains that, when combined with the melting snow from the nearby mountains, (IMPACT) caused the river to swell beyond its banks, flooding the town and threatening its infrastructure.

The people of Valuatu realized that they needed to take action to protect (EXPOSURE) their homes, their livelihoods, and their way of life. Some in the town were more sensitive to the changing climate than others, particularly the farmers who depended on predictable weather patterns. But also, the elderly, who were more prone to get ill from high temperatures. Children felt uncomfortable at school and could not concentrate well. Some people felt more aggressive during extended hot periods. Young people enjoyed drinking beer on the square when days were hot. Many got heat strokes. Some of those who ventured to swim in the cold lake, got hypothermia.

In response, the town of Valuatu came together, recognizing that they needed to adapt to the changing climate.

The town organized workshops and seminars to educate residents about climate change and its impacts. They began by building resilient infrastructure, raising their homes on stilts to mitigate flood damage and installing rainwater harvesting systems to cope with droughts. They also planted drought-resistant crops.

But Valuatu didn't stop there. They knew that knowledge was power, so they set out to generate data to better understand the risks they faced. With the help of technology and collaboration with universities, they started sharing social, economic and environmental data. They increased their efforts to integrate data from various sources, including remote sensing, ground-based measurements, and modelling, to provide a holistic view of climate trends and impacts. Data sharing and collaboration among government agencies, research institutions, and non-governmental organizations was key. They developed standardized metadata and data formats to facilitate data interoperability and exchange.

They established a weather monitoring system that tracked rainfall patterns and river levels in real-time. This data was made available to all residents, allowing them to plan and respond to changing conditions more effectively. Training and capacity-building opportunities were offered to data managers, scientists, the community and decision-makers to enhance data management skills and knowledge.

Annex 3. Climate Impact chain Prerov

I. Introduction

The Climate Impact chain for the city of Přerov in the context of the Valorada-EU project, focuses on the risk of degradation of urban ecosystems due to urban heat, urban warming, and droughts.

The development of the climate impact chain occurred in two stages. Initially, a participatory workshop involving city representatives was held in October 2023. The preliminary climate impact chain was formulated based on the insights gathered during this workshop, supplemented by a comprehensive literature review. Subsequently, the initial draft of the climate impact chain was shared with city officials and consortium partners ASITIS for feedback. This document incorporates all the suggestions provided by the local stakeholders, resulting in the final version of the impact chains.

The document is organised as follows:

- Section II presents a brief definition and schema describing a climate impact chain.
- Section III discusses key **climate change and urban ecosystems.**
- Section IV delineates the identified climate hazards.
- Section V outlines the schema proposed for the climate impact chain.
- Section VI presents the key risks identified during the workshop and outlines the eight impact sequences associated to this risk.
- Section VII outlines the exposure factors associated to each of the sequence of impacts identified in section VI.
- Section VIII outlines the sensitivity factors associated to each of the sequence of impacts identified in section VI.
- Section IX outlines the adaptive capacity factors associated to each of the sequence of impacts identified in section VI.
- Section X presents the bibliography, indicating the literature reviewed for generating this document.

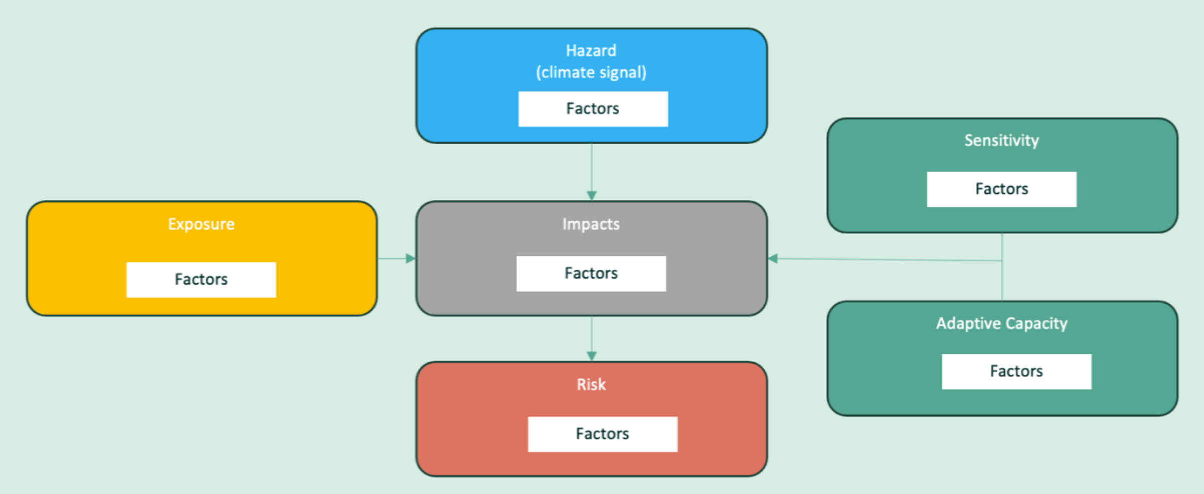
II. Climate-impact chains

A climate-impact chain delineates the connection between a specific climate hazard and a designated impact area. These chains aim to elucidate cause-and-effect relationships within various components of a system. By defining these relationships, impact chains ascertain how a hazard transforms into a risk, factoring in exposure, potential intermediate impacts, sensitivity factors, and response/adaptation capacities that mitigate vulnerability. In cases where applicable, intermediate impacts can be identified, each with its exposure, sensitivity, and adaptation factors (GIZ and EURAC, 2017).

A chain is composed of risk components (hazard, vulnerability, exposure) and underlying factors associated to each component. A climate signal, e.g. a heavy rain event, may lead to a direct physical impact, e.g. a flood, causing a sequence of intermediate impacts, which finally lead to the risk. The hazard component includes factors related to the climate signal and direct

physical impact. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised by one or more exposure factors (GIZ and EURAC, 2017).

Schema of a Climate Impact Chain (adapted from GIZ and EURAC 2017)



III. Climate change and urban ecosystems

- Urban ecosystems, known for their biodiversity, play a crucial role in natural capital for climate change adaptation and mitigation (Rosenzweig et al. 2015); while at the same time, urban habitats contribute to the well-being of urban residents (Solecki & Marcotullio, 2013).
- However, climate change is already impacting urban biodiversity and ecosystems (Rosenzweig et al. 2015). The combination of climate change and urbanization (for example, through increased patch fragmentation and diversity), is expected to heighten the vulnerability of biodiversity hotspots, urban species, and essential ecosystem services (Luck & Wu, 2002).
- Virtually all climate change effects have direct or indirect repercussions for urban ecosystems, biodiversity, and the vital ecosystem services that enhance human health and well-being in cities (Rosenzweig et al. 2015). For example, climate change will increase the susceptibility and vulnerability of urban ecosystems to various geohydrological threats, such as diminished groundwater and aquifer quality, subsidence, and intensified salinity intrusion (Praskievicz & Chang, 2009).
- Furthermore, because of the interconnectedness between ecosystem well-being and ecosystem services, growing ecological stress diminishes the quality and quantity of ecological services (Cairns and Pratt, 1995).
- Climate change and the urban heat island (UHI) effect impact ecosystem services and green infrastructure by causing shifts in temperature and precipitation patterns, evaporation rates, humidity levels, soil moisture content, vegetation growth rates, water tables, aquifer levels, and air quality (Solecki & Marcotullio, 2013). These changes can bring about cascading effects that further affect urban ecosystems (Frumkin et al., 2008; Keim, 2008).

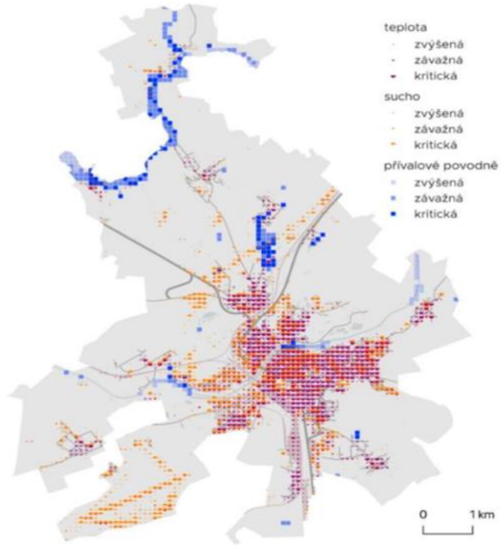
IV. Climate hazards:

Climate hazards for the city of Prerov were defined as the increasing urban temperature (extreme heat as well as overall warming) and drought. This is consistent with Prerov's climate adaptation, which states that the three main climate threats for the city are drought, heat waves and floods (ASITIS, 2021). The plan specifies the following elements:

By 2030 the average temperature in Přerov will increase by **0,5 °C, by 2050 by more than 1 °C, and by 2100 the temperature could increase up to 4,2 °C.** The increase will be most noticeable in summer and winter.

- Along with the increase of temperature the **number of hot days** (with temperature above 30 °C) **will increase.** In the middle of the century, 20-30 hot days with temperatures above 30 °C can be expected every year. More frequent and longer occurrences of heat waves (periods of extremely high temperatures lasting for days or even weeks) can also be expected.
- Winters will be also getting warmer with a significant decrease of cold days when temperatures stay below 0°C at all times.
- There will be no major change in the total amount of annual precipitation – alternatively, there may be a slight increase. However, the distribution (intensity) of precipitation will change throughout the year. It will rain more often in spring, autumn, and winter.
- In summer, on the other hand, there will be a decrease in precipitation and periods of drought will be prolonged. This can lead to some rivers drying up. **Extreme rains** (20-50 mm per day) will occur more often and cause flash floods.

Areas most vulnerable to heat waves:



Picture 1: Climate change vulnerability synthesis of the city of Přerov, source: ASITIS, 2021

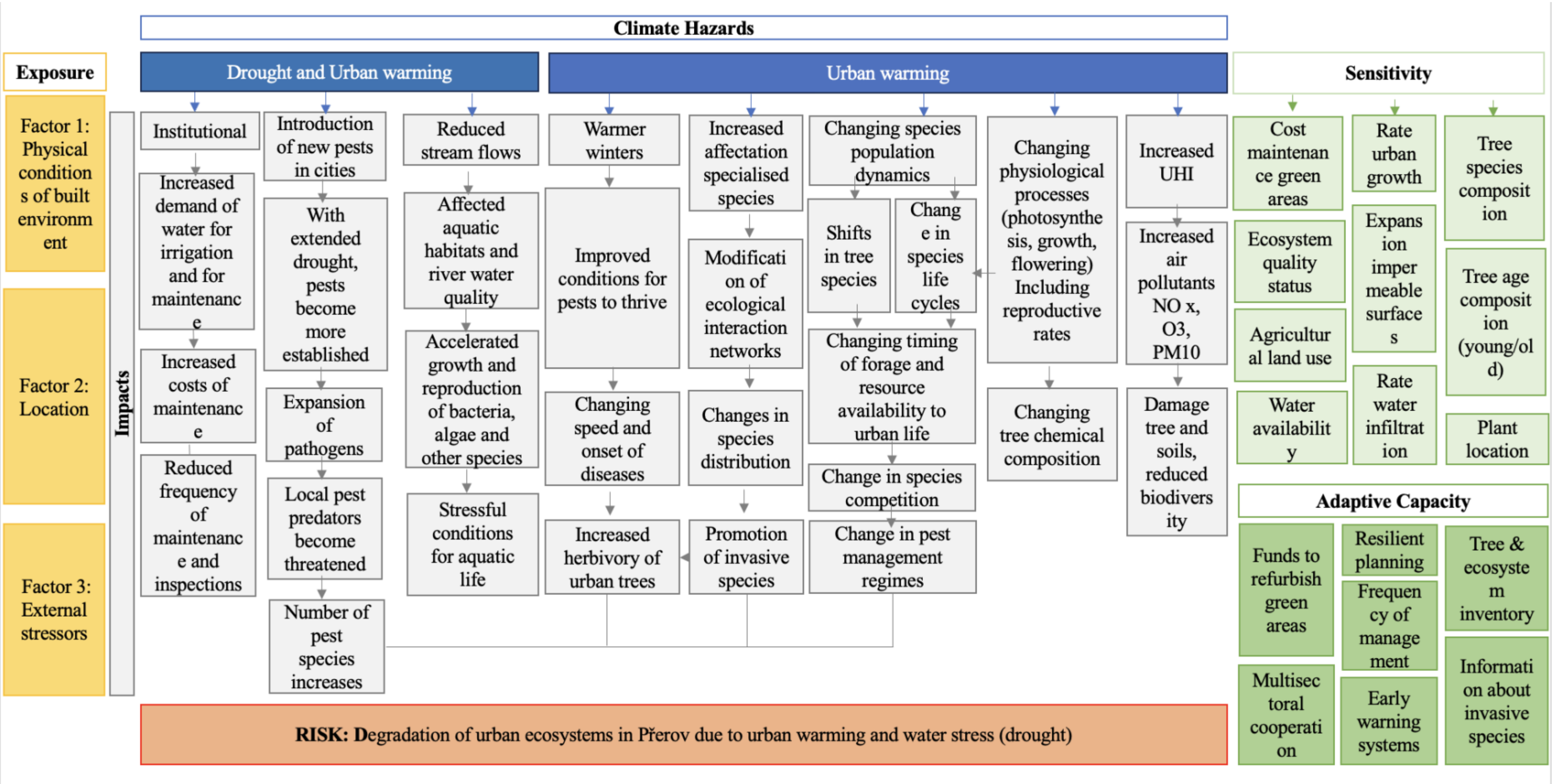
- historical city centre (area along *Kopaniny* street)
- residential area in *nábřeží Dr. Edvarda Beneše* embankment and *Na Hrázi* street.
- area along *Jaselská* street and *Gen. Štefánika* street
- area between *Bečva* river and the *17. Listopad* avenue or *Dvořákova* street

Areas most vulnerable to droughts:

• surroundings of industrial areas *Přerovské strojírny* and *Precheza* and *Tržní* street
• shopping centre surroundings near the former *Želatovská kasárna* barracks.

• the most vulnerable residential areas are: the city centre area between *Bečva* river and *Horní náměstí* square, segments between the streets *Palackého* and *Kratochvílova* and south from *Komenského* street.

V. Climate Impact chain for Přerov



VI. Risk:

Understanding risks: Climate change and urban ecosystems

- Urban ecosystems, known for their biodiversity, play a crucial role in natural capital for climate change adaptation and mitigation (Rosenzweig et al. 2015); while at the same time, urban habitats contribute to the well-being of urban residents (Solecki & Marcotullio, 2013).
- However, climate change is already impacting urban biodiversity and ecosystems (Rosenzweig et al. 2015). The combination of climate change and urbanization (for example, through increased patch fragmentation and diversity), is expected to heighten the vulnerability of biodiversity hotspots, urban species, and essential ecosystem services (Luck & Wu, 2002).
- Virtually all climate change effects have direct or indirect repercussions for urban ecosystems, biodiversity, and the vital ecosystem services that enhance human health and well-being in cities (Rosenzweig et al. 2015). For example, climate change will increase the susceptibility and vulnerability of urban ecosystems to various geohydrological threats, such as diminished groundwater and aquifer quality, subsidence, and intensified salinity intrusion (Praskievicz & Chang, 2009).
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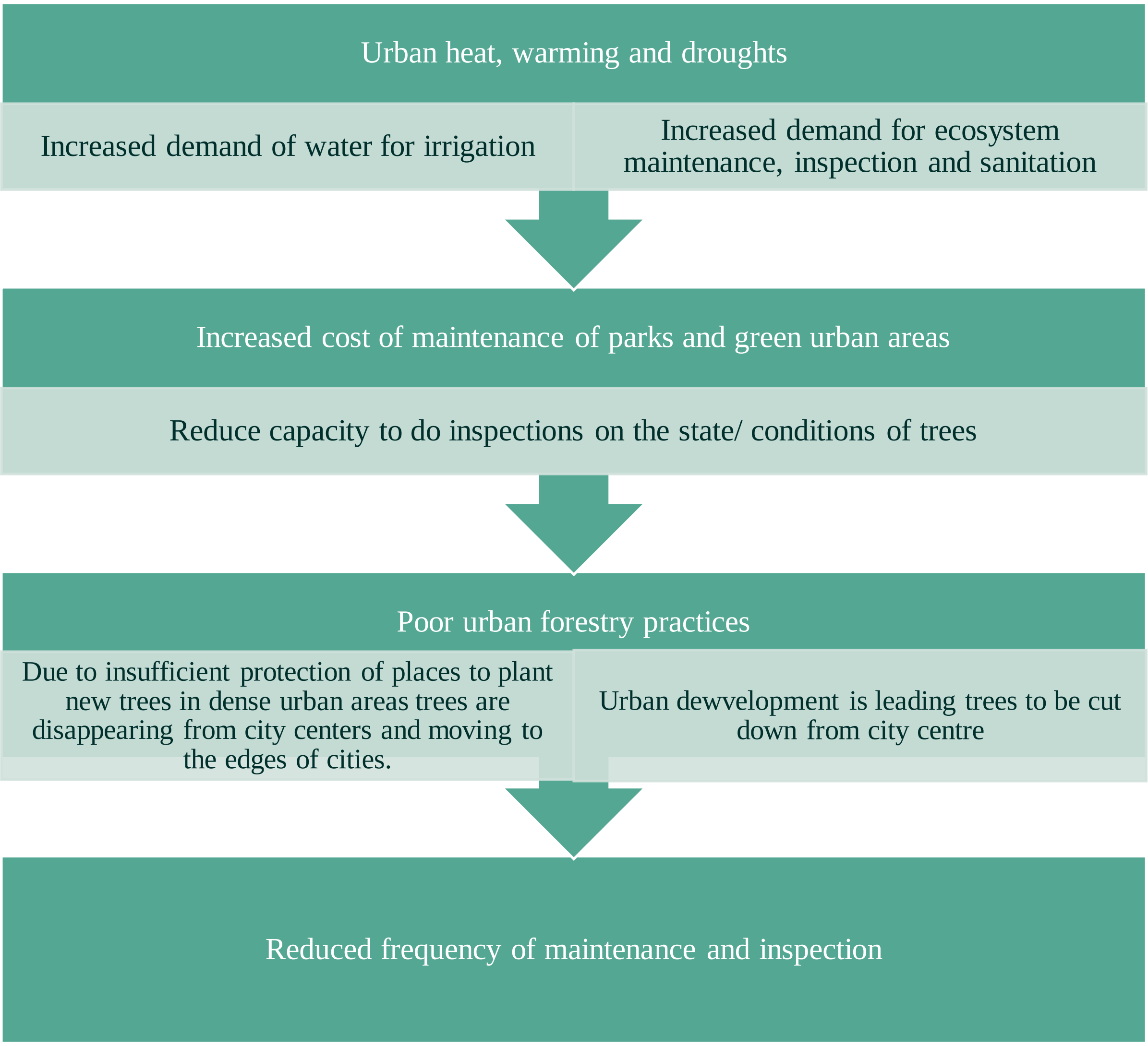
- Climate change and the urban heat island (UHI) effect impact ecosystem services and green infrastructure by causing shifts in temperature and precipitation patterns, evaporation rates, humidity levels, soil moisture content, vegetation growth rates, water tables, aquifer levels, and air quality (Solecki & Marcotullio, 2013). These changes can bring about cascading effects that further affect urban ecosystems (Frumkin et al., 2008; Keim, 2008).

During the workshop, city representatives of Přerov decided to attend the risk of urban heat, urban warming, and droughts in relation to the degradation of urban ecosystems. As shown in the figure above, overall, the risk of urban ecosystem degradation was associated in connection with eight sequences of impacting factors: (1) foreign pests increasing and stabilising (and changing patterns of disease), (2) changing water conditions posing stressful conditions for aquatic life, (3) changes in species distribution, (4) changes in species competition for forage and new pest management regimes, (5) changing physiological processes, (6) reduced biodiversity and tree and soil damage provoked by air pollution, (7) the modification of ecological interaction networks, and (8) reduced institutional capacities to maintain and inspect the conditions of urban ecosystems.

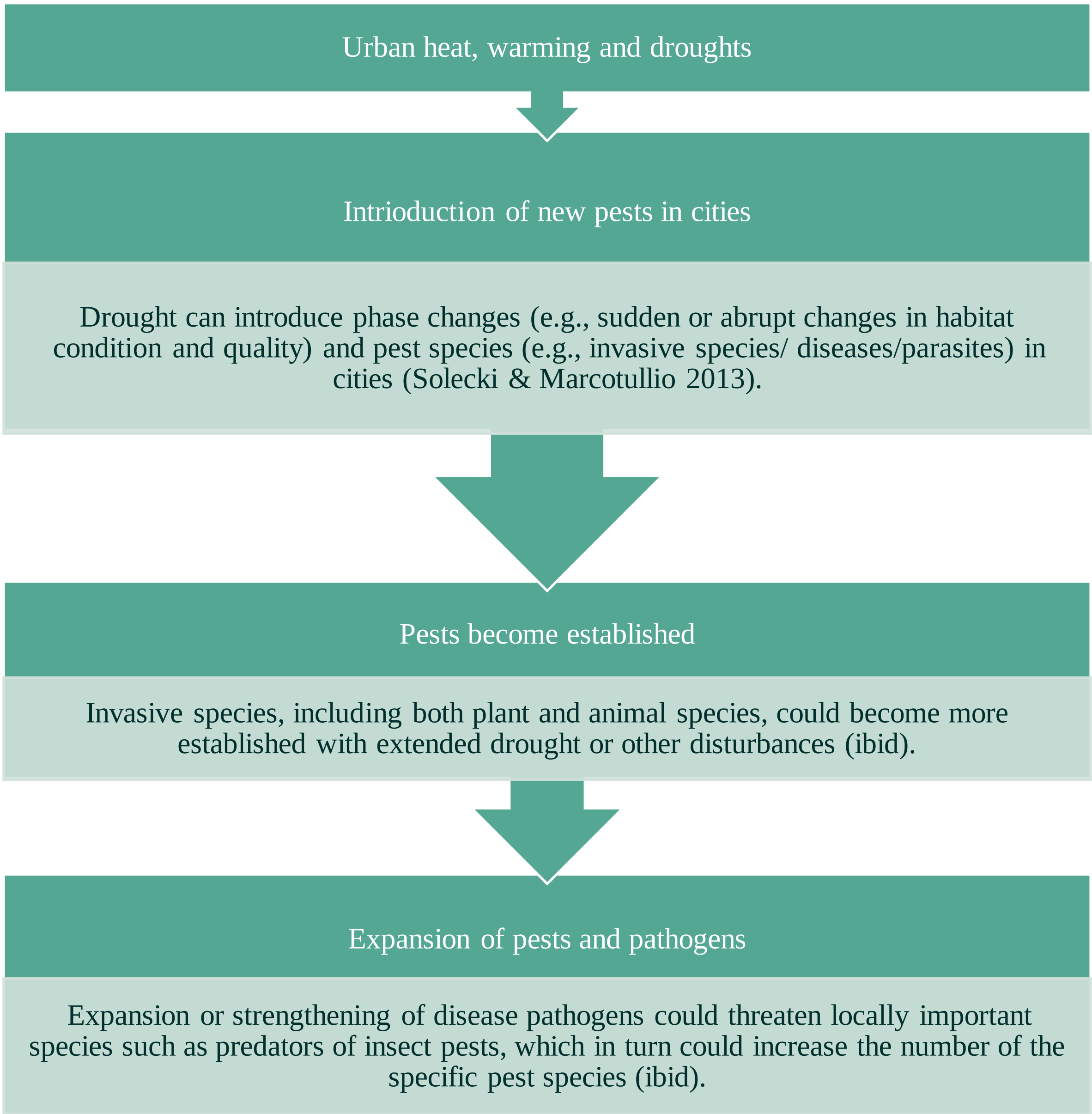
Sequence 1. Institutional impacts

In the first sequence of impacts proposed, the focus is on the reduced capacity to keep appropriate and frequent maintenance and inspection to degrading urban ecosystems provoked by urban heat, warming and droughts. The proposed impact factors in this first sequence emerge as propositions provided by the participants during the workshop. The cause-effect relationships are presented below.



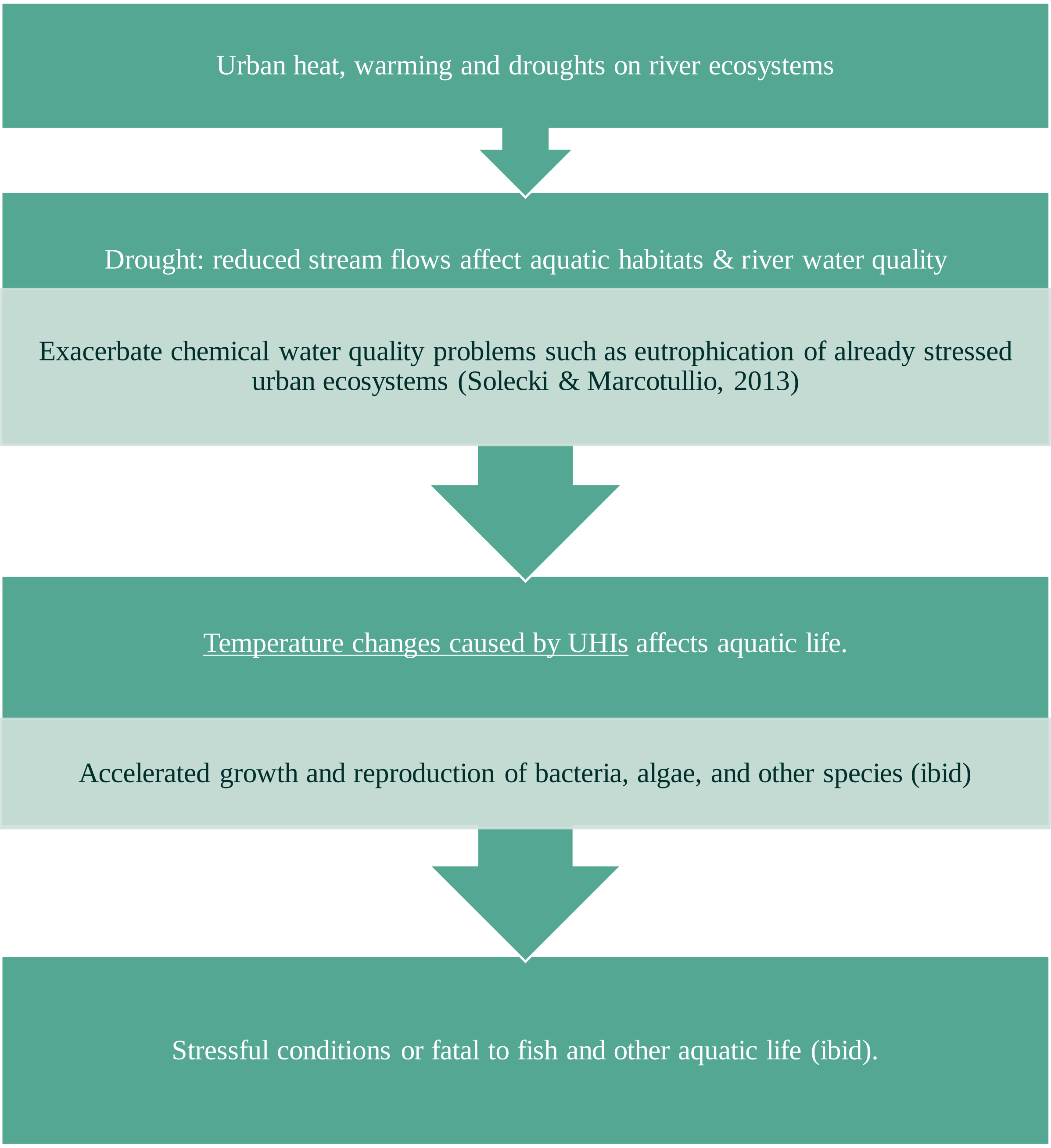
Sequence 2: Expansion of pests and pathogens

In the second sequence of impacts proposed, the focus is on the expansion of pests and pathogens provoked by urban heat, warming and droughts. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented below.



Sequence 3: Drought and urban heat on river ecosystems

In the third sequence of impacts proposed, the focus is on the degradation of aquatic habitats provoked by urban heat, warming and droughts. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented below.



Sequence 4: Urban heat on pests and tree degradation

In the fourth sequence of impacts proposed, the focus is on expansion of new pests and tree degradation provoked by urban heat and warming. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented below.

Urban heat and warming

Better conditions for pests

Changing climate may also affect the introduction of new species in urban ecosystems by reducing noninvasive and native species while favoring weedy and urban-adapted species (Rosenzweig et al. 2015).

Warming cities may find new problems with invasive species and pests that had formerly been limited by cold conditions (Rosenzweig et al. 2015).

Winter warming and absence of cold waves will benefit certain species of insect pests and diseases that are sensitive to prolonged periods of cold; other invasive species may be able to respond more readily to warmer winterand spring- time temperatures (Solecki and Marcotullio 2013).

Changing speed and onset of diseases

Climate shifts can adjust the speed of onset of emerging diseases and other pathogens and alien/invasive species entering the extended regions around cities (Solecki and Marcotullio 2013).

Increased herbivory of urban trees

Urban trees could face greater herbivory in the future as a consequence of the increased fitness of some herbivorous arthropods under warming scenarios. However, more research is needed to generalize these results to more urban areas (Rosenzweig et al. 2015).

Sequence 5: Urban heat on the promotion of invasive species

In the fifth sequence of impacts proposed, the focus is on the affectation of specialised species and the promotion of invasive species degradation provoked by urban heat and warming. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented below.

Extreme heat

↓

Increased affectation on specialised species

Species that are highly specialized and heat sensitive may be threatened with local extinction driven also by an inability to move to new areas as urban development expands (Rosenzweig et al. 2015).

↓

Changes in species distribution and promotion of invasive species

Ultimately, changes in species distributions are expected to modify the ecological interaction networks in cities and have the potential to promote invasive species, which could accelerate the loss of urban biodiversity (Kendal et al., 2012)

Sequence 6: Urban heat on population dynamics and forage availability

In the sixth sequence of impacts proposed, the focus is on the changing population dynamics and forage availability provoked by extreme heat. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented below.

Extreme heat affects species dynamics

Changing population dynamics

The UHI effect in cities can change the reproductive and population dynamics of animals (Rosenzweig et al. 2015)	Insect life cycles and migration patterns have been well-documented, with changes in the life cycle of certain insects having already occurred in response to urban warming (Parmesan, 2006; Parmesan and Yohe 2003).

Change resource availability

Climate shifts will impact the resources available to urban wildlife including insects, birds, and other larger animals by changing the quantity, quality, and timing of forage for animals (Solecki and Marcotullio 2013).	Forest tree species shifts, such as the decline in one species to be replaced by another better suited to the likely warming and moisture-limiting climate-, could result in an important loss of forage for one or more animal species (Solecki and Marcotullio 2013).

Changes in species competition and pest management regimes

The shifts in forage and in species composition will result in changes in species competition and pest management regimes (Ibid).

Sequence 7: Urban heat on physiology

In the seventh sequence of impacts proposed, the focus is on plant physiological impacts provoked by urban heat and warming. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented below.

Changing physiological processes

At the individual and species population level, many physiological processes such as photosynthesis, respiration, growth, and flowering of plants are affected by changing temperature (Rosenzweig et al. 2015)

Changing reproductive rates

Elevated temperature can affect growth and reproductive rates either positively or negatively for plants (Hatfield, 2011).

Higher temperatures can also lead to increased physiological stress on wildlife, affecting their behavior and reproduction (Marzluf, 2001).

Changes in tree chemistry

Warming conditions in New York City, for example, have led to changes in tissue chemistry in tree seedlings relative to cooler, non-urban settings, resulting in more rapid shoot growth but reduced root mass (Searle et al., 2012).

Sequence 8: Heat on air pollution

In the eighth sequence of impacts proposed, the focus is on the degradation of urban ecosystems due to increasing levels of air pollution as provoked by urban heat and warming. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented below.

Heat increases urban heat island effect

Heat waves and warm spells could exacerbate urban heat island effects, including increased air pollution (Solecki & Morcotullio, 2013).

↓

Increasing production of pollutants

Increased temperatures will promote the increased production of secondary air pollutants such as ozone, NO_x and SO_x (ibid)

↓

Urban ecosystems affected

Air pollution has multiple health, infrastructure, ecosystem and climate impacts (Molina and Molina 2004).

Pollutants such as sulfur can lead to excess levels of acid in lakes and streams, and damage trees and forest soils; atmospheric nitrogen can reduce the biodiversity of plant communities and harm fish and other aquatic life; ozone damages tree leaves and negatively affects scenic vistas in protected natural areas; mercury and other heavy metal compounds emitted as exhaust from fuel combustion can eventually accumulate in plants and animals (EPA)

Ground-level ozone damages vegetation and reduces biodiversity (EEA).

Ozone damages agricultural crops and reduces yields (EEA).

Nitrogen oxides (NO_x), ozone (O_3) and fine particulate matter (PM10), are major problems for urban vegetation. Both fungal pathogens and insect pests of plants are also impacted-particularly lichens- (Bell et al. 2011)

VII. Exposure

Resulting from the previous hazard-impact-risk cause-effect relations, the following elements were identified during the workshop to be exposed to the effects of urban heat, warming and droughts.

Factor 1: Physical conditions of built environment

- Urban heat island can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning, inducing also earlier spring-time flowering in urbanized areas compared to surrounding rural areas (Richter 2015).
- High building density and a lack of urban green and water spaces determine the adverse bioclimatic evaluation of urban environments (Richter 2015).
- Urban temperatures are enhanced by anthropogenic heat from vehicular transport, heat emitted from building energy waste (Ebi et al 2021).

Factor 2: Location

- During the workshop, it was indicated by participants that trees tend to be taken away from the city centre due to land use planning the use of space. Trees enter in competition with other spatial needs such as the provision of urban lightning, and the distribution of electricity cables.

Factor 3: External stressors

- During the workshop, it was indicated by participants that trees tend to be taken away from the city centre since trees enter in competition with spatial need uses such as traffic.

Resulting from this characterisation of exposure factors, the following table identifies the connection between the impact sequences with exposure factors:

Impact Sequence	Association to Exposure Factor
Sequence 1	2, 3
Sequence 2	1
Sequence 3	1
Sequence 4	1, 2
Sequence 5	1, 2, 3
Sequence 6	1
Sequence 7	1
Sequence 8	1

Areas in the city under exposure identified by participants during the workshop:

a) National nature reserve Žebračka, the floodplain forest (affected by factor 1)
b) Bečva river (affected by factor 1)
c) Water area Laguna (affected by factor 1)
d) Urban parks (affected by factor 1, 2, 3)
e) Agricultural land (affected by factor 1, 2, 3)
f) Street greenery (affected by factor 1, 2, 3)

VIII. Sensitivity

Sensitivity is associated with three major elements: (1) water availability; (2) urban dynamics (rate of urban growth and expansion of impermeable surfaces which decrease infiltration rates and strengthens the UHI); and (3) ecological properties of trees in the city (species type, age composition and tree location). The relationship between sensitivity factors and impact factors are displayed according to each of the impact sequences:

- **<u>Factor 1: Water availability</u>**:
    - The biggest water demand in Přerov is generated by industry. Generally, if prolonged periods of drought appear there is a new "Plan to handle drought" which identifies which segments will be/will not be allowed to access water. Přerov is part of Olomoucký kraj which has insufficient number of large water bodies (dams) to overcome such periods by suppling from the dam or dam cascade (which is the way in other regions of the Czech Republic). The problem with periods of drought in the area is that at the same time demand for water rises across all the sectors, this demand is met by local rivers and streams. However, water streams that usually support industry run the risk of drying up.
    - The issue of urban water security remains an ongoing challenge, particularly in lower-income countries. Many cities face difficulties in providing essential services to their residents, especially those residing in informal settlements. As cities continue to expand, the demand for limited water resources will grow, and the effects of climate change are poised to exacerbate these challenges in numerous urban areas (Rosenzweig et al. 2015).
    - Elevated temperatures play a critical role in increasing the rate of drought onset, overall drought intensity, and drought impact through altered water availability and demand (Gowda et al. 2018)

- **<u>Factor 2: Urban dynamics.</u>**
    - **Rate of urban growth**: Urban ecosystems face unique stressors, leading to heightened exposure to hazards such as high population density, the influence of non-climate-related stressors, and the urban heat island (UHI) phenomenon (Farrell et al., 2015).
    - **Expansion of impermeable surfaces**: One of the most significant alterations impacting urban streams is the proliferation of impervious surfaces. This transformation modifies the hydrological dynamics and channels pollutants that accumulate from buildings, roadways, and parking lots into the streams (Grimm, et al. 2008).
    - **Rate of water infiltration**: Associated to previous factor.

- **Factor 3: Ecological properties.**
  - **Tree species composition**: McKinney (2006) notes that certain "urban-adapted" species flourish in urban environments globally, often outcompeting indigenous species and becoming prevalent at local and regional levels. The process of homogenizing terrestrial and aquatic ecosystems through urbanization occurs at varying rates across different geographic regions, influenced by factors such as human population growth and the specific composition of species (Olden, 2006). Additionally, while various ecological and socioeconomic factors impact vegetation in urban areas, a significant portion of non-native invasive species that thrive in cities originate from warmer regions, benefiting from shifting climate conditions (Sukopp & Wurzel, 2003).
  - **Tree age composition**: Currently, trees lack protection, although discussions are underway to amend legislation under the auspices of the Ministry of Environment. Consequently, numerous mature trees face a gradual decline in vitality, subject to partial, piece-by-piece removal without any plans for replacement. While a significant number of trees have reached maturity, the absence of replanting initiatives persists due to potential interference with existing electricity networks. It is estimated that newly planted trees in Prerov have a life expectancy of 14 years.
  - **Plant location**: Přerov (like most of other Czech cities except for Prague) do not have funds to implement permanent irrigation, neither invest in habitat conditions improvement (root aeration; extension of permeability of surrounding surfaces; rootable cells in new plantings; "micro water management" - drainage of water from surrounding paved surfaces to the roots of the tree). All these factors increase sensitivity to climate-related issues and deepen possible risks and increase negative impacts of climate change.

Impact Sequence	Sensitivity factor
Sequence 1	1, 2, 3
Sequence 2	1, 2, 3
Sequence 3	1, 2
Sequence 4	3
Sequence 5	2, 3
Sequence 6	1, 2, 3
Sequence 7	2, 3
Sequence 8	2, 3

IX. Adaptive Capacity

Adaptive capacity is normally determined in terms of knowledge, financial resources, technologies, legislations, and infrastructures that enable people to adapt to the effects of climate change. Seven adaptation factors were identified. These were complemented with additional scientific publications, which results in the following schema:

<table>
<tr><th>Factors identified during the workshop</th><th>Literature supports</th></tr>
<tr><td>Funds to refurbish green areas.</td><td rowspan="6">Conserving, restoring, and expanding urban ecosystems to enhance climate resilience and other co-benefits under mounting climatic and non-climatic stresses of growing urbanization and development processes will require improved urban and regional planning, policy, and governance and multi-sectorial cooperation to protect and manage urban ecosystems and biodiversity (Solecki and Marcotullio, 2013).

Also, greater coordination and networks among governance structures that manage local ecosystems and urban biodiversity, including cemeteries, golf courses, urban parks, and neighbourhood gardens, would strengthen ecosystem functioning as well as the associated and essential social-ecological engagement (Ernstson et al., 2010).</td></tr>
<tr><td>Multi-sectorial cooperation</td></tr>
<tr><td>Resilient Planning</td></tr>
<tr><td>Frequency of management</td></tr>
<tr><td>Early-warning systems</td></tr>
<tr><td>Information about invasive species</td></tr>
<tr><td>Tree and ecosystem inventory</td><td>The adaptive capacity of species in urban landscapes is a function of ecology, physiology, and genetic diversity (Williams et al., 2008).

In the context of urban biodiversity and ecosystems, nonhuman actors, behaviour, species interactions, and human–ecological interventions are also important for adaptive capacity. For example, human-induced adaptive capacity could include planting species that are more tolerant of higher temperatures and droughts. Nonhuman-</td></tr>
</table>

	derived adaptive capacity could include natural processes that change ecosystem components rapidly for organisms like insect populations persisting despite changing climate (Rosenzweig et al. 2015).

Two main strands of adaptive factors emerge in the context of Prerov. One, attending institutional factors and human decisions related to resources and capabilities to plan, manage and monitor urban ecosystems; while a second one looks more into nonhuman-derived adaptive capacity related to natural processes and ecosystem dynamics.

As a way of contextualisation, the specific set of actions included in Prerov's adaptation plan (ASITIS 2021), are presented below:

- Increase the ecological stability of the territory.
    - Revitalisation of ponds in Předmostí.
    - Extension of the orchard area in Žernava.
    - Support of biodiversity of the Popovický hill (natural monument).
- Improve microclimatic conditions in the city and reduce the risks associated with high temperatures during heat waves.
    - Implementation of extensive and intensive green roofs
    - shading of pavements and public spaces
- Reduce transport emissions.
    - Implementation of projects for the development of low or zero emission transport
    - Development of a network of cycle paths

These measures respond to three specific goals:

Strategic goal 1:

- Restore ponds in wetlands in Popovice near Přerov in NNR *Žebračka.*
- Optimize the capacity of the sewer system for cases of flash floods.
- Revitalize ponds in *Předmostí.*
- Support ecological stability in the *Malé laguny* area.
- Revise the flood plan and crisis plan in relation to climate change.

Strategic goal 2:

• Make green roofs

• Revitalize the historical centre

• Revitalize the park at the *náměstí Svobody* square

• Install shades above sidewalks and in other public spaces

• Subsidize rainwater utilization projects

• Create a system of financial microgrants for associations and a participatory budget

Strategic goal 3:

• Implement energy saving measures and install renewable energy sources in buildings (in

• Develop networks of cycle paths and cycle two-way routes

• Secure subsidies for environmental education

X. Bibliography

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Annex 4. Climate Impact chain Mlada Boleslav

I. Introduction

The Climate Impact chain for the city of Mladá Boleslav in the context of the Valorada-EU project, focuses on the risk of extreme high temperatures on people's health in the context of urban transport.

The development of the climate impact chain occurred in two stages. Initially, a participatory workshop involving city representatives was held in October 2023. The preliminary climate impact chain was formulated based on the insights gathered during this workshop, supplemented by a comprehensive literature review. Subsequently, the initial draft of the climate impact chain was shared with city officials and consortium partners ASITIS for feedback. This document incorporates all the suggestions provided by the local stakeholders, resulting in the final version of the impact chains.

The document is organised as follows:

- Section II presents a brief definition and schema describing a climate impact chain.
- Section III discusses key climate risk concerning high temperatures and health issues.
- Section IV delineates the identified climate hazards affecting public transport.
- Section V outlines the schema proposed for the climate impact chain.
- Section VI presents the key risks identified during the workshop and outlines the four impact sequences associated to this risk.
- Section VII outlines the exposure factors associated to each of the sequence of impacts identified in section VI.
- Section VIII outlines the sensitivity factors associated to each of the sequence of impacts identified in section VI.
- Section IX outlines the adaptive capacity factors associated to each of the sequence of impacts identified in section VI.
- Section X presents the bibliography, indicating the literature reviewed for generating this document.

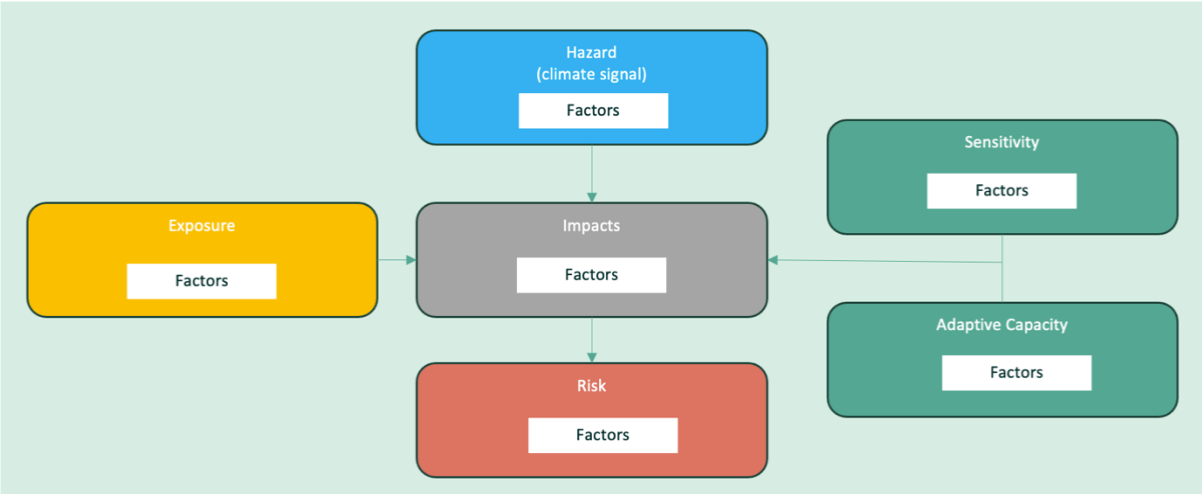
II. Climate-impact chains

A climate-impact chain delineates the connection between a specific climate hazard and a designated impact area. These chains aim to elucidate cause-and-effect relationships within various components of a system. By defining these relationships, impact chains ascertain how a hazard transforms into a risk, factoring in exposure, potential intermediate impacts, sensitivity factors, and response/adaptation capacities that mitigate vulnerability. In cases where applicable, intermediate impacts can be identified, each with its exposure, sensitivity, and adaptation factors (GIZ and EURAC, 2017).

A chain is composed of risk components (hazard, vulnerability, exposure) and underlying factors associated to each component. A climate signal, e.g. a heavy rain event, may lead to a direct physical impact, e.g. a flood, causing a sequence of intermediate impacts, which finally lead to the risk. The hazard component includes factors related to the climate signal and direct

physical impact. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised by one or more exposure factors (GIZ and EURAC, 2017).

Schema of a Climate Impact Chain (adapted from GIZ and EURAC 2017)

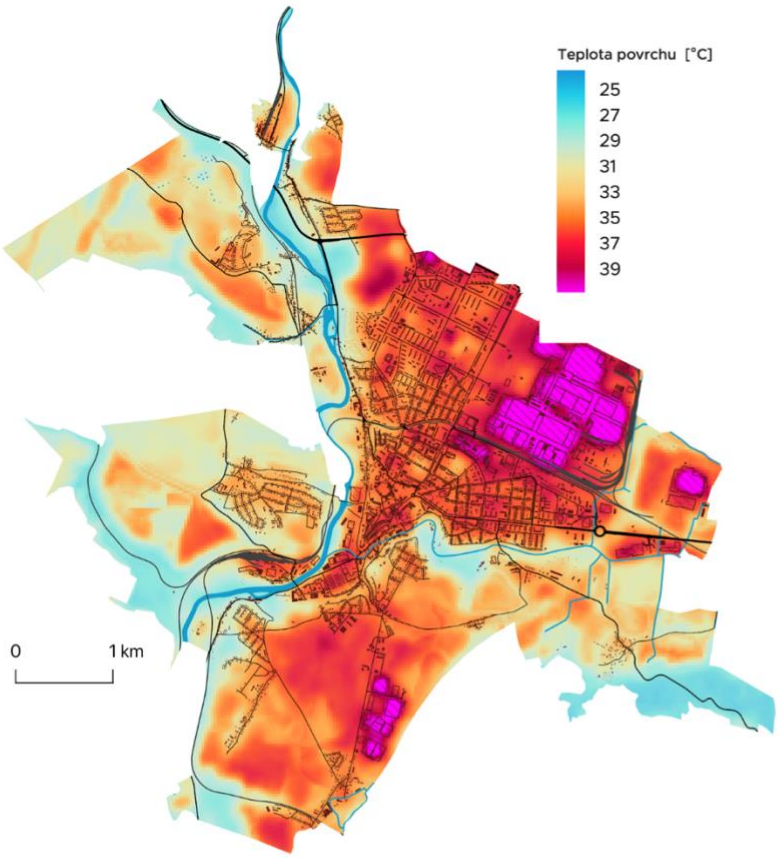


III. Risks: What is distinctive about urban warming in the context of people's health status?

- The frequency, intensity, duration, and spatial extent of some extreme weather events, particularly heat waves, has been increased by climate change, with further increases projected (Richter, 2016).
- Intense heatwaves in Europe are expected to happen more frequently and become more intense with climate change. With 1.5°C, each year more than 100 million Europeans would be exposed to a present intense heatwave (Feyen et al 2020).
- Compared with pre-industrial times, the mean average European surface air temperature increase has been almost 1°C higher than the average global temperature increase, and 2022 was the hottest European summer on record (van Daalen et al 2022). The record hot summer caused almost 62 000 deaths in Europe in 2022 (Romanello et al. 2023)
- Climate change is interacting with other trends, such as population growth and ageing, urbanisation, and socioeconomic development, that can either exacerbate or ameliorate heat-related hazards (Ebi et al 2021).
- Urban temperatures are enhanced by anthropogenic heat from vehicular transport, heat emitted from building energy waste, and minimally by human metabolic heat (Ebi et al 2021).
- Europe had the highest rate of heat-related mortality in recent years (2017–22) (Romanello et al. 2023).
- Vulnerability to heat exposure has increased steadily across all European regions, with an increase of 6% from 1990 to 2019. Although northern Europe is the most vulnerable region, the highest relative increase of 9,8% is observed in central Europe (van Daalen et al 2022)
- Assuming present vulnerability and no additional adaptation, annual fatalities from extreme heat in Europe could rise from 2,700 deaths now to nearly 30,000 with 1.5°C global warming, 50,000 with 2°C and 90,000 with 3°C (Feyen et al 2020).

- While summer heat waves have become more frequent since the 1960s, and average annual temperatures have risen over the past three decades, these trends are expected to persist in the future, increasing the likelihood of record-breaking summer temperatures and heatwaves which significantly affect transportation and human health (Jacobs et al 2014).
- High temperatures can result in heat-related illnesses, including heat exhaustion, heatstroke, and dehydration. They can also exacerbate respiratory and cardiovascular issues, particularly affecting individuals with pre-existing conditions and particularly affect people with pre-existing conditions like diabetes, kidney disease, or mental health disorders. In severe cases, prolonged exposure to high temperatures can be fatal, with vulnerable populations such as the elderly, children, and those with chronic illnesses at a higher risk.

Extreme temperatures affecting Mladá Boleslav



As shown in the map on the left, densely built-up areas, especially industrial areas, are the hottest, and can average up to 10°C warmer in summer than sparsely built-up residential areas. The most overheated places include the Škoda Auto industrial complex, where the highest temperature in the city was detected (46.7 °C) and the Bezděčín - CTPark industrial complex in the south of the city.

Map 1: Overheated areas during heat waves. Source: ASITIS based on Landsat 8 satellite data from 2015-2020

IV. Climate hazards in the context urban transport

With the global urban population expected to reach nearly 70% by 2040 (Black et al. 2021), the need to plan for the risk of extreme temperatures on people's health -particularly as people travel through the city- become paramount.

Transport is a key issue for Mladá Boleslav because the life of the city is significantly linked to industry. The city's service vehicles alone account for around 6,000 vehicles, which practically clog the city at regular intervals at the end of the shifts of the largest of the factories. However, it is not only Mladá Boleslav, but also its surroundings, from which public transport brings workers and where several industrial facilities of the automotive supply and demand chain have been built in the last two decades.

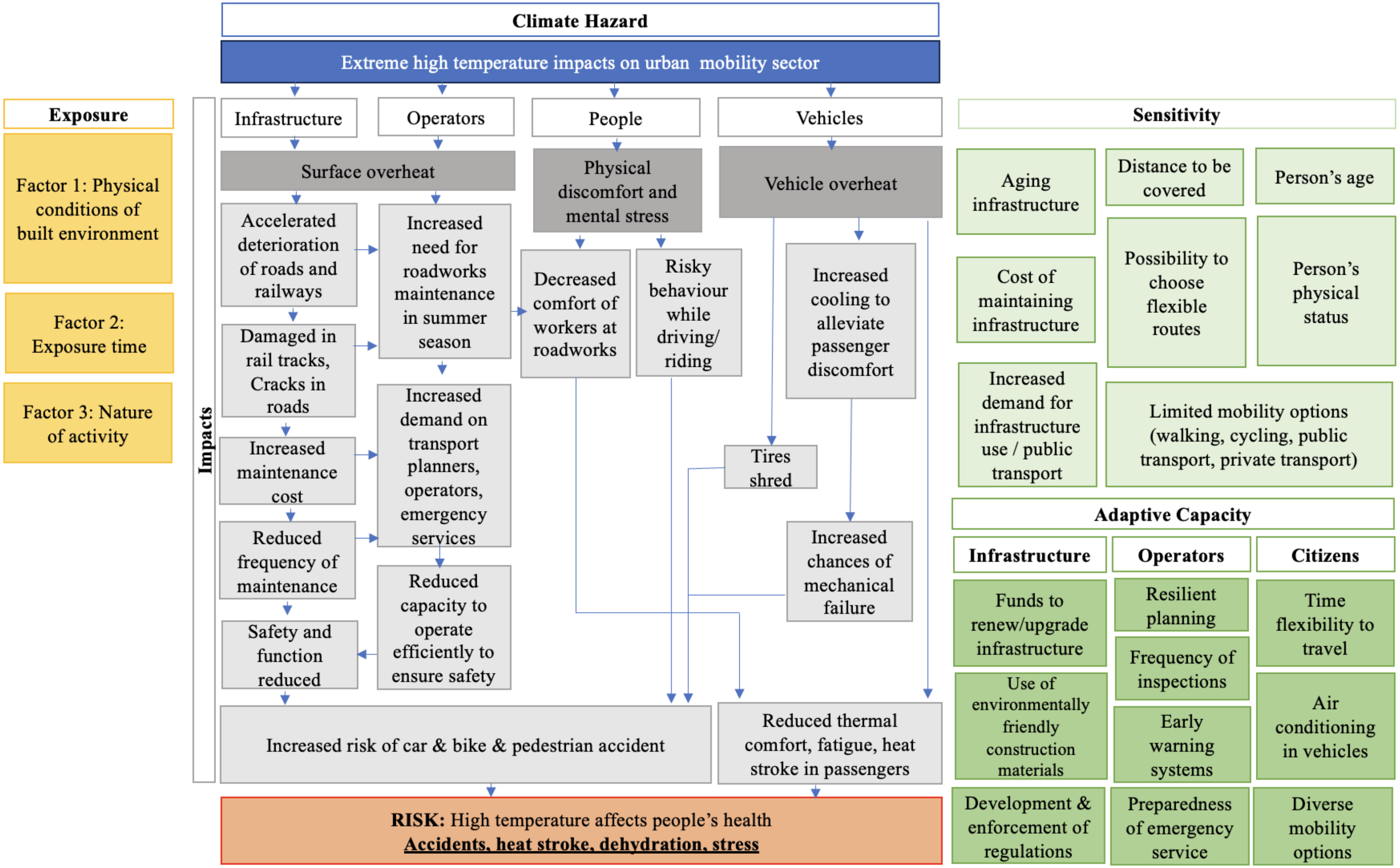
The expected Impacts of climate change in the urban transport sector Mladá Boleslav described in the Adaptation Plan include the following elements.

- Increased traffic accidents due to drivers' attention deficit during heatwaves.
- The necessity to introduce air conditioning in public transport.
- Increased energy consumption for vehicle operation.
- Decreased ice-related incidents.
- Reduced costs for winter road maintenance.

The risk of extreme high temperatures on people's health in the context of urban transport is characterised through four sequences of impact:

(1) road infrastructure.
(2) Operators.
(3) Pedestrians and drivers; and
(4) Vehicles.

V. Schema proposed for the climate impact chain.



VI. Impact sequences:

Sequences 1 and 2: Infrastructure and operators: In the first sequence of impacts, the focus is on people's health which is expected to be affected by the increased risk of car, bike, and pedestrian accident due to reduce safety and by the reduced performance of infrastructure. This sequence of impacts includes also the pressure exerted on the capacity of operators to keep pace with worsening infrastructure.

Surface overheat resulting from prolonged-extreme temperatures.

Accelerated deterioration of roads and railways

Future temperature increases are projected to reduce infrastructure lifetime and increase road costs (Jacobs et al 2014). Elevated temperature, combined with increased salinity and humidity, accelerates deterioration in bridges and roads constructed with concrete (Ibid).

Damaged in rail tracks, cracks in roads

High temperatures can lead to infrastructure damage, affecting roads with issues like deformation and asphalt melting, resulting in unsafe conditions and increased maintenance costs (Slavich et al. 2022).

Elevated temperatures along with the increased occurrence of hot summers, is expected to contribute to a higher frequency of rail buckling incidents posing risks for train travel (Jaroszweski et al. 2014).

Increased maintenance cost

Higher ambient temperatures and extreme heat events can negatively impact pavement performance and, in turn, increase costs due to material upgrades to accommodate higher temperatures (Jacobs et al. 2014)

Increased maintenance costs and rapid maintenance planning increases presure on transport planners, operators, emergency services

Reduced frequency of maintenance

As costs due to material upgrades to accommodate higher temperatures increase; these costs are only modestly reduced by less frequent maintenance (Jacobs et al. 2014).

However, as roads deteriorate more rapidely, the need for maintenance work during the summer season increase, exposing workers to working under extreme temperature conditions.

Safety and function reduced

Higher ambient temperatures and extreme heat events can negatively impact pavement performance; Buckled roadway joints can send vehicles airborne (Jacobs et al. 2014)

Operators' capacity to operate efficiently to ensure safety is reduced

Increased risk of car & bike & pedestrian accident

Sequence 3: Drivers and pedestrians: In the second sequence of impacts proposed, the focus is on the risk of accidents as people are affected by physical discomfort and mental stress due to high temperatures, resulting in more risky behaviour.

Physical discomfort and mental stress

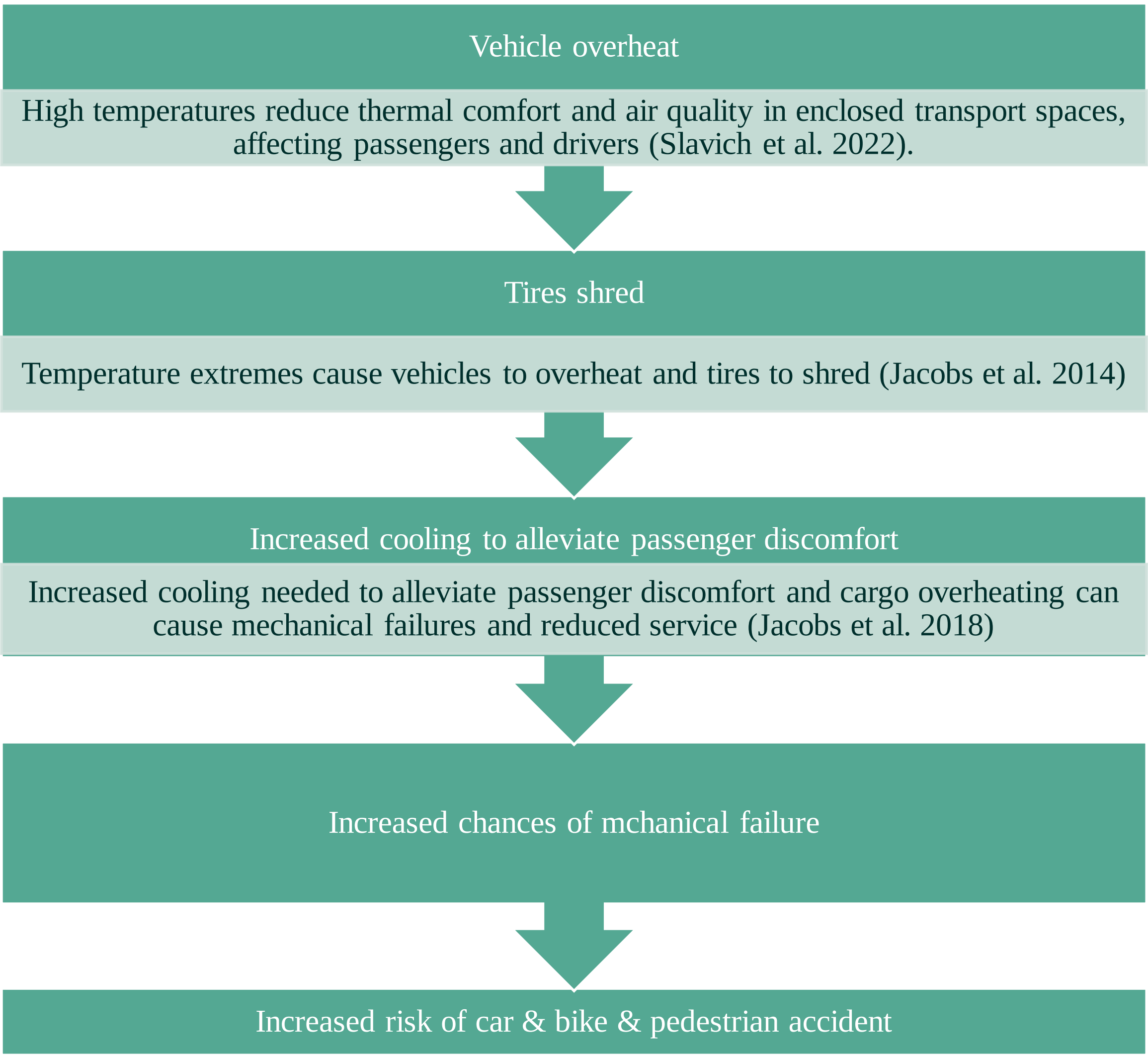
Heat impacts both public and private transportation, including passengers, service workers, and infrastructure staff (Jaroszweski et al. 2014)

Risky behaviour while driving or riding

Nofal et al (1996) research based on 13,390 police records over three years shows that most road traffic accidents occurred on sunny days between 12 noon and 3 pm. Driver error was the primary contributing factor, primarily linked to reckless driving, carelessness, lack of experience, knowledge, attention, as well as over-exhaustion or fatigue and over speed.

Increased risk of car & bike & pedestrian accident

Sequence: 4. Affected performance of vehicles: In the fourth sequence of impacts proposed, the focus is on the risk of accidents emerging from high temperatures affecting vehicle performance and safety.



VII. Exposure:

Resulting from the previous impact cause-effect relations, the following elements could be identified to be exposed to the effects of extreme heat. Some elements emerge directly from the previous impact chain, while others are supported by additional literature:

Factor 1: Physical conditions of built environment

- Urban environment and building structure play a vital role in determining the vulnerability of urban populations to heat stress, such as access to vegetation and green space, development intensity, living on a high floor of multi-storey buildings, building materials, land cover and housing density (Puntub et al 2022).
- High building density and a lack of urban green and water spaces determine the adverse bioclimatic evaluation of urban environments (Richter 2015).
- Urban temperatures are enhanced by anthropogenic heat from vehicular transport, heat emitted from building energy waste (Ebi et al 2021).
- Urban heat island can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning, inducing also earlier spring-time flowering in urbanized areas compared to surrounding rural areas (Richter 2015).

Factor 2: Exposure time

- Overall, the number of hours of risk per person is increasing across all European regions. In southern Europe, the number of hours with heat-related health risks during medium-intensity activities (e.g., football or tennis) increased relatively by 106% between 1990 and 2020 and increased to 429 hours per person in 2020. For strenuous activities (e.g., mountain biking), there was a relative increase of 77% in southern Europe, leading to 627 hours at risk per person in 2020 (van Daalen et al. 2022).
- Equipment operators and road builders can be exposed to hight temperatures for long periods (maintenance and building staff working in hot weather may experience intense fatigue) (Jacobs et al. 2014).
- People at bus stops exposed for long time periods (waiting at unsheltered transit stations during peak hours can lead to severe heat stress (Slavich et al. 2022).

Factor 3: Nature of activity (indoor – outdoor activity and timing of activity)

- For outdoor workers, high metabolic heat production associated with occupational tasks combined with high ambient and radiant heat, low air flow, and sometimes high humidity, add to human heat strain (Ebi et al 2021)
- Cyclists exposed to dehydration and heat strokes (pedestrians and cyclists might also suffer from heat stress and health problems, potentially shifting to public transit or avoiding travel if they can't use a private vehicle (Jaroszweski et al. 2014).
- Bike ridership increases with temperature but falls back with very high temperature (Jaroszweski et al. 2014).

- A literature review performed by Böcker (2013) finds that warmer temperatures, up to certain thresholds, positively influence outdoor place attendance and generally leads to a threefold increase in cycling. Additionally, the review finds that the effects of temperature on travel behaviour differ depending on the purpose of the trip, demographic factors, and geographical context. Recreational trips see an increase in distance.

Resulting from this characterisation of exposure factors, the following table identifies the connection between the impact sequences with exposure factors:

Impact Sequence	Association to Exposure Factor
Sequence 1	1
Sequence 2	1, 2, 3
Sequence 3	1, 2, 3
Sequence 4	1, 2

VIII. Sensitivity

Sensitivity is associated to three major areas: infrastructure, behaviour physical conditions affecting the person or its journey:

- **Infrastructure:** The following behavioural elements are derived from the workshop.
  - Factor 1: Aging infrastructure (sequence 1).
  - Factor 2: Cost of maintenance (sequence 1).
  - Factor 3: Increased demand for infrastructure use (global urban population expected to reach nearly 70% by 2040 (Black et al. 2021)).
  - Factor 4: Urbanisation
    - increasing urbanisation could amplify the urban heat island effect, which causes urban and metropolitan areas to be significantly warmer than their surrounding rural areas (Feyen et al 2020)
    - The combined effects of heatwaves and air pollution might further exacerbate human stress in densely populated areas (Feyen et al 2020)
    - Urban areas are vulnerable to the health impacts of climate change due to their high population density, concentration of vulnerable populations, higher temperatures compared to surrounding areas (Barata et al 2018).
  - Factor 5: Existence of air conditioning in transport

- **Behaviour:** Behavioural factors indicated as relevant by workshop participants.
  - Factor 6: Distance to be covered.
  - Factor 7: Possibility to choose flexible routes.
  - Factor 8: Limited mobility options.

- **Human physical attributes** affecting a person and his/her journey include:

- Factor 9: Person’s age:
  - Population exposure to heatwaves increased by 57% on average in 2010–19 compared with 2000–09, and by more than 250% in some regions, putting older people, young children, people with underlying chronic health conditions, at high risk of heat-related morbidity and mortality (van Daalen et al. 2022).
  - Future susceptibility likely to be increased with ageing populations, (Hajat et al. 2010).
  - Population ageing in Europe is a major demographic trend for the coming decades. It could further increase the effect on human beings of temperature extremes (Feyen et al 2020).
  - Adults older than 65 years and infants younger than 1 year, for whom extreme heat can be particularly life-threatening, are now exposed to twice as many heatwave days as they would have experienced in 1986–2005 (Ebi et al. 2021).
  - heat- related deaths of people older than 65 years increased by 85% compared with 1990–2000, substantially higher than the 38% increase that would have been expected had temperatures not changed (Hajat et al, 2010).

- Factor 10: Person’s physical/ health status
  - Studies consistently show that adults older than 65 years, people with cardiopulmonary and other chronic diseases, and very young children are particularly vulnerable to the effects of heat, irrespective of income level or geo- graphical region (Ebi et al 2021).
  - pre-existing physical conditions (such as cardio-vascular and cerebrovascular conditions and diabetes) or those related to mental health (such as depression) potentially leading to mortality and morbidity, age (particularly children and the elderly) (Puntub et al 2022)
  - Rates of heat-related mortality and morbidity are high in elderly and chronically ill individuals, particularly those with cardiovascular, respiratory, and renal diseases. People with diabetes, neurological disorders, and psychiatric illnesses might also be at increased risk (Hajat et al, 2010).

Sequence	Association to sensitivity factor
Sequence 1	1, 2, 3, 4, 5
Sequence 2	1, 2, 3, 4, 5
Sequence 3	6, 7, 8, 9, 10
Sequence 4	1, 6, 7, 8, 9

IX. Adaptive capacity

Adaptive capacity is normally determined in terms of knowledge, financial resources, technologies, legislations, and infrastructures that enable people to adapt to the effects of climate change. The literature informs of three key elements shaping a well-adapted transport system in the context of climate change:

- To be climate change resilient, transport systems should be operated by adaptive organizations, which embed adaptation across all functions, understand current and future weather conditions and have strategies in place to address them (Black et al. 2021).
- Improving adaptive capacity involves assessing design capability, financial capability, and organizational capability to respond to climate change risks. For instance, transport planners and operators adhere to design standards that consider specific temperature and precipitation ranges and return intervals for extreme events (ibid).
- Nonetheless, these standards are becoming less applicable over the extended lifespan of infrastructure investments, particularly for durable structures such as bridges and roads, underscoring the necessity for comprehensive asset lifecycle planning in climate adaptation endeavours (ibid).

Existing assessments:

The current state of transport in Mladá Boleslav is summarised in the Sustainable Mobility Plan for the city (Plán udržitelné městské mobility města Mladá Boleslav).

The plan presents a SWOT analysis of the entire urban transport sector. Based on this assessment, figure 5 below presents a summary of key factors that provide a picture of the state of adaptative capacity.

Road and railways	**Cyclists**
• Intense automobile traffic in the city • Inadequate road infrastructure (capacity). • Lack of funds for road maintenance • Conflicts between transportation needs and environmental quality. • Low utilization of public transport. • Inadequate standard, comfort, and speed of railway transport. • Bad location of main railway station. • Outdated suburban bus transport system. • Unacceptably high prices for public transport • Complex and slow main routes of public transport	• A small compact city. • Cycling infrastructure within the city. • Approved strategic documents to support cycling. • Discontinuous route alignments. • Cycling may remain on the periphery of political interest. • Low-quality cycling infrastructure projects. • Ongoing high intensity of motor vehicle traffic. • Failure to reflect cycling in strategic, development, and planning documents.

Pedestrian traffic	Organization and traffic management
• Compact small-sized city • Wide street space • Minimal calm areas • Complete accessibility not guaranteed. • High-intensity car traffic	• Lack of central traffic management. • Lack of information systems at public transport stops.

Mladá Boleslav's Sustainable Urban Mobility Plan, emphasizes the promotion of urban public transport and cycling (Attractive and reliable transportation for all residents, adequate capacity roads and spaces for motorized transport where desired, providing people with more space and a better living environment in the city, Traveling mainly by bike and on foot throughout the city).

In line with this, the adaptation plan of the city recommends key activities:

- Renewal of the public transport fleet to provide better thermal comfort in the summer.
- Establish a system for the rapid reconstruction of transportation infrastructure sections affected by natural disasters.
- Restrict parking areas in locations with a lack of greenery and revitalize them.

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Annex 5. Climate Impact chain Molise

I. INTRODUCTION

The Climate Impact chain for the region of Molise in the context of the Valorada-EU project, focuses on the **risk of hydrogeologic affectation on rural livelihoods, rural infrastructure, and agricultural means of production**.

The development of the climate impact chain occurred in two stages. Initially, a participatory workshop involving regional representatives of Molise and Valorada-consortium members CMCC was held in October 2023, in Campobasso, Italy. The preliminary climate impact chain was formulated based on the insights gathered during this workshop, supplemented by a comprehensive literature review. Subsequently, the initial draft of the climate impact chain was shared with regional officials and consortium partners CMCC for feedback. This document incorporates all the suggestions provided by the local stakeholders, resulting in the final version of the impact chains.

The document is organised as follows:

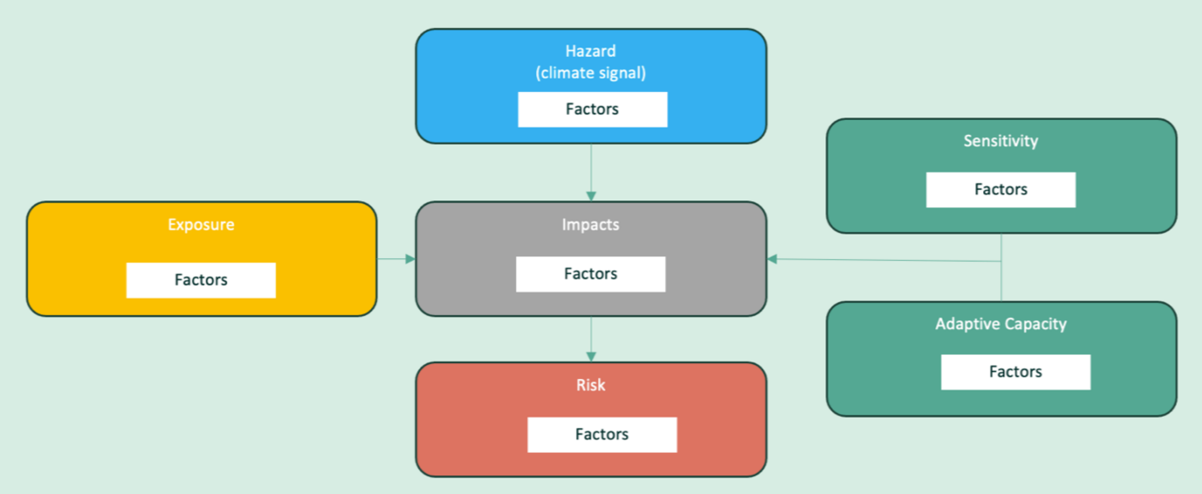
- Section II presents a brief definition and schema describing a climate impact chain.
- Section III discusses key climate hazards for the region of Molise.
- Section IV delineates the identified climate impacts for the region of Molise.
- Section V outlines the exposure factors associated to each of the sequence of impacts.
- Section VI outlines the sensitivity factors associated to each of the sequence of impacts.
- Section VII outlines the adaptive capacity factors associated to each of the sequence of impacts.
- Section VIII presents the bibliography, indicating the literature reviewed for generating this document.

II. CLIMATE IMPACT CHAINS

A climate-impact chain delineates the connection between a specific climate hazard and a designated impact area. These chains aim to elucidate cause-and-effect relationships within various components of a system. By defining these relationships, impact chains ascertain how a hazard transforms into a risk, factoring in exposure, potential intermediate impacts, sensitivity factors, and response/adaptation capacities that mitigate vulnerability. In cases where applicable, intermediate impacts can be identified, each with its exposure, sensitivity, and adaptation factors (GIZ and EURAC, 2017).

A chain is composed of risk components (hazard, vulnerability, exposure) and underlying factors associated to each component. A climate signal, e.g. a heavy rain event, may lead to a direct physical impact, e.g. a flood, causing a sequence of intermediate impacts, which finally lead to the risk. The hazard component includes factors related to the climate signal and direct physical impact. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised by one or more exposure factors (GIZ and EURAC, 2017).

Figure 1: Schema of a climate impact chain (source: GIZ and EURAC, 2017)



III. CLIMATE HAZARDS AND CLIMATE RISKS IN MOLISE REGION

Climate hazards are defined as the potential occurrence of a climate-related event, trend or physical impact that may cause loss of life, injury, damage and loss of infrastructure, livelihoods, service provision, ecosystems (Rosenzweig et al. 2015).

Climate risks are defined as the potential for consequences where something of value is at stake and where the outcome is uncertain (Rosenzweig et al. 2015).

During the workshop, regional representatives of Molise decided to attend the risk of hydrogeologic affectation on rural livelihoods, rural infrastructure and agricultural means of production.

What is distinctive about rural areas in the context of climate change impacts, vulnerability, and adaptation? Rural areas can be characterized by a dependence on agriculture and natural resources; higher prevalence of poverty, isolation, and marginality; neglect by policymakers; and lower human development. Particularly in developed countries, there are closer interdependencies between rural and urban areas (such as commuting), and there are also newer forms of land use such as tourism and recreational activities (although these also generally depend on natural resources) (Dasgupta et al. 2014).

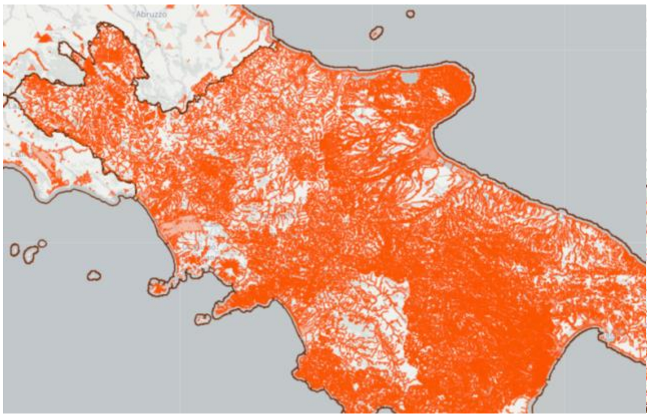
Key contextual aspects characterising climate risk linked to floods:

- Europe has experienced an increase in flood risk in recent years. In the last three decades, the number of extreme weather events, including hydrological events, has increased by 60% in Europe (Furtak et al. 2022)
- Projections show that climate change will lead to an increase in the intensity of storms and floods in Europe by 2100. An increase in the frequency of rainfall intensity is estimated to increase the occurrence of flash floods and urban flooding (Furtak et al. 2022).
- Due to the conformation of the territory and its geographical location in Europe, Italy is an area strongly affected by geological, hydrological, and hydraulic instability phenomena. In

Italy about 94% of the municipalities are affected by risks of landslides, flooding and coastal erosion (more than 8 million people, or 12,5% of the national population). This critical situation is likely to be exacerbated due to future climate trends (Italian ministry of environment and energy security, 2022).

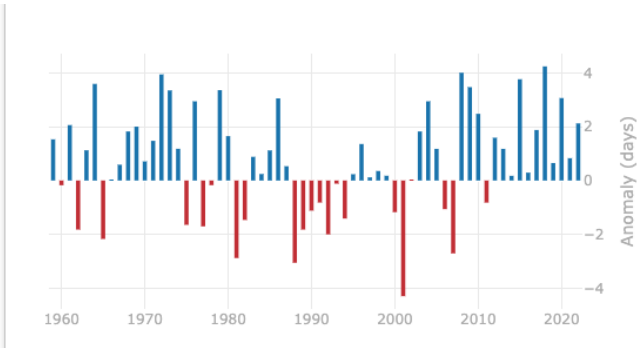
- The increase in localised precipitation phenomena plays an important role in aggravating the risk of geohydrological instability throughout all the peninsula. In this context, anthropogenic factors - such as soil use and sealing or occupation of river areas - combined with climate change hazards play a significant role in exacerbating risks (ibid).
- The most affected areas in relation to this hazard are (and will be) on the Alps and Apennines, both in terms of magnitude and seasonality of disturbances (ibid).
- The expected rise in intense rainfall contributes to a further increase in the hydraulic risk for small basins, and amplifies the risk associated with surface landslides in areas with more permeable soils (such as urban areas) (ibid).
- **In the region of Molise**, there is a prevalence of landslide risk over flood risk. There has been a significant increase of landslides in a relatively short period of time (increase in both the number of landslides and the affected area). The percentage of regional territory classified as having high hydrogeological criticality is 18.8%. All 136 municipalities in Molise are affected, although with varying levels of risk and danger **(**Region Molise-b, 2017)**.**
- The percentage of the population residing in areas with high hydrogeological criticality in Molise is 19.4% of the total population (60,859 inhabitants and 25,444 families (Region Molise-b, 2017).

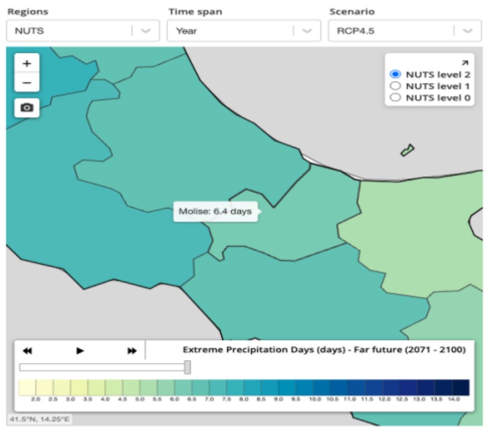
The European Commission's Flood risk viewer[4] displays areas of potentially significant flood risk (shown with orange colour), as identified by each Member State. As shown below, the map on the left (figure 1) highlights the prevalence of flood risk in the Region of Molise, suggesting potential affectation virtually in the entire region. The map on the right (figure 2) zooms in into Campobasso area, showing the significance of flood risk in areas close to river basins.



[4] Source: https://discomap.eea.europa.eu/floodsviewer/ checked on 16th November 2023

Figures 3 and 4 below show the Historical precipitation and projected flood risk respectively. Based on data provided by the European Climate Data Explorer, the plot on the left shows the deviations of the historical annual Extreme Precipitation Days from the 1981-2010 average (also called 'Anomaly') based on the ERA5 reanalysis. Figure 4 (right) shows a 4.5° warming scenario for the period 2071-2100, which suggests an increase of 6.4 additional days of extreme precipitation a year.





IV. IMPACTS

The threat of hydrogeologic events provoking affectation on rural livelihoods, rural infrastructure and agricultural means of production is connected through four sequences of impacting factors: (1) Hydrogeological events impact public infrastructure and increase the risk of disseminating chemical pollutants; (2) Interruption of public services (affectation provoked by hydrogeological events particularly on roads); (3) the affectation provoked by hydrogeological events on soil degradation and associated reduced productivity; and (4) the affectation provoked by hydrogeological events on demographic trends and change in land use.

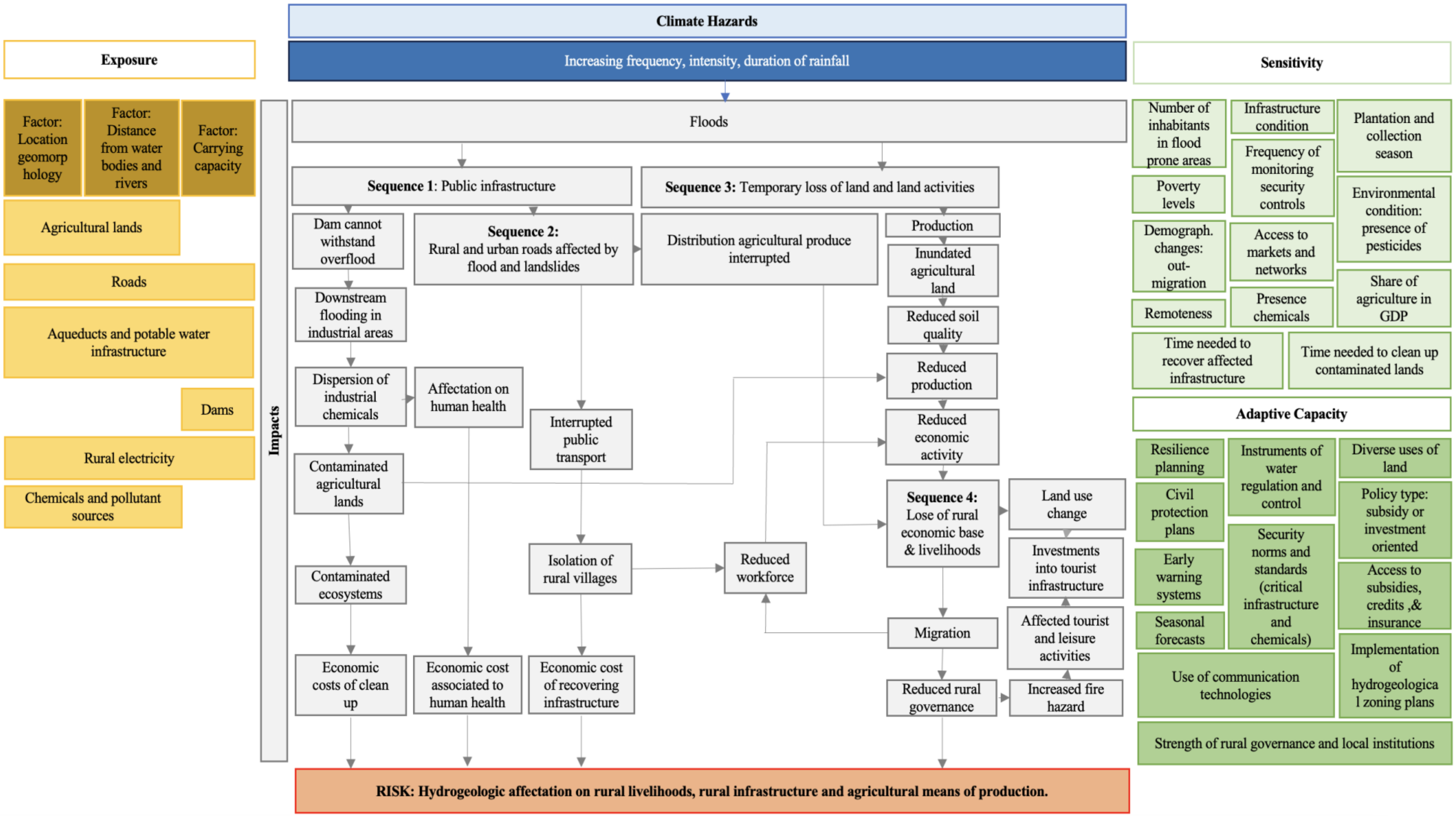
Key messages emerging from the impact sequences:

Key Message 1: Reduced Agricultural Productivity: Agricultural production may decline due to shifting precipitation patterns which provokes soil degradation. Production is threatened by excessive runoff, leaching, and flooding, which results in soil erosion and nutrient depletion.
Key Message 2: Ongoing demographic trends such as out-migration may be exacerbated due to livelihood lose as floods reduce local agricultural production and affect the local workforce, affecting rural governance and local institutions. Pre-existing conditions such as lower income, high dependency level on agricultural production and low access to networks and innovation could further affect this trend.
Key message 3: Health challenges to rural populations and ecosystems emerge from risks of chemical contamination and pollutants being spread during flood events. Costs of chemical

clean up and associated temporary loss of land activities may need to be considered as additional costs in recovery plans.

Key message 4: Interrupted roads may place additional burden to Molise's rural communities if no alternative connectivity means are available, increasing the isolation of villages. Timing needed to reconnect transportation roads may place a critical aspect in the level of affectation that communities experience.

Figure 5: Climate Impact Chain for the region of Molise



Sequence 1. Hydrogeological events impact public infrastructure

In the first sequence of impacts proposed, the focus is on how hydrogeological events affect the dissemination of chemical pollutants. Concern was raised during the workshop regarding the risk of the "Ponte Liscione" dam being overflowed, water running of and inundating industrial areas, spreading chemical pollutants to nearby agricultural lands.

Hydrogeological events impacts public infrastructure

Flooding events may cause sediment transport and damage roads and bridges as well as affecting reservoir storing capacity (Dasgupta et al. 2014). Floods are also generated from catastrophic failure of artificial (reservoirs) (Benito and Hudson, 2010).

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Extreme flood events represent one pathway of chemical substances into the environment resulting in acute exposure to high pollutant concentrations. (Völker et al. 2023)

(Re)mobilization and (re)distribution of pollutants due to damaged wastewater infrastructure and sediment-bound pollutants resulting from historical discharges (Völker et al. 2023)

Chemical substances are continuously emitted into the environment. Suspended particulate matter continuously enters fluvial systems as a result of the erosion of terrestrial surfaces and the riverbed itself. These particles are transported along with the water current and are ultimately deposited in regions of low water flow through sedimentation processes, e.g., in harbors, groin fields, lowland rivers, floodplains, wetlands, or estuaries (Crawford et al 2022).

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Impacts on ecosystem and human health

Chemical material may contaminate homes. Flooding may lead to mobilization of dangerous chemicals from storage or remobilization of chemicals already in the environment, e.g. pesticides. Hazards may be greater when industrial or agricultural land adjoining residential land is affected (Euripidou et al. 2004).

The re-suspension and consequent widespread distribution of highly contaminated sediments into adjacent natural floodplains, farmland, urban centers, or artificially constructed flood retention areas can devastate the environment and the wildlife and affect humans that depend upon it. Dioxins and DLCs are known to cause a range of toxic effects when humans and wildlife are exposed, including neuro-, immuno- and hepatotoxicity, reproductive toxicity, and certain types of cancer (Crawford et al. 2022).

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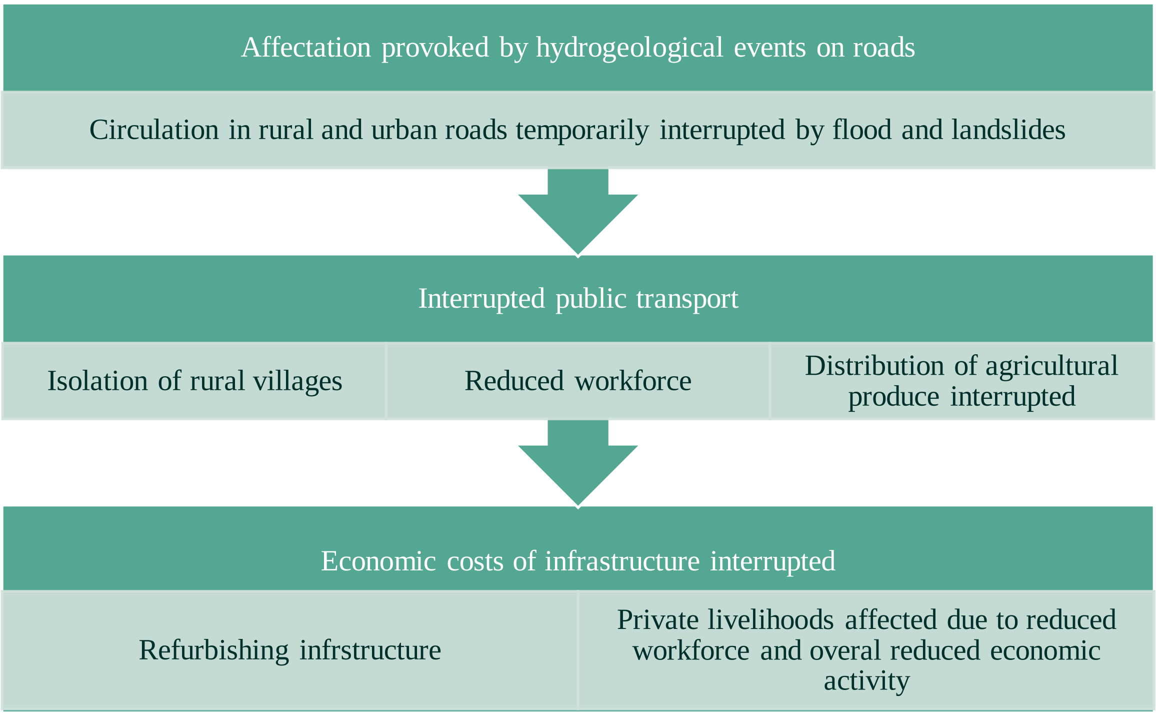
Increased economic costs related to chemical contamination

The environmental, economic, and societal consequences of remobilization and distribution of pollutants during flood events are not widely recognized. Loss of life, damage to infrastructure, and monetary cleanup costs associated with floods are important direct effects. It would be beneficial to determine economic tradeoffs between flood prevention measures, measures to avoid the remobilization of hazardous substances in toxic sediments, and measures dealing with the cleanup and restoration of the affected areas (Crawford et al. 2022)

Sequence 2. Interruption of public services

In the second sequence of impacts proposed, the focus is on the affectation provoked by hydrogeological events on roads. The proposed impact factors in this first sequence emerge as propositions provided by the participants during the workshop.



Sequence 3. Soil degradation and reduced productivity

In the third sequence of impacts proposed, the focus is on the affectation provoked by hydrogeological events on soil degradation and associated reduced productivity.

River flooding will produce temporary loss of land and land activities, and damage to transportation infrastructure (Dasgupta et al. 2014)

Floods damage farms, crops, livestock, the physical infrastructure of agriculture, and the food supply chain, reducing agricultural productivity and food availability (Atanga and Tankpa, 2021). Human interference with floodplain landscaping causes water levels in rivers to move rapidly from low to high levels as a result of precipitation events. This leads to changes in the flow and flooding of water from canals (Furtak et al. 2023).

Floods affect the physical structure of soils and nutrient cycling, resulting in potentially irreversible damage to agricultural productivity and ecosystem functioning (Furtak et al, 2023)

Flooding compacts the soil with water. Increased moisture reduces oxygen and nitrogen diffusion in the soil. C and N mineralisation is reduced. Flooding results in loss of soil P. Flooding increases Fe phosphate solubility due to pH changes. Changes in soil moisture affect the soil microbiome which affect the long-term productivity of plants (Furtak et al. 2023).

Economic impacts: Unhealthy soil cannot provide plants with the nutrition they need to grow correctly and abundantly, resulting in shortages and economic strain on people linked to production chains

Excessive soil moisture is also associated with disruptions to planned field practices and forces farmers to use greater amounts of lime to improve pH and other techniques to improve soil quality (aeration) (Furtak et al. 2023).

Post-harvest aspects of agriculture—storage on-farm and commercially, handling, and transport—have been relatively neglected in discussions of climate change, but will be affected by changes in temperature, rainfall, humidity, and by extreme events (Dasgupta et al. 2014).

Climate change may also affect investment patterns in rural areas. Sectors that are expected to be affected adversely by climate change may have difficulty attracting investment (Dasgupta et al. 2014).

Sequence 4. Affectation of hydrogeological events on demographic trends and land uses

In the third sequence of impacts proposed, the focus is on the affectation provoked by hydrogeological events on demographic trends and land uses.

Impacts of climate change on the rural economic base and livelihoods, land use, and regional interconnections are at the latter stages of complex causal chains (high confidence) (Dasgupta et al. 2014).

Migration patterns will be driven by multiple factors of which climate change is only one (*high confidence*). Climate impacts may contribute to migration away from rural areas, but this is contested by other bodies of literature. Attribution of migration to climate change is extremely complex, because life in rural areas involves complex patterns of rural- urban and rural-rural migration, subject to economic, political, social, and demographic drivers, patterns that are modified or exacerbated by climate events and trends rather than solely caused by them (Dasgupta et al. 2014).

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The Centrality of Rural Development for the Molise Region

The population in Molise has decreased from over 320,000 in 2010 to 313,341 in 2013 (87,124 in the province of Isernia and 226,217 in the province of Campobasso). Need to keep land available for agriculture, for the sake of employment and wealth production.

Agriculture in inland areas plays a fundamental role in preventing landslides, fires, and other natural disasters. The phenomenon of abandoning agricultural activities has triggered processes of lack of territorial governance, which increases the risk of both fires (recolonization of these areas begins with the settlement of shrub species) and hydrogeological instability (Region Molise-b, 2017).

↓

Land use changes demand bew investments which may become jeopardized by enviuronmental threats, further deepening impacts on local livelihoods

Shift from agricultural (production) to leisure (consumption) activities; focus on broader amenity values of rural landscapes for recreation, tourism, forests, and ecosystem services (Dasgupta et al. 2014)

V. EXPOSURE

Factor 1: Location: Whether geomorphology amplifies exposure (physical extent of floodplains and catchment hydrology (Thomson and Clayton, 2022).

Factor 2: Distance from water bodies and rivers (in relation to figure 2, section 1, hazards).

- It has been evidenced that the risk of overflowing concerns the "Ponte Liscione" dam, also known as the "Guardialfiera" dam, with the consequent risk of flooding in the industrial areas of the Consortium for the Industrial Development of the Biferno Valley (COSIB), located in the municipalities of Termoli, Campomarino, Guglionesi, Portocannone, S. Martino in Pensilis, Ururi, S. Giacomo degli Schiavoni and Petacciato.
- It has also been highlighted that, in addition to overflow, particular attention should be paid to the concept of the openness of discharges, combined with the interaction of agricultural and anthropised areas.

Factor 3: Carrying capacity: Floods are also generated from catastrophic failure of artificial (reservoirs) (Benito and Hudson, 2010).

Resulting from the previous impact cause-effect relations, the following elements could be identified to be exposed to the effects of increased frequency, intensity and duration of rainfall:

Exposed element	Association to Exposure Factor
Agricultural lands	1,2,3
Roads	1,2,3
Aqueducts and potable water infrastructure	1,2,3
Dams	3
Rural electricity	1,2,3
Chemical and pollutant sources (industry)	1,2, 3

VI. SENSITIVITY

Climate change in rural areas will take place against the background of the trends in demography, economics, and governance that are shaping those areas. Existing vulnerabilities caused by poverty, lower levels of education, isolation, and can all aggravate climate change impacts in many ways (Dasgupta et al. 2014).

Some key characteristics considered by the IPCC for a European level, include the following:

- Rural population has peaked (absolute numbers) in Europe
- Agriculture accounts for only 13% of rural employment in the EU (OECD, 2006)
- Increased competition as a result of economic globalization has resulted in agriculture no longer being the main pillar of the rural economy in Europe.
- Economic policies are primary drivers, with social re-composition and economic restructuring taking place.

The IPCC (Dasgupta et al. 2014) has also highlighted a number of non-climate factors affecting vulnerability in rural areas at both, individual and community levels:

- Physical geography,
- Remoteness,
- Economic constraints and poverty,
- Demographic changes such as out-migration and aging,
- Density of social networks,
- Neglect by policymakers and short-time policy horizons,
- Low levels of public services,
- Memories of past climate variations and knowledge.

Based on information gathered during the workshop and in the context of previous impact sequences and vulnerability factors identified in the literature, the following sensitivity factors are identified:

Sensitivity factor	Impact sequence	Description
Number of inhabitants in flood risk areas	**1,2,3**	The percentage of the population residing in areas with high hydrogeological criticality in Molise is 19.4% of the total population (60,859 inhabitants and 25,444 families (Region Molise-b, 2017).
Age group	**2,3,4**	Demographic characteristics could represent a vulnerability factor for Molise's rural areas due to the aging population, low birth rates, and the relative economic fragility of the population (with income levels below the national average and high unemployment rates in some areas) (Apreda et al.). Per capita gross domestic product (GDP) in rural areas of OECD countries is only 83% of national average (but significant variation within and between countries (Dasgupta et al. 2014)
Poverty levels	**2,3,4**	
Share of agriculture in GDP	**2,3,4**	Level of dependence on climate conditions (high share of agriculture in GDP) (Dasgupta et al. 2014). Molise is considered a territory with a duality of land uses, with a predominantly agricultural character for the areas in the lower Molise, while the territories of the upper Molise exhibit a more "natural" character (Region Molise-b, 2017).
Demographic changes (out-migration, aging)	**3,4**	The phenomenon of abandoning agricultural activities has triggered processes of lack of territorial governance, which increases the risk of both fires (recolonization of these areas begins with the settlement of shrub species) and hydrogeological instability **(**Region Molise-b, 2017).
Remoteness	**1,2,3,4**	Importantly, in rural areas usually there are few alternatives once a road is blocked and that may increase vulnerability of rural areas when facing extreme hydroclimatological events that impact transportation infrastructure (Dasgupta et al. 2014)
Time/cost needed to recover infrastructure/	**1,2**	
Access to markets and networks and density of social networks	**3,4**	Innovation and the ability of agricultural businesses to access markets and networks are below the national average and may not facilitate adaptive responses (Apreda et al.).
Presence of industry close to agricultural lands	**1**	Presence of industries in the context of risk of dispersion of chemical pollutants due to flooding (suggested during workshop).
Environmental condition (presence of chemicals)/	**1,3**	Flooding may lead to mobilization of dangerous chemicals from storage or remobilization of chemicals already in the environment, e.g., pesticides (Euripidou et al. 2004).

time needed to clean up chemical contamination		Resource degradation, environmentally fragile lands subject to overuse and population pressures, exacerbating social and environmental challenges (Dasgupta et al. 2014).
Policy making: Frequency of monitoring critical infrastructure/ dams, roads; Infrastructure baseline condition	**1,2,3,4**	Neglect by policymakers can aggravate climate change impacts in many ways. Neglect by policymakers and underinvestment in infrastructure and services has negatively affected rural areas (Dasgupta et al. 2014).
Plantation and collection season	**1,2,3,4**	**Proposed during workshop.** The change in the planting and harvesting season can be a factor of vulnerability to climate change: intense weather events, opening of dam drains, flooding of flat areas with seasonal crops, with a low impact if the event is recorded in autumn, after the harvest period, and a high impact on production if the event occurs in April. This could slightly change according to the different areas: for example, in the area closer to the coastline ("Basso Molise"), there are different types of crops, production seasons and planting distances from other areas, which are also closely linked to the crop cycle (seasonal, annual, perennial).

VII. ADAPTIVE CAPACITY

Adaptive capacity is normally determined in terms of knowledge, financial resources, technologies, legislations and infrastructures that enable people to adapt to the effects of climate change. The IPCC (Dasgupta et al. 2014) informs of key variables shaping a resilient rural system in the context of climate change:

- Structural features of farm households and communities affect their vulnerability to climate change in complex ways. Resilience of access to land and natural resources, flexible local institutions, and knowledge and information, and on the association of gender inequalities with vulnerability are key.
- Accelerating globalization, through migration, labour linkages, regional and international trade, and new information and communication technologies, is bringing about economic transformation in rural areas of both developing and developed countries.
- In developed countries, there are important shifts toward multiple uses of rural areas, especially leisure uses, and new rural policies based on the collaboration of multiple stakeholders, the targeting of multiple sectors, and a change from subsidy-based to investment-based policy.
- Agricultural subsidies under pressure from international trade negotiations and domestic budgetary constraints. As a result of recent price hikes, domestic price support has been lowered in OECD countries.
- Institutions and networks can affect vulnerability to climate change: through distribution of climate risks between social groups; by determining the incentive structures for adaptation responses; and by mediating external interventions (e.g., finances, knowledge and information, skills training) into local contexts (e.g., if decision makers resist seeing climate change as within their responsibilities, this may contribute to low levels of planning for either adaptation or mitigation, and thus to greater vulnerability.
- Access to information alone is not a guarantee of success. Despite access to weather forecasting, people may not rely on such information.
- Rural households' lack of access to technologies and infrastructure (e.g., markets) is also a major barrier to adaptation for certain production systems.
- Access to water, credit, extension services, and off-farm income and employment opportunities, tenure security, farmers' asset base, and farming experience are key to enhancing farmers' adaptive capacity.

Contextual elements:

- Molise is a region is characterized by a high presence of green areas, particularly forests in the west and agricultural areas in the east, which act as a factor of lower vulnerability to heatwaves and flooding but higher vulnerability to drought (Apreda et al.).
- In general, the Molise agricultural system has the prerequisites to be a guarantor of biodiversity, environmental protection, and landscape preservation, with growth potential

for rural structures and increased employment. Starting from this awareness, the Molise region must employ all available tools for full and sustainable growth (Apreda et al.).

- However, no plans or strategies for adaptation at the municipal and regional levels have been identified, indicating a limited capacity to assess and respond to climate risks. Therefore, the analysis reveals a composite picture in which some characteristics contribute to increased vulnerability, while others reduce it (Apreda et al.).
- **Institutional context (existing assessments)**
    - The Hydrogeological Zoning Plan (PAI) relates to landslide and hydraulic hazards, hydrogeological risk areas and the associated safeguard measures. It is a programmatic document that identifies risk scenarios related to landslide and flood phenomena present and/or predicted in the territory and links them to regulations, land use limitations, and types of structural and non-structural interventions aimed at mitigating expected damages (Region Molise-b, 2017):
    - The National Rural Development Program (PSRN) operated by the Italian Ministry of Agriculture, identifies key areas of intervention which orient Molise's rural policy (Region Molise-a, 2022):

        - Enhancing the competitiveness of the agricultural system in a sustainable perspective.
        - Improving the climatic and environmental performance of production systems.
        - Strengthening the resilience and vitality of rural areas.
        - Promoting quality agricultural and forestry work.
        - Enhancing the ability to promote knowledge exchange and innovations.
        - Making the governance system more efficient.
        - Promotion of value chains to protect and enhance small local producers and ensure greater traceability of products for food safety and waste reduction, as envisaged in the new CAP 2023 – 2027.

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Annex 6. Climate Impact chain Sicoval, Occitanie

I. INTRODUCTION

The Climate Impact chain for the region of Occitanie for the rural sector developed in the context of the Valorada-EU project, focuses on the **risk posed to agricultural production and livelihoods due to increasing temperatures and droughts.**

The development of the climate impact chain occurred in two stages. Initially, a participatory workshop involving city representatives of Occitania and Valorada-consortium members Terranis was held in November 2023. The preliminary climate impact chain was formulated based on the insights gathered during this workshop, supplemented by a comprehensive literature review. Subsequently, the initial draft of the climate impact chain was shared with city officials and consortium partners TERRANIS for feedback. This document incorporates all the suggestions provided by the local stakeholders, resulting in the final version of the impact chains.

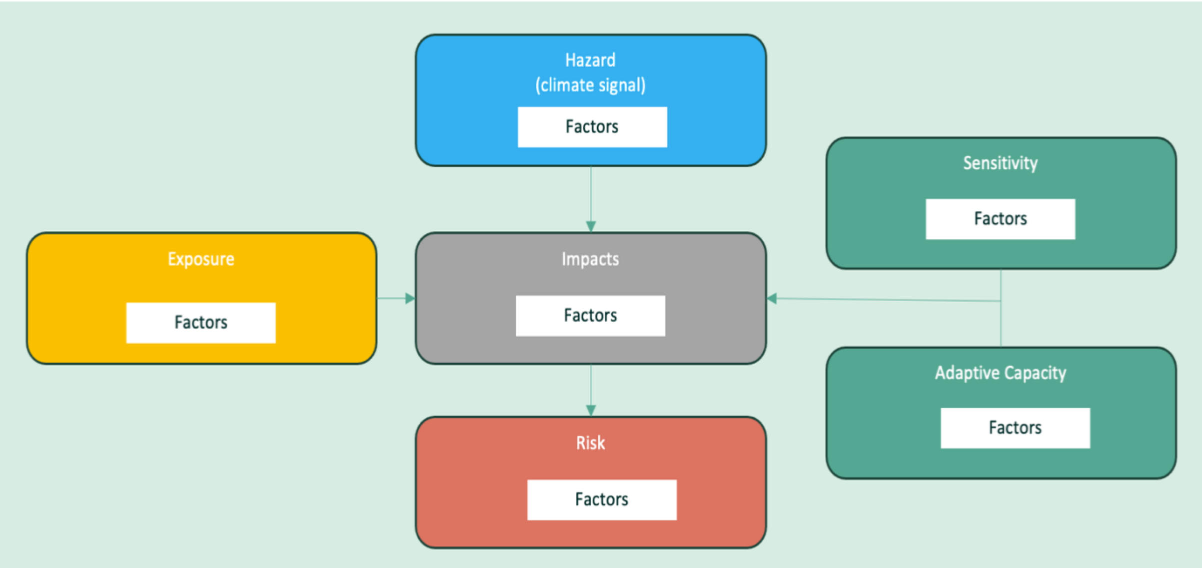
The document is organised as follows:

- Section II presents a brief definition and schema describing a climate impact chain.
- Section III discusses key climate hazard concerning high temperatures and health issues.
- Section IV delineates the identified climate risks affecting people's health.
- Section V outlines the schema proposed for the climate impact chain.
- Section VI presents the key risks identified during the workshop and outlines the impact sequences associated to this risk.
- Section VII outlines the exposure factors associated to each of the sequence of impacts identified in section VI.
- Section VIII outlines the sensitivity factors associated to each of the sequence of impacts identified in section VI.
- Section IX outlines the adaptive capacity factors associated to each of the sequence of impacts identified in section VI.
- Section X presents the bibliography, indicating the literature reviewed for generating this document.

II. CLIMATE-IMPACT CHAINS

A climate-impact chain delineates the connection between a specific climate hazard and a designated impact area. These chains aim to elucidate cause-and-effect relationships within various components of a system. By defining these relationships, impact chains ascertain how a hazard transforms into a risk, factoring in exposure, potential intermediate impacts, sensitivity factors, and response/adaptation capacities that mitigate vulnerability. In cases where applicable, intermediate impacts can be identified, each with its exposure, sensitivity, and adaptation factors (GIZ and EURAC, 2017).

A chain is composed of risk components (hazard, vulnerability, exposure) and underlying factors associated to each component. A climate signal, e.g. a heavy rain event, may lead to a direct physical impact, e.g. a flood, causing a sequence of intermediate impacts, which finally lead to the risk. The hazard component includes factors related to the climate signal and direct physical impact. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised by one or more exposure factors (GIZ and EURAC, 2017).



III. CLIMATE HAZARDS

Climate hazards are defined as the potential occurrence of a climate-related event, trend or physical impact that may cause loss of life, injury, damage and loss of infrastructure, livelihoods, service provision, ecosystems (Rosenzweig et al. 2015).

During the workshop, regional representatives of Occitanie decided to attend the risk of ***increasing temperatures and droughts affecting agricultural production and livelihoods***. On the one hand, the report considers the increase of temperatures as both: average temperature and as extreme high temperature occurring in the context of climate variability. On the other hand, this report builds on the understanding of drought as multifaceted phenomena whose impacts manifest differently throughout time and across sectors, from which different types of droughts are considered:

- Meteorological drought: broadly defined by low precipitation.
- Agricultural drought: deficiency in soil moisture, increased plant water stress.
- Hydrological drought: reduced streamflow.
- Socio-economic drought: balance of supply and demand of water to society (Gornall et al 2010).

IV. CLIMATE RISKS

Climate risks are defined as the potential for consequences where something of value is at stake and where the outcome is uncertain (Rosenzweig et al. 2015).

What is distinctive about rural warming and droughts in the context of agricultural production and rural livelihoods?

"Rural" refers generally to areas of open country and small settlements (Dasgupta et al., 2014). The distinctive characteristics of rural areas make them uniquely vulnerable to the impacts of climate change because:

- The impacts of climate change on patterns of settlement, livelihoods, and incomes in rural areas will be the result of multi-step causal chains of impact. Typically, those chains will be of two sorts. One sort will involve extreme events, such as floods and storms, as they impact on rural infrastructure and cause direct loss of life. The other sort will involve impacts on agriculture or on ecosystems on which rural people depend. These impacts may themselves stem from extreme events, from changing patterns of extremes due to climate change, or from changes in mean conditions (Dasgupta et al., 2014)
- Greater dependence on agriculture and natural resources makes them highly sensitive to climate variability, extreme climate events, and climate change. (Dasgupta et al., 2014)
- Existing vulnerabilities caused by poverty, lower levels of education, isolation, and neglect by policymakers can all aggravate climate change impacts in many ways (Dasgupta et al., 2014)
- Rural communities globally have adapted to climate variability over extended periods, employing agricultural methods, utilization of natural resources, livelihood diversification, and informal risk-sharing institutions. These existing adaptive strategies, supported by appropriate policies and institutions, can serve as the foundation for addressing climate change impacts, contingent on the severity and pace of these changes (Dasgupta et al., 2014).

Climate observation on the Occitania Region:

Source: Meteo-France

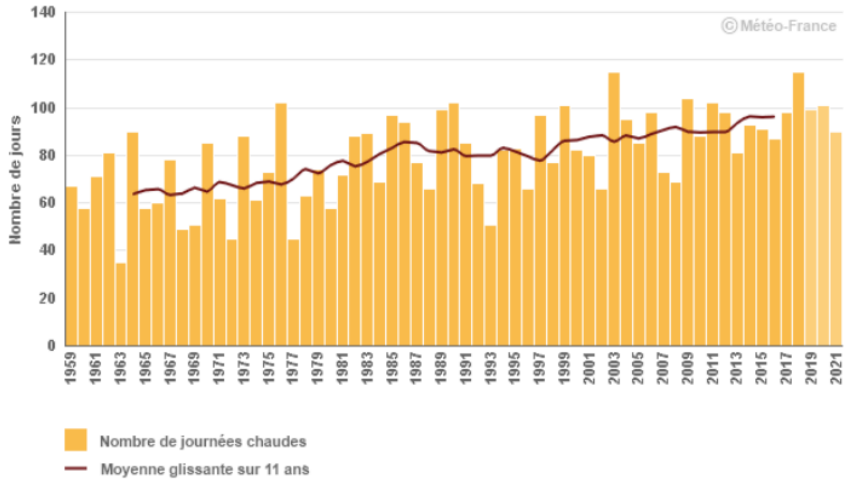
The evolution of average annual temperatures in the Occitania Region shows a clear warming over the last 20 years. The trend observed in average annual temperatures is +0.3°C per decade. MétéoFrance affirms that the year 2022 was the hottest year ever recorded in France since the beginning of the 20th century. The summer was punctuated by 3 heat waves (June 15 to 19, July 12 to 25, July 31 to August 13). Over most of the country, temperatures were, on average over the year, 1 to 3°C above seasonal values. It was also in 2022 that the absolute temperature record ever recorded was reached, of 37.6°C on July 18. We also note that the fall, winter and spring seasons are on average milder and the summers significantly warmer. Regarding annual precipitation in the Occitania Region, it has shown a slight decline over the last 20 years and is characterized by great variability from one year to the next.

Climate change trends in the 21st century in the Occitania region

Source: Meteo-France

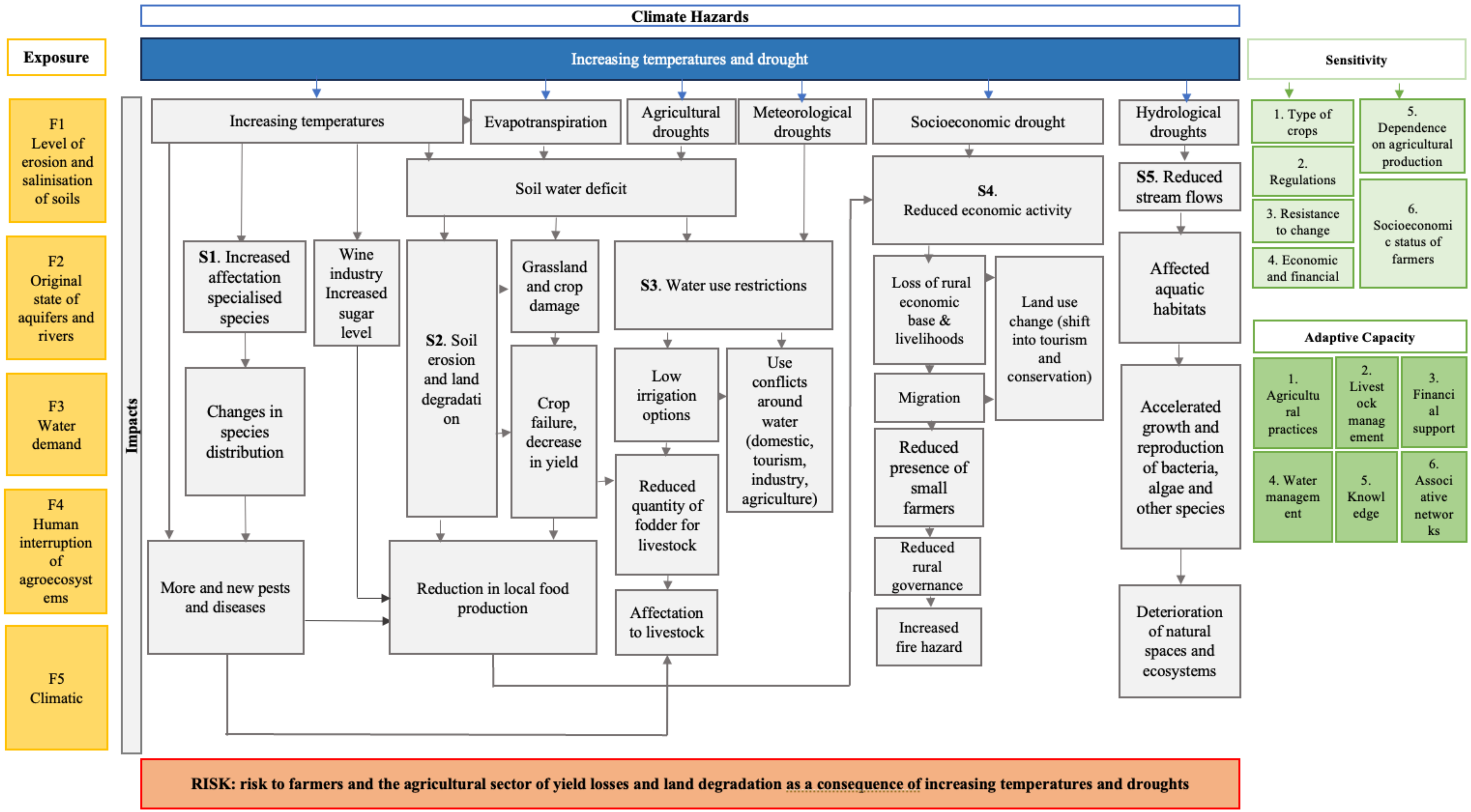
- Continued warming during the 21st century in Occitania, whatever the scenario
- According to the high emissions scenario, warming in average annual temperature could exceed 4.9°C at the end of the century compared to the period 1976-2005
- Little change in annual precipitation in the 21st century, but seasonal contrasts
- Continued decrease in the number of frosty days and increase in the number of hot days, whatever the scenario
- Increasingly marked drying of soils during the 21st century in all seasons

To conclude, in the Occitania Region, as throughout the metropolitan territory, climate change results mainly in an increase in temperatures, especially marked since the 1980s. Consistent with this increase in temperatures, the number of scalding days (day where the maximum temperature is greater than or equal to 25°C) increases and the number of frost days (days where the minimum temperature is less than or equal to 0°C) decreases. Annual precipitation shows great variability from one year to the next. Precipitation is more frequent in winter than in summer but is more intense in summer than in winter. The cumulative rainfall is therefore more important in the summer period than in the winter period. Precipitation is generally decreasing, due to a drop in winter precipitation. In the absence of an increase in cumulative rainfall, the increase in temperature favors the increase in phenomena such as drought and water deficit in the soil, which therefore have significant impacts on the rural areas of the Region.



Evolution of the number of hot days (Toulouse Blagnac measuring station) - Source: Météo-France

V. Climate Impact Chain for the region of Occitanie



VI. IMPACTS

The risk of ***increasing temperatures and droughts affecting agricultural production and livelihoods*** is characterised through 5 sequences of impacting factors:
(1) The increased affectation of plant specialised species due to increasing temperatures and the resulting increased risks of new pests and diseases affecting livestock and agricultural production; (2) the combined effects of high temperatures and evapotranspiration in connection with agricultural droughts impacting soil erosion and reducing food production; (3) the effects provoked by both, agricultural and meteorological droughts on water restrictions on reduced quantity of fodder for livestock. This sequence also includes the effects of extreme high temperature on animal wellbeing; (4) the impact generated by socioeconomic droughts on rural livelihoods; (5) the effects of hydrological droughts on the accelerated growth and reproduction of bacteria, algae and other species which affects aquatic ecosystems.

Key messages

- In the last century, 45 severe droughts occurred in Europe, affecting millions of people, and causing economic losses of more than $27.8 billion. Currently, on average, 15% of the European Union's land area and 17% of its population are affected by drought (Furtak et al. 2023)
- Droughts are expected to increase in frequency (by 22–123%), extent (23–46%) of occurrence, and duration (16–48%) in the coming years (Furtak et al. 2023)
- The degradation of critical soil and water resources will expand as extreme precipitation events increase across the agricultural landscape (Gowda et al 2018).
- The area of arid zones is also increasing. About 72% of the world's land area may become arid in the future, particularly in the Middle East, southern Europe, southern Africa, and Australia (Furtak et al. 2023)
- Food and forage production will decline in regions experiencing increased frequency and duration of drought (Gowda et al 2018).
- Shifting precipitation patterns, when associated with high temperatures, will intensify wildfires that reduce forage on rangelands, accelerate the depletion of water supplies for irrigation, and expand the distribution and incidence of pests and diseases for crops and livestock (Gowda et al 2018).
- Challenges to human and livestock health are growing due to the increased frequency and intensity of high temperature extremes. Heat stress in livestock results in large economic losses for producers (Gowda et al 2018).
- Residents in rural communities often have limited capacity to respond to climate change impacts, due to poverty and limitations in community resources (Gowda et al 2018).

Sequence 1.

In the first sequence, the focus is on increased affectation of plant specialised species due to increasing temperatures and the resulting increased risks of new pests and diseases affecting livestock and agricultural production.

Increasing temperatures

↓

Increased affectation of specialised plant species

Species that are highly specialized and heat sensitive may be threatened with local extinction (Rosenzweig et al. 2015).

↓

Changes in species distribution affecting plants

Arthropod-borne diseases (viruses and phytoplasmas), winter infection root and stem diseases (phoma stem canker of oilseed rape and eyespot of wheat); Fusarium blight, grapevine moth, and a black rot fungus in fruit trees could create increasing damages in Europe under climate change.

However, other pathogens such as cereal stem rots (e.g., Puccinia striiformis) and grapevine powdery mildew could be limited by increasing temperatures (Kovats et al 2014).

Some pests, such as the European corn borer could also extend their climate niche in Central Europe (Kovats et al 2014).

↓

More and new pests and diseases affecting livestock

The spread of bluetongue virus in sheep across Europe has been partly attributed to climate change through increased seasonal activity of the Culicoides vector. The distribution of this vector is unlikely to expand but its abundance could increase in Southern Europe (Kovats et al 2014).

Ticks have changed distributions towards higher altitudes and latitudes with climate change (ibid).

Exposure to fly strike could increase in a warmer climate but adaptation in husbandry practices would limit impacts on livestock (Ibid).

Sequence 2.

In the second sequence, the focus is on the combined effects of high T and evapotranspiration in connection with agricultural droughts impacting soil erosion and reducing food production.

Combined effect of increasing temperatures, increased evapotranspiration and agricultural drought

Soil water deficit

Droughts affect the soil environment by altering soil moisture. Soil is a complex and dynamic ecosystem whose functionality is linked to the sustainability of chemical, physical, and biological parameters and its microbial communities. Changes in these properties can cause fluctuations in the abundance, activity, and diversity of soil microorganisms (Furtak et al. 2023)

Soil erosion and land degradation

The current cost of soil erosion, organic matter decline, salinization, landslides, and contamination is estimated to be €38 billion annually for the EU (damage to infrastructures, treatment of water contaminated through the soil, disposal of sediments, depreciation of land, ecosystem functions of soil) (Kovats et al 2014).

Drought can alter soil functions, particularly, the biogeochemical cycling of key nutrients and microbial activity, which affects plant growth and affect the entire soil food web (Kovats et al 2014).

Grassland and crop damage

Drought stress leads to crop failure when it is prolonged or occurs during key stages of plant development (from just before flowering to the next month or two). Soil drought affects plant growth, development, and yield. Metabolic and morphological processes in plants at all stages of their life cycle are affected by drought, with some growth phases being more sensitive to water stress (Furtak et al. 2023).

Crop failure, decrease in yield

Drought combined with heat waves significantly affects yields by reducing the harvest index, shortening the plant life cycle, and altering the number, size, and composition of seeds (Kovats et al 2014). Climate-induced variability in wheat production has increased in recent decades in Southern and Central Europe. Southern Europe would experience the largest yield losses (–25% by 2080 under a 5.4°C warming), with increased risks of rainfed summer crop failure. In Western Europe, increased heat stress around flowering could cause considerable yield losses in wheat (ibid).

Reduction in local food production

Low moisture is also associated with fruit shrivelling, tree mortality, and rice cracking, especially when combined with heat (Furtak et al. 2023).

Drought during plant reproductive stages can significantly reduce the yield potential of winter wheat (18.8%), maize (30.5%), and sugar beet (27.2%) (Furtak et al. 2023).

High temperatures and droughts during grain filling have contributed to the lack of yield increase of winter wheat in France despite improvements in crop breeding (ibid).

Wine production affected by increasing temperatures

Climate impacts such as increasing number of hot days and decreasing frost risk may benefit some varieties. Future climate change will exceed climatic thresholds affecting ripening for existing varieties grown at the margins of their climatic limits (Dasgupta et al., 2014).

Higher temperatures are also expected to affect wine quality by changing the ratio between sugar and acids. Wine is usually produced within rigid, regionally specific, regulatory frameworks that often prescribe, among other things, what grapes can be grown where, for example, the French AOC (Appellation d'Origine Controlee) designations (Kovats et al 2014).

Sequence 3.

In the third sequence, the focus is on the effects provoked by both, agricultural and meteorological droughts on water restrictions on reduced quantity of fodder for livestock.

High temperatures, agricultural and meteorological droughts

Soil water deficit

In Southern Europe, soil water content will decline, saturation conditions and drainage will be increasingly rare and restricted to periods in winter and spring, and snow accumulation and melting will change, especially in the mid-mountain areas (Kovats et al 2014).

Increased water restrictions.

Climate change is likely to have significant impacts on future water availability, and the increased risks of water restrictions in Southern, Central, and Atlantic sub-regions (Kovats et al 2014). Significant reduction in water availability from river abstraction and from groundwater resources, combined with increased water demand (e.g., for irrigation, energy and industry, domestic use) and with reduced water drainage and runoff as a result of increased evaporative demand, particularly in southern Europe (Kovats et al 2014). Since aquatic and terrestrial ecosystems are affected by agricultural water use, irrigation demand restrictions are projected in environmentally focussed future regional scenarios (Kovats et al 2014)

Low irrigation options

Reduced suitability for rainfed agricultural production will increase water demand for crop irrigation. However, increased irrigation may not be a viable option, especially in the Mediterranean area, because of projected declines in total runoff and groundwater resources (Kovats et al 2014). In certain catchments, water resources are already over-licensed and/or over abstracted, facing reliability challenges due to climate change-induced reductions in groundwater recharge and increased potential demand for irrigation. Meeting this demand may lead to elevated irrigation system costs, necessitating new irrigation infrastructures in specific regions (Kovats et al., 2014).

Reduced quantity of fodder for livestock

Drought may threaten pasture and feed supplies and reduce the amount of quality forage available to grazing livestock (USGCRP 2014) .

Climate conditions projected for the 2070s in central France (A2 scenario) reduced significantly grassland production in a 4-year experiment under elevated CO2 (Kovats et al 2014).

Affectation to livestock due to increased temperature

High temperature and air humidity during breeding increased cattle mortality risk (Kovats et al 2014).

Temperatures beyond the optimal range alter the physiological functions of animals and affects reproductive efficiency (Gowda et al 2018).

Dairy cows are particularly sensitive to heat stress, as it negatively affects their appetite, rumen fermentation and lactation yield. Frequent higher temperatures also lower milk quality (Gowda et al 2018).

Affectation to livestock due to increased prevalence of parasites

Climate change may increase the prevalence of parasites and diseases that affect livestock. The earlier onset of spring and warmer winters could allow some parasites and pathogens to survive more easily. In areas with increased rainfall, moisture-reliant pathogens could thrive (CCSP 2008)

Sequence 4.

In the fourth sequence, the focus is on the impact of droughts on rural livelihoods.

Socioeconomic drought

↓

Reduced economic activity

Impacts of climate change on the rural economic base and livelihoods, land use, and regional interconnections are at the latter stages of complex causal chains (Dasgupta et al. 2014)

↓

Loss of rural economic base and livelihoods

Climate change will affect rural livelihoods, or “the capabilities, assets (stores, resources, claims, and access) and activities required for a means of living” (Dasgupta et al., 2014). Increased economic losses and people affected by extreme heat events: impacts on health and well-being, labour productivity, crop production, air quality, and increasing risk of wildfires in southern Europe (Kovats et al 2014).

Decline in economic activity may increase rural depopulation and harm the development of rural communities in southern Europe (Dasgupta et al., 2014)

↓

Migration

Migration patterns will be driven by multiple factors of which climate change is only one. Climate impacts may contribute to migration away from rural areas, but attribution of migration to climate change is extremely complex, because life in rural areas involves complex patterns of rural- urban and rural-rural migration, subject to economic, political, social, and demographic drivers, patterns that are modified or exacerbated by climate events and trends rather than solely caused by them (Dasgupta et al. 2014).

Migrant workers, who provide much of the agricultural labour in some regions and some enterprises, are particularly vulnerable (Gowda et al 2018).

↓

Land use changes

Climate change will affect rural landscapes by modifying relative land values, and hence competition, between different land uses. This will occur directly, for example, through changes in the productivity of crops and trees, and indirectly through climate change impacts on the global supply of land-based commodities and their movement through international trade (Kovats et al 2014).

Shift from agricultural (production) to leisure (consumption) activities; focus on broader amenity values of rural landscapes for recreation, tourism, forests, and ecosystem services (Dasgupta et al. 2014)

↓

Reduced rural governance

Agriculture in inland areas plays a fundamental role in preventing landslides, fires, and other natural disasters. As shown in the region of Molise, Italy, the phenomenon of abandoning agricultural activities can trigger processes of lack of territorial governance, which increases the risk of both fires (recolonization of these areas begins with the settlement of shrub species) and hydrogeological instability (Region Molise-b, 2017).

The consequences of climate change on the incidence of drought also impact the frequency and intensity of wildfires, and this holds implications for agriculture and rural communities (Gowda et al 2018).

Sequence 5.

In the fifth sequence, the focus is on the effects of hydrological droughts on the accelerated growth and reproduction of bacteria, algae and other species which affects aquatic ecosystems.

Hydrological droughts

Much of the rural economy is closely tied to the natural environment (Gowda et al 2018).

Drought could threaten biodiversity and traditional ecosystems particularly in southern Europe, with problems exacerbated by declining water quality (Dasgupta et al., 2014) Climate change's impact on water quality has multifaceted implications for agriculture, forestry, ecosystem dynamics, human and animal health, and compliance with environmental quality standards, including those outlined in the Water Framework Directive (Kovats et al., 2014).

↓

Reduced stream flows and water quality

Climate change-induced shifts in rainfall, runoff, and water temperature will result in varying water quality impacts across sub-regions. In Southern Europe, climate change is anticipated to elevate nutrient loadings due to increased evapotranspiration and heightened concentrations resulting from reduced lake volumes. This trend is generally supported by local studies (Kovats et al., 2014).

↓

Affected undergrownd reservois

Reduced summer precipitation and heightened winter rainfall may intensify nitrate leaching, adversely affecting water quality. Even with reduced nitrogen fertilizer application, groundwater nitrate concentrations are projected to rise by the end of the century in the Seine River basin (Kovats et al., 2014).

↓

Affected aquatic habitats

Aquatic habitats and habitat connectivity in river networks may become increasingly fragmented. Despite some local successes and increasing responses, the rate of biodiversity loss does not appear to be slowing (Kovats et al 2014).

Shallower waters will witness a more rapid temperature increase than deeper waters. In parallel, a decrease in saturating oxygen concentrations occurs. Since AR4, there is further evidence of adverse effects caused by extreme weather events: reductions in dissolved oxygen, algal blooms during hot weather, and contamination of surface and coastal waters with sewage and/or chemicals (pesticides) after rainfall. A reduction in rainfall may lead to low flows that increase concentrations of biological and chemical contaminants (Kovats et al 2014).

V. EXPOSURE

Drawing from the preceding characterization of impacts, four exposure factors have been identified during the workshop. Exposure factors explain why certain assets may be particularly exposed to the effects of high temperatures and droughts.

Factor 1: Level of erosion and salinisation (proposed during workshop)

- Soils are one of the most complex and varied ecosystems in the world. However, climate change is altering the capacity of soils to provide its many ecosystem services. For example, climate change is accelerating the intrusion of salt water into soils due to rising sea levels, increased temperature, increased evaporation, and overexploitation of groundwater. In certain regions. Soil erosion and salinization are threats to agriculture. This leads to negative impacts on soil properties and plant physiology, and therefore significantly reduces agricultural production.

Factor 2: Water demand (proposed during workshop)

- Some areas are more exposed to climate change if they have high water demands. Water demand can come from the presence of agricultural activities, but also from tourism or industry. Conflicts of interest around water are therefore numerous in some regions.

Factor 3: Original condition of aquifers and water bodies (proposed during workshop)

Another exposure factor is the level of water resources. Indeed, a region whose water level in aquifers and rivers is currently relatively low will be more exposed to the effects of climate change.

Factor 4: Human interruption in agroecosystem:

- Insects are powerful and rapid adaptive organisms with high fecundity rate and short life cycle. Due to human interruption in agroecosystem and global climatic variations are disturbing the insect ecosystem. Erosion of natural habitats, urbanization, pollution and use of chemicals in agroecosystem manifold the intensity of environmental variations. Both a-biotic (temperature, humidity, light) and biotic (host, vegetative biodiversity, crowding and diets) stresses significantly influence the insects and their population dynamics (Gouda et al. 2022).

Factor 5: Climatic factors

- **Changes in mean climate**: The nature of agriculture and farming practices in any particular location are strongly influenced by the long-term mean climate state—the experience and infrastructure of local farming communities are generally appropriate to particular types of farming and to a particular group of crops which are known to be productive under the current climate. Changes in the mean climate away from current states may require adjustments to current practices in order to maintain productivity, and in some cases the optimum type of farming may change (Gowda et al 2018).
- **Climate variability and extreme weather events**: While change in long-term mean climate will have significance for global food production and may require ongoing

adaptation, greater risks to food security may be posed by changes in year-to-year variability and extreme weather events. Historically, many of the largest falls in crop productivity have been attributed to anomalously low precipitation events. However, even small changes in mean annual rainfall can impact on productivity (Gowda et al 2018).

Resulting from this characterisation of exposure factors, the following table identifies the connection between the impact sequences with exposure factors:

Impact Sequence	Association to Exposure Factor
Sequence 1	4, 5
Sequence 2	1, 2, 5
Sequence 3	2, 3, 5
Sequence 4	1, 2, 3, 5
Sequence 5	3, 5

VI. SENSITIVITY

FACTOR 1: Type of crops

- At the high range of the projected temperature changes, only plant breeding aimed at increasing yield potential jointly with drought resistance and adjusted agronomic practices may reduce risks of yield shortfall (Kovats et al 2014).

FACTOR 2: Regulations

- Neglect by policymakers and underinvestment in infrastructure and services has negatively affected rural areas (Dasgupta et al., 2014)
- Agricultural subsidies under pressure from international trade negotiations and domestic budgetary constraints. As a result of recent price hikes, domestic price support has been lowered in OECD countries (Dasgupta et al., 2014)

FACTOR 3: Resistance to change (proposed during workshop)

- Climate change has many consequences that require the agricultural world to adapt. Adapting means changing practices and habits. However, it is sometimes difficult for farmers to take ownership of these innovation processes, these new practices, or ways of doing things. This is called resistance to change. It is then necessary to tame these obstacles to change to support farmers in the ecological and climatic transition.

FACTOR 4: Economic and financial factors

- Increased competition as a result of economic globalization has resulted in agriculture no longer being the main pillar of the rural economy in Europe. Economic policies are primary

drivers, with social re-composition and economic restructuring taking place (Dasgupta et al., 2014).
- Economic heterogeneity of farm households within communities, in terms of farm and household size, crop choices, and input use, will be important in determining impacts, as will social relations within households that affect production (Dasgupta et al., 2014).

FACTOR 5: Dependence on agricultural production

- Agriculture accounts for only 13% of rural employment in the EU and less than 10% on average across developed countries; however, it has a strong indirect influence on rural economies. (Dasgupta et al., 2014)
- The sovereignty rate over the regional consumption is 18% for the agricultural production and 44% for processed food in Occitanie but “more than a third of the regional production is exported” especially as the region reexports fruits and vegetables from Spain and Morocco. Also, the diversity of its agricultural production is one of the lowest in France, because of a high specialisation in meet production (Source: Nourrir les territoires en temps d’incertitudes,UTOPIES n°25, 2022)
- High demand for water from agriculture: 42% of the annual water extraction is dedicated to the agriculture, four points more than household consumption. In its climate vulnerability assessment, Occitanie states that “Agricultural activity […] is likely to see its irrigation needs increase as rainfall falls and temperatures rise.” (Source: L’évaluation environnementale du SRADDET Occitanie 2040 – Annexe 1a, Juin 2022)
- Fragmentation of the production: the resilience of the region's agricultural economy is “marked by a highly fragmented sector with very few large structures” (Source: Diagnostic et tendances à horizon 2040, SRADDET “Occitanie 2040”, Décembre 2019)

FACTOR 6: Socioeconomic status of farmers

- Climate change in rural areas will take place against the background of the trends in demography, economics, and governance that are shaping those areas (Dasgupta et al., 2014)
- Per capita GDP in rural areas of OECD countries is only 83% of national average (but significant variation within and between countries): driven by out-migration, aging, lower educational attainment, lower productivity of labour, low levels of public services (Dasgupta et al., 2014)
- The Regional Council foresees increased disparities and pressures due to demographic changes like aging population, dependency of seniors and challenges linked to positive net migration. (Source: Diagnostic et tendances à horizon 2040, SRADDET “Occitanie 2040”, Décembre 2019)

FACTOR 7: Presence of chemicals due to agricultural practices (fertilisers and pesticides)

Based on the impact-sequences previously characterised, a few sensitivity factors have been associated to each sequence, as shown below.

Sequence	Association to sensitivity factor
Sequence 1	1
Sequence 2	1,2,3,4,5
Sequence 3	2,3, 6
Sequence 4	5,6
Sequence 5	7

VII. ADAPTIVE CAPACITY

Adaptive capacity is normally determined in terms of knowledge, financial resources, technologies, legislations, and infrastructures that enable people to adapt to the effects of climate change. In the agricultural sector, adaptations include altering what is produced, modifying the inputs used for production, adopting new technologies, and adjusting management strategies (Gowda et al 2018).

Factor 1: Agricultural practices

- Autonomous adaptation by farmers, through the advancement of sowing and harvesting dates and the use of longer cycle varieties could result in a general improvement of European wheat yields in the 2030s compared to the 2000s (Kovats et al 2014).
- Earlier sowing dates, increased soil organic matter content, low-energy systems, deficit irrigation, and improved water use efficiency of irrigation systems and crops can be used as adaptation pathways, especially in Southern and southeaster regions of Europe (Kovats et al 2014).
- Adaptive land use management can reduce the impact of climate change through soil conservation methods such as zero tillage and conversion of arable land to grasslands (Kovats et al 2014).
- Preserving upland vegetation reduced both erosion and loss of soil carbon and favoured the delivery of a high-quality water resource (Kovats et al 2014).
- Maintaining soil water retention capacity contributes to reduce risks of flooding as soil organic matter absorbs up to 20 times its weight in water (Kovats et al 2014).
- Other strategies to reduce climate change impacts include integrated pest and disease management (Gowda et al 2018)
- Change and rotate crops and/or crop varieties, adjust planting and harvesting dates, manage and conserve resources (soil and water), change the number as well as modes and practices of application of inputs (especially fertilisers and irrigation), plant trees, and diversify livestock. Farmers can also try to support drought- stressed crops by using biofertilizers, stimulants, vaccines, etc. Their use can at least partially mitigate the effects of crop water shortage, and the potential of microorganisms is truly significant (Furtak et al. 2023)

Factor 2: Livestock management practices.

- Expanded health services in rural areas, heat-tolerant livestock, and improved design of confined animal housing (Gowda et al 2018).
- Managing heat stress by altering diets, providing adequate shade and clean drinking water supplies, monitoring stock rates continuously to match forage availability, altering the timing of feeding/ grazing and reproduction, and selecting the species/breeds that match climatic conditions (Gowda et al 2018).
- Adaptation requires changes in diets and in farm buildings as well as targeted genetic improvement programs (Kovats et al 2014).

Factor 3: Financial support

- Development of insurance products against weather-related yield variations (Kovats et al 2014).

Factor 4: Water management

- Proven adaptation potential from adoption of more water-efficient technologies and of water-saving strategies (e.g., for irrigation, crop species, land cover, industries, domestic use). Implementation of best practices and governance instruments in river basin management plans and integrated water management (Kovats et al 2014).
- More robust water management, pricing, and recycling policies to secure adequate future water supply and prevent tensions among users could be required in Southern Europe (Kovats et al 2014).

Factor 5: Knowledge

- Traditional knowledge of agriculture and natural resources is an important resilience factor (Dasgupta et al., 2014)
- Implementation of warning systems (Kovats et al 2014).
- The monitoring of soil changes induced by various factors is important in microbiology, ecology, and agriculture (Furtak et al. 2023)
- Epidemiological surveillance and increased coordinated regional monitoring and control programs have the potential to reduce the incidence of vector-borne animal diseases (Kovats et al 2014).
- "Research capacity": Occitanie is the only French region that reached the objective of spending 3% of its GDP to R&D. In addition, it claims to be worldwide leader in agronomical innovation.
- Agricultural/agronomical institutions (Inrae, Cirad, Research Institute for Sustainable Development [IRD], Institut Agro Montpellier, Agri Sud-Ouest Innovation cluster) fund numerous research projects (Montpellier University of Excellence [MUSE]) and research laboratories (Les recherches du centre INRAE Occitanie-Toulouse | INRAE), completed by research on biodiversity loss in its 7 regional natural parks (Causses du Quercy, Grands

Causses, Haut-Languedoc, Narbonnaise en Méditerranée, Pyrénées catalanes, Pyrénées ariègeoises, Aubrac).

Emergence of associative and technical networks to support farmers with changes in practices and agricultural developments imposed by climate change.

Sequence	Association to adaptive capacity factor
Sequence 1	1, 5
Sequence 2	1, 2, 3, 4, 5
Sequence 3	1, 2, 3, 4, 5
Sequence 4	1, 2, 3, 4
Sequence 5	1, 4, 5

Contextual adaptive capacity elements:

Today, agriculture faces significant challenges, and this is why the Region is committed, through innovative policies, to meeting major challenges:

- Promote the diversification of farms, the preservation of soil and biodiversity.
- Relocalize our food and support the processing of our products to limit our dependence on imports (food, fertilizers), create added value on the territory, ensure better income for our farmers.
- Coping with the increase in production costs governed internationally, impacting on the price of products.
- Support our farmers and preserve agricultural land through land use planning that respects these food production areas.
- Rebuilding the link between farmers and consumers
- Consider the growing demands of consumers.

Developed by Sicoval stakeholders engaged in the ecological transition, the **Territorial Food Project (PAT)** aims to develop actions in response to economic, environmental, and social issues. Fight against food waste, support for sectors, organic production, food education, financial accessibility, or even the development of short circuits, all subjects on which the intermunicipality is committed (Source: https://www.sicoval.fr/publications/plan-dactions-projet-alimentaire-de-territoire/)

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Annex 7. Climate Impact chain Toulouse, Occitanie

I. Introduction

The Climate Impact chain for the region of Occitanie developed in the context of the Valorada-EU project, focuses on the **risk of deterioration of people's health status due to urban warming**.

The development of the climate impact chain occurred in two stages. Initially, a participatory workshop involving city representatives of Occitania and Valorada-consortium members Terranis was held in November 2023. The preliminary climate impact chain was formulated based on the insights gathered during this workshop, supplemented by a comprehensive literature review. Subsequently, the initial draft of the climate impact chain was shared with city officials and consortium partners TERRANIS for feedback. This document incorporates all the suggestions provided by the local stakeholders, resulting in the final version of the impact chains.

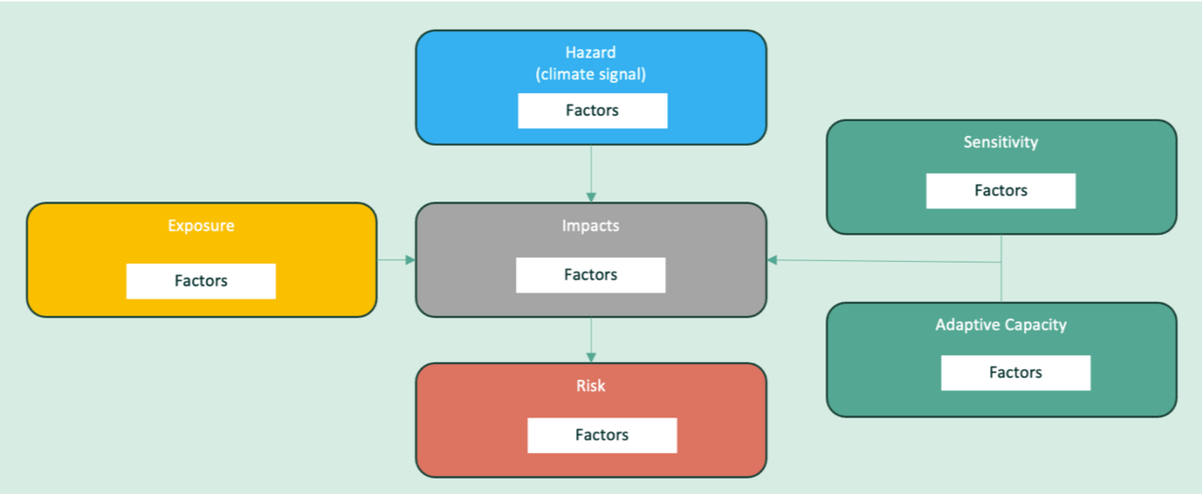
The document is organised as follows:

- Section II presents a brief definition and schema describing a climate impact chain.
- Section III discusses key climate risk concerning high temperatures and health issues.
- Section IV delineates the identified climate hazards affecting people's health.
- Section V outlines the schema proposed for the climate impact chain.
- Section VI presents the key risks identified during the workshop and outlines the impact sequences associated to this risk.
- Section VII outlines the exposure factors associated to each of the sequence of impacts identified in section VI.
- Section VIII outlines the sensitivity factors associated to each of the sequence of impacts identified in section VI.
- Section IX outlines the adaptive capacity factors associated to each of the sequence of impacts identified in section VI.
- Section X presents the bibliography, indicating the literature reviewed for generating this document.

II. Climate-impact chains

A climate-impact chain delineates the connection between a specific climate hazard and a designated impact area. These chains aim to elucidate cause-and-effect relationships within various components of a system. By defining these relationships, impact chains ascertain how a hazard transforms into a risk, factoring in exposure, potential intermediate impacts, sensitivity factors, and response/adaptation capacities that mitigate vulnerability. In cases where applicable, intermediate impacts can be identified, each with its exposure, sensitivity, and adaptation factors (GIZ and EURAC, 2017).

A chain is composed of risk components (hazard, vulnerability, exposure) and underlying factors associated to each component. A climate signal, e.g. a heavy rain event, may lead to a direct physical impact, e.g. a flood, causing a sequence of intermediate impacts, which finally lead to the risk. The hazard component includes factors related to the climate signal and direct physical impact. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised by one or more exposure factors (GIZ and EURAC, 2017).



III Climate Hazards and Climate risks in Occitania region

Climate hazards are defined as the potential occurrence of a climate-related event, trend or physical impact that may cause loss of life, injury, damage and loss of infrastructure, livelihoods, service provision, ecosystems (Rosenzweig et al. 2015).

Climate risks are defined as the potential for consequences where something of value is at stake and where the outcome is uncertain (Rosenzweig et al. 2015).

During the workshop, regional representatives of Occitania, decided to attend the risk of ***Increased urban warming affecting people's health through the deterioration of social and environmental determinants of health***. In this report, the definition of social and environmental determinants of health are specified as:

- **Social determinants of health**, which include "the unequal distribution of power, income, goods, and services, globally and nationally, the consequent unfairness in the immediate, visible circumstances of peoples lives' – their access to health care, schools, and education, their conditions of work and leisure, their homes, communities, towns, or cities – and their chances of leading a flourishing life" (Commission on Social Determinants of Health, 2008).
- **Environmental determinants of health,** which include "… all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours …

targeted towards preventing disease and creating health-supportive environments (including clean air and water, healthy workplaces, safe houses, community spaces and roads and managing climate change) (WHO 2014).

IV: Risks: What is distinctive about urban warming in the context of people's health status?

- The frequency, intensity, duration, and spatial extent of some extreme weather events, particularly heat waves, has been increased by climate change, with further increases projected (Richter, 2016).
- Intense heatwaves in Europe are expected to happen more frequently and become more intense with climate change. With 1.5°C, each year more than 100 million Europeans would be exposed to a present intense heatwave (Feyen et al 2020).
- Compared with pre-industrial times, the mean average European surface air temperature increase has been almost 1°C higher than the average global temperature increase, and 2022 was the hottest European summer on record (van Daalen et al 2022). The record hot summer caused almost 62 000 deaths in Europe in 2022 (Romanello et al. 2023)
- Climate change is interacting with other trends, such as population growth and ageing, urbanisation, and socioeconomic development, that can either exacerbate or ameliorate heat-related hazards (Ebi et al 2021).
- Urban temperatures are enhanced by anthropogenic heat from vehicular transport, heat emitted from building energy waste, and minimally by human metabolic heat. (Ebi et al 2021).
- Worldwide, Europe had the highest rate of heat-related mortality in recent years (2017–22) (Romanello et al. 2023).
- Vulnerability to heat exposure has increased steadily across all European regions, with an increase of 6% from 1990 to 2019. Although northern Europe is the most vulnerable region, the highest relative increase of 9,8% is observed in central Europe (van Daalen et al 2022)
- Assuming present vulnerability and no additional adaptation, annual fatalities from extreme heat in Europe could rise from 2,700 deaths now to nearly 30,000 with 1.5°C global warming, 50,000 with 2°C and 90,000 with 3°C. The increase in human exposure to and fatalities from extreme heat is most pronounced in southern European countries and the highest number of fatalities will occur in France, Italy and Spain (Feyen et al 2020).
- Urban heat island (temperature difference between inside the city and outside it) can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning, inducing also earlier spring-time flowering in urbanized areas compared to surrounding rural areas (Richter 2015).
- Climate change and the urban heat island (UHI) effect impact ecosystem services and green infrastructure by causing shifts in temperature and precipitation patterns, evaporation rates, humidity levels, soil moisture content, vegetation growth rates, water tables, aquifer levels, and air quality (Solecki & Marcotullio, 2013). These changes can bring about cascading effects that further affect urban ecosystems (Frumkin et al., 2008; Keim, 2008).

Drawing from the preceding characterization, this report builds on the Health and Cities Framework (IPCC 2007) to encompass the myriad relationships and causal chains intertwining climate and non-climate determinants of risk. The framework underscores that "…long-term projections of global health outcomes now explicitly include factors such as unsafe water, food, and residence; poor sanitation; urban air pollution; and indoor air pollution – all of which are aggravated by climate change" (Barata et al 2018 p.366).

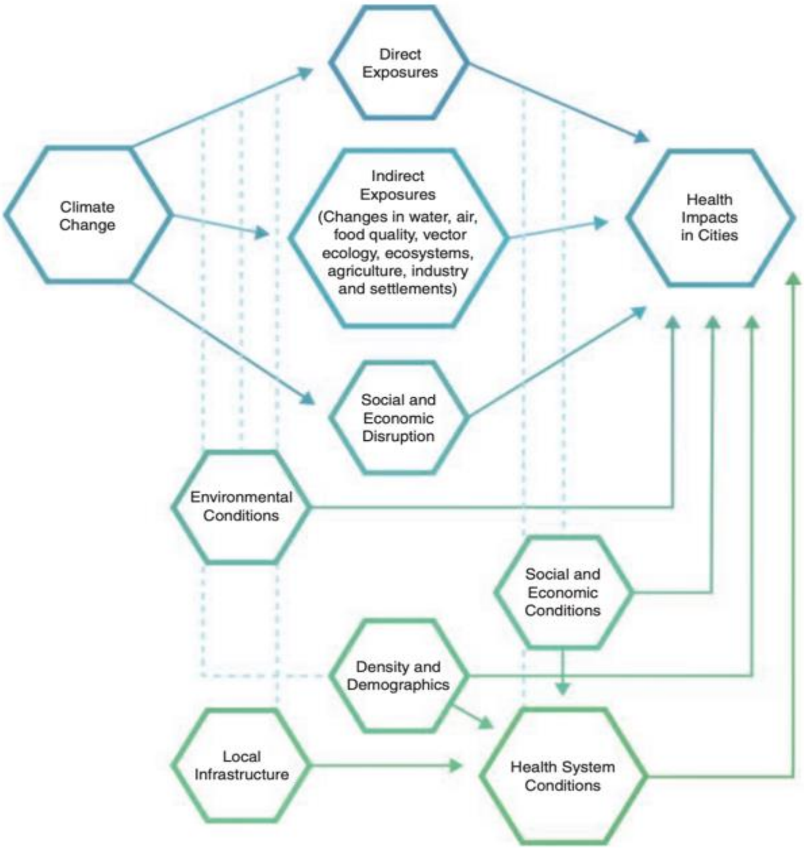


Figure source: Barata et al. 2018

Key contextual aspects in Occitania driving climate risks.

The Occitanie region is particularly vulnerable a rise in temperatures linked to climate change. The heat waves experienced in recent years, with frequent temperatures above 40°C, have given a preview of heatwaves to come. Many indicators make it possible to measure this warming, such as temperature anomalies, number of heat wave days, or the frequency of summer days (maximum temperature above 25°C) and tropical nights (minimum temperature does not fall below 20°C).

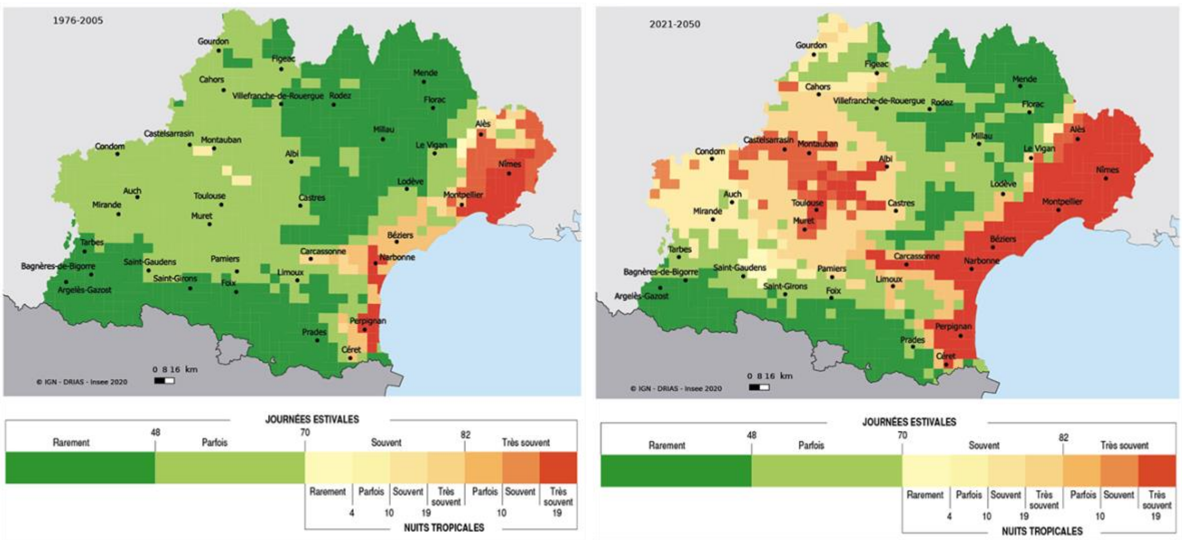
Taking night-time temperatures into account – in addition to daytime temperatures – is essential from a public health perspective. It is in fact the night-time drops in temperature that allow people to better withstand the intense heat during the day, particularly for the elderly.

In the future, hot days and nights will become more and more frequent throughout the region. Thus, on the coast and in the Mediterranean hinterland, which are regularly affected by summer days, intense daytime but also night-time heat will increase.

Until the beginning of the 2000s, the rest of the Occitania region was not subject to these very frequent extreme heat phenomena. With up to 70 summer days per year, the plain territories (Gers, Haute-Garonne, Tarn-et-Garonne, south of the Lot and west of the Tarn) were however distinguished from the medium or high mountain territories where this number does not did not exceed 48 days (Massif central and Pyrenees).

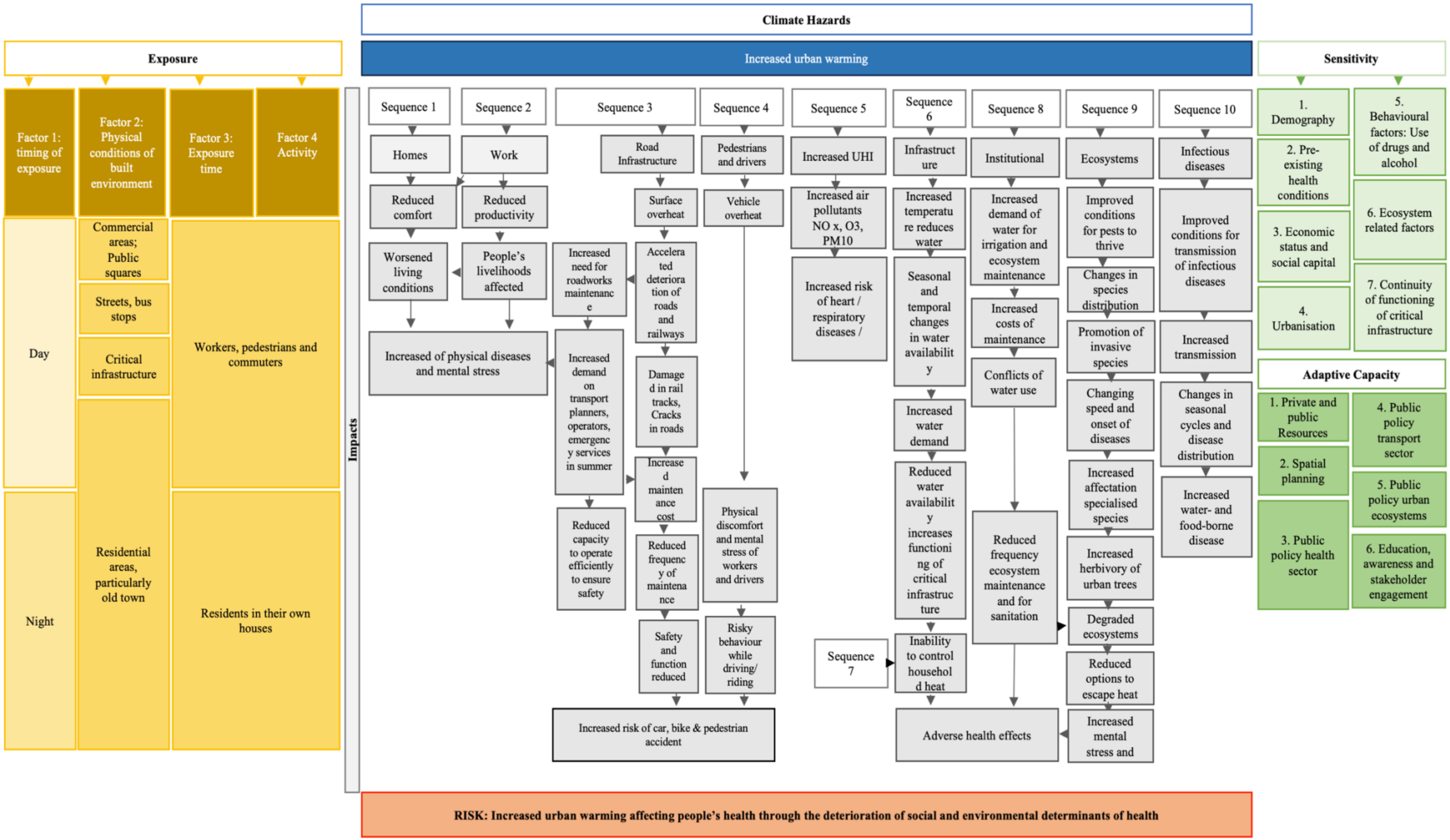
In the coming decades, some areas of the interior plain will be in a configuration similar to that experienced by the coast in the past. Thus, within a vast triangle around Toulouse, the number of summer days would increase to more than 82 per year, even though their frequency remained close to 70 until 2005. The perimeter of mountain areas rarely subject to summer days will be more and more restricted. The recurring high temperatures will thus extend to new areas of the region while the phenomenon will gain in intensity in the territories which are already subject to it.

Thus, the territories which will be marked by the multiplication of episodes of extreme heat are precisely those where a large majority of the regional population lives: the Mediterranean coast and around the Garonne plain. In addition, in these highly urbanized areas, there are very localized phenomena such as urban heat islands. These phenomena could increase temperatures on a sub-urban scale and therefore make episodes of extreme heat even more frequent in certain neighbourhoods. Episodes of extreme heat can in fact lead to dehydration, the aggravation of certain chronic illnesses or even heat stroke. Infants, pregnant women, the elderly and those with chronic illnesses are particularly vulnerable.



Legend: *Frequency zones for extreme heat in Occitania for the periods 1976-2005 and 2021-2050 (Source: Insee based on the DRIAS Climate Service, Météo-France, Euro-Cordex simulations, RCP 8.5, median frequencies)*

V. Climate Impact Chain for the region of Occitania



VI. Impacts

The risk of ***Increased urban warming affecting people's health through the deterioration of social and environmental determinants of health*** is characterised through ten impact sequences:
(1) People's health being affected by the increased temperatures in their private households; (2) affectation on people's health and on the reduction of people's productivity while working due to increase temperature; (3) people's health as being affected by the increased risk of car, bike, and pedestrian accident due to mental stress and reduced performance of infrastructure; (4) risk of accidents as people are affected by physical discomfort and mental stress while driving and commuting due to high temperatures, resulting in more risky behaviour.; (5) increase of air pollution as provoked by urban warming and related health effects; (6) reduced availability of water and increased demand during summer provoked by urban warming, which in turns, affects the functioning of critical energy infrastructure; (7) impacts on critical urban infrastructure which supports people's health following extreme temperatures; (8) institutional impacts related to extreme temperatures, particularly on the costs and barriers affecting the local government to ensure appropriate water management; (9) degradation of urban ecosystems due to extreme temperatures and the loss of cooling spaces for people during extreme heat; (10) shifting the environmental suitability for the transmission of various infectious diseases due to extreme temperatures.

Key messages emerging from the impact sequences:

1. Urban warming deteriorates environmental and social determinants of health, causing direct threats to people's health status.
2. Deteriorating social determinants of health highlight issues of social justice as shed light on people's limited private resources and capacities to cope with high temperatures.
3. Urban ecosystems play a crucial role in natural capital for climate change adaptation and mitigation (Rosenzweig et al. 2015); while at the same time, urban habitats contribute to the well-being of urban residents (Solecki & Marcotullio, 2013). Climate change and the urban heat island (UHI) effect impact ecosystem services and green infrastructure by causing shifts in temperature and precipitation patterns, evaporation rates, humidity levels, soil moisture content, vegetation growth rates, water tables, aquifer levels, and air quality (Solecki & Marcotullio, 2013; Frumkin et al., 2008; Keim, 2008).
4. In consideration to vulnerabilities and exposure, impacts are perceived differently through society. However, the impact chains reveal how some impacts may be more prominent at different times (difference between day and night highlighted). This is particularly relevant for the impacts related to the Heat Island Effect (sequence 5).
5. Disruption in the normal and steady functioning of critical infrastructure due to high temperature can cause dramatic impacts to populations depending on these infrastructures for their coping capacity against heat. This is particularly the case for energy grids that experience above-normal demand during pick-times, provoking blackouts that limit access to air conditioning. However, water systems can also be exposed to stress under high temperatures, either due to water overdemand, low provision capacity, or reduced water quality.
6. People's activities and routines greatly change their exposure to heat stress.

Sequence 1.

In the first sequence, the focus is on people's health being affected by the increased temperatures in their private households.

Generation of Urban Heat Islands

One consequence of urban development is the urban heat island (temperature difference between inside the city and outside it) that results in cities being, on average, warmer than adjacent rural landscapes (Ebi et al 2021)

↓

Difficulties to escape heat at night time

The urban heat island is amplified at night when stored daytime heat is emitted and intensified with increasing city size and population density (Ebi et al 2021)

↓

Increasing energy demand threatens cooling devises

Urban heat island can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning (Richter 2015).

An approach focusing on air conditioning as a preventive measure for reducing heat-related morbidity and mortality is vulnerable to failure when the underlying infrastructure – the electrical grid – weakens or fails during a summer heat wave (Barata et al).

↓

Increased affectation to vulnerable groups

Hot weather and heat extremes are associated with increased emergency room visits and hospital admittance, increased deaths from cardiorespiratory and other diseases, mental health issues, adverse pregnancy and birth outcomes, and increased health-care costs (Ebi et al 2021).

In Europe, population exposure to heatwaves increased by 57% on average in 2010–19 compared with 2000–09, and by more than 250% in some regions, putting older people, young children, people with underlying chronic health conditions, and people who do not have adequate access to health care at high risk of heat-related morbidity and mortality (van Daalen et al. 2023)

↓

Worsening living conditions and increased mental stress

Sequence 2.

In the second sequence of impacts proposed, the focus is on the affectation on people's health and on the reduction of people's productivity while working due to increase temperature.

Hyperthermia provoked by heat stress directly impairs physical work capacity and tasks relying on complex cognitive functions or skilled motor performances (Ebi et al. 2021).

High heat stress can reduce physical work capacity and motor-cognitive performances, with consequences for productivity, and increase the risk of occupational health problems (Ebi et al 2021).

Workers exposed to elevated environmental heat will typically reduce their work output, taking more unplanned breaks or working at a slower pace than normal to adjust the overall occupational heat stress (ibid).

Increased susceptibility due to activity nature

Many workers are repetitively exposed to daily occupational heat stress over extended periods, thereby making them more susceptible to both acute and chronic effects of heat strain (Ebi et al 2021)

For outdoor workers, high metabolic heat production associated with occupational tasks combined with high ambient and radiant heat, low air flow, and sometimes high humidity, add to human heat strain (Ibid)

Workers following a fixed or externally dictated pace (eg, buckets per h) or piecemeal will face higher heat strain than those workers who are free to self-pace (ibid).

Affected people's livelihoods and social determinats of health

Heat exposure undermines people's livelihoods and the social determinants of health by reducing labour capacity (van Daalen et al. 2023).

Increased mental stress

Sequence 3

In the third sequence, the focus is on people's health as being affected by the increased risk of car, bike, and pedestrian accident due to mental stress and reduced performance of infrastructure. This sequence of impacts includes also the pressure exerted on the capacity of operators to keep pace with worsening infrastructure.

Surface overheat resulting from prolonged-extreme temperatures.

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Accelerated deterioration of roads and railways

Future temperature increases are projected to reduce infrastructure lifetime and increase road costs (Jacobs et al 2014). Elevated temperature, combined with increased salinity and humidity, accelerates deterioration in bridges and roads constructed with concrete (Ibid).

↓

Damaged in rail tracks, cracks in roads

High temperatures can lead to infrastructure damage, affecting roads with issues like deformation and asphalt melting, resulting in unsafe conditions and increased maintenance costs (Slavich et al. 2022).

Elevated temperatures along with the increased occurrence of hot summers, is expected to contribute to a higher frequency of rail buckling incidents posing risks for train travel (Jaroszweski et al. 2014).

↓

Increased maintenance cost

Higher ambient temperatures and extreme heat events can negatively impact pavement performance and, in turn, increase costs due to material upgrades to accommodate higher temperatures (Jacobs et al. 2014)

Increased maintenance costs and rapid maintenance planning increases presure on transport planners, operators, emergency services (ibid)

↓

Reduced frequency of maintenance

As costs due to material upgrades to accommodate higher temperatures increase; these costs are only modestly reduced by less frequent maintenance (Jacobs et al. 2014).

However, as roads deteriorate more rapidely, the need for maintenance work during the summer season increase, exposing workers to working under extreme temperature conditions (ibid).

↓

Safety and function reduced

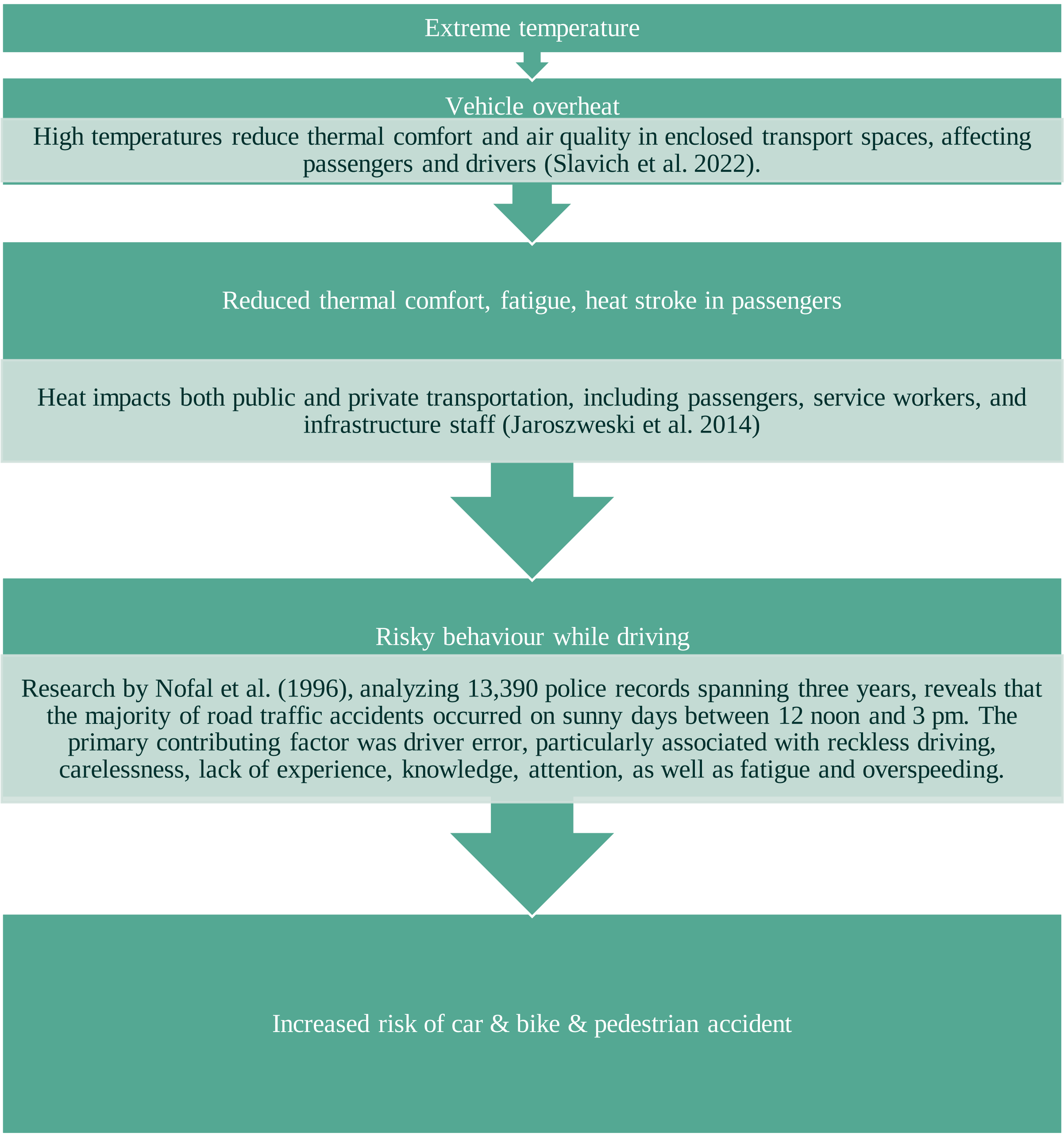
Higher ambient temperatures and extreme heat events can negatively impact pavement performance; Buckled roadway joints can send vehicles airborne (Jacobs et al. 2014)

↓

Increased risk of car & bike & pedestrian accident

Sequence 4.

In the fourth sequence of impacts proposed, the focus is on the risk of accidents as people are affected by physical discomfort and mental stress while driving and commuting due to high temperatures, resulting in more risky behaviour.



Sequence 5.

In the fifth sequence of impacts proposed, the focus is on the increase of air pollution as provoked by urban warming and related health effects.

Air pollution might also increase during heatwaves, leading to possible synergistic effects on health (Hajat et al. 2010)

Heat waves and warm spells could exacerbate urban heat island effects, including increased air pollution (Solecki & Morcotullio, 2013).

Other impacts of extreme temperature on ambient air quality, such as ozone pollution under heatwaves (Feyen et al 2020)

Ozone production is dependent on temperature and the presence of sunlight, with higher temperatures and still, cloudless days leading to increased production (Barata et al 2018)

Increased of polluants due to transport

Urban temperatures are further enhanced by anthropogenic heat from vehicular transport and heat waste from buildings (Ebi et al 2021)

Reduced health status

Exposure to ozone is associated with decreased lung function, increased premature mortality, increased cardiopulmonary mortality, increased hospital admissions, and increased emergency room visits (Barata et al 2018)

Sequence 6:

In the sixth sequence of impacts proposed, the focus is on the reduced availability of water and increased demand during summer provoked by urban warming, which in turns, affects the functioning of critical energy infrastructure.

Increased temperature affect water quality, quantity and access

Climatic pressures will interact at different spatial scales to have a synergistic impact on water availability, on water quality, infrastructural integrity, arrangements among competing users, and strength of institutions (Vicuña et al. 2018).

↓

Increased temperature affects water chemistry and biology

Warmer water temperatures can change the solubility and transport of contaminants as well as promote algal and other biological outbreaks (including invasive species) in water supply and wastewater/sanitation systems. However, warmer temperatures are generally conducive to improved biological reactions in water and wastewater treatment processes (Vicuña et al. 2018).

↓

Seasonal and tempoeral changes in water availability

Warming-induced declines in snowpack, glaciers, and less seasonally persistent snowpack (e.g., earlier snowmelt) are expected to change the timing of water availability. This alters the natural storage of water from cooler seasons with low water demands to warm seasons when demands are commonly highest. This is expected to challenge water management systems (Vicuña et al. 2018).

↓

Higher temperature increases water demand

Warmer temperatures result in larger demands for water in many cities, particularly for household consumption and thermoelectric cooling. Extreme heat waves, which are projected to become more common and severe in the future, typically lead to disproportionately elevated demands for water (Vicuña et al. 2018).

↓

Reduced water availability affects functioning of critical infrastructure

Warmer temperatures can affect water use for industry and power generation that are serve urban systems; can decrease the efficiency of cooling for thermoelectric power generation. As a result, decreasing efficiency can have a dramatic effect on electricity generation in urban areas (Vicuña et al. 2018).

Sequence 7.

In the seventh sequence of impacts proposed, the focus is on the impacts on critical urban infrastructure which supports people's health following extreme temperatures. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented below.

When climate-related extreme events threaten critical urban infrastructure, reverberations can be felt in the health of urban populations (Barata et al 2018)

The health of urban residents is closely linked to key infrastructure, such as public transportation, sewerage, waste management, the efficiency of rainwater drainage systems, and the utility supply.

Connected disruptions

Many health hazards associated with extreme climate events in urban areas operate through disruptions in critical infrastructure (Barata et al 2018).

Lack of electricity can make it difficult or impossible to control the interior climate, refrigerate food, physically move about in high-rise buildings, pump water to upper floors, and operate medical support equipment. While a lack of air conditioning in homes increases the risk of heat-related death, air conditioning also contributes to higher power demand during heat waves, which increases the risk of power disruptions and blackouts. When blackouts occur, exposure to heat increases, with a corresponding increase in health risks (ibid).

Adverse health effects due to disrupted infrastructure

These infrastructure disruptions can lead to a wide range of adverse health effects depending on the age, health status, and economic resources of residents in the affected households. An approach focusing on air conditioning as a preventive measure for reducing heat-related morbidity and mortality is vulnerable to failure when the underlying infrastructure – the electrical grid – weakens or fails during a summer heat wave (Barata et al 2018)

Sequence 8:

In the eighth sequence of impacts proposed, the focus is on the institutional impacts related to extreme temperatures, particularly on the costs and barriers affecting the local government to ensure appropriate water management.

Increase temperature affects institutional functioning

↓

Increased demand for water for urban ecosystem maintenance and sanitation

Continuity of delivery of local public services such as transportation (ex. impact of heat on road infrastructures), energy provision networks (pumps), water provision networks

Continuity of activities related to clean water production et distribution to households

↓

Increased costs of maintenance for ecosystes and sanitation

Lack of water for cleaning public spaces, watering green spaces

↓

Increased conflicts due to water use

Usage conflicts over water use : irrigation vs tourism for instance

↓

reduced frequency of ecosystem maintenance and sanitation

↓

Increased risk of sanitatry and mental diseases

Sequence 9:

In the nineth sequence of impacts proposed, the focus is on the degradation of urban ecosystems due to extreme temperatures and the loss of cooling spaces for people during extreme heat.

Urban heat and warming

Climate change is already impacting urban biodiversity and ecosystems (Rosenzweig et al. 2015). The combination of climate change and urbanization (i.e., increased patch fragmentation and diversity), is expected to heighten the vulnerability of biodiversity hotspots, urban species, and essential ecosystem services (Luck & Wu, 2002)

Better conditions for pests

Changing climate may also affect the introduction of new species in urban ecosystems by reducing noninvasive and native species while favoring weedy and urban-adapted species (Rosenzweig et al. 2015).

Winter warming and absence of cold waves will benefit certain species of insect pests and diseases that are sensitive to prolonged periods of cold (Solecki and Marcotullio 2013).

Changes in species distribution and promotion of invasive species

Ultimately, changes in species distributions are expected to modify the ecological interaction networks in cities and have the potential to promote invasive species, which could accelerate the loss of urban biodiversity (Kendal et al., 2012)

Changing speed and onset of diseases

Climate shifts can adjust the speed of onset of emerging diseases and other pathogens and alien/invasive species entering the extended regions around cities (Solecki and Marcotullio 2013).

Increased affectation on specialised species

Species that are highly specialized and heat sensitive may be threatened with local extinction driven also by an inability to move to new areas as urban development expands (Rosenzweig et al. 2015).

Increased herbivory of urban trees

Urban trees could face greater herbivory in the future as a consequence of the increased fitness of some herbivorous arthropods under warming scenarios. However, more research is needed to generalize these results to more urban areas (Rosenzweig et al. 2015).

Degrarded ecosystems

As a result of the interconnectedness between ecosystem well-being and ecosystem services, growing ecological stress diminishes the quality and quantity of ecological services (Cairns and Pratt, 1995).

Reduced options to escape heat

Sequence 10:

In the tenth sequence of impacts proposed, the focus is on the shifting the environmental suitability for the transmission of various infectious diseases due to extreme temperatures.

Changing environmental conditions shift the environmental suitability for the **transmission of various infectious diseases**.

An increasing percentage of coastal waters in Europe are showing suitable conditions for the transmission of pathogenic non-*cholerae Vibrio*, the climatic suitability for the transmission of dengue increased by 30% in the past decade compared with the 1950s, and the environmental risk of West Nile virus outbreaks increased by 149% in southern Europe and 163% in central and eastern Europe in 1986–2020 compared with 1951–85. West Nile virus has emerged in the Americas and expanded in Europe, where it is becoming a public health concern (Hajat et al. 2010).

Increased transmission

Vector-borne disease incidence is influenced by temperature and precipitation, which can affect the range, prevalence, and reproductive cycle of disease vectors, among other determinants (Hajat et al, 2010).

Transmission season for dengue combining information on temperature, rainfall, mosquito abundance, and human population density in the period 1986–2020 has increased by 17·3% in Europe compared with 1951–1985. This pattern is also observed for chikungunya and Zika virus. The greatest upward shift in transmission season is observed in central eastern Europe, with a gain of about 0,2 suitable months for dengue (van Daalen et al 2023).

Dengue fever transmitters, the Aedes aegypti mosquito, can be easily found in regions of tropical and subtropical climate, having an ideal temperature of transmission of between 23°C and 27°C, although temperatures from 18°C can also trigger its transmission (Barata et al 2018)

Changes in seasonal cycle and spatial distribution of vector-borne diseases

Climate change may lead to changes in the seasonal cycle and spatial distribution of some vector-borne diseases... it is also possible that optimal temperature conditions for certain vector species will be exceeded and thus potentially reduce the risk of infection, particularly under high warming scenarios (Barata et al 2018)

Warmer temperatures are also shifting flowering seasons of several allergenic tree species, with birch, olive, and alder seasons beginning 10–20 days earlier than 41 years ago, affecting the health of around 40% of the population in Europe who have pollen allergies (van Daalen et al 2023)

Increased water- and Food-Borne Disease

Humans can be exposed to water- and food-borne pathogens through a variety of routes, including via the ingestion of polluted drinking water, consumption of contaminated food, inhalation of aerosols containing bacteria, and by direct contact with recreational or floodwaters. A number of pathogens that cause water- and food-borne illnesses in humans are sensitive to climate parameters, including increased temperature, changing precipitation patterns, extreme precipitation events, and associated changes in seasonal patterns in the hydrological cycle (Romanello, 2023).

IV. Exposure

Factor 1: Timing of exposure

- The timing of exposure, encompassing distinct exposures during daytime and nighttime, gives rise to varied risks among different demographic groups. As highlighted in the workshop session, individuals may have access to cooler environments, such as shopping centres or swimming pools during the day. Conversely, during the night, individuals are often confined to their residences, occasionally lacking the necessary cooling amenities for comfort. This situation may pose additional challenges for individuals living alone and facing mobility issues, particularly the elderly.

Factor 2: Physical conditions of built environment

- Urban environment and building structure play a vital role in determining the vulnerability of urban populations to heat stress, such as access to vegetation and green space, development intensity, living on a high floor of multi-storey buildings, building materials, land cover and housing density (Puntub et al 2022).
- High building density and a lack of urban green and water spaces determine the adverse bioclimatic evaluation of urban environments (Richter 2015).
- Urban temperatures are enhanced by anthropogenic heat from vehicular transport, heat emitted from building energy waste (Ebi et al 2021).
- Urban heat island can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning, inducing also earlier spring-time flowering in urbanized areas compared to surrounding rural areas (Richter 2015).

Factor 3: Exposure time

- Overall, the number of hours of risk per person is increasing across all European regions. In southern Europe, the number of hours with heat-related health risks during medium-intensity activities (e.g., football or tennis) increased relatively by 106% between 1990 and 2020 and increased to 429 hours per person in 2020. For strenuous activities (e.g., mountain biking), there was a relative increase of 77% in southern Europe, leading to 627 hours at risk per person in 2020 (van Daalen et al. 2022).
- Equipment operators and road builders can be exposed to hight temperatures for long periods (maintenance and building staff working in hot weather may experience intense fatigue) (Jacobs et al. 2014).
- People at bus stops exposed for long time periods (waiting at unsheltered transit stations during peak hours can lead to severe heat stress (Slavich et al. 2022).

Factor 4: Nature of activity (indoor – outdoor activity and timing of activity)

- Heat exposure in sport events: In 2019, examples of heat-related disruptions to major sporting events include the Women's Fédération Internationale de Football Association (FIFA) World Cup in France, the Australian Open tennis tournament in Melbourne, VIC, Australia, the Olympic test triathlon event in Tokyo, Japan, the World Track and Field

Championships in Doha, Qatar, and the New York City Triathlon, NY, USA; each had either interrupted or postponed competition due to the anticipated high risk of exertional heat illness in competitors (Ebi et al. 2021).

- Projections suggest that by 2085, very few major cities will be able to host the summer Olympic games due to heat-related risks for athletes. Heat-related concerns could be even greater for the Paralympic games because they will involve more vulnerable populations (Ebi et al 2021).
- For outdoor workers, high metabolic heat production associated with occupational tasks combined with high ambient and radiant heat, low air flow, and sometimes high humidity, add to human heat strain (Ebi et al 2021)
- Cyclists exposed to dehydration and heat strokes (pedestrians and cyclists might also suffer from heat stress and health problems, potentially shifting to public transit or avoiding travel if they can't use a private vehicle (Jaroszweski et al. 2014).

Resulting from this characterisation of exposure factors, the following table identifies the connection between the impact sequences with exposure factors:

Impact Sequence	Association to Exposure Factor
Sequence 1	1, 2, 3, 4
Sequence 2	1, 2, 3, 4
Sequence 3	1, 2, 3, 4
Sequence 4	1, 2, 4
Sequence 5	2
Sequence 6	1, 2
Sequence 7	1, 2
Sequence 8	2
Sequence 9	2
Sequence 10	2

V. Sensitivity

Climate change in urban areas will take place against the background of the trends in demography, economics, and governance that are shaping those areas. Existing vulnerabilities caused by poverty, lower levels of education, isolation can all aggravate climate change impacts (Dasgupta et al. 2014).

Factor 1: Demography

- UHI increases with city size and the number of inhabitants (Richter 2015).

- As urban populations steadily increase, larger numbers of people are at risk of heat stress in the built-up environment of cities (Richter 2015).

Factor 2: Pre-existing health preconditions

- Population exposure to heatwaves increased by 57% on average in 2010–19 compared with 2000–09, and by more than 250% in some regions, putting older people, young children, people with underlying chronic health conditions, at high risk of heat-related morbidity and mortality (van Daalen et al. 2022).
- Future susceptibility likely to be increased with ageing populations, (Hajat et al. 2010).
- Population ageing in Europe is a major demographic trend for the coming decades. It could further increase the effect on human beings of temperature extremes (Feyen et al 2020).
- Adults older than 65 years and infants younger than 1 year, for whom extreme heat can be particularly life-threatening, are now exposed to twice as many heatwave days as they would have experienced in 1986–2005 (Ebi et al. 2021).
- heat- related deaths of people older than 65 years increased by 85% compared with 1990–2000, substantially higher than the 38% increase that would have been expected had temperatures not changed (Hajat et al, 2010).
- Studies consistently show that adults older than 65 years, people with cardiopulmonary and other chronic diseases, and very young children are particularly vulnerable to the effects of heat, irrespective of income level or geo- graphical region (Ebi et al 2021).
- pre-existing physical conditions (such as cardio-vascular and cerebrovascular conditions and diabetes) or those related to mental health (such as depression) potentially leading to mortality and morbidity, age (particularly children and the elderly) (Puntub et al 2022)
- Rates of heat-related mortality and morbidity are high in elderly and chronically ill individuals, particularly those with cardiovascular, respiratory, and renal diseases. People with diabetes, neurological disorders, and psychiatric illnesses might also be at increased risk (Hajat et al, 2010).

Factor 3: Economic status and social capital

- Household income, poverty, unemployment, social isolation, social cohesion, household structure, gender, education attainment, language proficiency, race, house-ownership and more (Puntub et al 2022).
- Social isolation and little mobility were identified as key risk factors during heatwaves. Other contextual risk factors include no access to an air-conditioned environment, living in homes with high thermal mass and little ventilation, and living on the upper floors of high-rise buildings (Hajat et al, 2010).
- People who do not have adequate access to health care at high risk of heat-related morbidity and mortality (van Daalen et al. 2023).
- increased mortality during heat extremes is associated with being confined to bed, living alone, being unable to care for oneself, not leaving the residence to cool down their body temperature, and having a pre-existing mental health condition (Ebi et al 2021).
- The highest risk of death during heatwaves were confinement to bed; pre-existing psychiatric illness; not leaving home every day; and an inability to care for oneself (Hajat et al, 2010).

- Risk of water-borne illness is greater among the poor, infants, elderly, pregnant women, and immune-compromised individuals. Food/ water scarcities impact human health (Barata et al 2018).

Factor 4: Urbanisation

- increasing urbanisation could amplify the urban heat island effect, which causes urban and metropolitan areas to be significantly warmer than their surrounding rural areas (Feyen et al 2020)
- The combined effects of heatwaves and air pollution might further exacerbate human stress in densely populated areas (Feyen et al 2020)
- Urban areas are vulnerable to the health impacts of climate change due to their high population density, concentration of vulnerable populations, higher temperatures compared to surrounding areas (Barata et al 2018).

Factor 5: Behavioural factors: Use of alcohol and drugs

- The use of alcohol, medications, and illegal narcotics is associated with increased mortality during heat extremes. Many commonly prescribed medications, such as general anticholinergics, antidepressants, and opioids and illegal narcotics such as cocaine, might compromise physiological heat loss responses (Ebi et al 2021)
- The magnitude and pattern of future heat-related morbidity and mortality will depend on climate change and other important factors such as population growth and ageing, urbanisation trends, adaptation efforts, and development choices (Ebi et al 2021).
- Some drugs, notably diuretic, psychotropic, and anticholinergic drugs, have been implicated in increasing the risk of heat-related death or illness (Hajat et al 2010).

Factor 6: Ecosystem-related factors

- **Rate of urban growth:** Urban ecosystems face unique stressors, leading to heightened exposure to hazards such as high population density, the influence of non-climate-related stressors, and the urban heat island (UHI) phenomenon (Farrell et al., 2015).
- **Expansion of impermeable surfaces**: One of the most significant alterations impacting urban streams is the proliferation of impervious surfaces. This transformation modifies the hydrological dynamics and channels pollutants that accumulate from buildings, roadways, and parking lots into the streams (Grimm, et al. 2008).
- **Water availability**: The issue of urban water security remains an ongoing challenge, particularly in lower-income countries. Many cities face difficulties in providing essential services to their residents, especially those residing in informal settlements. As cities continue to expand, the demand for limited water resources will grow, and the effects of climate change are poised to exacerbate these challenges in numerous urban areas (Rosenzweig et al. 2015).
- **Tree species composition**: Certain "urban-adapted" species flourish in urban environments globally, often outcompeting indigenous species and becoming prevalent at local and regional levels. While various ecological and socioeconomic factors impact vegetation in urban areas, a significant portion of non-native invasive species that thrive in cities

originate from warmer regions, benefiting from shifting climate conditions (Sukopp & Wurzel, 2003).

Factor 7: Continuity of functioning of critical infrastructure

- Many health hazards associated with extreme climate events in urban areas operate through disruptions in critical infrastructure. Lack of electricity can make it difficult or impossible to control the interior climate, refrigerate food, physically move about in high-rise buildings, pump water to upper floors, and operate medical support equipment. While a lack of air conditioning in homes increases the risk of heat-related death, air conditioning also contributes to higher power demand during heat waves, which increases the risk of power disruptions and blackouts. When blackouts occur, exposure to heat increases, with a corresponding increase in health risks (Barata et al 2018).

Sensitivity factors for Urban areas in Occitania

Based on the impact-sequences previously characterised, a few sensitivity factors have been associated to each sequence, as shown below. This association explains that risks can be exacerbated when particular conditions (sensitivity factors) come and interplay with specific impact factors.

Sequence	Association to sensitivity factor
Sequence 1	2,3,4,5
Sequence 2	2,3,4,5
Sequence 3	4, 7
Sequence 4	4, 5
Sequence 5	1,4
Sequence 6	4, 7
Sequence 7	2,7
Sequence 8	4,6,7
Sequence 9	4, 6
Sequence 10	4,6

VI. Adaptive Capacity

Adaptive capacity is normally determined in terms of knowledge, financial resources, technologies, legislations, and infrastructures that enable people to adapt to the effects of climate change.

Factor 1. Resources

- Provision of air conditioning, increasing urban vegetation, accessibility to medical services and insurance, and accessibility to nearby public heat refuges as crucial (Puntub 2022)
- Financial options for refurbishment (identified during workshop)

Factor 2. Spatial planning

- Spatial planning influences the spatial configuration, type and degree of development of buildings and land use, as well as landscapes and green spaces (Richter 2015).
- Improved design and insulation of houses, schools and hospitals, sound urban planning (increasing tree and vegetative cover, installing green or reflecting roofs, or using cool pavements) (Feyen et al 2020)
- Building codes (Hajat et al 2010)
- Implementation of thermal regulations (PLUiH) (identified during workshop)

Factor 3. Policy public health

- Focus on identifying and informing effective and cost-efficient public health and climate change adaptation and mitigation interventions; on monitoring these interventions to reduce health burdens and inequities; promote and facilitate the active involvement of young people and minoritised groups in identifying health and climate change solutions that minimise or eliminate health inequities (Hajat et al 2010)
- Public health protection measures, with the timely provision of appropriate home-based prevention advice to the general public (Hajat et al 2010).
- Heat health warning systems that trigger community alerts and emergency actions in response to forecasts of adverse weather conditions. Because heat- related illness is largely avoidable, the most crucial point of intervention concerns the use of appropriate prevention strategies by susceptible individuals and their carers. Although such home-based prevention advice already forms an integral part of many heat health warning systems, the extent to which the advice is based on medical evidence is unclear. Knowledge of effective prevention and first-aid treatment, besides an awareness of potential side- effects of prescription drugs during hot weather, is crucial for physicians and pharmacists (Hajat et al 2010).
- Upgrading health infrastructure, improving the capacity of health workforces, enhancing disease surveillance, and conducting health-specific vulnerability and risk assessments (United Nations Environment Programme, 2023).
- Multisectorial cooperation (identified during workshop)

Factor 4: Public policy in transport sector

- Transport systems should be operated by adaptive organizations, which embed adaptation across all functions, understand current and future weather conditions and have strategies in place to address them (Black et al. 2021).
- Improving adaptive capacity involves assessing design capability, financial capability, and organizational capability to respond to climate change risks. For instance, transport planners and operators adhere to design standards that consider specific temperature and precipitation ranges and return intervals for extreme events (Black et al. 2021).
- Nonetheless, these standards are becoming less applicable over the extended lifespan of infrastructure investments, particularly for durable structures such as bridges and roads,

underscoring the necessity for comprehensive asset lifecycle planning in climate adaptation endeavours (Black et al. 2021).

- Time flexibility for commuting (identified during workshop)
- Multisectoral cooperation (identified during workshop)

Factor 5: Public policy urban ecosystem

- Conserving, restoring, and expanding urban ecosystems to enhance climate resilience and other co-benefits under mounting climatic and non-climatic stresses of growing urbanization and development processes will require improved urban and regional planning, policy, and governance and multi-sectorial cooperation to protect and manage urban ecosystems and biodiversity (Solecki and Marcotullio, 2013).
- Also, greater coordination and networks among governance structures that manage local ecosystems and urban biodiversity, including cemeteries, golf courses, urban parks, and neighbourhood gardens, would strengthen ecosystem functioning as well as the associated and essential social-ecological engagement (Ernstson et al., 2010).
- The adaptive capacity of species in urban landscapes is a function of ecology, physiology, and genetic diversity (Williams et al., 2008).
- In the context of urban biodiversity and ecosystems, nonhuman actors, behaviour, species interactions, and human–ecological interventions are also important for adaptive capacity. For example, human-induced adaptive capacity could include planting species that are more tolerant of higher temperatures and droughts. Nonhuman-derived adaptive capacity could include natural processes that change ecosystem components rapidly for organisms like insect populations persisting despite changing climate (Rosenzweig et al. 2015)
- multisectoral cooperation (identified during workshop)

Factor 6. Education, awareness, and stakeholder engagement

- Education and awareness raising of potential risk factors and recommended responses (Feyen et al 2020)
- Skill preparation of public officials (identified during workshop)
- Vector-borne and infectious diseases: Epidemiologists (to identify changes in infection rates), hospitals (to respond to public health emergencies and treat patients), and social workers and local community members and groups (to help identify vulnerable populations and respond to environmental health needs) (Barata et al 2018)
- Heat-related illnesses (including stroke, respiratory and cardiovascular distress): Local municipalities' decision-makers (to develop and implement heat-health warning and response policies), the media (to alert the public to extreme heat events and locations of cooling centers), and independent power producers and utilities (who provide electricity for cooling and maintain infrastructure) (Barata et al 2018)
- Water quality and water-borne diseases: Emergency preparedness organizations (first responders for flood events), municipal planning departments (to upgrade sewer and drainage systems), and water management departments (to detect changes in water quality)
- Air quality, asthma, allergies: Meteorology services, air quality managers, public health and/or medical schools, NGOs and research scientists (to conduct research on air quality

and health impacts), private sectors (who may contribute to GHG emissions but may also produce valuable products, including medications for respiratory distress) (Barata et al 2018)

Sequence	Association to adaptive capacity factor
Sequence 1	1, 2, 3
Sequence 2	1, 2, 3, 4
Sequence 3	2, 3, 4, 6
Sequence 4	3, 4
Sequence 5	2, 3, 4
Sequence 6	1, 2, 3, 4
Sequence 7	1,3,6
Sequence 8	1, 2, 3, 4, 5, 6
Sequence 9	2, 3, 4, 5
Sequence 10	2, 3, 4, 6

Adaptation measures in the Occitania

Source: "Plan Climat Air Energie Territorial for Montpellier Méditerranée Métropole"

Launched in November 2020, the "Pacte Vert" is an answer to the climate emergency which impacts our territory. This is a framework of concrete actions that combines ecological transition, solidarity, and economic opportunity for our territories. It joins a European ambition, the Green New Deal, launched by the European Commission in 2019.

This "Pacte Vert" includes 6 major ambitions translated into concrete actions:

- **The decarbonization of mobility**: the Occitania Region aims to become the first positive energy region in Europe. To do this, it is investing in carbon-free trains (hybrid, battery, hydrogen) and clean energy coaches. It is also deploying several measures to facilitate the use of bicycles (support for the construction of cycle paths, greenways and cycle routes, assistance with the acquisition of a bicycle, support for the economic cycle sector).

- **A sovereign and sustainable agricultural model**: between 2016 and 2022, the Occitania Region tripled (from €30 to €90 million) the regional budget dedicated to agriculture, or €12 per inhabitant compared to €5 on average at the national level. These investments made it possible to launch concrete and innovative actions (sustainable agriculture contracts, deployment plan for resistant grape varieties, etc.).

- **Water management, organized around 3 levels**: 1/ the mobilization of the State, the Region and water stakeholders through, in particular, the revision of climate change adaptation plans by basin and the implementation of appropriate quantitative management strategies; 2/ the Government Water Plan which notably provides for 10% water savings on the horizon 2030. To do this, water agencies support the territories through calls for projects or securing distribution networks; 3/ at the same time, the Region adopted its water plan in June, with a budget of €162 million by 2030. The result of citizen consultation, it is focused on 41 strategic challenges to be taken up to strengthen sustainable water management in the Occitania region.

- **The decarbonization of energy and the development of renewable energies**: to achieve the objectives set by the European Union, the Region has deployed the Positive Energy Region scenario which is based on halving consumption and multiplying by three of local renewable energy production.

- The **thermal renovation of buildings** which is the subject of several aids: aid from the National Housing Agency (€114.6 million), MaPrimeRénov' (€237 million), the Rénov'Occitanie regional system and support from Arec, regional public service operator.

- **Decarbonization of industry**: 1/ since mid-2020, 17 industrial decarbonization projects have benefited from support from Ademe of €48 million (nearly €214 million in investments); 2/ An ecological transition contract was signed with the State on November 22 with the three cement plants in the region. Around fifty companies are supported by the State, in particular thanks to France 2030 calls for projects; 3/ deployment by the Region of a regional sovereign fund of €400 million, including in particular the Fiteeo system (€100 million) supported by Arec and dedicated to energy transition projects in industry; 4/ The Region also supports the decarbonization of its territory's flagship sectors: aeronautics (objective of 0 carbon emissions in 2050) and the construction sector (adoption of a sustainable housing plan and a building sector contract).

- **Waste management and recycling**: the regional waste management plan and the circular economy action plan aim to drastically reduce waste production in the Occitania region. For this, support systems, developed jointly between the Region and Ademe, are implemented.

<u>Adaptation measures specific to Montpellier:</u>

- The Montpellier Metropolis adopted a new Solidarity Territorial Climate Air Energy Plan on February 2, 2023. This PCAETs is a regulatory tool allowing the Metropolis to implement a policy of mitigation and adaptation to climate change. The metropolis is entering a 6-year implementation phase, during which all stakeholders in the region will have to mobilize around achieving its objectives.

- As part of the development of the new Climate Plan, the Metropolis is committing to an ambitious strategy that meets the challenges defined in each of these 10 orientations which are broken down into 25 concrete actions with the implementation of general public indicators.

Orientation 1: Massively renovate buildings (housing and tertiary) and fight against energy poverty

- Action 1.1: Create a one-stop shop for building energy renovation
- Action 1.2: Reorganize and expand support systems for households experiencing energy poverty

Orientation 2: Decarbonize mobility, preserve health by offering everyone an alternative to travel differently

- Action 2.1: Make public transport accessible to all, through free access and optimization of the network
- Action 2.2: Deploy the bicycle system for all
- Action 2.3: Establish the low emissions – mobility zone
- Action 2.4: Appease the Metropolis

Orientation 3: Contribute to energy sovereignty and develop renewable energies

- Action 3.1: Implement the energy master plan with an objective of energy sobriety
- Action 3.2: Deploy renewable and recovery energies
- Action 3.3: Develop renewable heat and cold networks

Orientation 4: Strive towards the "Zero net artificialization" objective by 2040 and make any development or urban renewal operation carbon neutral

- Action 4.1: Guarantee land sobriety
- Action 4.2: Integrate carbon neutrality into urban development

Orientation 5: Make the territory resilient to present and future risks, ensure the protection of populations and reduce the cost of damage, taking into account the natural functioning of environments

- Action 5.1: Protect the population and activities from climate risks
- Action 5.2: Preserve the water cycle and aquatic environments
- Action 5.3: Make the coastline resilient to climate change

Orientation 6: Preserve biodiversity, refresh the city and sequester carbon

- Action 6.1: Implement the biodiversity strategy
- Action 6.2: Refresh the city by greening
- Action 6.3: Initiate reflection on carbon sequestration and the air quality-plant link

Orientation 7: Sustain water resources and promote sobriety for equitable access to all, for all uses

- Action 7.1: Preserve water resources in quantity and quality
- Action 7.2: Secure and diversify raw water resources

Orientation 8: Become a Zero Waste Territory

- Action 8.1: Direct the behavior of residents towards prevention and sorting at source
- Action 8.2: Develop a circular economy

Orientation 9: Build the region's sustainable and equitable food system

- Action 9.1: Shape an agroecological territory
- Action 9.2: Structuring sustainable and resilient supply
- Action 9.3: Allow everyone access to quality and selected food

Orientation 10: Support the region's socio-economic stakeholders in their ecological transition

- Action 10.1: Develop an economy with a positive impact

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Annex 8. Climate Impact chain Central Greece: Floods

I. INTRODUCTION

The Climate Impact chain for the region of Central Greece in the context of the Valorada-EU project, focuses on the **risk of hydrogeologic affectation due to flash floods on livelihoods, infrastructure, and agricultural means of production.**

The development of the climate impact chain occurred in two stages. Initially, a participatory workshop involving regional representatives Valorada-consortium members Terra Spatium and Aristotle University of Thessaloniki was held on 23rd and 24rth of November 2023 in Chalkida, at the premises of Central Greece Region. The preliminary climate impact chain was formulated based on the insights gathered during this workshop, supplemented by a comprehensive literature review. Subsequently, the initial draft of the climate impact chain was shared with city officials and VALORADA consortium partners. This document incorporates all the suggestions provided by the local stakeholders, resulting in the final version of the impact chains.

The document is organised as follows:

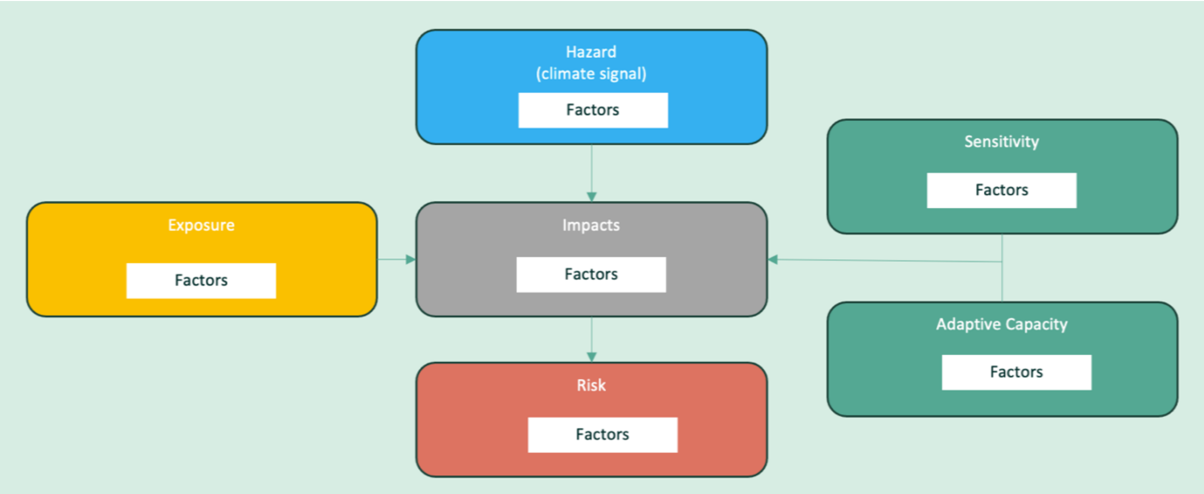
- Section II presents a brief definition and schema describing a climate impact chain.
- Section III discusses key climate hazards.
- Section IV delineates the identified climate impacts.
- Section V outlines the exposure factors associated to each of the sequence of impacts.
- Section VI outlines the sensitivity factors associated to each of the sequence of impacts.
- Section VII outlines the adaptive capacity factors associated to each of the sequence of impacts.
- Section VIII presents the bibliography, indicating the literature reviewed for generating this document.

II. CLIMATE-IMPACT CHAINS

A climate-impact chain delineates the connection between a specific climate hazard and a designated impact area. These chains aim to elucidate cause-and-effect relationships within various components of a system. By defining these relationships, impact chains ascertain how a hazard transforms into a risk, factoring in exposure, potential intermediate impacts, sensitivity factors, and response/adaptation capacities that mitigate vulnerability. In cases where applicable, intermediate impacts can be identified, each with its exposure, sensitivity, and adaptation factors (GIZ and EURAC, 2017).

A chain is composed of risk components (hazard, vulnerability, exposure) and underlying factors associated to each component. A climate signal, e.g. a heavy rain event, may lead to a direct physical impact, e.g. a flood, causing a sequence of intermediate impacts, which finally lead to the risk. The hazard component includes factors related to the climate signal and direct physical impact. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised by one or more exposure factors (GIZ and EURAC, 2017).

Figure 1: Composition of a Climate Impact Chain (GIZ and EURAC, 2017)



III. CLIMATE HAZARDS AND CLIMATE RISKS IN CENTRAL GREECE

Climate hazards are defined as the potential occurrence of a climate-related event, trend or physical impact that may cause loss of life, injury, damage and loss of infrastructure, livelihoods, service provision, ecosystems (Rosenzweig et al. 2015).

Climate risks are defined as the potential for consequences where something of value is at stake and where the outcome is uncertain (Rosenzweig et al. 2015).

During the workshop, regional representatives of Central Greece decided to attend the risk of hydrogeologic affectation on livelihoods, infrastructure and agricultural production.

Key contextual aspects characterising climate risk linked to floods:

- Europe has experienced an increase in flood risk in recent years. In the last three decades, the number of extreme weather events, including hydrological events, has increased by 60% in Europe (Furtak et al. 2022)
- Projections show that climate change will lead to an increase in the intensity of storms and floods in Europe by 2100. An increase in the frequency of rainfall intensity is estimated to increase the occurrence of flash floods and urban flooding (Furtak et al. 2022).
- The frequency of river flood events, and annual flood and windstorm damages, in Europe have increased over recent decades, but this increase is attributable mainly to increased exposure and the contribution of observed climate change is unclear (Barredo, 2010).

- Flood damage constitutes about a third of the economic losses inflicted by natural hazards worldwide (Arent et al. 2014).
- Future flood damages will depend not only on changes in the climate regime, but also on settlement patterns, land use planning decisions, flood forecasting quality, warning and response systems, and other adaptive measures (ibid).

IV. IMPACTS

The threat of hydrogeologic events provoking affectation on livelihoods, infrastructure and agricultural production is connected through four sequences of impacting factors: (1) Hydrogeological events impact public infrastructure and increase the risk of disseminating chemical pollutants; (2) Interruption of public services; (3) the affectation provoked by hydrogeological events on soil degradation; (4) the affectation provoked by hydrogeological events on demographic trends and changes in land use.

The full climate impact chain is presented below in figure 3.

Key messages emerging from the impact sequences:

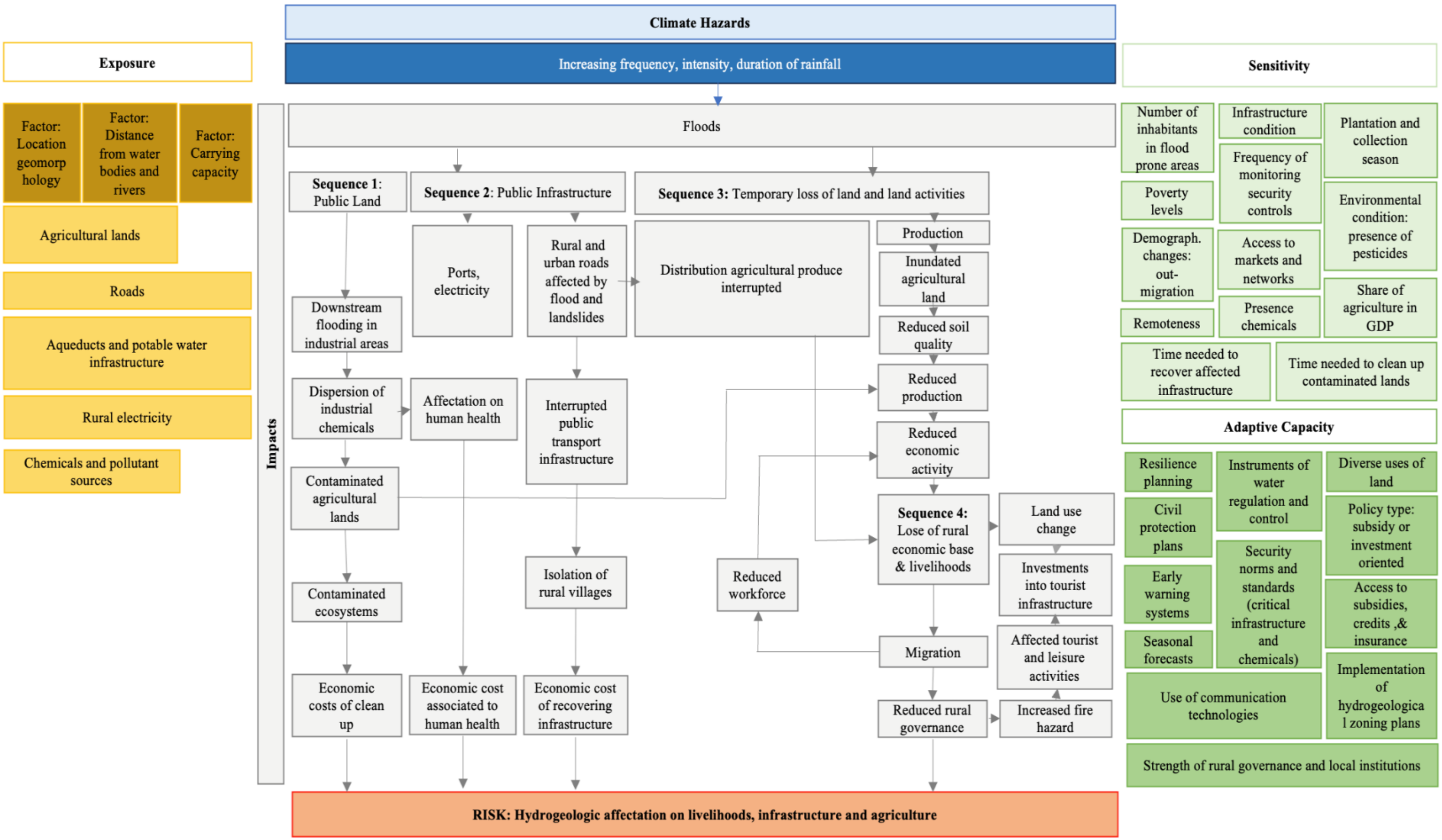
Key Message 1: Agricultural production may decline due to shifting precipitation patterns which provokes soil degradation. Production is threatened by excessive runoff, leaching, and flooding, which results in soil erosion and nutrient depletion.

Key Message 2: Ongoing demographic trends such as out-migration may be exacerbated due to livelihood lose as floods reduce local agricultural production and affect the local workforce, affecting rural governance and local institutions. Pre-existing conditions (lower income, high dependency level on agricultural production) could further affect this trend.

Key message 3: Health challenges to rural populations and ecosystems emerge from risks of chemical contamination and pollutants being spread during flood events. Costs of chemical clean up and associated temporary loss of land activities may need to be considered.

Key message 4: Interrupted infrastructure may place additional burden to rural communities if no alternative connectivity means are available, increasing the isolation of villages.

Figure 3: Climate Impact Chain for the region of Central Greece



Sequence 1. Hydrogeological events impact distribution of pollutants

In the first sequence of impacts proposed, the focus is on how hydrogeological events affect the dissemination of chemical pollutants.

Hydrogeological events impacts public infrastructure

Flooding events may cause sediment transport and damage roads and bridges, coastal and deltaic areas, as well as affecting reservoir storing capacity (Dasgupta et al. 2014). Floods are also generated from catastrophic failure of artificial reservoirs (Benito and Hudson, 2010).

↓

Extreme flood events represent one pathway of chemical substances into the environment resulting in acute exposure to high pollutant concentrations. (Völker et al. 2023)

(Re)mobilization and (re)distribution of pollutants due to damaged wastewater infrastructure and sediment-bound pollutants resulting from historical discharges (Völker et al. 2023)

Chemical substances are continuously emitted into the environment. Suspended particulate matter continuously enters fluvial systems as a result of erosion of terrestrial surfaces and the riverbed itself. These particles are transported along with the water current and are ultimately deposited in regions of low water flow through sedimentation processes, e.g., in harbors, groin fields, lowland rivers, floodplains, wetlands, or estuaries (Crawford et al 2022).

↓

Impacts on ecosystem and human health

Chemical material may contaminate households. Flooding may lead to mobilization of dangerous chemicals from storage or remobilization of chemicals already in the environment, e.g. pesticides. Hazards may be greater when industrial or agricultural land adjoining residential land is affected (Euripidou et al. 2004).

The re-suspension and consequent widespread distribution of highly contaminated sediments into adjacent natural floodplains, farmland, urban centers, or artificially constructed flood retention areas can devastate the environment and the wildlife and affect humans that depend upon it. Dioxins and DLCs are known to cause a range of toxic effects when humans and wildlife are exposed, including neuro-, immuno- and hepatotoxicity, reproductive toxicity, and certain types of cancer (Crawford et al. 2022).

↓

Increased economic costs related to chemical contamination

The environmental, economic, and societal consequences of remobilization and distribution of pollutants during flood events are not widely recognized. Loss of life, damage to infrastructure, and monetary cleanup costs associated with floods are important direct effects. It would be beneficial to determine economic tradeoffs between flood prevention measures, measures to avoid the remobilization of hazardous substances in toxic sediments, and measures dealing with the cleanup and restoration of the affected areas (Crawford et al. 2022)

Sequence 2. Interruption of public services

In the second sequence of impacts proposed, the focus is on the effect of hydrogeological events on public services.

Affectation provoked by hydrogeological events on public infrastructure

Roads: Circulation in rural and urban roads temporarily interrupted by floods and landslides

As the risk of extreme sea level events increases with climate change coastal flood risk will remain a key challenge for several European cities, port facilities, and other infrastructure (Hallegatte et al., 2008)

Interrupted public transport - Interrupted public services

Isolation of rural villages: Adverse impacts on transportation (such as flooded roads) can further affect access and evacuation. The ability of health care facilities to properly care for the affected and for those with ongoing health issues requiring medication or treatment may be compromised by very large events that affect multiple health care facilities. Areas projected to experience increases in extreme events could consider additional “surge capacity” to manage such events without interruption of service (Banks et al., 2007; Hess et al., 2009 in Arent et al 2014).

Infrastructure at risk: More frequent heavy rainfall events may overload the capacity of sewer systems and water and wastewater treatment plants more often, and increased occurrences of low flows that will lead to higher pollutant concentrations.

Unpaved roads are vulnerable to a number of climate-based factors especially to increasingly intense precipitation, leading to wash out and disruption of service (Chinowsky and Arndt, 2012).

Rail beds are susceptible to increases in precipitation, flooding and subsidence (Arent et al. 2014)

Economic costs of infrastructure interrupted

Costs of Refurbishing infrstructure:

Private livelihoods affected due to reduced workforce and overal reduced economic activity.

Flood losses in the UK in 2000, 2007, and 2009 have put the insurance market under further pressure, with increasing need for the government to reduce risk (Ward et al., 2008 in Arent et al 2014)

Public attitudes in Scotland and the Netherlands would support insurance of private property and public infrastructure damages in the case of increasing flood risk (Botzen et al., 2009 in Arent et al 2014).

Sequence 3. Soil degradation and reduced productivity

In the third sequence of impacts proposed, the focus is on the affectation provoked by hydrogeological events on soil degradation and associated reduced productivity.

River flooding will produce temporary loss of land and land activities, and damage to transportation infrastructure (Dasgupta et al. 2014)

Future vulnerability will also be strongly affected by cross-sectoral (indirect) interactions, for example, flooding-ecosystems, agriculture-species, agriculture-cultural landscapes, and so on (Kovats et al 2014).

Floods damage farms, crops, livestock, the physical infrastructure of agriculture, and the food supply chain, reducing agricultural productivity and food availability. Human interference with floodplain landscaping causes water levels in rivers to move rapidly from low to high levels as a result of precipitation events. This leads to changes in the flow and flooding of water from canals (Furtak et al. 2023).

Floods affect the physical structure of soils and nutrient cycling, resulting in potentially irreversible damage to agricultural productivity and ecosystem functioning (Furtak et al, 2023)

Flooding compacts the soil with water. Increased moisture reduces oxygen and nitrogen diffusion in the soil. C and N mineralisation is reduced. Flooding results in loss of soil P. Flooding increases Fe phosphate solubility due to pH changes. Changes in soil moisture affect the soil microbiome which affect the long-term productivity of crops (Furtak et al. 2023).

Across most of Northern and Continental Europe, an increase in flood hazards (Arent et al 2014) could increase damages to crops and plant growth, complicate soil workability, and increase yield variability (ibid).

Economic impacts: Unhealthy soil cannot provide crops with the nutrition they need to grow correctly and abundantly, resulting in shortages and economic strain on people linked to production chains

Excessive soil moisture is also associated with disruptions to planned agricultural practices and forces farmers to use greater amounts of lime to improve pH and other techniques to improve soil quality (aeration) (Furtak et al. 2023).

Post-harvest aspects of agriculture—storage on-farm and commercially, handling, and transport—have been relatively neglected in discussions of climate change, but will be affected by changes in temperature, rainfall, humidity, and by extreme events (Dasgupta et al. 2014).

Climate change may also affect investment patterns in rural areas. Sectors that are expected to be affected adversely by climate change may have difficulty attracting investment (Dasgupta et al. 2014).

Sequence 4. Affectation of hydrogeological events on demographic trends and land uses

In the third sequence of impacts proposed, the focus is on the affectation provoked by hydrogeological events on demographic trends and land uses.

Impacts of climate change on the rural economic base and livelihoods, land use, and regional interconnections are at the latter stages of complex causal chains (high confidence) (Dasgupta et al. 2014).

Migration patterns will be driven by multiple factors of which climate change is only one (*high confidence*). Climate impacts may contribute to migration away from rural areas, but this is contested by other bodies of literature. Attribution of migration to climate change is extremely complex, because life in rural areas involves complex patterns of rural- urban and rural-rural migration, subject to economic, political, social, and demographic drivers, patterns that are modified or exacerbated by climate events and trends rather than solely caused by them (Dasgupta et al. 2014).

Current damages from weather-related disasters (floods and storms) are significant. Disasters have long lasting effects on the affected populations (Schnitzler et al., 2007). Households are often displaced while their homes are repaired (Whittle et al., 2010). Little research has been carried out on the impact of extreme weather events such as heat waves and flooding on temporary or permanent displacement in Europe (Kovats et al 2014).

Impacts of migration

The phenomenon of abandoning agricultural activities has triggered processes of lack of territorial governance, which increases the risk of both fires (recolonization of these areas begins with the settlement of shrub species) and hydrogeological instability (Region Molise-b, 2017).

Processes that influence flash flood risk include increasing exposure from urban expansion, and forest fires that lead to erosion and increased surface runoff (Lasda et al., 2010).

Land use changes demand bew investments which may become jeopardized by enviuronmental threats, further deepening impacts on local livelihoods

Shift from agricultural (production) to leisure (consumption) activities; focus on broader amenity values of rural landscapes for recreation, tourism, forests, and ecosystem services (Dasgupta et al. 2014)

V. EXPOSURE

Factor 1: Location: Whether geomorphology amplifies exposure (physical extent of floodplains and catchment hydrology (Thomson and Clayton, 2022).

Factor 2: Distance from water bodies and rivers people's location near coastal areas; slope of the terrain, the proximity to streams and torrents and location of upstream or downstream of a river or deltaic areas (proposed during workshop, in strong connection with the severe floods of August 2020 in the island of Evoia, that caused the overflow of Lilas river and its populated deltaic area, the Messapian river and the Politikon stream.).

Factor 3: Carrying capacity of specific infrastructure: Floods are also generated from catastrophic failure of artificial reservoirs (Benito and Hudson, 2010).

Exposed element	Association to Exposure Factor
Agricultural lands	1,2
Roads	1,2,3
Aqueducts and potable water infrastructure	1,2,3
Rural electricity	1,2,3
Chemical and pollutant sources (industry)	1,2, 3

VI. SENSITIVITY

Climate change in rural areas will take place against the background of the trends in demography, economics, and governance that are shaping those areas. Existing vulnerabilities caused by poverty, lower levels of education, isolation, can all aggravate climate change impacts in many ways (Dasgupta et al. 2014).

The IPCC (Dasgupta et al. 2014) has also highlighted a number of non-climate factors affecting vulnerability in rural areas at both, individual and community levels:

- Physical geography,
- Remoteness,
- Economic constraints and poverty,
- Demographic changes such as out-migration and aging,
- Density of social networks,
- Neglect by policymakers and short-time policy horizons,
- Low levels of public services,
- Memories of past climate variations and knowledge.

Sensitivity factors for Central Greece

Based on information gathered during the workshop and in the context of previous impact sequences and vulnerability factors identified in the literature, the following sensitivity factors are identified:

Sensitivity factor	Impact sequence	Description
Number of inhabitants in flood risk areas	**1,2,3**	
Age group	**2,3,4**	Per capita gross domestic product (GDP) in rural areas of OECD countries is only 83% of national average (but significant variation within and between countries (Dasgupta et al. 2014). Central Greece appears to be producing a very large part of the country's industrial product and, as a result, it is one of the most developed regions in Greece. Central Greece is generating 4.7% of the National GDP being the 5th largest regional economy in Greece. Its development level, in GDP per capita terms, is close to the national average (90%), but very low compared to the EU average (60%). The sectoral share of industry in GDP in Central Greece (38%) is more than 2 times the national average, and about 1.5 the European average, while the share of employment is also high (21%). The relative productivity of the secondary sector is also very high. Central Greece is probably a unique case in the EU-28, in that the significantly higher GDP per capita is not found in the Region's capital or in one of its major urban centres but in a former rural area of the Region (near the Attica borders). Both GDP and GDP per capita have declined during the last decade by 3.2%, experiencing a high drop in welfare levels. Central Greece is facing significant social problems as almost 6% of the population of the region does not have access to health services, 74.3% of jobless people are long-term unemployed, and 18.9% of the young people in the age group 15-24 are excluded from education or the labour market. Moreover, the share of population in danger of poverty and social exclusion is more than 31%. (Source: Territorial Review of Greece, OECD 2020)
Poverty levels	**2,3,4**	
Share of agriculture in GDP	**2,3,4**	The primary sector of the Region of Central Greece is dominated by agriculture production, while livestock and fishery also have a significant presence. In Central Greece there is approximately 10% (ie 3,256,099 acres) of the cultivated area as well as the fallow land in the whole country. It is the fifth region in terms of agricultural land in the country. The irrigated lands correspond to 33% of the total. The value of the Produced Agricultural Product corresponds to approximately 9% of the value of the country's total product. This means that the Region is in seventh place in terms of value (€813.37 million in 2014). The main agricultural products with the greatest economic value, are vegetables and horticultural crops amounting to €245 million, which correspond to 14% of the total value at country level. Industrial plants also

		make a significant contribution with approximately 84 million of which the most important are cotton and industrial tomato. Of the total value of cereals, durum wheat has the largest share, amounting to approximately €54 million. Fodder plants are also of significant size, the value of which amounts to €72 million, representing 14% of the total value of the product at national level. Viticulture also seems to have a particular dynamic for the sector. The total sum of the produced product (edible grapes and wine) exceeds €43 million. The high added value of this specific agricultural product is demonstrated by the fact that grape cultivation at the regional level ranges from 2%, but owns 10% of the total value at the national level. (Hellenic Statistical Authority, 2014)
Demographic changes	**3,4**	Central Greece is the eighth most populated region of Greece with 555,623 inhabitants in 2018, and the eighth most urbanized. While Lamia is the administrative centre of the region, the city of Chalkida, has a greater population size. Moreover, Chalkida is a major port city and a significant industrial hub at the regional level. The region has experienced a modest increase in population in the post-2008 period and a corresponding trend in its population density, which is significantly lower than the national and the EU average. The population of the region lives predominantly in cities, as the urbanization rate is 58.3%, a value that is, however, below the national average. (Territorial Review of Greece, OECD 2020) Ageing in Central Greece is an important issue as the share of population over 70 years old is higher compared to the Greek or EU levels and has also increased significantly (2.9%) during the crisis. This is also verified from the elderly dependency ratio that, in 2019, was at the level of 37.4%, above the national average. The index of crude rate of net migration for the region of Central Greece, is one of the highest in the country (3rd place) and has slightly increased (by 0.4%) over time. (Territorial Review of Greece, OECD 2020)
Remoteness	**1,2,3,4**	Importantly, in rural areas usually there are few alternatives once a road is blocked and that may increase vulnerability of rural areas when facing extreme hydroclimatological events that impact transportation infrastructure (Dasgupta et al. 2014)
Time/cost needed to recover infrastructure/	**1,2**	
Access to markets and networks and density of social networks	**3,4**	Geography advantages the region of Central Greece, as it is located on the main development axis of the country. However, its transport infrastructure, as the relevant indicators show, is below the national average and (in a number of them) among the last places among regions. In terms of road density, Central Greece is one of the less equipped regions as it holds the 11th position, but in freight transport it holds the second position among Greek regions due to the large industrial production.

		In terms of air and marine transport, the region although there are enough available infrastructures does not have a noteworthy traffic. None of the airports or ports belongs to the core network in the European scale (one airport and one out of twenty-one ports has a comprehensive position in the Trans European Transport Network). Worth to note that the economic crisis has affected negatively both maritime and freight transport. Similarly, in terms of health infrastructure, the region holds the last position in the country with respect to the number of hospital beds per inhabitant, a fact that also the neighbour presence of Attica affects. (Territorial Review of Greece, OECD 2020)
Presence of industry close to agricultural lands	**1**	Central Greece relies on labour-intensive industries (such as food, and paper), resource-intensive industries (such as plastic, basic metals, and non-metallic minerals) and on capital-intensive products (such as electrical machinery), with high levels of relative productivity. Central Greece faces, apparently, the challenge to regulate the spatial development of manufacturing (spatial plan) along the borders with Attica, given that the latter is, mainly, the outcome of the corresponding restrictions imposed in the neighbouring metropolitan region of Attica in order to deal with major congestion and environmental degradation problems.
Environmental condition (presence of chemicals)/ time needed to clean up chemical contamination	**1,3**	Flooding may lead to mobilization of dangerous chemicals from storage or remobilization of chemicals already in the environment, e.g., pesticides (Euripidou et al. 2004). Resource degradation, environmentally fragile lands subject to overuse and population pressures, exacerbating social and environmental challenges (Dasgupta et al. 2014).
Policy making: Frequency of monitoring critical infrastructure/ dams, roads; Infrastructure baseline condition	**1,2,3,4**	Neglect by policymakers can aggravate climate change impacts in many ways. Neglect by policymakers and underinvestment in infrastructure and services has negatively affected rural areas (Dasgupta et al. 2014).

Plantation and collection season	**1,2,3,4**	**Vegetables and Horticultural crops:** Autumn planting vegetables also called winter vegetables, as their planting starts in the autumn season and they are harvested in the winter, such as cabbage, broccoli and cauliflower. Spring planting vegetables which are also called summer vegetables, as their planting starts in the spring season and they are harvested in the winter, such as for example tomato, cucumber and pepper. **Cotton:** Planting period between April to May and harvesting is in autumn. **Cereals:** The sowing season starts from the beginning of October to the middle of January, with the most important factor being the weather conditions. The harvest takes place in the month of June until the beginning of July. **Fodder plants:** Planting period is during autumn, harvest in winter (3-5 months after planting). **Viticulture:** Harvest period end of August until beginning of September. **Olive trees:** Harvest takes place in late September and early October.

VII. ADAPTIVE CAPACITY

Adaptive capacity is normally determined in terms of knowledge, financial resources, technologies, legislations and infrastructures that enable people to adapt to the effects of climate change. The IPCC (Dasgupta et al. 2014) informs of key variables shaping a resilient rural system in the context of climate change:

- Structural features of farm households and communities affect their vulnerability to climate change in complex ways. Resilience of access to land and natural resources, flexible local institutions, and knowledge and information, and on the association of gender inequalities with vulnerability are key.
- Accelerating globalization, through migration, labour linkages, regional and international trade, and new information and communication technologies, is bringing about economic transformation in rural areas of both developing and developed countries.
- In developed countries, there are important shifts toward multiple uses of rural areas, especially leisure uses, and new rural policies based on the collaboration of multiple stakeholders, the targeting of multiple sectors, and a change from subsidy-based to investment-based policy.
- Agricultural subsidies under pressure from international trade negotiations and domestic budgetary constraints. As a result of recent price hikes, domestic price support has been lowered in OECD countries.
- Institutions and networks can affect vulnerability to climate change: through distribution of climate risks between social groups; by determining the incentive structures for adaptation responses; and by mediating external interventions (e.g., finances, knowledge and information, skills training) into local contexts (e.g., if decision makers resist seeing climate change as within their responsibilities, this may contribute to low levels of planning for either adaptation or mitigation, and thus to greater vulnerability.
- Access to information alone is not a guarantee of success. Despite access to weather forecasting, people may not rely on such information.
- Rural households' lack of access to technologies and infrastructure (e.g., markets) is also a major barrier to adaptation for certain production systems.
- Access to water, credit, extension services, and off-farm income and employment opportunities, tenure security, farmers' asset base, and farming experience are key to enhancing farmers' adaptive capacity.

Sequence	Association to adaptive capacity factor
Sequence 1	6,7
Sequence 2	1,2,3,5,6,
Sequence 3	3,4,5,6
Sequence 4	1,2,3,4,5,6,7,8

Contextual elements characterising adaptive capacity:

In December 2014, the Ministry of Environment, Energy and Climate Change (currently the Ministry of Environment and Energy), the Medical Biological Research Foundation of the Academy of Athens and the Bank of Greece, signed a memorandum of cooperation which, among other things, concerned the composition of the text of the National Strategy for Adaptation to Climate Change (ESPKA). In April 2016, the National Strategy for Adaptation to Climate Change was issued.

The primary purpose of the ESPKA is to contribute to strengthening the country's resilience in terms of the effects of climate change and to creating the conditions for decisions to be made based on the correct information and with long-term targeting, facing the risks and taking advantage of the opportunities that arise. stem from climate change. The main objectives of ESPKA are:

- Improving the decision-making process through the acquisition of more complete information and scientific data related to adaptation.
- The promotion of the development and implementation of regional/local action plans in accordance with this strategy.
- The promotion of adaptation actions and policies in all sectors with an emphasis on the most vulnerable.
- The creation of a monitoring and evaluation mechanism for adaptation actions and policies.
- The information and awareness of society.

The Regional Plan for Adaptation to Climate Change - PeSPKA, (2019), which specifies the National Plan for Energy and Climate, foresees measures in sectors recorded as most vulnerable (agricultural/livestock activities, biodiversity, ecosystems, wetlands, protected areas). Impacts are expected both in the forests from the increase in the risk of fires, and in winter tourism due to an increase in temperature and a decrease in snowfall that affect the operation of the ski centers of Parnassos and Karpenisi, main poles of tourist attraction. Extreme weather phenomena create problems in the transport network, while subsidence, landslides and floods can create problems in the road network and in mountainous settlements.

Among the measures-interventions proposed by the PeSPKA, the following are included, among others:

- Urban Revitalization of cities through regeneration of areas and public buildings.
- Erosion Protection Interventions – Soil Desertification.
- Flood Risk Prevention and Management Measures.

Water resources are adversely affected in terms of surface and groundwater quality, due to the lower rate of recharge of mountain aquifers due to the steep slope, while problems arise in terms of water supply and irrigation infrastructure.

The Flood Risk Management Plans of Eastern and Western Central Greece (2018) list potentially high flood risk zones, assess the risks per area and indicate prevention, protection, preparedness and restoration measures for their management, in synergy with the Water Basins Management Plans. The Flood Risk Management Plans of Eastern are the framework for the implementation of the projects in the new period.

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Annex 9. Climate Impact chain Central Greece: Wildfires

I. INTRODUCTION

The Climate Impact chain for the region of Central Greece in the context of the Valorada-EU project, focuses on the **risk of wildfires in forests and peri-urban areas due to increase in temperature and droughts.**

The development of the climate impact chain occurred in two stages. Initially, a participatory workshop involving regional representatives Valorada-consortium members Terra Spatium and Aristotle University of Thessaloniki was held on 23rd and 24rth of November 2023 in Chalkida, at the premises of Central Greece Region. The preliminary climate impact chain was formulated based on the insights gathered during this workshop, supplemented by a comprehensive literature review. Subsequently, the initial draft of the climate impact chain was shared with city officials and VALORADA consortium partners. This document incorporates all the suggestions provided by the local stakeholders, resulting in the final version of the impact chains.

The document is organised as follows:

- Section II presents a brief definition and schema describing a climate impact chain.
- Section III discusses key climate hazards.
- Section IV delineates the identified climate risks.
- Section V outlines the exposure factors associated to each of the sequence of impacts.
- Section VI outlines the sensitivity factors associated to each of the sequence of impacts.
- Section VII outlines the adaptive capacity factors associated to each of the sequence of impacts.
- Section VIII presents the bibliography, indicating the literature reviewed for generating this document.

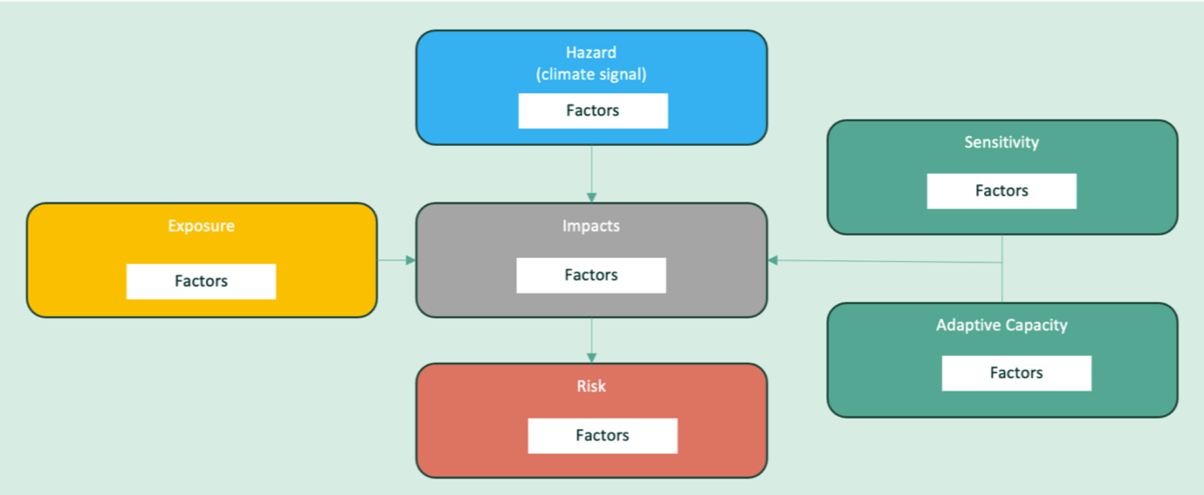
II. CLIMATE-IMPACT CHAINS

A climate-impact chain delineates the connection between a specific climate hazard and a designated impact area. These chains aim to elucidate cause-and-effect relationships within various components of a system. By defining these relationships, impact chains ascertain how a hazard transforms into a risk, factoring in exposure, potential intermediate impacts, sensitivity factors, and response/adaptation capacities that mitigate vulnerability. In cases where applicable, intermediate impacts can be identified, each with its exposure, sensitivity, and adaptation factors (GIZ and EURAC, 2017).

A chain is composed of risk components (hazard, vulnerability, exposure) and underlying factors associated to each component. A climate signal, e.g. a heavy rain event, may lead to a direct physical impact, e.g. a flood, causing a sequence of intermediate impacts, which finally lead to the risk. The hazard component includes factors related to the climate signal and direct

physical impact. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised by one or more exposure factors (GIZ and EURAC, 2017).

Figure 1: Composition of a Climate Impact Chain (GIZ and EURAC, 2017)



III. CLIMATE HAZARDS IN CENTRAL GREECE

Climate hazards are defined as the potential occurrence of a climate-related event, trend or physical impact that may cause loss of life, injury, damage and loss of infrastructure, livelihoods, service provision, ecosystems (Rosenzweig et al. 2015). The climate hazard discussed in this Climate impact chain is the increase in temperature and droughts in central Greece.

The key issues of concern linking wildfires to the increase in temperature and the extent of drought are reflected in the following facts:

- Human-caused climate change is causing profound changes in global fire regimes through changes in fire season length, fuel moisture, fire intensity and fire severity. Climate plays a role in determining the fuel available to burn, the length of the fire season as well as the presence of lightning, which is the most common natural source of ignition (Chuvieco et al. 2023).
- Climate change threatens to increase the frequency and length of the wildfire season, as well as the size and extent of large fires (Gowda et al. 2018).
- Atmospheric variables that affect ignition or propagation include temperature, relative humidity, precipitation, wind speed and direction (Chuvieco et al. 2023).
- Forest fires, like all other ecosystem processes, are highly sensitive to climate change, as fire behaviour responds immediately to fuel moisture, which in turn is affected by precipitation, relative humidity, air temperature and wind speed. The projected rise in temperature as a result of climate change should therefore increase fuel dryness and reduce relative humidity, more markedly in those regions where rainfall will decrease. The increased frequency of extreme climate events is expected to have a significant impact on the vulnerability of forests to fires (Ministry of Environment and Energy, 2022).

IV. CLIMATE RISKS IN CENTRAL GREECE

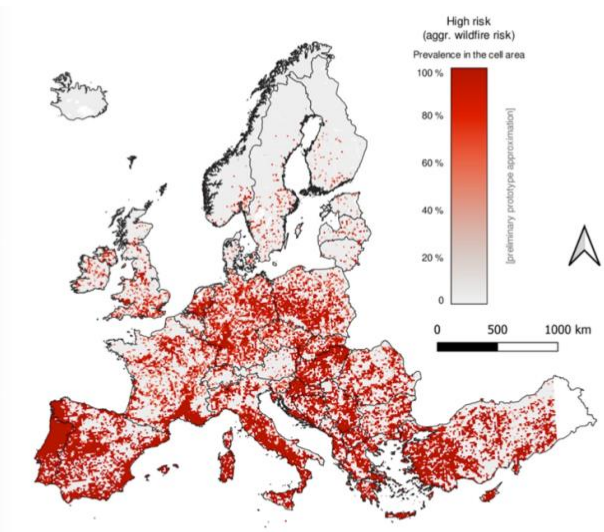
Climate risks are defined as the potential for consequences where something of value is at stake and where the outcome is uncertain (Rosenzweig et al. 2015). During the workshop, regional representatives of the Central Greece administration decided to attend the risk of wildfires in forests and peri-urban areas due to increase in temperature and droughts.

In the particular context of wildfires, Chuvieco (et al 2023) explain that risk assessment encompasses an extensive array of factors influencing fire ignition, spread, potential consequences, and an evaluation of the significance of those consequences. As a result, the aim of wildfire risk assessment is to estimate when, where, why and how wildfires are more likely to occur and propagate, shedding light also on potentially exposed assets and places.

A central issue concerning the increasing risk of wildfires in the region:

- The climate change impact of wildfires on the ecosystems of Greece under a RCP4.5 and RCP8.5 scenarios (2022 to 2098) suggest a significant intensification of fire and increased likelihood of severe wildfires. By the end of the century, most ecosystems will be prone to intense fire activity under RCP8.5. Even under the milder RCP4.5 scenario, high-intensity wildfires are projected to occur with increasing frequency in places that are currently rare. (Malisovas et al., 2023)
- Central and north-eastern parts of Greece will be affected with 30 or more extreme consecutive days of prolonged fire weather, under RCP4.5, in the near future and under RCP8.5 in the far future (2075–2099). Finally, the expected rate of fire spread is more spatially extended all over the country and particularly from southern to northern parts compared to the historical state (Politi, et al. 2023)
- European Forest Fire Information System (EFFIS) data shows 42,900 hectares have been already burned in Greece in 2023, nearly double the area compared to 2022 and triple the area of 2020 (Greenpeace, 2023).

Figure 2. Final aggregated wildfire risk by pixel level for higher-risk class in each EURO-CORDEX spatial cell prototype version 1 (Oom et al. 2022 in Chiuveco et al. 2023)

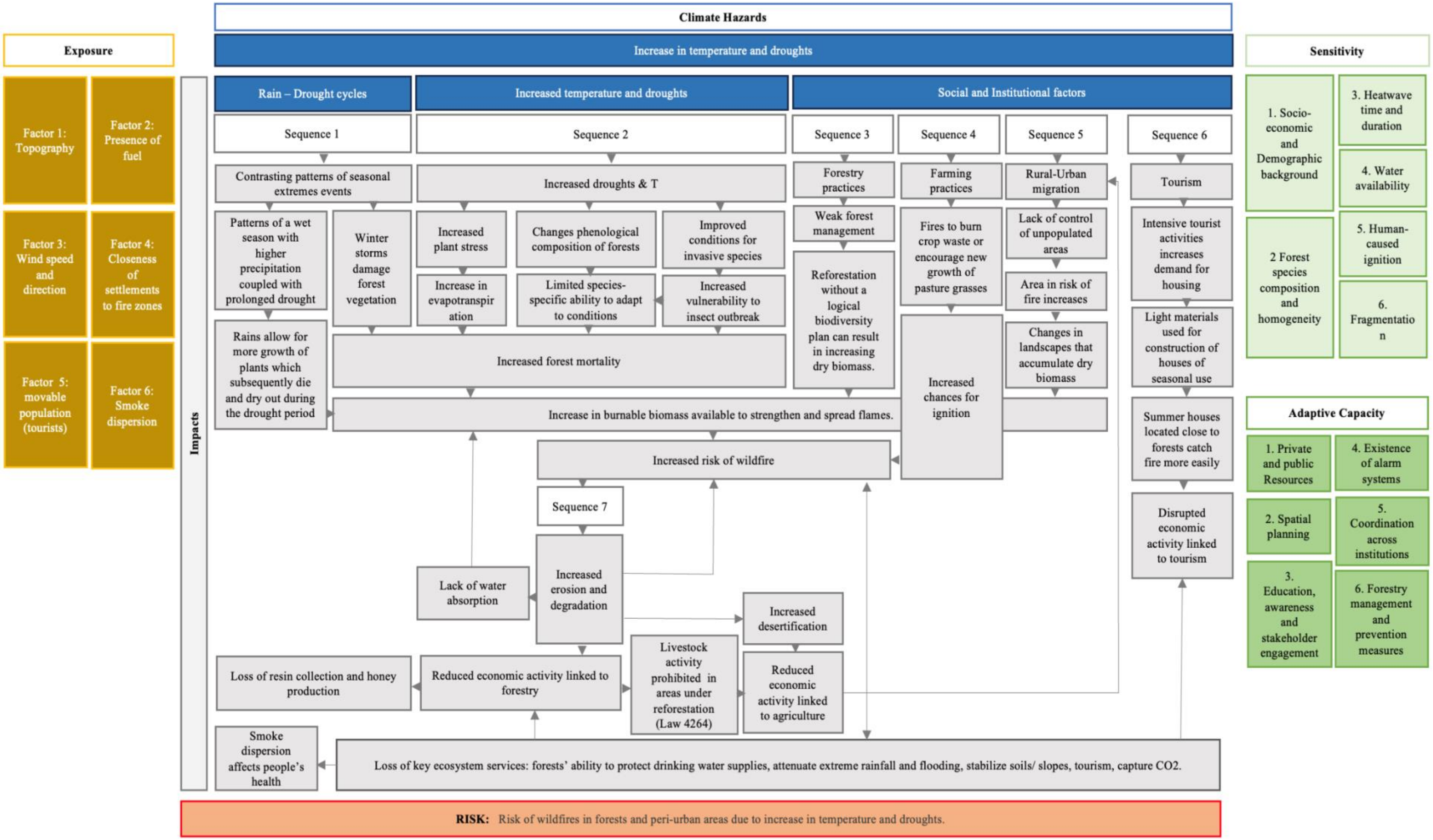


V. IMPACTS

The threat of wildfires occurring in forests and peri-urban areas due to increase in temperature and droughts is connected through seven sequences of impacting factors: (1) Contrasting patterns of seasonal extremes events; (2) Increased drought and temperature; (3) Forestry practices; (4) Farming practices; (5) Rural-Urban migration; (6) Tourism; (7) Socio-economic and ecological impacts.

The full climate impact chain is presented below in figure 3.

Figure 3: Climate Impact Chain for the region of Central Greece



Sequence 1. Contrasting patterns of seasonal extremes events

In the first sequence of impacts proposed, the focus is on the effects provoked by seasonal extreme events (extreme precipitation followed by drought and extreme temperatures) on the generation of fuels.

Contrasting patterns of seasonal extremes events

↓

Precipitation coupled with prolonged drought

Studies have shown patterns of a wet season with higher precipitation coupled with prolonged drought to be a particularly dangerous combination, as rains allow for more growth of plants which subsequently die and dry out during the drought period, increasing burnable biomass available to strengthen and spread flames (Greenpeace, 2023)

↓

Storms increase dead trees as fuel during dry/hot seasons

In 2021 (mid-February), the snowstorm "Medea" had caused significant damage to the forested areas of Attica, with several trees broken and downed. This situation greatly influenced the forest fuel load and, in particular, the quantity and distribution of the downed heavy fuels. An urgent cleaning program was decided … but due to legal constraints and conflicts, the local authorities did not complete the cleaning of broken and fallen trees caused by the Medea storm… the fuel load remained excessive during the entire fire season (Almeida et al. 2023).

In the last 30 years, tree canopy mortality has doubled in European temperate forests because of natural disturbances, land-use change, and especially because of an intensified wood extraction from naturally disturbed areas where trees were dying (Seidl. et al 2014 in Chuvieco et al. 2023).

↓

Increased in burnable biomass vailable to strengthen and spreas flames

Fuel limited regions are positively related to precipitation prior to the fire season that promotes vegetation growth and subsequent biomass for combustion during the fire season (Chuvieco et al. 2023)

Sequence 2. Increased drought and temperature

Increased drought and temperature

Increased evaporation rates caused by high temperatures, in association with drought, will exacerbate plant stress, yield reduction, fire risks, and depletion of surface and groundwater resources (Gowda et al. 2018)

Evapotranspiration represents an important hydrological loss, occurring both on the surface and in upper soil layers. Evapotranspiration rates in Greece are high, particularly in the drier eastern regions (Ministry of Environment and Energy, 2022).

Elevated temperatures play a critical role in increasing the rate of drought onset, overall drought intensity, and drought impact through altered water availability and demand (Gowda et al. 2018).

Drought, coupled with extreme heat and low humidity, can increase the risk of wildfire (IPCC, 2012).

Southern Europe is already experiencing extremely dry weather conditions, with precipitation levels having declined by as much as 20% in the course of the 20th century (Ministry of Environment and Energy, 2022).

↓

Changes in the composition of forests

Observed and future responses of forests to climate change include changes in growth rates, phenology, composition of animal and plant communities, increased fire and storm damage, and increased insect and pathogen damage (Kovaks et al. 2014).

↓

Improved conditions for invasive species

Increasing temperatures promote an increased spread of invasive or encroaching species, which exacerbate wild- fire risks (Gowda et al. 2018)

The combination of different vegetation stressors such as high temperatures, droughts and windstorms in homogeneous forests increases the probability of bark beetle outbreaks at landscape scales (Raffa et al. 2008 in Chuvieco et al. 2023)

↓

Increasing fire risk caused by forest plagues

Seidl et al. (2014) estimated that climate change will increase the damage from windstorms, bark beetle (*Ips typographus*) attacks, and wildfires up to +0.91× 106 m3 of timber per year until 2030. However, in the last decades, massive bark beetle outbreaks and wildfires have already occurred at an un- precedented scale and in unusual regions (Seidl et al 2014, Lausch et al. 2013 in Chuvieco et al 2023).

↓

Increased tree mortality and burnable biomass

Tree mortality and forest decline due to severe drought events were observed in forest populations in Southern Europe including Greece (Kovaks et al. 2014).

Sequence 3. Forestry practices

In the third sequence of impacts proposed, the focus is on the negative effect that poor forestry practices provoke by increasing the accumulation of burnable biomass.

Poor forestry practices

Combined with a lack of forest management and the surge in dry biomass due to human activity being abandoned, fires can spread uncontrollably, reaching urban areas and homes without mandatory preventive plans (Greenpeace, 2023).

Wildfire is a natural process of many landscapes, having a crucial role in nutrient cycling, habitat creation and maintenance, and natural succession of plant communities. Blind wildfire suppression without understanding these ecological aspects has led to unintended and often adverse consequences, including the accumulation of inflammable biomass and the disruption of natural re regimes (Eftychidis et al. 2023)

Wrong reforestation techniques

Reforestation activities including mixed plantings of conifers (black pine, maritime pine, and Cedrus spp.) can further agravate the risk of wildfires (Alemeida et al. 2023)

For decades, the national forestry service has suffered from severe underfunding and a lack of a proper management plan for wildfire prevention. Consequently, reforestation without a logical biodiversity plan has accumulated significant amounts of dry biomass. Sparse forests and shrubs grew from 1990-2020, reducing open spaces between forestry tree species by 4%. These hectares form a vulnerable, continuous and unmanaged mass, making them more flammable and promoting the spread of large forest fires (Greenpeace 2023)

Increase in burnable biomass

In Southern Europe, fire frequency and wildfire extent significantly increased after the 1970s compared with previous decades as a result of fuel accumulation, climate change and extreme weather events (Kovaks et al. 2014)

Sequence 4. Farming practices

In the fourth sequence of impacts proposed, the focus is on the higher chance of fire ignition due to human negligence linked to poor farming practices.

Many references acknowledge that humans are behind most fire ignitions (90% according to FAO [136]), (Chuvieco et al. 2023)

Humans have an indirect effect on fire via land cover change, particularly through fragmentation (increase in land use intensity) and permanent agriculture which impact fire propagation (Chuvieco et al. 2023)

firest to burn crop waste or encourage new growth of pasture grasses

Most (fires) in Greece in the last 20 years arose from fires on farmland initially started to burn crop waste or encourage new growth of pasture grasses, or from fires on scrubland and grassland that were lit to manage unwanted vegetation (Preventionweb, 2023).

Increase chances of ignition due to human negligence

Sequence 5. Rural-Urban migration

In the fifth sequence of impacts proposed, the focus is on the higher risk of fire ignition linked to abandoned rural lands due to urban migration. This sequence is connected to sequence 7, as far as migration and reduced economic activity are closely linked together, enhancing the likelihood of wildfires through increased amounts of burnable biomass, and further affecting local economy and need to migrate.

Rural-Urban migration

Abandonment of lands

Humans have an indirect effect on fire via land cover change, particularly abandonment (reduction), which impact fire propagation (Chuvieco et al. 2023).

Fires spread fastest in areas where there is little to no human presence to control them (Greenpeace, 2023).

When the land is no longer used, fragmentation decreases while fuel connectivity increases and thus the fuel horizontal and vertical continuity, leading to fire risk increments. (Chuvieco et al. 2023)

Changes in landscape accumulates burnable biomass

Climatological changes interact with trends of agricultural abandonment, particularly in the South of Europe, as many areas experience a rural exodus. Therefore, these areas face new and heightened risks as landscapes shift from managed, mosaic types with ample variation in fuel density and distribution, to more pyrologically homogenous land covers of even-aged stands with dense, continuous understories (Sil et al. 2019 in Chuvieco et al. 2023)

Sequence 6. Tourism

In the sixth sequence of impacts proposed, the focus is on the higher risk of fire propagation linked to the increased demand for holidays housing and the use of light material for their construction, as well as due to closeness to wildfire-risk-prone areas.

This sequence is connected to sequence 7, as far as tourism is disrupted in the short term due to wildfires and smokes, as well as in the long term due to loss of ecosystem services that make a touristic destination to be attractive.

Tourism

↓

Increased demand for holiday housing

Greece's real estate market is experiencing a **significant boom**, particularly in the sales of villas and holiday homes, including Mainland locations such as Athens and Thessaloniki (ever-growing.org)

↓

Light materials used for second housing

Due to the intensive touristic activity in the North Evia region and the light materials used for construction, associated with its seasonal use, and the need for aesthetic integration in the environment, several relative facilities experienced very severe damage (Almeida et al. 2023)

↓

Locartion near forests allowed

Especially, the constructions in contact with or under high forest vegetation were destroyed (Almeida et al. 2023)

↓

Wildfires disrupt tourist activities and destinations

Sequence 7. Socio-economic and ecological impacts

Increased erosion and land degadation due to wildfires

As a result of changes in forest structure (such as reduced canopy density) and the increased severity of weather extremes, surface runoff and erosion are expected to increase by 16 to 30% with adverse repercussions on deep infiltration and underground aquifer recharge. This, combined with the expected higher evapotranspiration, will reduce the amounts of usable water resources (Arora and Boer 2001) by 25 to 40% i.e. by 5 to 8 billion m3/year (Ministry of Environment and Energy, 2022).

Increased desertification

The impacts of climatic change on water systems include an overall decrease in aquifer infiltration and recharge, as a result of decreased rainfall and higher evapotranspiration; as well as the amplification of the desertification due to water deficits and soil changes (Ministry of Environment and Energy, 2022).

Soil degradation is already intense in parts of the Mediterranean and Central-Eastern Europe and, together with prolonged drought periods and fires, is already contributing to an increased risk of desertification (Kovaks et al. 2014)

Reduced economic activity linked to livestock activity

The livestock activity (in North Evia) is quite extensive. There is now a challenge concerning this issue since, according to article 60th of the Greek Law 4264/2014, the state considers livestock as a threat to the burned forests, and grazing is forbidden with an order issued ex officio by the forest service, which prohibits the grazing of any animal in an area that has been declared under reforestation (Almeida et al. 2023).

Reduced economic activity linked to the loss of resin collection and honey production

North Evia is considered a significant region for honey and resin production, cattle breeding, and mild touristic activity associated with the combination of forests and beaches. Thus, the fire had a very negative impact not only on the natural environment and the landscape aesthetics but also on the local economy due to the damage and loss of houses or farm properties, leaving the local population deprived of their main source of income (Almeida et al. 2023)

Loss of ecosystem services further affecting economic activity (forestry, tourism and rural-urban migration)

Wildfires are one of the critical factors affecting global ecosystems and societies, impacting atmospheric composition, vegetation succession, soil erosion and runoff, and societal values (resources and assets) (Chuvieco et al. 2023).

The ecosystem services most commonly affected by fire are timber supply, carbon sequestration and storage, pastures... and recreation (Martino et al. 2022 in Chuvieco et al. 2023)

V. EXPOSURE

- Exposure indicates the extent to which people, infrastructures and other tangible human assets, as well as ecosystems, could be affected by wildfires (Chuvieco et al. 2023). In instances of fire events, the notion of exposure is broad reaching, given that most regions with combustible vegetation have the potential to experience varying degrees of burning, influenced by factors such as fuel composition and weather conditions (ibid).

Factor 1: Topography

- The terrain shape and morphology have great importance both for fire ignition and behaviour. The former through wind regimes, solar exposure, rainfall and air temperature and humidity distribution, which all impact vegetation distribution and moisture contents (Tymstra et al 2010 and Nyman et al 20915 in Chuvieco et al 2023). Impacts of terrain on fire behaviour include the shape of the terrain and relations to prevailing winds (Chuvieco et al. 2023).
- Fire spread depends on concrete weather, topography, fuel conditions and on fire dynamics (Chuvieco et al. 2023).

Factor 2: Presence of fuel

- Vegetation load, structure, composition and moisture status play a key role in wildfire ignition and spread. Fuels include canopy, shrubs, non-woody vegetation, woody fuels, litter-lichen-moss and ground fuels (Chuvieco et al. 2023).

Factor 3: Wind speed and direction

- Either through windstorms that increase dead tree (and hence increased burnable biomass) wind speed (Ministry of Environment and Energy, 2022; Seidlk et al. 2014 in Chuvieco et al. 2023), wind plays a key role in wildfire behaviour.

Factor 4: Closeness of settlements to risk-prone areas

- Areas may be exposed directly through contact with the fire front or via flaming embers; or indirectly through the dispersion of smoke, or by fire-caused changes in hydrological cycles or soil erosion (Chuvieco et al. 2023)
- The increased extent of high-severity fire expanding into communities further reduces the capacity to provide other services and puts communities, personnel, and infrastructures at higher risk (Gowda et al. 2018)

Factor 5: Movable population (linked to tourism)

- The actual exposure to fire may change even in short periods of time as a result of weather patterns (e.g., heatwaves, changes in wind conditions that transport smoke in different directions) or population movements (summer holidays) (Chuvieco et al. 2023).

Factor 6: Smoke dispersion

- Areas affected indirectly by the dispersion of smoke (Chuvieco et al. 2023)

Resulting from the previous impact cause-effect relations, the following elements could be identified to be exposed to the effects of increased frequency, intensity and duration of rainfall:

Exposure factor	Association to Impact sequence
1	1,2
2	1,2,3,4,5
3	1,2,3,4,5
4	5,6,7
5	5,6,7
6	6,7

VI. SENSITIVITY

Based on information gathered during the workshop and in the context of previous impact sequences and vulnerability factors identified in the literature, the following sensitivity factors are identified:

1. Socio-economic and demographic background

- Societal vulnerability to wildfires may be understood as both the magnitude of the socio-economic impacts deriving from wildfires, and the inability of local societies to cope with stressors to which they are exposed as a consequence of a wildfire (Chuvieco et al. 2023).
- Regarding the human component in wildfire risk assessment, key aspects relate to social capital in relation to the relationships between communities, their activities to contain fire ignition and spread and their strengths and relations with the current institutional system (Chuvieco et al 2023).

2. Forest species composition and homogeneity

- Pine trees and evergreen shrubs possess abundant fuel for wildfires, and they have developed natural adaptations to withstand fires as a normal part of their life cycle. However, when combined with strong winds and high temperatures, prolonged dry seasons create an environment where burnable fuels become more readily available, intensifying wildfires and making them increasingly dangerous and uncontrollable (Greenpeace, 2023).

- Sparse forests and shrubs grew in Greece from 1990-2020, reducing open spaces between forestry tree species by 4%. These hectares form a vulnerable, continuous and unmanaged mass, making them more flammable and promoting the spread of large forest fires (Greenpeace, 2023)
- Areas covered by homogeneous high vegetation: The more flammable forest vegetation in the area is represented mainly by mature Aleppo pine (Pinus halepensis) (Almeida et al. 2023)

3. Heatwave time and duration

- The most severe events in France, Greece, Italy, Portugal, Spain, and Turkey in 2010 were associated with strong winds during a hot dry period (Kovaks et al. 2014).

4. Water availability

- Elevated temperatures play a critical role in increasing the rate of drought onset, overall drought intensity, and drought impact through altered water availability and demand (Gowda et al. 2018)

5. Human-caused ignition

- Population density and aging, proximity to roads and urbanized areas, livestock density and social conflicts have been identified as closely related to human fire ignition (Knorr et al 2016 in Chuvieco et al. 2023)
- Human negligence (statistics show this represents the majority of cases), unregulated holiday home real estate speculation, private interests or illegal forestry practices, the reality they shed light on is the rising heat and a failure to adequately prepare for and contain such disasters, which pose a severe threat not only to human lives but to the country's precious biodiversity (Greenpeace, 2023).

6. Fragmentation

- Humans fragment the landscape due to settlements, infrastructure (e.g., roads, powerlines, railroad tracks) which impact fire propagation (Chuvieco et al. 2023)

Sensitivity factor	Association to impact sequence
1	5,6,7
2	1,2,3,4
3	1,2
4	1,2,3,4,7
5	3,4,5,6
6	3,4,5

VII. ADAPTIVE CAPACITY

Adaptive capacity is normally determined in terms of knowledge, financial resources, technologies, legislations, and infrastructures that enable people to adapt to the effects of climate change.

Factor 1. Public and private resources

- Greece is a forested and mountainous country without an effective, enforced National Forestry Strategy. For decades, the national forestry service has suffered from severe underfunding and a lack of a proper management plan for wildfire prevention. Consequently, reforestation without a logical biodiversity plan has accumulated significant amounts of dry biomass (Greenpeace, 2023).
- The current distribution of resources in Greece appears to heavily favour firefighting, rather than the recommended approach which emphasises the crucial role of prevention. The available funds for forest services are barely enough to cover 10% of their needs while 80% of the budget covers suppression, and only 20% is used for prevention (Greenpeace, 2023)

Factor 2. Spatial planning

- Landscape planning and fuel load management may reduce the risk of wildfires but may be constrained by the higher flammability owing to warmer and drier conditions (Moreira et al., 2011 in Kovaks et al. 2014).
- Strategies to reduce forest mortality include preference of species better adapted to relatively warm environmental conditions (Resco de Dios et al., 2007 in Kovaks et al. 2014).
- The selection of tolerant or resistant families and clones may also reduce the risk of damage by pests and diseases in pure stands (Jactel et al., 2009 in Kovaks et al. 2014).

Factor 3. Education, awareness, and stakeholder engagement (proposed during workshop)

Zabaniotou et al. 2021, conducted a study on Observational Evidence of the Need for Gender-Sensitive Approaches to Wildfires Locally and Globally: Case Study of 2018 Wildfire in Mati, Greece, a wildfire that took place on the 23rd July 2018 and is referred to as the deadliest natural disaster in the history of the Modern Greek state, according to EFFIS. According to this study, actors contributing to wildfire vulnerability are both social and ecological and they need strategies for resilience planning with consideration of the following principles:

- Include public education: Fire-prevention strategies should include public education and real-time mass communication.
- Devolution of political power: Communities need advice on managing fire risk. This requires devolution of political power from centralized bureaucracies to local organizations.
- Real-time mass communication: Fire-prevention strategies should include public education and real-time mass communication.
- Increase participation: The fire prevention and emergency warming plans need to plan with the engagement with local communities and inclusion of women.

- Think diversity: Promotion of disciplinary, sectoral, social and gender diversity among fire scientists, policymakers and wildfire managers must established.

Factor 4. Existence of alarm systems (proposed during workshop)

According to Zabaniotou et al. 2021, there is a lack in alarm systems, for a fire prevention and emergency warning that should be tailored to specific groups.

Factor 5. Coordination across institutions

- Firefighting in the wildland-urban interface is a complicated issue since it involves citizens/people safety and management, addressing challenges in protecting properties dispersed in forested areas and buildings occluded by flammable vegetation, as well as ensuring evacuation for older people, children, and animals (Almeida et al. 2023).
- Whatever the cause or source of each fire, it is virtually impossible to monitor every corner of the Greek mountains and forests. Establishing a well-organised and efficient forest fire extinction body equipped with the necessary staff, support and resources is crucial (Greenpeace 2023).

Factor 6. Forestry management and prevention measures

- As with water resources, forests can adapt through management of forest fires, silvicultural practices, and the conservation of forest genetic resources. Ecological restoration, where required, is another effective adaptation measure that enhances biodiversity and environmental services, increases the potential for carbon sequestration, and promotes economic livelihoods in rural areas (Dasgupta et al. 2014)
- As the climate changes, part of adaptive management may entail modification of existing biodiversity management practices. Manipulating vegetation composition and stand structure, for example, has been proposed as an adaptation option to wildfires in Canada (Dasgupta et al. 2014)
- Fires spread fastest in areas where there is little to no human presence to control them. There is a need to revitalise the rural environment in a way that encourages people to settle in those areas, mitigating the effects of depopulation due to the concentration of economic opportunities in major cities. A mosaic agroforestry landscape, with activities linked to a primary sector deeply rooted in the territory, is a landscape more resilient against major forest fires, climate change and the loss of biodiversity (and agrodiversity) (Greenpeace, 2023).
- In North Hevia, the lack of fuel management over a series of years, coupled with the damage caused by an early spring snowstorm, created a situation that could not be addressed by the fire suppression mechanism. A balanced relationship between fire prevention and suppression, not only in terms of financing but also in terms of perceived interest, and forest management and status monitoring across the entire year are prerequisites for sound protection from landscape fires (Almeida et al. 2023)

- Possible response approaches to the impacts of climate change on forestry include short- and long-term strategies that focus on enhancing ecosystem resistance and resilience and responding to potential limits to carbon accumulation (Millar et al., 2007 in Kovaks et al. 2014)

Adaptive capacity factor	Association to impact sequence
1	1,2,3,4,5,6,7
2	1,2,3,4,5,6,7
3	3,4,5,6,7
4	1,2,3,4
5	1,2,3,4,5,6,7
6	1,2,3,4,5,6,7

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Annex 10. Climate Impact chain Burgas: Flood

I. Introduction

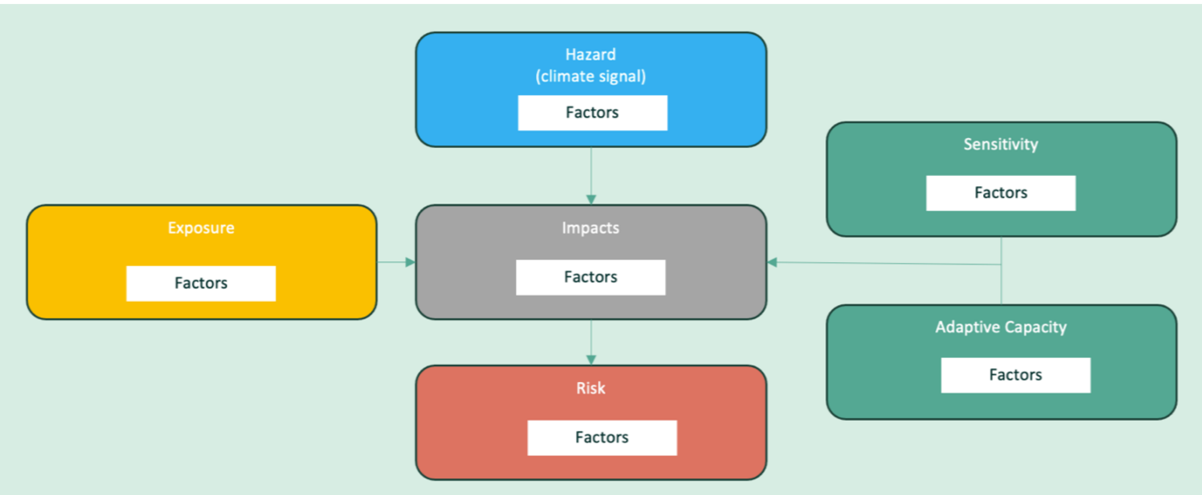
The Climate Impact chain for the region of Burgas in the context of the Valorada-EU project, focuses on the risk of hydrogeologic affectation due to flash floods on livelihoods, infrastructure, and agricultural means of production. The climate impact chain has been developed in two stages. Firstly, a participatory workshop including regional representatives took place in November 2023 in Burgas, Bulgaria. The climate impact chain presented in this interim report has been complemented and reconstructed based on a literature review. City officials as well as consortium partners TAKT will at this stage provide feedback to the proposed climate impact chain delivered in this document.

Climate-impact chains

A climate-impact chain delineates the connection between a specific climate hazard and a designated impact area. These chains aim to elucidate cause-and-effect relationships within various components of a system. By defining these relationships, impact chains ascertain how a hazard transforms into a risk, factoring in exposure, potential intermediate impacts, sensitivity factors, and response/adaptation capacities that mitigate vulnerability. In cases where applicable, intermediate impacts can be identified, each with its exposure, sensitivity, and adaptation factors (GIZ and EURAC, 2017).

A chain is composed of risk components (hazard, vulnerability, exposure) and underlying factors associated to each component. A climate signal, e.g. a heavy rain event, may lead to a direct physical impact, e.g. a flood, causing a sequence of intermediate impacts, which finally lead to the risk. The hazard component includes factors related to the climate signal and direct physical impact. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised by one or more exposure factors (GIZ and EURAC, 2017).

Figure 1: Schema of a Climate Impact chain (GIZ and EURAC, 2017)



II. Climate Hazards and Climate risks in Burgas

Climate hazards are defined as the potential occurrence of a climate-related event, trend or physical impact that may cause loss of life, injury, damage and loss of infrastructure, livelihoods, service provision, ecosystems (Rosenzweig et al. 2015).

Climate risks are defined as the potential for consequences where something of value is at stake and where the outcome is uncertain (Rosenzweig et al. 2015).

During the workshop, regional representatives of Burgas decided to attend the risk of hydrogeologic affectation on livelihoods, infrastructure and agricultural production.

Burgas, key considerations:

According to the calculated climate change vulnerability index for the regions (NUTS 2) for the whole EU, South-East region, the municipality of Burgas falls into the fourth group with high vulnerability. The most sensitive sectors to climate change are agriculture, tourism, water resources management and forestry. The influence of global climate changes is most evident in average annual temperatures, average annual precipitation, as well as in terms of the intensity of the manifestation of adverse and risky atmospheric and hydrospheric phenomena.

The territory of the municipality of Burgas falls in the Black Sea climatic region of the country, which to a significant extent predetermines the main characteristics of the formed local climate - with a well-expressed sea influence, mild and humid winter and hot, but relatively dry and sunny summer. These features are especially well expressed in the southern part of the Bulgarian Black Sea coast, incl. on the territory of the municipality. In winter and autumn, the temperature of the sea surface is higher than the temperature over land and the air masses advancing from the sea are significantly warmer. Therefore, in the coastal zone, winter and autumn are significantly warmer (but also windier) than inland. In spring and summer, the temperatures are not too high due to the influence of the immediate neighborhood of the Black Sea. An important role in the formation of the climate in the coastal zone is played by the breeze circulation. For example, the summer breeze circulation is responsible for the small diurnal temperature amplitudes. Although the sea has a mitigating influence on the climate, although rarely, very cold winters occur along our Black Sea coast, such as in 1907, 1927, 1942, 1954, 1972, and in 1942 sea ice briefly formed in Burgas Bay.

The average annual temperature in Burgas is 12.7 °C. The lowest average monthly temperature is recorded in January (1.8 °C), and the highest average monthly temperatures are recorded in July and August (23.1 and 23.0 °C, respectively). The average annual temperature amplitude is 21.3 °C. Autumn (September-November) is warmer than spring (March-May) by an average of 3.6 °C. The reason is that the water surface cools more slowly and warms more slowly compared to land. The comparison of the temperature in 2020 for Burgas against the average temperature for the base period 1961–1990 shows a continuing trend for the average annual temperature to rise.

Two monthly maximums (November-December, June) and two minimums (March and August) stand out in the intra-annual distribution of precipitation in the municipality of Burgas. In general, more precipitation falls in autumn and winter than in spring and summer. Precipitation during the cold half-year is mostly rain (*Plan for the integrated development of the municipality of Burgas 2021-2027*).

Key contextual aspects characterising climate risk linked to floods:

- Europe has experienced an increase in flood risk in recent years. In the last three decades, the number of extreme weather events, including hydrological events, has increased by 60% in Europe (Furtak et al. 2022)
- Projections show that climate change will lead to an increase in the intensity of storms and floods in Europe by 2100. An increase in the frequency of rainfall intensity is estimated to increase the occurrence of flash floods and urban flooding (Furtak et al. 2022).
- The frequency of river flood events, and annual flood and windstorm damages, in Europe have increased over recent decades, but this increase is attributable mainly to increased exposure and the contribution of observed climate change is unclear (Barredo, 2010).
- Flood damage constitutes about a third of the economic losses inflicted by natural hazards worldwide (Arent et al. 2014).
- Future flood damages will depend not only on changes in the climate regime, but also on settlement patterns, land use decisions, flood forecasting quality, warning and response systems, and other adaptive measures (ibid).

Flooding in the context of sea level raise: a key risk to Burgas:

- As a result of the combination of various natural factors, the sea level is subjected to fluctuating movements (tidal, baric, etc.) with different periodicity and height. The formation of extreme fluctuations in the sea level in the Burgas Bay is mainly explained by the wind and wave energy brought into the coastal zone during strong storm conditions. Usually this happens during the cold half-year under the influence of stormy east and northeast winds. An example of such phenomena are the maximum sea levels recorded in February 1979 at the tide gauge stations in Burgas, Ahtopol and Irakli, when for several consecutive days the sea levels rose by 1.5-2.5 meters. On the other hand, there is a clear trend towards a steady rise in mean sea level over a long period of time, which can be seen in Fig. 2. The established sea level rise in the Burgas Bay is mainly due to two factors – the global eustatic sea level rise as a result of climate changes and the tectonic subsidence of the coastal parts of the land (*Plan for the integrated development of the municipality of Burgas 2021-2027*).

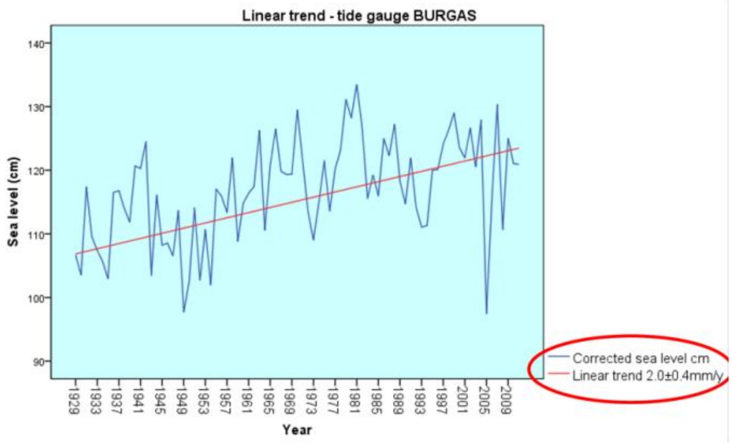


Figure 2. Rise of the sea level according to data from the tide station in Burgas for the period 1929-2009 *(Source: Plan for the integrated development of the municipality of Burgas 2021-2027)*

As a result of global climate change and the associated continuously rising mean sea level of the World Ocean, there is a serious risk to the population, material assets and natural habitats located at the lowest altitude in the coastal zone, which necessitates the need to adapt and undertake of preventive measures to reduce the risk (Fig. 3).

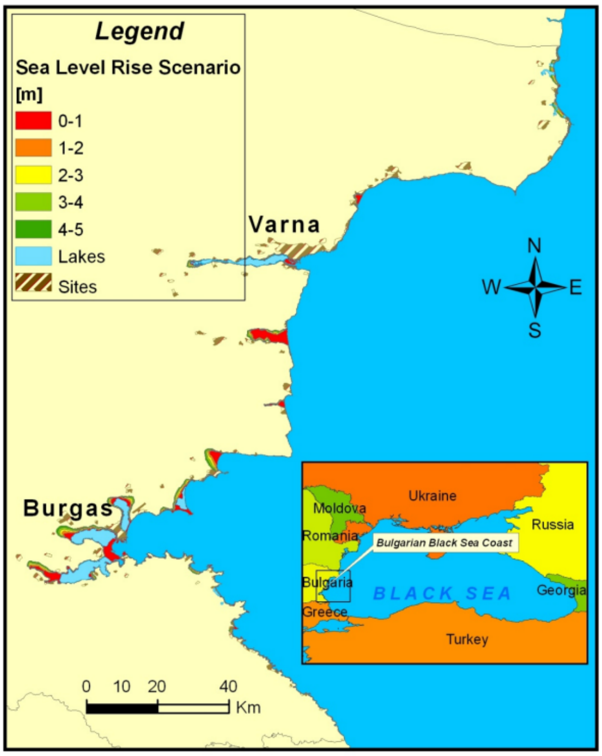


Figure 3. Flood-prone territories along the Bulgarian Black Sea coast under different sea level rise scenarios *(Source: Plan for the integrated development of the municipality of Burgas 2021-2027)*

Areas with water pollution have been identified on the territory of the municipality of Burgas. One of the most significant problems is the pollution of Vaya Lake /Burgas Lake/ and its catchment basin. Its pollution is the result of the significant amounts of untreated waste water - industrial and household-fecal, flowing directly or indirectly through the rivers Aitoska and Chakarliyska. Oil spills from the tanker fleet are also a significant source of pollution of the waters of the bay. (*Plan for the integrated development of the municipality of Burgas 2021-2027*)

III. Impacts

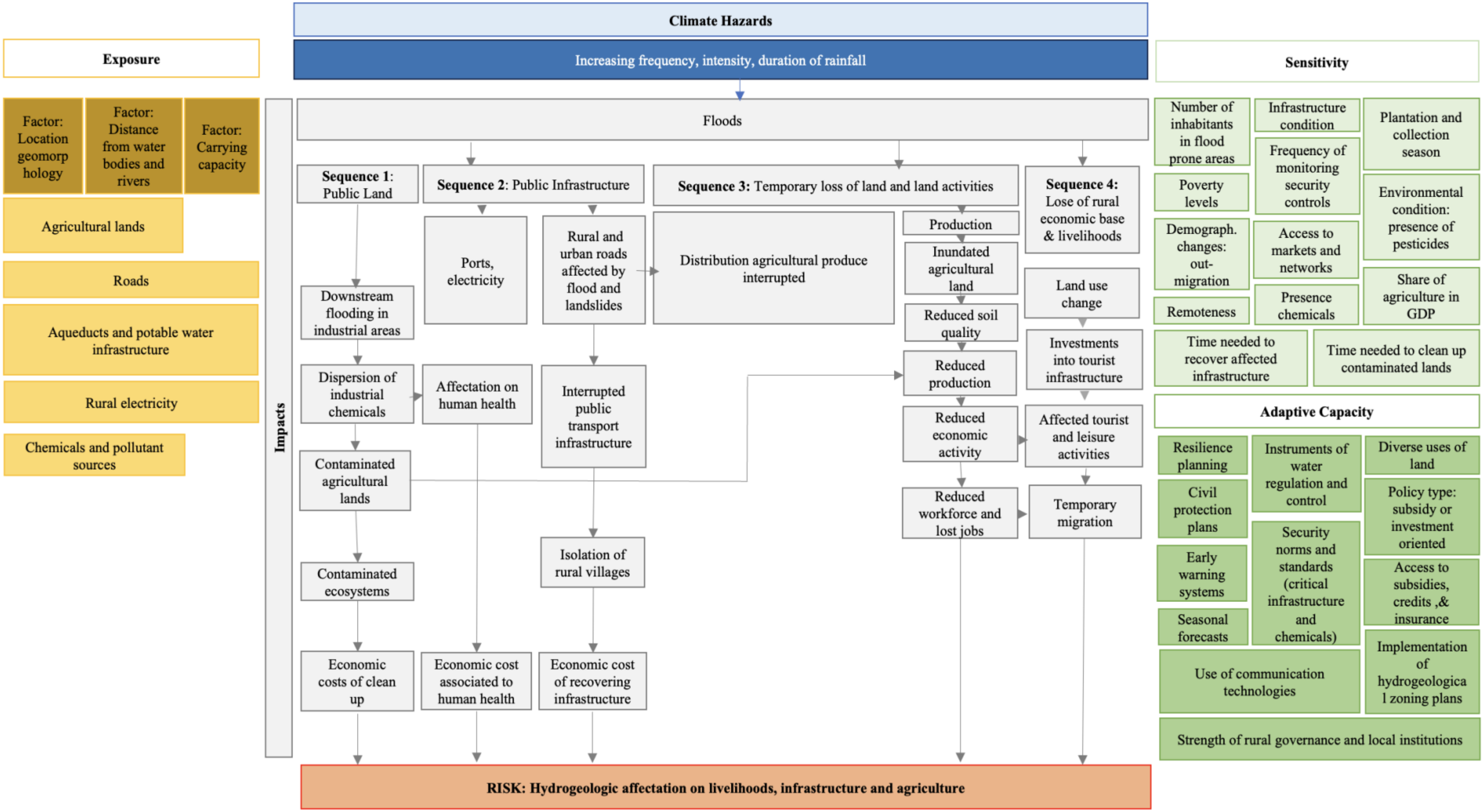
The threat of hydrogeologic events provoking affectation on livelihoods, infrastructure and agricultural production is connected through four sequences of impacting factors: (1) Hydrogeological events impact public infrastructure and increase the risk of disseminating chemical pollutants; (2) Interruption of public services; (3) the affectation provoked by hydrogeological events on soil degradation; (4) the affectation provoked by hydrogeological events on demographic trends and change in land use.

Key messages emerging from the impact sequences:

In the medium and long term, the main risks for Burgas due to climate change, are the following:

1. Flooding: the frequency and impact of flooding is expected to increase under all climate change scenarios. Floods cause significant damage to road and rail infrastructure by damaging sub-base layers of road or rail infrastructure. Water can erode foundations, which can cause catastrophic damage to utilities.
2. Landslides: Precipitation is a major factor in the occurrence of landslides and although the total average annual rainfall is expected to decrease, landslides will continue to be a serious problem due to the expected higher frequency of extreme rainfall events. Landslides cause serious damage to road and rail infrastructure and riverbanks. They may become the cause of long-term interruption of operation and/or limited access of certain population groups and in certain economic areas to certain settlements and/or economic areas.
3. Blizzards and snowfall: In the long term, annual snowfall is expected to decrease, but in the short to medium term, blizzards and heavy snowfall will continue to be a major source of service disruption for all modes of transportation. The northern and north-eastern parts of the country are particularly prone to traffic disruptions in winter due to strong winds and snowfall.
4. It should be noted, however, that in the national Analysis and Assessment of the Risk and Vulnerability of the Sectors in the Bulgarian Economy to Climate Change (MOEW 2014), the transport sector is assessed as extremely resilient for the period up to 2035. This is due, first of all, to the expected moderate climate change by 2035, and secondly, of a transport system that is designed and built with local climate conditions in mind (*National Strategy for Adaptation to Climate Change and Action Plan, MoEW, 2018)*
5. Heavy rainfall: Flooding will increase in frequency and affect all populated areas, causing damage in both large and small towns. The most vulnerable will be neighbourhoods located near watercourses and those of large cities built illegally on their fringes in flood-prone areas (*National Strategy for Adaptation to Climate Change and Action Plan, MoEW, 2018)*.

Climate Impact Chain for the region of Burgas



Sequence 1. Hydrogeological events impact distribution of pollutants

In the first sequence of impacts proposed, the focus is on how hydrogeological events affect the dissemination of chemical pollutants.

Hydrogeological events impacts public infrastructure

Flooding events may cause sediment transport and damage roads and bridges as well as affecting reservoir storing capacity (Dasgupta et al. 2014). Floods are also generated from catastrophic failure of artificial (reservoirs) (Benito and Hudson, 2010).

↓

Extreme flood events represent one pathway of chemical substances into the environment resulting in acute exposure to high pollutant concentrations. (Völker et al. 2023)

(Re)mobilization and (re)distribution of pollutants due to damaged wastewater infrastructure and sediment-bound pollutants resulting from historical discharges (Völker et al. 2023)

Chemical substances are continuously emitted into the environment. Suspended particulate matter continuously enters fluvial systems as a result of the erosion of terrestrial surfaces and the riverbed itself. These particles are transported along with the water current and are ultimately deposited in regions of low water flow through sedimentation processes, e.g., in harbors, groin fields, lowland rivers, floodplains, wetlands, or estuaries (Crawford et al 2022).

↓

Impacts on ecosystem and human health

Chemical material may contaminate homes. Flooding may lead to mobilization of dangerous chemicals from storage or remobilization of chemicals already in the environment, e.g. pesticides. Hazards may be greater when industrial or agricultural land adjoining residential land is affected (Euripidou et al. 2004).

The re-suspension and consequent widespread distribution of highly contaminated sediments into adjacent natural floodplains, farmland, urban centers, or artificially constructed flood retention areas can devastate the environment and the wildlife and affect humans that depend upon it. Dioxins and DLCs are known to cause a range of toxic effects when humans and wildlife are exposed, including neuro-, immuno- and hepatotoxicity, reproductive toxicity, and certain types of cancer (Crawford et al. 2022).

↓

Increased economic costs related to chemical contamination

The environmental, economic, and societal consequences of remobilization and distribution of pollutants during flood events are not widely recognized. Loss of life, damage to infrastructure, and monetary cleanup costs associated with floods are important direct effects. It would be beneficial to determine economic tradeoffs between flood prevention measures, measures to avoid the remobilization of hazardous substances in toxic sediments, and measures dealing with the cleanup and restoration of the affected areas (Crawford et al. 2022)

Sequence 2. Interruption of public services

In the second sequence of impacts proposed, the focus is on the affectation provoked by hydrogeological events on public services.

Affectation provoked by hydrogeological events on public infrastructure

Roads: Circulation in rural and urban roads temporarily interrupted by flood and landslides

As the risk of extreme sea level events increases with climate change coastal flood risk will remain a key challenge for several European cities, port facilities, and other infrastructure (Hallegatte et al., 2008)

Interrupted public transport - Interrupted public services

Isolation of rural villages: Adverse impacts on transportation (such as flooded roads) can further affect access and evacuation. The ability of health care facilities to properly care for the affected and for those with ongoing health issues requiring medication or treatment may be compromised by very large events that affect multiple health care facilities. Areas projected to experience increases in extreme events could consider additional "surge capacity" to manage such events without interruption of service (Banks et al., 2007; Hess et al., 2009 in Arent et al 2014).

Infrastructure at risk: More frequent heavy rainfall events may overload the capacity of sewer systems and water and wastewater treatment plants more often, and increased occurrences of low flows will lead to higher pollutant concentrations.

Unpaved roads are vulnerable to a number of climate-based factors especially to increasingly intense precipitation, leading to wash out and disruption of service (Chinowsky and Arndt, 2012).

Rail beds are susceptible to increases in precipitation, flooding and subsidence (Arent et al. 2014)

Economic costs of infrastructure interrupted

Costs of Refurbishing infrstructure:

Private livelihoods affected due to reduced workforce and overal reduced economic activity.

Flood losses in the UK in 2000, 2007, and 2009 have put the insurance market under further pressure, with increasing need for the government to reduce risk (Ward et al., 2008 in Arent et al 2014)

Public attitudes in Scotland and the Netherlands would support insurance of private property and public infrastructure damages in the case of increasing flood risk (Botzen et al., 2009 in Arent et al 2014).

Sequence 3. Soil degradation and reduced productivity

In the third sequence of impacts proposed, the focus is on the affectation provoked by hydrogeological events on soil degradation and associated reduced productivity.

River flooding will produce temporary loss of land and land activities, and damage to transportation infrastructure (Dasgupta et al. 2014)

Future vulnerability will also be strongly affected by cross-sectoral (indirect) interactions, for example, flooding-ecosystems, agriculture-species, agriculture-cultural landscapes, and so on (Kovats et al 2014).

Floods damage farms, crops, livestock, the physical infrastructure of agriculture, and the food supply chain, reducing agricultural productivity and food availability. Human interference with floodplain landscaping causes water levels in rivers to move rapidly from low to high levels as a result of precipitation events. This leads to changes in the flow and flooding of water from canals (Furtak et al. 2023).

↓

Floods affect the physical structure of soils and nutrient cycling, resulting in potentially irreversible damage to agricultural productivity and ecosystem functioning (Furtak et al, 2023)

Flooding compacts the soil with water. Increased moisture reduces oxygen and nitrogen diffusion in the soil. C and N mineralisation is reduced. Flooding results in loss of soil P. Flooding increases Fe phosphate solubility due to pH changes. Changes in soil moisture affect the soil microbiome which affect the long-term productivity of plants (Furtak et al. 2023).

Across most of Northern and Continental Europe, an increase in flood hazards (Arent et al 2014) could increase damages to crops and plant growth, complicate soil workability, and increase yield variability (ibid).

↓

Economic impacts: Unhealthy soil cannot provide plants with the nutrition they need to grow correctly and abundantly, resulting in shortages and economic strain on people linked to production chains

Excessive soil moisture is also associated with disruptions to planned field practices and forces farmers to use greater amounts of lime to improve pH and other techniques to improve soil quality (aeration) (Furtak et al. 2023).

Post-harvest aspects of agriculture—storage on-farm and commercially, handling, and transport—have been relatively neglected in discussions of climate change, but will be affected by changes in temperature, rainfall, humidity, and by extreme events (Dasgupta et al. 2014).

Climate change may also affect investment patterns in rural areas. Sectors that are expected to be affected adversely by climate change may have difficulty attracting investment (Dasgupta et al. 2014).

Sequence 4. Affectation of hydrogeological events on rural livelihoods

Extreme precipitation on rural livelihoods

Impacts of climate change on the rural economic base and livelihoods, land use, and regional interconnections are at the latter stages of complex causal chains (high confidence) (Dasgupta et al. 2014).

↓

Land use changes demand new investments which may become jeopardized by enviuronmental threats, further deepening impacts on local livelihoods

Shift from agricultural (production) to leisure (consumption) activities; focus on broader amenity values of rural landscapes for recreation, tourism, forests, and ecosystem services (Dasgupta et al. 2014)

↓

Temporary migration

Current damages from weather-related disasters (floods and storms) are significant. Disasters have long lasting effects on the affected populations (Schnitzler et al., 2007). Households are often displaced while their homes are repaired (Whittle et al., 2010).

IV. Exposure

Factor 1: Location: Whether geomorphology amplifies exposure (physical extent of floodplains and catchment hydrology (Thomson and Clayton, 2022);

Factor 2: Distance from water bodies and rivers (proposed during workshop).

Factor 3: Carrying capacity of specific infrastructure: Floods are also generated from catastrophic failure of artificial (reservoirs) (Benito and Hudson, 2010).

Resulting from the previous impact cause-effect relations, the following elements could be identified to be exposed to the effects of increased frequency, intensity and duration of rainfall:

Exposed element	Association to Exposure Factor
Agricultural lands	1,2
Roads	1,2,3
Aqueducts and potable water infrastructure	1,2,3
Rural electricity	1,2,3
Chemical and pollutant sources (industry)	1,2, 3

V. Sensitivity

Climate change in rural areas will take place against the background of the trends in demography, economics, and governance that are shaping those areas. Existing vulnerabilities caused by poverty, lower levels of education, isolation, and can all aggravate climate change impacts in many ways (Dasgupta et al. 2014).

The IPCC (Dasgupta et al. 2014) has also highlighted a number of non-climate factors affecting vulnerability in rural areas at both, individual and community levels:

- Physical geography,
- Remoteness,
- Economic constraints and poverty,
- Demographic changes such as out-migration and aging,
- Density of social networks,
- Neglect by policymakers and short-time policy horizons,
- Low levels of public services,
- Memories of past climate variations and knowledge.

Sensitivity factors for Burgas

Sensitivity factor	Impact sequence	Description
Number of inhabitants in flood risk areas	**1,2,3**	
Age group	**2,3,4**	Per capita gross domestic product (GDP) in rural areas of OECD countries is only 83% of national average (but significant variation within and between countries (Dasgupta et al. 2014)
Poverty levels	**2,3,4**	
Share of agriculture in GDP	**2,3,4**	Agriculture plays a key, but disproportionate, role in the socio-economic structure of rural areas in Bulgaria. The agricultural sector generated 4.4 percent of the country's total gross value added and provided employment to 5.8 percent of the labour force (the second highest rate in the EU-28) in 2015. The agricultural sector as a source of food, as a provider of ecosystem services and a livelihood for the rural population, as well as a pillar of economic growth, is highly vulnerable to the impact of climate change.
Remoteness	**1,2,3,4**	Importantly, in rural areas usually there are few alternatives once a road is blocked and that may increase vulnerability of rural areas when facing extreme hydro climatological events that impact transportation infrastructure (Dasgupta et al. 2014)
Time/cost needed to recover infrastructure/	**1,2**	
Access to markets and networks and density of social networks	**3,4**	Large amount of water can cause flooding of agricultural lands and disrupt the balance of production; accordingly, this will also reflect on animal husbandry.
Presence of industry close to agricultural lands	**1**	Presence of industries in the context of risk of dispersion of chemical pollutants due to flooding.
Environmental condition (presence of chemicals)/ time needed to clean up chemical contamination	**1,3**	Flooding may lead to mobilization of dangerous chemicals from storage or remobilization of chemicals already in the environment, e.g., pesticides (Euripidou et al. 2004). Resource degradation, environmentally fragile lands subject to overuse and population pressures, exacerbating social and environmental challenges (Dasgupta et al. 2014).
Policy making: Frequency of monitoring critical infrastructure/ dams, roads; Infrastructure baseline condition	**1,2,3,4**	Neglect by policymakers can aggravate climate change impacts in many ways. Neglect by policymakers and underinvestment in infrastructure and services has negatively affected rural areas (Dasgupta et al. 2014).

VI. Adaptive Capacity

Adaptive capacity is normally determined in terms of knowledge, financial resources, technologies, legislations and infrastructures that enable people to adapt to the effects of climate change. The IPCC (Dasgupta et al. 2014) informs of key variables shaping a resilient rural system in the context of climate change:

- Structural features of farm households and communities affect their vulnerability to climate change in complex ways. Resilience of access to land and natural resources, flexible local institutions, and knowledge and information, and on the association of gender inequalities with vulnerability are key.
- Accelerating globalization, through migration, labour linkages, regional and international trade, and new information and communication technologies, is bringing about economic transformation in rural areas of both developing and developed countries.
- In developed countries, there are important shifts toward multiple uses of rural areas, especially leisure uses, and new rural policies based on the collaboration of multiple stakeholders, the targeting of multiple sectors, and a change from subsidy-based to investment-based policy.
- Agricultural subsidies under pressure from international trade negotiations and domestic budgetary constraints. As a result of recent price hikes, domestic price support has been lowered in OECD countries.
- Institutions and networks can affect vulnerability to climate change: through distribution of climate risks between social groups; by determining the incentive structures for adaptation responses; and by mediating external interventions (e.g., finances, knowledge and information, skills training) into local contexts (e.g., if decision makers resist seeing climate change as within their responsibilities, this may contribut to low levels of planning for either adaptation or mitigation, and thus to greater vulnerability.
- Access to information alone is not a guarantee of success. Despite access to weather forecasting, people may not rely on such information.
- Rural households' lack of access to technologies and infrastructure (e.g., markets) is also a major barrier to adaptation for certain production systems.
- Access to water, credit, extension services, and off-farm income and employment opportunities, tenure security, farmers' asset base, and farming experience are key to enhancing farmers' adaptive capacity.

Sequence	Association to adaptive capacity factor
Sequence 1	6,7
Sequence 2	1,2,3,5,6,
Sequence 3	3,4,5,6
Sequence 4	1,2,3,4,5,6,7,8

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Annex 11. Climate Impact chain Burgas: Heat

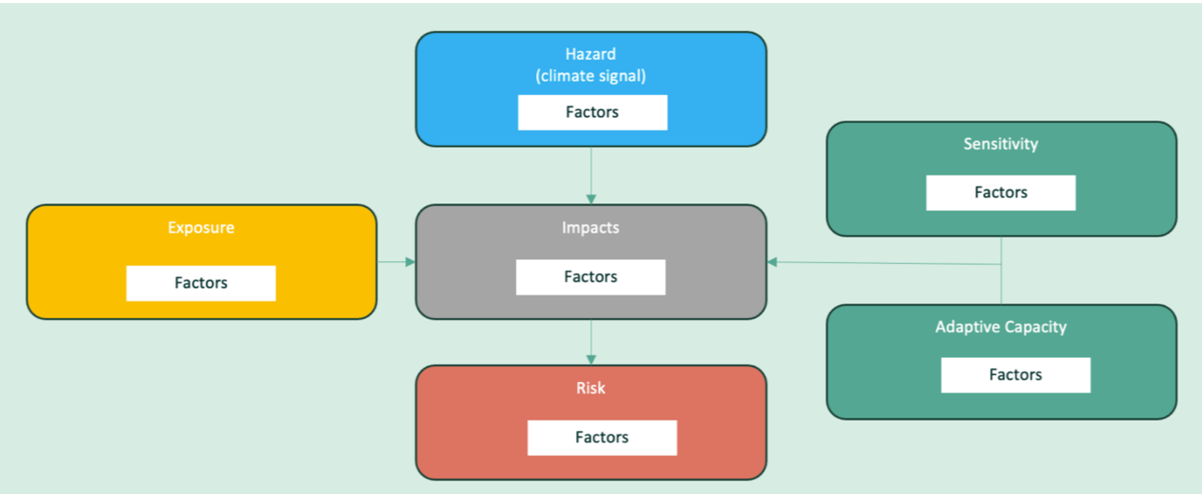
I. Introduction

The Climate Impact chain for the region of Burgas developed in the context of the Valorada-EU project, focuses on the risk of deterioration of social and environmental determinants of (human and ecosystem) health due to urban warming. The climate impact chain has been developed in two stages. Firstly, a participatory workshop including regional representatives of Burgas and Valorada-consortium members TAKT, took place in November 2023 in Burgas, Bulgaria. The climate impact chain presented in this interim report has been complemented and reconstructed based on a literature review. City officials as well as consortium partners TAKT will at this stage provide feedback to the proposed climate impact chain delivered in this document.

Climate-impact chains

A climate-impact chain delineates the connection between a specific climate hazard and a designated impact area. These chains aim to elucidate cause-and-effect relationships within various components of a system. By defining these relationships, impact chains ascertain how a hazard transforms into a risk, factoring in exposure, potential intermediate impacts, sensitivity factors, and response/adaptation capacities that mitigate vulnerability. In cases where applicable, intermediate impacts can be identified, each with its exposure, sensitivity, and adaptation factors (GIZ and EURAC, 2017).

A chain is composed of risk components (hazard, vulnerability, exposure) and underlying factors associated to each component. A climate signal, e.g. a heavy rain event, may lead to a direct physical impact, e.g. a flood, causing a sequence of intermediate impacts, which finally lead to the risk. The hazard component includes factors related to the climate signal and direct physical impact. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised by one or more exposure factors (GIZ and EURAC, 2017).



II. Climate Hazards and Climate risks in Burgas

Climate hazards are defined as the potential occurrence of a climate-related event, trend or physical impact that may cause loss of life, injury, damage and loss of infrastructure, livelihoods, service provision, ecosystems (Rosenzweig et al. 2015).

Climate risks are defined as the potential for consequences where something of value is at stake and where the outcome is uncertain (Rosenzweig et al. 2015).

Key climate facts for Burgas

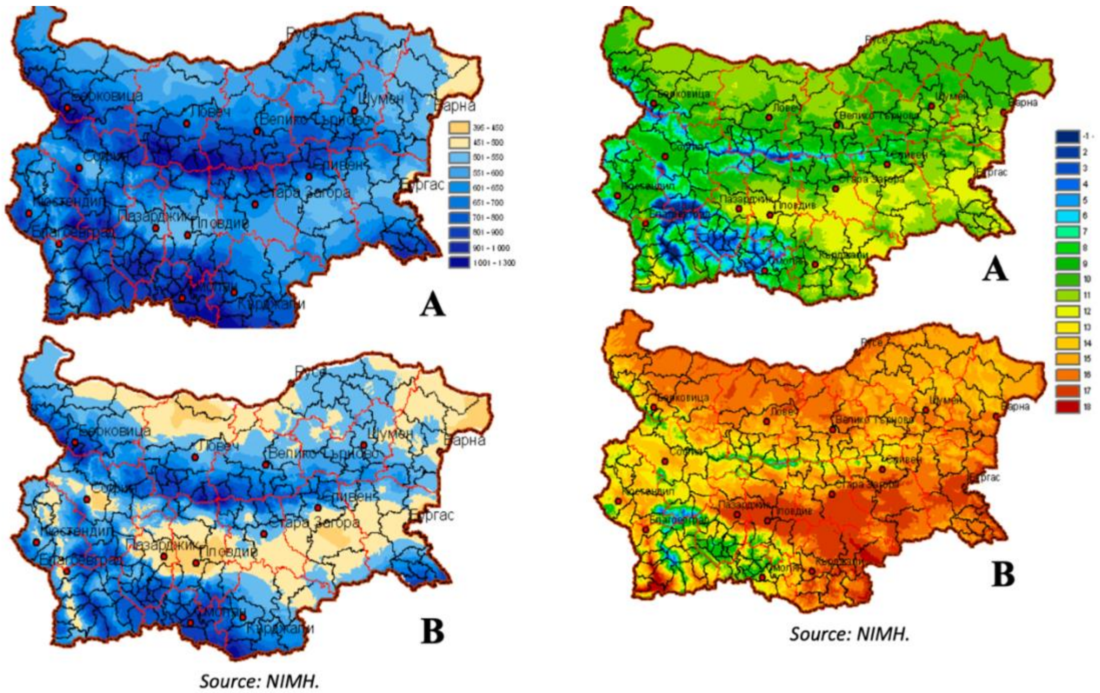
- According to the calculated climate change vulnerability index for the regions (NUTS 2) for the whole EU, South-East region, the municipality of Burgas falls into the fourth group with high vulnerability. The most sensitive sectors to climate change are agriculture, tourism, water resources management and forestry. The influence of global climate changes is most evident in average annual temperatures, average annual precipitation, as well as in terms of the intensity of the manifestation of adverse and risky atmospheric and hydrospheric phenomena.
- The territory of the municipality of Burgas falls in the Black Sea climatic region of the country, which to a significant extent predetermines the main characteristics of the formed local climate - with a well-expressed sea influence, mild and humid winter and hot, but relatively dry and sunny summer. These features are especially well expressed in the southern part of the Bulgarian Black Sea coast, incl. on the territory of the municipality. In winter and autumn, the temperature of the sea surface is higher than the temperature over land and the air masses advancing from the sea are significantly warmer. Therefore, in the coastal zone, winter and autumn are significantly warmer (but also windier) than inland. In spring and summer, the temperatures are not too high due to the influence of the immediate neighborhood of the Black Sea. An important role in the formation of the climate in the coastal zone is played by the breeze circulation. For example, the summer breeze circulation is responsible for the small diurnal temperature amplitudes. Although the sea has a mitigating influence on the climate, although rarely, very cold winters occur along our Black Sea coast, such as in 1907, 1927, 1942, 1954, 1972, and in 1942 sea ice briefly formed in Burgas Bay.
- The average annual temperature in Burgas is 12.7 °C. The lowest average monthly temperature is recorded in January (1.8 °C), and the highest average monthly temperatures are recorded in July and August (23.1 and 23.0 °C, respectively). The average annual temperature amplitude is 21.3 °C. Autumn (September-November) is warmer than spring (March-May) by an average of 3.6 °C. The reason is that the water surface cools more slowly and warms more slowly compared to land. The comparison of the temperature in 2020 for Burgas against the average temperature for the base period 1961–1990 shows a continuing trend for the average annual temperature to rise.
- Two monthly maximums (November-December, June) and two minimums (March and August) stand out in the intra-annual distribution of precipitation in the municipality of Burgas. In general, more precipitation falls in autumn and winter than in spring and

summer. Precipitation during the cold half-year is mostly rain (*Plan for the integrated development of the municipality of Burgas 2021-2027*).

Figure 1: Projections on temperature and precipitation for Bulgaria

Precipitation per Year for 1961–1990 (A) Precipitation per Year for 2080, According to the Pessimistic Scenario (B)

Average Year Temperature for 1961–1990 (A); Pessimistic Climate Scenario for Average Year Temperature for 2080 (B)



Source: Bulgaria's 8th National communication (2022)

During the workshop, regional representatives of Burgas decided to attend the risk of ***Increased urban warming affecting people's health through the deterioration of social and environmental determinants of health***.

Understanding risks: What is distinctive about urban warming in the context of people's and healthy-ecosystem status?

- The frequency, intensity, duration, and spatial extent of some extreme weather events, particularly heat waves, has been increased by climate change, with further increases projected (Richter, 2016).
- Intense heatwaves in Europe are expected to happen more frequently and become more intense with climate change. With 1.5°C, each year more than 100 million Europeans would be exposed to a present intense heatwave (Feyen et al 2020).
- Compared with pre-industrial times, the mean average European surface air temperature increase has been almost 1°C higher than the average global temperature increase, and 2022 was the hottest European summer on record (van Daalen et al 2022).

- The record hot summer caused almost 62 000 deaths in Europe in 2022 (Romanello et al. 2023)
- Climate change is interacting with other trends, such as population growth and ageing, urbanisation, and socioeconomic development, that can either exacerbate or ameliorate heat-related hazards (Ebi et al 2021).
- Urban temperatures are enhanced by anthropogenic heat from vehicular transport, heat emitted from building energy waste, and minimally by human metabolic heat. (Ebi et al 2021).
- Europe had the highest rate of heat-related mortality in recent years (2017–22) (Romanello et al. 2023).
- Vulnerability to heat exposure has increased steadily across all European regions, with an increase of 6% from 1990 to 2019. Although northern Europe is the most vulnerable region, the highest relative increase of 9,8% is observed in central Europe (van Daalen et al 2022)
- Assuming present vulnerability and no additional adaptation, annual fatalities from extreme heat in Europe could rise from 2,700 deaths now to nearly 30,000 with 1.5°C global warming, 50,000 with 2°C and 90,000 with 3°C (Feyen et al 2020).
- Urban heat island (temperature difference between inside the city and outside it) can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning, inducing also earlier spring-time flowering in urbanized areas compared to surrounding rural areas (Richter 2015).
- Climate change and the urban heat island (UHI) effect impact ecosystem services and green infrastructure by causing shifts in temperature and precipitation patterns, evaporation rates, humidity levels, soil moisture content, vegetation growth rates, water tables, aquifer levels, and air quality (Solecki & Marcotullio, 2013). These changes can bring about cascading effects that further affect urban ecosystems (Frumkin et al., 2008; Keim, 2008).

Key risks identified for Burgas:

- Effect of temperature and humidity on health. These include the expected increase in: the number of deaths from cardiovascular disease and stroke in major cities during the summer due to heat waves and the urban heat island effect; vector-borne diseases; campylobacter infections; respiratory diseases due to the stronger influence of CO_2, dust and atmospheric particulate matter in the warmer air; and allergic diseases due to earlier flowering and increased concentration of pollen, spores and other allergens in the air (Mihailova, 2014).
- Emergency health effects related to weather conditions. These include the expected increase in: mortality from extreme weather events and fires, with this increase being greater for vulnerable groups; water and food-borne illness due to damaged infrastructure; and post-traumatic stress disorder (Mihailova, 2014).
- Change in health effects associated with precipitation. It includes the expected increase in: occurrence of cryptosporidiosis and campylobacteriosis due to a combination of more frequent rainfall and higher average annual temperatures; and infections caused by non-cholera vibrio (enteritis in which no vibrio-cholera is isolated) due to heavier rainfall and

higher humidity levels, as well as higher water temperature in the Black Sea (Kovats et al., 2003).

- The Black Sea region appears most vulnerable to the risk of shortages because it uses surface water and is the most visited by tourists.
- Key vulnerabilities to these climate hazards (and their impact on water scarcity) are:
  - Infrastructure condition and preparedness: If it is congested, aging, or not good maintained and therefore the infrastructure is highly vulnerable and most likely inadequate to cope with climate change.
  - Preparedness: The population and infrastructure operators should have experience and good practices in floods and droughts.
  - Hydroelectric plants – operation vulnerable to drought.
  - Water services (water supply, sewerage, land reclamation) - vulnerable to drought.

The main risks to managed systems are therefore risks to infrastructure and services: Damage, improper operation and low level or insufficient services; Risks to hydroelectric plants due to low or high river flows.

The main risks to natural systems are damaged biodiversity due to both floods and droughts (*Plan for the integrated development of the municipality of Burgas 2021-2027).*

In this report, the definition of social and environmental determinants of health are specified as:

Social determinants of health, which include "the unequal distribution of power, income, goods, and services, globally and nationally, the consequent unfairness in the immediate, visible circumstances of peoples lives' – their access to health care, schools, and education, their conditions of work and leisure, their homes, communities, towns, or cities – and their chances of leading a flourishing life" (Commission on Social Determinants of Health, 2008).

Environmental determinants of health, which include "… all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours … targeted towards preventing disease and creating health-supportive environments (including clean air and water, healthy workplaces, safe houses, community spaces and roads and managing climate change) (WHO 2014).

Drawing from the preceding characterization, this report builds on the Health and Cities Framework (IPCC 2007) to encompass the myriad relationships and causal chains intertwining climate and non-climate determinants of risk. The framework underscores that "…long-term projections of global health outcomes now explicitly include factors such as unsafe water, food, and residence; poor sanitation; urban air pollution; and indoor air pollution – all of which are aggravated by climate change" (Barata et al 2018 p.366).

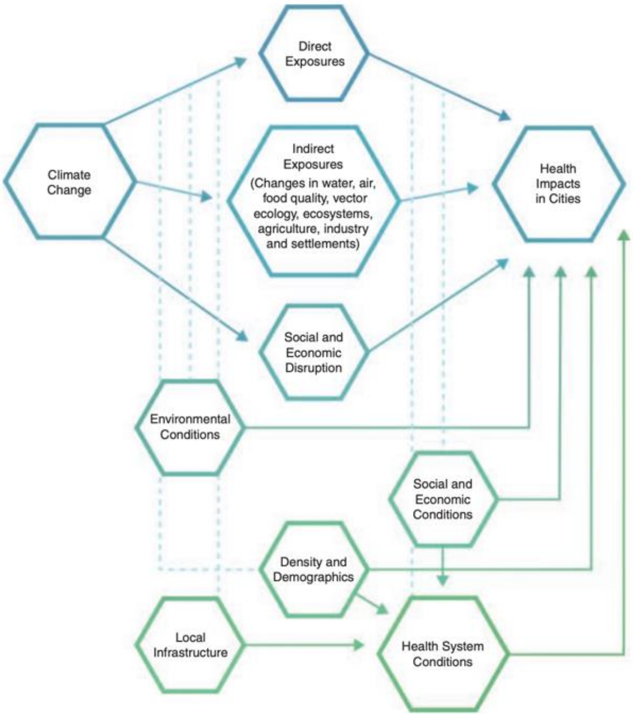
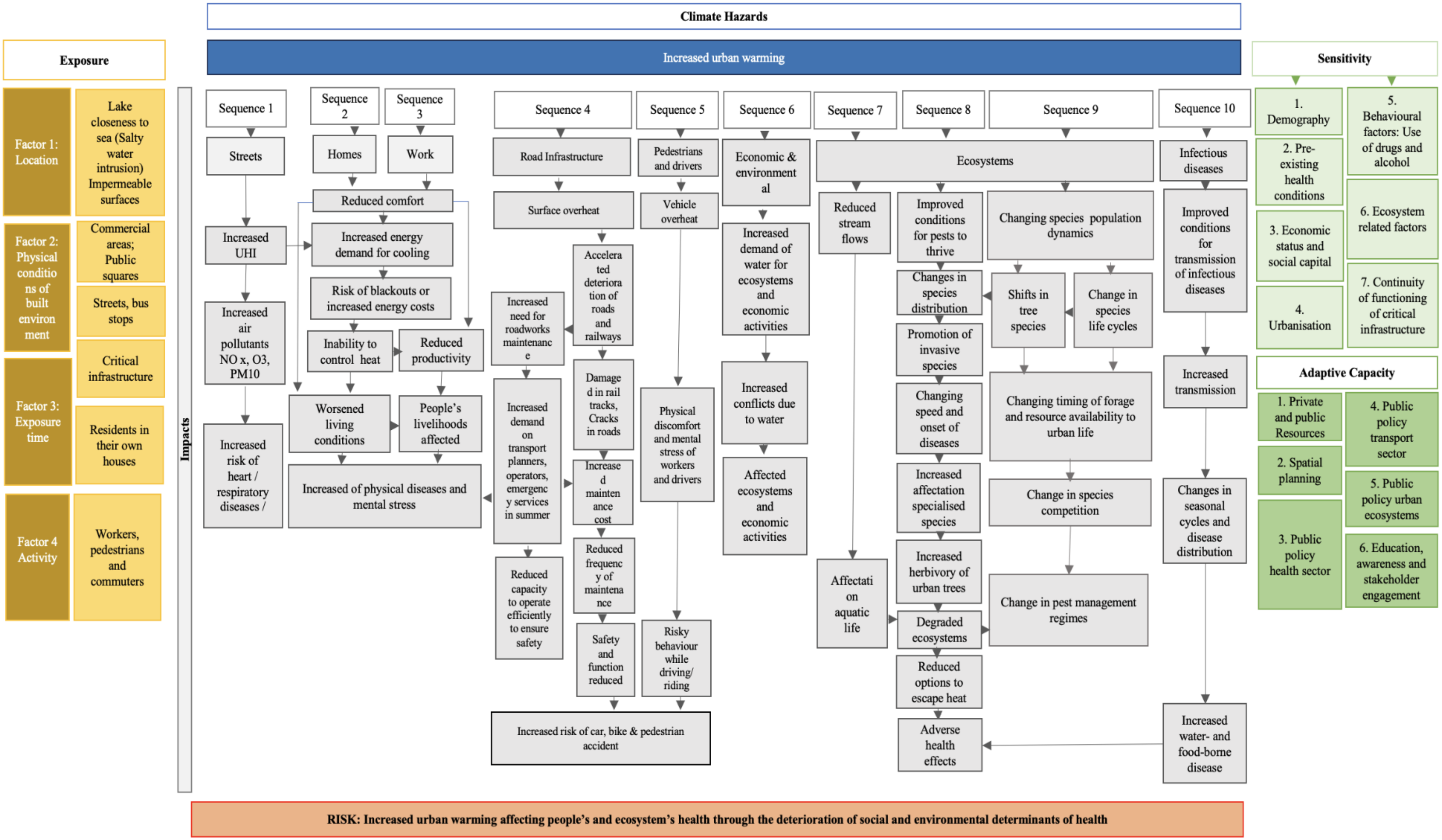


Figure source: Barata et al. 2018.

Climate Impact Chain for Burgas



III. Impacts

The risk of ***Increased urban warming affecting people's health through the deterioration of social and environmental determinants of health*** is characterised through ten sequences of impacting factors.

Key messages emerging from the impact sequences:

1. Urban warming deteriorates environmental and social determinants of health, causing direct threats to people's health status.

2. Deteriorating social determinants of health highlight issues of social justice as shed light on people's limited private resources and capacities to cope with high temperatures.

3. Urban ecosystems play a crucial role in natural capital for climate change adaptation and mitigation (Rosenzweig et al. 2015); while at the same time, urban habitats contribute to the well-being of urban residents (Solecki & Marcotullio, 2013). Climate change and the urban heat island (UHI) effect impact ecosystem services and green infrastructure by causing shifts in temperature and precipitation patterns, evaporation rates, humidity levels, soil moisture content, vegetation growth rates, water tables, aquifer levels, and air quality (Solecki & Marcotullio, 2013). These changes can bring about cascading effects that further affect urban ecosystems (Frumkin et al., 2008; Keim, 2008).

4. In consideration to vulnerabilities and exposure, impacts are perceived differently through society. However, the impact chains reveal how some impacts may be more prominent at different times (difference between day and night highlighted). This is particularly relevant for the impacts related to the Heat Island Effect (sequence 5).

5. Disruption in the normal and steady functioning of critical infrastructure due to high temperature can cause dramatic impacts to populations depending on these infrastructures for their coping capacity against heat. This is particularly the case for energy grids that experience above-normal demand during pick-times, provoking blackouts that limit access to air conditioning. However, water systems can also be exposed to stress under high temperatures, either due to water overdemand, low provision capacity, or reduced water quality.

6. People's activities and routines greatly change their exposure to heat stress.

Sequence 1.

In the first sequence of impacts proposed, the focus is on the increase of air pollution as provoked by urban warming and related health effects. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented below.

Air pollution might also increase during heatwaves, leading to possible synergistic effects on health (Hajat et al. 2010)

Heat waves and warm spells could exacerbate urban heat island effects, including increased air pollution (Solecki & Morcotullio, 2013).

Other impacts of extreme temperature on ambient air quality, such as ozone pollution under heatwaves (Feyen et al 2020)

Ozone production is dependent on temperature and the presence of sunlight, with higher temperatures and still, cloudless days leading to increased production (Barata et al 2018)

Increased of pollutantst due to transport

Urban temperatures are further enhanced by anthropogenic heat from vehicular transport and heat waste from buildings (Ebi et al 2021)

Reduced health status

Exposure to ozone is associated with decreased lung function, increased premature mortality, increased cardiopulmonary mortality, increased hospital admissions, and increased emergency room visits (Barata et al 2018)

Sequence 2. People's health being affected by the increased temperatures in their private households.

Reduced at night time

One consequence of urban development is the urban heat island (temperature difference between inside the city and outside it) that results in cities being, on average, warmer than adjacent rural landscapes (Ebi et al 2021). The urban heat island is amplified at night when stored daytime heat is emitted and intensified with increasing city size and population density (Ebi et al 2021)

Increasing energy demand threatens cooling devises

Urban heat island can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning (Richter 2015).

An approach focusing on air conditioning as a preventive measure for reducing heat-related morbidity and mortality is vulnerable to failure when the underlying infrastructure – the electrical grid – weakens or fails during a summer heat wave (Barata et al).

Adverse health effects due to disrupted infrastructure

These infrastructure disruptions can lead to a wide range of adverse health effects depending on the age, health status, and economic resources of residents in the affected households. An approach focusing on air conditioning as a preventive measure for reducing heat-related morbidity and mortality is vulnerable to failure when the underlying infrastructure – the electrical grid – weakens or fails during a summer heat wave (Barata et al 2018)

Increased affectation to vulnerable groups

Hot weather and heat extremes are associated with increased emergency room visits and hospital admittance, increased deaths from cardiorespiratory and other diseases, mental health issues, adverse pregnancy and birth outcomes, and increased health-care costs (Ebi et al 2021).

In Europe, population exposure to heatwaves increased by 57% on average in 2010–19 compared with 2000–09, and by more than 250% in some regions, putting older people, young children, people with underlying chronic health conditions, and people who do not have adequate access to health care at high risk of heat-related morbidity and mortality (van Daalen et al. 2023)

Worsening living conditions and increased mental stress

Sequence 3.

In the third sequence of impacts proposed, the focus is on the affectation on people's health and on the reduction of people's productivity while working due to increase temperature.

Hyperthermia provoked by heat stress directly impairs physical work capacity and tasks relying on complex cognitive functions or skilled motor performances (Ebi et al. 2021).

High heat stress can reduce physical work capacity and motor-cognitive performances, with consequences for productivity, and increase the risk of occupational health problems (Ebi et al 2021).

Workers exposed to elevated environmental heat will typically reduce their work output, taking more unplanned breaks or working at a slower pace than normal to adjust the overall occupational heat stress (ibid).

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Increased susceptibility due to activity nature

Many workers are repetitively exposed to daily occupational heat stress over extended periods, thereby making them more susceptible to both acute and chronic effects of heat strain (Ebi et al 2021)

For outdoor workers, high metabolic heat production associated with occupational tasks combined with high ambient and radiant heat, low air flow, and sometimes high humidity, add to human heat strain (Ibid)

Workers following a fixed or externally dictated pace (eg, buckets per h) or piecemeal will face higher heat strain than those workers who are free to self-pace (ibid).

↓

Affected people's livelihoods and social determinats of health

Heat exposure undermines people's livelihoods and the social determinants of health by reducing labour capacity (van Daalen et al. 2023).

↓

Increased mental stress

Sequence 4

In the fourth sequence, the focus is on people's health as being affected by the increased risk of car, bike, and pedestrian accident due to mental stress and reduced performance of infrastructure. This sequence of impacts includes also the pressure exerted on the capacity of operators to keep pace with worsening infrastructure.

Surface overheat resulting from prolonged-extreme temperatures.

Accelerated deterioration of roads and railways

Future temperature increases are projected to reduce infrastructure lifetime and increase road costs (Jacobs et al 2014). Elevated temperature, combined with increased salinity and humidity, accelerates deterioration in bridges and roads constructed with concrete (Ibid).

Damaged in rail tracks, cracks in roads

High temperatures can lead to infrastructure damage, affecting roads with issues like deformation and asphalt melting, resulting in unsafe conditions and increased maintenance costs (Slavich et al. 2022).

Elevated temperatures along with the increased occurrence of hot summers, is expected to contribute to a higher frequency of rail buckling incidents posing risks for train travel (Jaroszweski et al. 2014).

Increased maintenance cost

Higher ambient temperatures and extreme heat events can negatively impact pavement performance and, in turn, increase costs due to material upgrades to accommodate higher temperatures (Jacobs et al. 2014)

Increased maintenance costs and rapid maintenance planning increases presure on transport planners, operators, emergency services (ibid)

Reduced frequency of maintenance

As costs due to material upgrades to accommodate higher temperatures increase; these costs are only modestly reduced by less frequent maintenance (Jacobs et al. 2014).

However, as roads deteriorate more rapidly, the need for maintenance work during the summer season increase, exposing workers to working under extreme temperature conditions (ibid).

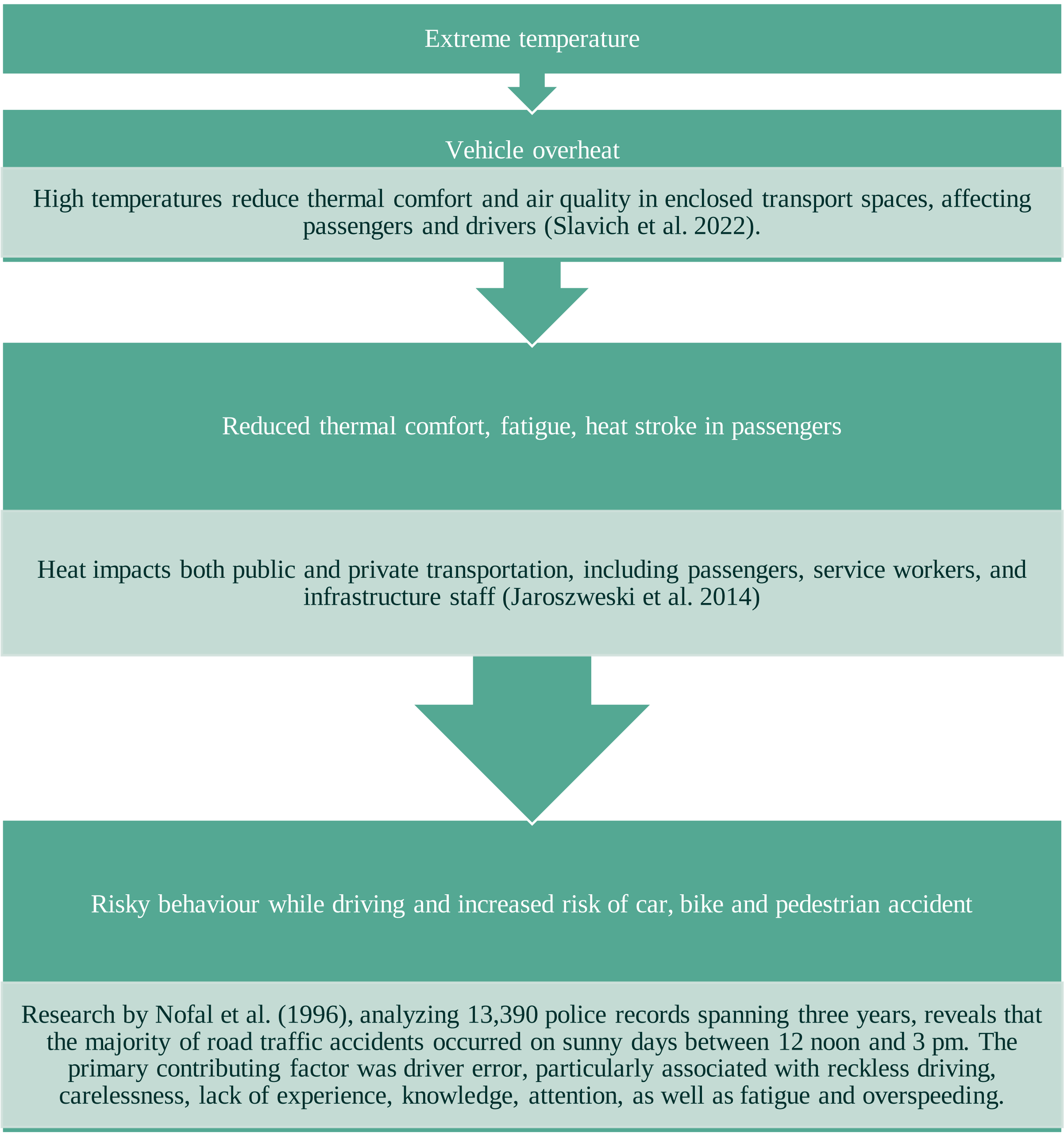
Safety and function reduced

Higher ambient temperatures and extreme heat events can negatively impact pavement performance; Buckled roadway joints can send vehicles airborne (Jacobs et al. 2014)

Increased risk of car & bike & pedestrian accident

Sequence 5.

In the fifth sequence of impacts proposed, the focus is on the risk of accidents as people are affected by physical discomfort and mental stress while driving and commuting due to high temperatures, resulting in more risky behaviour. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented in figure 5, below.



Sequence 6: Reduced water availability affecting urban ecosystems and economic activities.

Increase in temperature

Increased demand for water for urban ecosystems and economic activities

Warmer temperatures result in larger demands for water in many cities, particularly for household consumption and thermoelectric cooling. Extreme heat waves, which are projected to become more common and severe in the future, typically lead to disproportionately elevated demands for water (Vicuña et al. 2018). Warming-induced declines in snowpack, glaciers, and less seasonally persistent snowpack (e.g., earlier snowmelt) are expected to change the timing of water availability. This alters the natural storage of water from cooler seasons with low water demands to warm seasons when demands are commonly highest. This is expected to challenge water management systems (Vicuña et al. 2018).

Increased conflicts due to water use

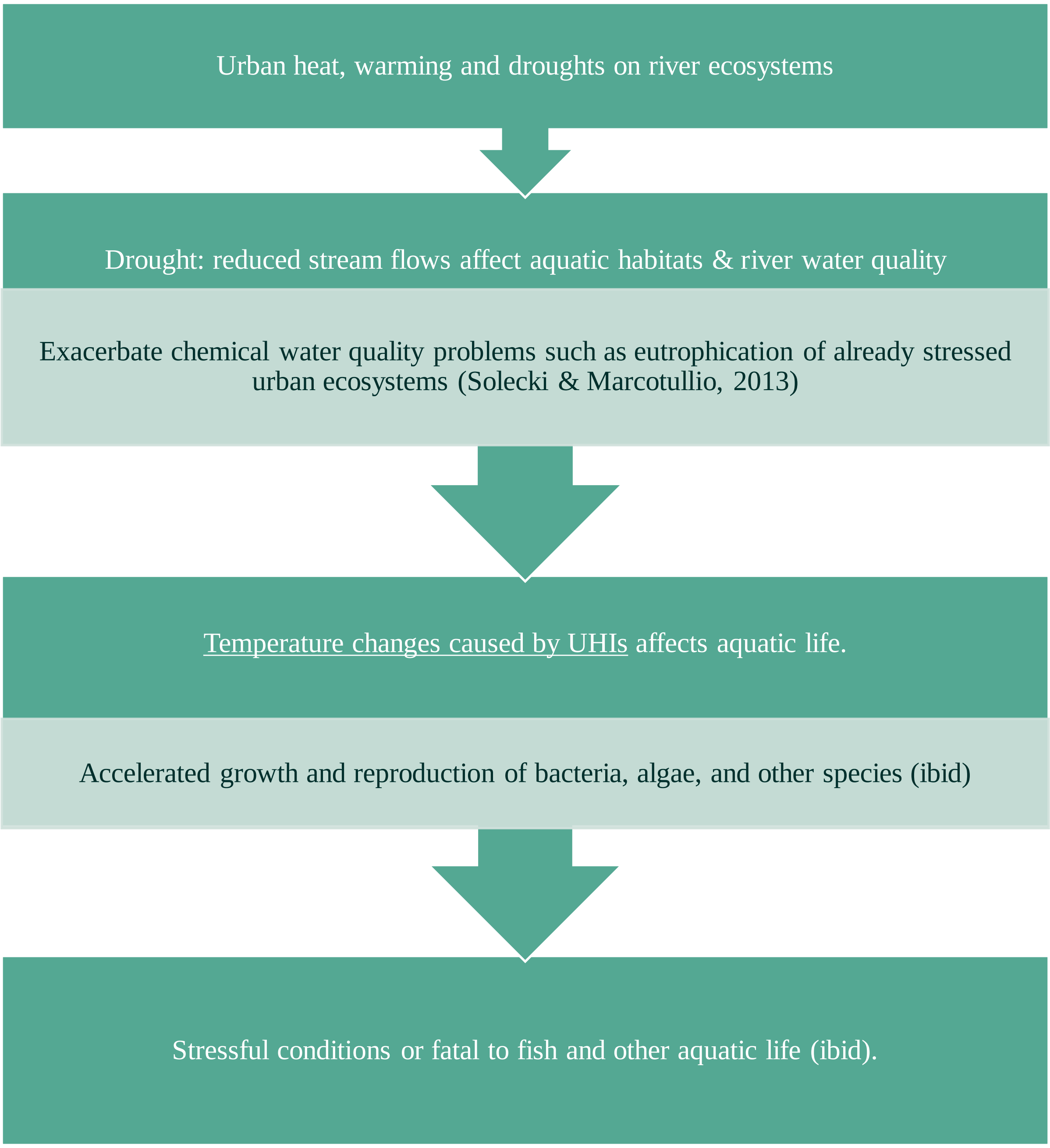
Reduced access to water due to extreme weather events and gradual climate change can cause competition between sectors such as the urban environment (drinking water), agriculture (irrigation), energy (electricity generation) and tourism (drinking water and water-intensive activities). Competition for water resources with irrigation infrastructure can also reduce the sustainability of ecosystem services, including in forests.

Climatic pressures will interact at different spatial scales to have a synergistic impact on water availability, on water quality, infrastructural integrity, arrangements among competing users, and strength of institutions (Vicuña et al. 2018).

Affected ecosystems and economic activities

Sequence 7: Drought and urban heat on river ecosystems

In the seventh sequence of impacts proposed, the focus is on the degradation of aquatic habitats provoked by urban heat, warming and droughts.



Sequence 8: Ecosystem degradation

In the eighth sequence of impacts proposed, the focus is on the degradation of urban ecosystems due to extreme temperatures and the loss of cooling spaces for people during extreme heat.

Urban heat and warming

Climate change is already impacting urban biodiversity and ecosystems (Rosenzweig et al. 2015). The combination of climate change and urbanization (i.e., increased patch fragmentation and diversity), is expected to heighten the vulnerability of biodiversity hotspots, urban species, and essential ecosystem services (Luck & Wu, 2002)

Improved conditions for pests

Changing climate may also affect the introduction of new species in urban ecosystems by reducing noninvasive and native species while favoring weedy and urban-adapted species (Rosenzweig et al. 2015).

Winter warming and absence of cold waves will benefit certain species of insect pests and diseases that are sensitive to prolonged periods of cold (Solecki and Marcotullio 2013).

Changes in species distribution and promotion of invasive species

Ultimately, changes in species distributions are expected to modify the ecological interaction networks in cities and have the potential to promote invasive species, which could accelerate the loss of urban biodiversity (Kendal et al., 2012)

Changing speed and onset of diseases

Climate shifts can adjust the speed of onset of emerging diseases and other pathogens and alien/invasive species entering the extended regions around cities (Solecki and Marcotullio 2013).

Increased affectation on specialised species

Species that are highly specialized and heat sensitive may be threatened with local extinction driven also by an inability to move to new areas as urban development expands (Rosenzweig et al. 2015).

Increased herbivory of urban trees

Urban trees could face greater herbivory in the future as a consequence of the increased fitness of some herbivorous arthropods under warming scenarios. However, more research is needed to generalize these results to more urban areas (Rosenzweig et al. 2015).

Degrarded ecosystems

As a result of the interconnectedness between ecosystem well-being and ecosystem services, growing ecological stress diminishes the quality and quantity of ecological services (Cairns and Pratt, 1995).

Reduced options to escape heat

Sequence 9: Urban heat on ecosystem population dynamics and forage availability

In the nineth sequence of impacts proposed, the focus is on the changing population dynamics and forage availability provoked by extreme heat.

Extreme heat affects species dynamics

Changing population dynamics

The UHI effect in cities can change the reproductive and population dynamics of animals (Rosenzweig et al. 2015)

Insect life cycles and migration patterns have been well-documented, with changes in the life cycle of certain insects having already occurred in response to urban warming (Parmesan, 2006; Parmesan and Yohe 2003).

Change resource availability

Climate shifts will impact the resources available to urban wildlife including insects, birds, and other larger animals by changing the quantity, quality, and timing of forage for animals (Solecki and Marcotullio 2013).

Forest tree species shifts, such as the decline in one species to be replaced by another better suited to the likely warming and moisture-limiting climate-, could result in an important loss of forage for one or more animal species (Solecki and Marcotullio 2013).

Changes in species competition and pest management regimes

The shifts in forage and in species composition will result in changes in species competition and pest management regimes (Ibid).

Sequence 10: Increased water- and food-borne disease

In the tenth sequence of impacts proposed, the focus is on the shifting the environmental suitability for the transmission of various infectious diseases due to extreme temperatures.

Changing environmental conditions shift the environmental suitability for the **transmission of various infectious diseases**.

An increasing percentage of coastal waters in Europe are showing suitable conditions for the transmission of pathogenic non-*cholerae Vibrio*, the climatic suitability for the transmission of dengue increased by 30% in the past decade compared with the 1950s, and the environmental risk of West Nile virus outbreaks increased by 149% in southern Europe and 163% in central and eastern Europe in 1986–2020 compared with 1951–85. West Nile virus has emerged in the Americas and expanded in Europe, where it is becoming a public health concern (Hajat et al. 2010).

↓

Increased transmission

Vector-borne disease incidence is influenced by temperature and precipitation, which can affect the range, prevalence, and reproductive cycle of disease vectors, among other determinants (Hajat et al, 2010).

Transmission season for dengue combining information on temperature, rainfall, mosquito abundance, and human population density in the period 1986–2020 has increased by 17·3% in Europe compared with 1951–1985. This pattern is also observed for chikungunya and Zika virus. The greatest upward shift in transmission season is observed in central eastern Europe, with a gain of about 0,2 suitable months for dengue (van Daalen et al 2023).

Dengue fever transmitters, the Aedes aegypti mosquito, can be easily found in regions of tropical and subtropical climate, having an ideal temperature of transmission of between 23°C and 27°C, although temperatures from 18°C can also trigger its transmission (Barata et al 2018)

↓

Changes in seasonal cycle and spatial distribution of vector-borne diseases

Climate change may lead to changes in the seasonal cycle and spatial distribution of some vector-borne diseases... it is also possible that optimal temperature conditions for certain vector species will be exceeded and thus potentially reduce the risk of infection, particularly under high warming scenarios (Barata et al 2018)

Warmer temperatures are also shifting flowering seasons of several allergenic tree species, with birch, olive, and alder seasons beginning 10–20 days earlier than 41 years ago, affecting the health of around 40% of the population in Europe who have pollen allergies (van Daalen et al 2023)

↓

Increased water- and Food-Borne Disease

Humans can be exposed to water- and food-borne pathogens through a variety of routes, including via the ingestion of polluted drinking water, consumption of contaminated food, inhalation of aerosols containing bacteria, and by direct contact with recreational or floodwaters. A number of pathogens that cause water- and food-borne illnesses in humans are sensitive to climate parameters, including increased temperature, changing precipitation patterns, extreme precipitation events, and associated changes in seasonal patterns in the hydrological cycle (Romanello, 2023).

IV. Exposure

Factor 1: Location

- To do with the closeness of lakes to the seaside in relation to the risk of salt intrusion (proposed during the workshop)

Factor 2: Physical conditions of built environment

- Urban environment and building structure play a vital role in determining the vulnerability of urban populations to heat stress, such as access to vegetation and green space, development intensity, living on a high floor of multi-storey buildings, building materials, land cover and housing density (Puntub et al 2022).
- High building density and a lack of urban green and water spaces determine the adverse bioclimatic evaluation of urban environments (Richter 2015).
- Urban temperatures are enhanced by anthropogenic heat from vehicular transport, heat emitted from building energy waste (Ebi et al 2021).
- Urban heat island can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning, inducing also earlier spring-time flowering in urbanized areas compared to surrounding rural areas (Richter 2015).

Factor 3: Time and timing of exposure

- The timing of exposure, encompassing distinct exposures during daytime and nighttime, gives rise to varied risks among different demographic groups. As highlighted in the workshop session, individuals may have access to cooler environments, such as shopping centres or swimming pools during the day. Conversely, during the night, individuals are often confined to their residences, occasionally lacking the necessary cooling amenities for comfort. This situation may pose additional challenges for individuals living alone and facing mobility issues, particularly the elderly.
- Overall, the number of hours of risk per person is increasing across all European regions. In southern Europe, the number of hours with heat-related health risks during medium-intensity activities (e.g., football or tennis) increased relatively by 106% between 1990 and 2020 and increased to 429 hours per person in 2020. For strenuous activities (e.g., mountain biking), there was a relative increase of 77% in southern Europe, leading to 627 hours at risk per person in 2020 (van Daalen et al. 2022).
- Equipment operators and road builders can be exposed to hight temperatures for long periods (maintenance and building staff working in hot weather may experience intense fatigue) (Jacobs et al. 2014).
- People at bus stops exposed for long time periods (waiting at unsheltered transit stations during peak hours can lead to severe heat stress (Slavich et al. 2022).

Factor 4: Nature of activity (indoor – outdoor activity and timing of activity)

- For outdoor workers, high metabolic heat production associated with occupational tasks combined with high ambient and radiant heat, low air flow, and sometimes high humidity, add to human heat strain (Ebi et al 2021)
- Cyclists exposed to dehydration and heat strokes (pedestrians and cyclists might also suffer from heat stress and health problems, potentially shifting to public transit or avoiding travel if they can't use a private vehicle (Jaroszweski et al. 2014).

Exposure:

Resulting from this characterisation of exposure factors, the following table identifies the connection between the impact sequences with exposure factors:

Impact Sequence	Association to Exposure Factor
Sequence 1	1,2
Sequence 2	2,3
Sequence 3	2,3
Sequence 4	1,2,3
Sequence 5	3, 4
Sequence 6	1,2,3,4
Sequence 7	1,2
Sequence 8	1,2
Sequence 9	1,2
Sequence 10	1,2,3

V. Sensitivity

Climate change in urban areas will take place against the background of the trends in demography, economics, and governance that are shaping those areas. Existing vulnerabilities caused by poverty, lower levels of education, isolation can all aggravate climate change impacts (Dasgupta et al. 2014).

Factor 1: Demography

- UHI increases with city size and the number of inhabitants (Richter 2015).
- As urban populations steadily increase, larger numbers of people are at risk of heat stress in the built-up environment of cities (Richter 2015).

Factor 2: Pre-existing health preconditions

- Population exposure to heatwaves increased by 57% on average in 2010–19 compared with 2000–09, and by more than 250% in some regions, putting older people, young children, people with underlying chronic health conditions, at high risk of heat-related morbidity and mortality (van Daalen et al. 2022).
- Future susceptibility likely to be increased with ageing populations, (Hajat et al. 2010).
- Population ageing in Europe is a major demographic trend for the coming decades. It could further increase the effect on human beings of temperature extremes (Feyen et al 2020).
- Adults older than 65 years and infants younger than 1 year, for whom extreme heat can be particularly life-threatening, are now exposed to twice as many heatwave days as they would have experienced in 1986–2005 (Ebi et al. 2021).
- heat- related deaths of people older than 65 years increased by 85% compared with 1990–2000, substantially higher than the 38% increase that would have been expected had temperatures not changed (Hajat et al, 2010).
- Studies consistently show that adults older than 65 years, people with cardiopulmonary and other chronic diseases, and very young children are particularly vulnerable to the effects of heat, irrespective of income level or geo- graphical region (Ebi et al 2021).
- pre-existing physical conditions (such as cardio-vascular and cerebrovascular conditions and diabetes) or those related to mental health (such as depression) potentially leading to mortality and morbidity, age (particularly children and the elderly) (Puntub et al 2022)
- Rates of heat-related mortality and morbidity are high in elderly and chronically ill individuals, particularly those with cardiovascular, respiratory, and renal diseases. People with diabetes, neurological disorders, and psychiatric illnesses might also be at increased risk (Hajat et al, 2010).

Factor 3: Economic status and social capital

- Household income, poverty, unemployment, social isolation, social cohesion, household structure, gender, education attainment, language proficiency, race, house-ownership and more (Puntub et al 2022).
- Social isolation and little mobility were identified as key risk factors during heatwaves. Other contextual risk factors include no access to an air-conditioned environment, living in homes with high thermal mass and little ventilation, and living on the upper floors of high-rise buildings (Hajat et al, 2010).
- People who do not have adequate access to health care at high risk of heat-related morbidity and mortality (van Daalen et al. 2023).
- increased mortality during heat extremes is associated with being confined to bed, living alone, being unable to care for oneself, not leaving the residence to cool down their body temperature, and having a pre-existing mental health condition (Ebi et al 2021).
- The highest risk of death during heatwaves were confinement to bed; pre-existing psychiatric illness; not leaving home every day; and an inability to care for oneself (Hajat et al, 2010).
- Risk of water-borne illness is greater among the poor, infants, elderly, pregnant women, and immune-compromised individuals. Food/ water scarcities impact human health (Barata et al 2018).

Factor 4: Urbanisation

- increasing urbanisation could amplify the urban heat island effect, which causes urban and metropolitan areas to be significantly warmer than their surrounding rural areas (Feyen et al 2020)
- The combined effects of heatwaves and air pollution might further exacerbate human stress in densely populated areas (Feyen et al 2020)
- Urban areas are vulnerable to the health impacts of climate change due to their high population density, concentration of vulnerable populations, higher temperatures compared to surrounding areas (Barata et al 2018).

Factor 5: Behavioural factors: Use of alcohol and drugs

- The use of alcohol, medications, and illegal narcotics is associated with increased mortality during heat extremes. Many commonly prescribed medications, such as general anticholinergics, antidepressants, and opioids and illegal narcotics such as cocaine, might compromise physiological heat loss responses (Ebi et al 2021)
- The magnitude and pattern of future heat-related morbidity and mortality will depend on climate change and other important factors such as population growth and ageing, urbanisation trends, adaptation efforts, and development choices (Ebi et al 2021).
- Some drugs, notably diuretic, psychotropic, and anticholinergic drugs, have been implicated in increasing the risk of heat-related death or illness (Hajat et al 2010).

Factor 6: Ecosystem-related factors

- **Rate of urban growth:** Urban ecosystems face unique stressors, leading to heightened exposure to hazards such as high population density, the influence of non-climate-related stressors, and the urban heat island (UHI) phenomenon (Farrell et al., 2015).
- **Expansion of impermeable surfaces**: One of the most significant alterations impacting urban streams is the proliferation of impervious surfaces. This transformation modifies the hydrological dynamics and channels pollutants that accumulate from buildings, roadways, and parking lots into the streams (Grimm, et al. 2008).
- **Water availability**: The issue of urban water security remains an ongoing challenge, particularly in lower-income countries. Many cities face difficulties in providing essential services to their residents, especially those residing in informal settlements. As cities continue to expand, the demand for limited water resources will grow, and the effects of climate change are poised to exacerbate these challenges in numerous urban areas (Rosenzweig et al. 2015).
- **Tree species composition**: Certain "urban-adapted" species flourish in urban environments globally, often outcompeting indigenous species and becoming prevalent at local and regional levels. While various ecological and socioeconomic factors impact vegetation in urban areas, a significant portion of non-native invasive species that thrive in cities originate from warmer regions, benefiting from shifting climate conditions (Sukopp & Wurzel, 2003).

Factor 7: Continuity of functioning of critical infrastructure

- Many health hazards associated with extreme climate events in urban areas operate through disruptions in critical infrastructure. Lack of electricity can make it difficult or impossible to control the interior climate, refrigerate food, physically move about in high-rise buildings, pump water to upper floors, and operate medical support equipment. While a lack of air conditioning in homes increases the risk of heat-related death, air conditioning also contributes to higher power demand during heat waves, which increases the risk of power disruptions and blackouts. When blackouts occur, exposure to heat increases, with a corresponding increase in health risks (Barata et al 2018).

Sensitivity factors for Burgas

Based on the impact-sequences previously characterised, a few sensitivity factors have been associated to each sequence, as shown below. This association explains that risks can be exacerbated when particular conditions (sensitivity factors) come and interplay with specific impact factors.

Sequence	Association to sensitivity factor
Sequence 1	1,4,6
Sequence 2	1,2,3,4,5,7
Sequence 3	1,2,3,4,5,7
Sequence 4	2,3,4,7
Sequence 5	1,2,5
Sequence 6	1,2,3,4,5,6,7
Sequence 7	4,6
Sequence 8	2,4,6
Sequence 9	4,6
Sequence 10	2,4,6

VI. Adaptive Capacity

Adaptive capacity is normally determined in terms of knowledge, financial resources, technologies, legislations and infrastructures that enable people to adapt to the effects of climate change.

Factor 1. Resources

- Provision of air conditioning, increasing urban vegetation, accessibility to medical services and insurance, and accessibility to nearby public heat refuges as crucial (Puntub 2022)
- Financial options for refurbishment (identified during workshop)

Factor 2. Spatial planning

- Spatial planning influences the spatial configuration, type and degree of development of buildings and land use, as well as landscapes and green spaces (Richter 2015).
- Improved design and insulation of houses, schools and hospitals, sound urban planning (increasing tree and vegetative cover, installing green or reflecting roofs, or using cool pavements) (Feyen et al 2020)
- Building codes (Hajat et al 2010)
- Implementation of thermal regulations (identified during workshop)

Factor 3. Policy public health

- Focus on identifying and informing effective and cost-efficient public health and climate change adaptation and mitigation interventions; on monitoring these interventions to reduce health burdens and inequities; promote and facilitate the active involvement of young people and minoritised groups in identifying health and climate change solutions that minimise or eliminate health inequities (Hajat et al 2010)
- Public health protection measures, with the timely provision of appropriate home-based prevention advice to the general public (Hajat et al 2010).
- Heat health warning systems that trigger community alerts and emergency actions in response to forecasts of adverse weather conditions. Because heat- related illness is largely avoidable, the most crucial point of intervention concerns the use of appropriate prevention strategies by susceptible individuals and their carers. Although such home-based prevention advice already forms an integral part of many heat health warning systems, the extent to which the advice is based on medical evidence is unclear. Knowledge of effective prevention and first-aid treatment, besides an awareness of potential side- effects of prescription drugs during hot weather, is crucial for physicians and pharmacists (Hajat et al 2010).
- Upgrading health infrastructure, improving the capacity of health workforces, enhancing disease surveillance and conducting health-specific vulnerability and risk assessments (United Nations Environment Programme, 2023).
- Multisectorial cooperation (identified during workshop)

Factor 4: Public policy in transport sector

- Transport systems should be operated by adaptive organizations, which embed adaptation across all functions, understand current and future weather conditions and have strategies in place to address them (Black et al. 2021).
- Improving adaptive capacity involves assessing design capability, financial capability, and organizational capability to respond to climate change risks. For instance, transport planners and operators adhere to design standards that consider specific temperature and precipitation ranges and return intervals for extreme events (Black et al. 2021).
- Nonetheless, these standards are becoming less applicable over the extended lifespan of infrastructure investments, particularly for durable structures such as bridges and roads, underscoring the necessity for comprehensive asset lifecycle planning in climate adaptation endeavours (Black et al. 2021).

- Time flexibility for commuting (identified during workshop)
- Multisectorial cooperation (identified during workshop)

Factor 5: Public policy urban ecosystem

- Conserving, restoring, and expanding urban ecosystems to enhance climate resilience and other co-benefits under mounting climatic and non-climatic stresses of growing urbanization and development processes will require improved urban and regional planning, policy, and governance and multi-sectorial cooperation to protect and manage urban ecosystems and biodiversity (Solecki and Marcotullio, 2013).
- Also, greater coordination and networks among governance structures that manage local ecosystems and urban biodiversity, including cemeteries, golf courses, urban parks, and neighbourhood gardens, would strengthen ecosystem functioning as well as the associated and essential social-ecological engagement (Ernstson et al., 2010).
- The adaptive capacity of species in urban landscapes is a function of ecology, physiology, and genetic diversity (Williams et al., 2008).
- In the context of urban biodiversity and ecosystems, nonhuman actors, behaviour, species interactions, and human–ecological interventions are also important for adaptive capacity. For example, human-induced adaptive capacity could include planting species that are more tolerant of higher temperatures and droughts. Nonhuman-derived adaptive capacity could include natural processes that change ecosystem components rapidly for organisms like insect populations persisting despite changing climate (Rosenzweig et al. 2015)
- Multisectorial cooperation (identified during workshop)

Factor 6. Education, awareness, and stakeholder engagement

- Education and awareness raising of potential risk factors and recommended responses (Feyen et al 2020)
- Skill preparation of public officials (identified during workshop)
- Vector-borne and infectious diseases: Epidemiologists (to identify changes in infection rates), hospitals (to respond to public health emergencies and treat patients), and social workers and local community members and groups (to help identify vulnerable populations and respond to environmental health needs) (Barata et al 2018)
- Heat-related illnesses (including stroke, respiratory and cardiovascular distress): Local municipalities' decision-makers (to develop and implement heat-health warning and response policies), the media (to alert the public to extreme heat events and locations of cooling centers), and independent power producers and utilities (who provide electricity for cooling and maintain infrastructure) (Barata et al 2018)
- Water quality and water-borne diseases: Emergency preparedness organizations (first responders for flood events), municipal planning departments (to upgrade sewer and drainage systems), and water management departments (to detect changes in water quality)
- Air quality, asthma, allergies: Meteorology services, air quality managers, public health and/or medical schools, NGOs and research scientists (to conduct research on air quality and health impacts), private sectors (who may contribute to GHG emissions but may also

produce valuable products, including medications for respiratory distress) (Barata et al 2018)

Sequence	**Association to adaptive capacity factor**
Sequence 1	2,4
Sequence 2	1,2,3
Sequence 3	1,2,3
Sequence 4	1,2,4
Sequence 5	2,4,6
Sequence 6	1,2,3,5
Sequence 7	2,5,6
Sequence 8	1,2,3,5,6
Sequence 9	1,2,5
Sequence 10	1,2,5

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Annex 12. Climate Impact chain Gabrovo

I. Introduction

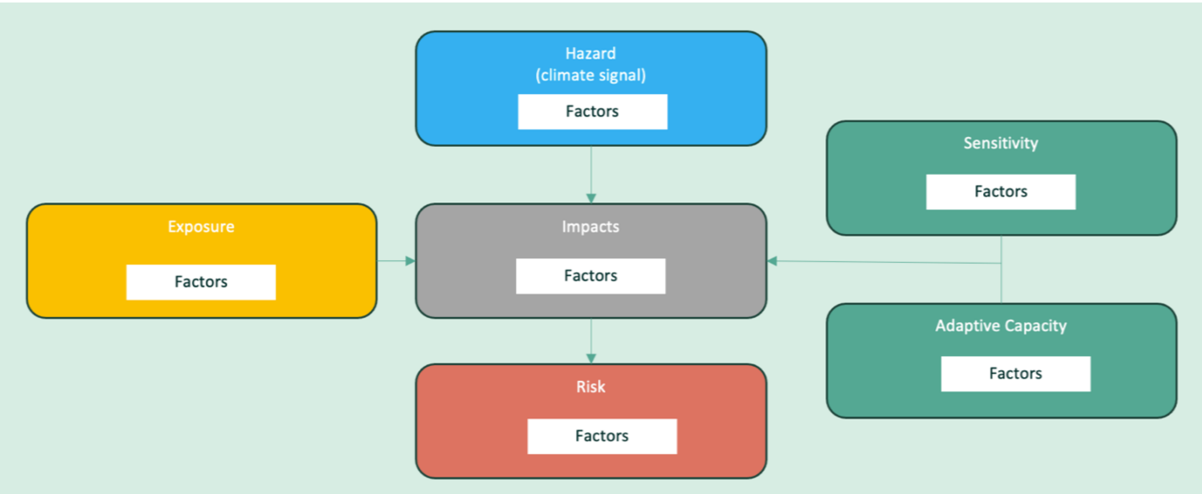
The Climate Impact chain for the region of Gabrovo in the context of the Valorada-EU project, focuses on the risk of increasing temperature and droughts affecting forests and urban ecosystems, as well as people's health status. The climate impact chain has been developed in two stages. Firstly, a participatory workshop including regional representatives took place in January 2024 in Gabrovo. The CIC was then revised, complemented and reconstructed based on a literature review. This report presents the interim climate impact chain to be reviewed by Municipal officials as well as consortium partners Takt. Based on the provided feedback a revised climate impact chain will be delivered.

Climate-impact chains

A climate-impact chain delineates the connection between a specific climate hazard and a designated impact area. These chains aim to elucidate cause-and-effect relationships within various components of a system. By defining these relationships, impact chains ascertain how a hazard transforms into a risk, factoring in exposure, potential intermediate impacts, sensitivity factors, and response/adaptation capacities that mitigate vulnerability. In cases where applicable, intermediate impacts can be identified, each with its exposure, sensitivity, and adaptation factors (GIZ and EURAC, 2017).

A chain is composed of risk components (hazard, vulnerability, exposure) and underlying factors associated to each component. A climate signal, e.g. a heavy rain event, may lead to a direct physical impact, e.g. a flood, causing a sequence of intermediate impacts, which finally lead to the risk. The hazard component includes factors related to the climate signal and direct physical impact. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised by one or more exposure factors (GIZ and EURAC, 2017).

Figure 1: Composition of a Climate Impact Chain (GIZ and EURAC, 2017)



II. Climate Hazards in Gabrovo

Climate hazards are defined as the potential occurrence of a climate-related event, trend or physical impact that may cause loss of life, injury, damage and loss of infrastructure, livelihoods, service provision, ecosystems (Rosenzweig et al. 2015). The climate hazard discussed in this Climate impact chain is the increase in temperature and droughts in Gabrovo.

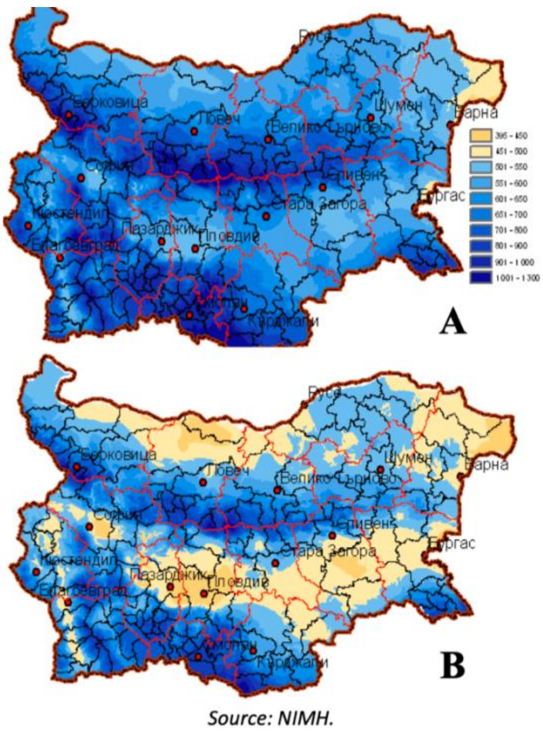
Climate projections:

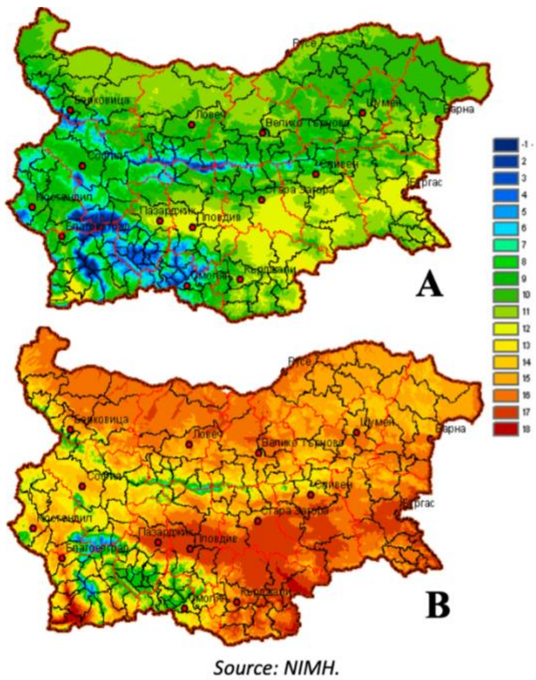
According to Bulgaria's 8th National Communication (2022), climate Scenarios for the 2080s and end of 21 Century show significant summer warming in the western Balkan countries. Air temperatures during this time of the year are expected to increase between 5° and 8°C over most of the countries in the peninsula. Summer precipitation is projected to decrease in the region of interest.

Figure 2: Projections on temperature and precipitation for Bulgaria

Precipitation per Year for 1961–1990 (A) Precipitation per Year for 2080, According to the Pessimistic Scenario (B)

Average Year Temperature for 1961–1990 (A); Pessimistic Climate Scenario for Average Year Temperature for 2080 (B)





Source: Bulgaria's 8th National communication (2022)

III. Climate risks in Gabrovo

Climate risks are defined as the potential for consequences where something of value is at stake and where the outcome is uncertain (Rosenzweig et al. 2015). During the workshop, regional representatives of the Gabrovo administration decided to attend the risk of increasing temperature and droughts affecting forests and urban ecosystems, as well as people's health status.

In order to convey a clearer picture of how environmental and social factors interact and generate risks, this report adopts the perspective of environmental and social determinants of health.

- **Social determinants of health**, which include "the unequal distribution of power, income, goods, and services, globally and nationally, the consequent unfairness in the immediate, visible circumstances of peoples lives' – their access to health care, schools, and education, their conditions of work and leisure, their homes, communities, towns, or cities – and their chances of leading a flourishing life" (Commission on Social Determinants of Health, 2008).
- **Environmental determinants of health,** which include "… all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours … targeted towards preventing disease and creating health-supportive environments (including clean air and water, healthy workplaces, safe houses, community spaces and roads and managing climate change) (WHO 2014).

Key risks aspects:

- Urban warming deteriorates environmental and social determinants of health, causing direct threats to people's health status.
- Deteriorating social determinants of health highlight issues of social justice as shed light on people's limited private resources and capacities to cope with high temperatures.
- Urban ecosystems play a crucial role in natural capital for climate change adaptation and mitigation (Rosenzweig et al. 2015); while at the same time, urban habitats contribute to the well-being of urban residents (Solecki & Marcotullio, 2013). Climate change and the urban heat island (UHI) effect impact ecosystem services and green infrastructure by causing shifts in temperature and precipitation patterns, evaporation rates, humidity levels, soil moisture content, vegetation growth rates, water tables, aquifer levels, and air quality (Solecki & Marcotullio, 2013). These changes can bring about cascading effects that further affect urban ecosystems (Frumkin et al., 2008; Keim, 2008).
- In consideration to vulnerabilities and exposure, impacts are perceived differently through society. However, the impact chains reveal how some impacts may be more prominent at different times (difference between day and night highlighted). This is particularly relevant for the impacts related to the Heat Island Effect.

Understanding risks: What is distinctive about urban warming in the context of people's health status?

- The frequency, intensity, duration, and spatial extent of some extreme weather events, particularly heat waves, has been increased by climate change, with further increases projected (Richter, 2016).

- Intense heatwaves in Europe are expected to happen more frequently and become more intense with climate change. With 1.5°C, each year more than 100 million Europeans would be exposed to a present intense heatwave (Feyen et al 2020).
- Climate change is interacting with other trends, such as population growth and ageing, urbanisation, and socioeconomic development, that can either exacerbate or ameliorate heat-related hazards (Ebi et al 2021).
- Vulnerability to heat exposure has increased steadily across all European regions, with an increase of 6% from 1990 to 2019 (van Daalen et al 2022)
- Assuming present vulnerability and no additional adaptation, annual fatalities from extreme heat could rise from 2,700 deaths now to nearly 30,000 with 1.5°C global warming, 50,000 with 2°C and 90,000 with 3°C (Feyen et al 2020).
- Urban temperatures are enhanced by anthropogenic heat from vehicular transport, heat emitted from building energy waste, and minimally by human metabolic heat (Ebi et al 2021).
- Urban heat island (temperature difference between inside the city and outside it) can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning, inducing also earlier spring-time flowering in urbanized areas compared to surrounding rural areas (Richter 2015).
- Climate change and the urban heat island (UHI) effect impact ecosystem services and green infrastructure by causing shifts in temperature and precipitation patterns, evaporation rates, humidity levels, soil moisture content, vegetation growth rates, water tables, aquifer levels, and air quality (Solecki & Marcotullio, 2013). These changes can bring about cascading effects that further affect urban ecosystems (Frumkin et al., 2008; Keim, 2008).

Understanding risks: Climate change and urban ecosystems

- Urban ecosystems, known for their biodiversity, play a crucial role in natural capital for climate change adaptation and mitigation (Rosenzweig et al. 2015); while at the same time, urban habitats contribute to the well-being of urban residents (Solecki & Marcotullio, 2013).
- However, climate change is already impacting urban biodiversity and ecosystems (Rosenzweig et al. 2015). The combination of climate change and urbanization (for example, through increased patch fragmentation and diversity), is expected to heighten the vulnerability of biodiversity hotspots, urban species, and essential ecosystem services (Luck & Wu, 2002).
- Virtually all climate change effects have direct or indirect repercussions for urban ecosystems, biodiversity, and the vital ecosystem services that enhance human health and well-being in cities (Rosenzweig et al. 2015). For example, climate change will increase the susceptibility and vulnerability of urban ecosystems to various geohydrological threats, such as diminished groundwater and aquifer quality, subsidence, and intensified salinity intrusion (Praskievicz & Chang, 2009).

- Furthermore, as a result of the interconnectedness between ecosystem well-being and ecosystem services, growing ecological stress diminishes the quality and quantity of ecological services (Cairns and Pratt, 1995).
- Climate change and the urban heat island (UHI) effect impact ecosystem services and green infrastructure by causing shifts in temperature and precipitation patterns, evaporation rates, humidity levels, soil moisture content, vegetation growth rates, water tables, aquifer levels, and air quality (Solecki & Marcotullio, 2013). These changes can bring about cascading effects that further affect urban ecosystems (Frumkin et al., 2008; Keim, 2008).

Understanding risk: What is distinctive about increasing temperatures and droughts in the context of wildfires, ecosystems and habitats loss?

- Forest fires, like all other ecosystem processes, are highly sensitive to climate change, as fire behaviour responds immediately to fuel moisture, which in turn is affected by precipitation, relative humidity, air temperature and wind speed. The projected rise in temperature as a result of climate change should therefore increase fuel dryness and reduce relative humidity, more markedly in those regions where rainfall will decrease. The increased frequency of extreme climate events is expected to have a significant impact on the vulnerability of forests to fires (B8NC, 2022).
- Human-caused climate change is causing profound changes in global fire regimes through changes in fire season length, fuel moisture, fire intensity and fire severity. Climate plays a role in determining the fuel available to burn, the length of the fire season as well as the presence of lightning, which is the most common natural source of ignition (Chuvieco et al. 2023)
- Climate change threatens to increase the frequency and length of the wildfire season, as well as the size and extent of large fires (Gowda et al. 2018)

Understanding risk: what is distinctive about increasing temperatures and droughts in the context of nature conservation in Bulgaria?

Bulgaria is a country of rich biodiversity. Its diverse physical geography and location on the border of different climatic and vegetation regions creates favorable conditions for the existence of nearly 41,493 plant and animal species—26 percent of European species, including 25 percent of those in the Red Book of Europe. NATURA 2000 sites, which occupy 34.4 percent of the territory, and protected areas with a range of 584,569.19 ha or 5.3 percent of the country's area, are dedicated for their conservation (Bulgaria's 8th National communication, 2022). Manifestations of climate change are expected to have different impacts on different types of ecosystems and affect biodiversity and ecosystem services in a range of ways including in an abrupt and even catastrophic manner:

  - **Loss of genetic diversity**. Genetic diversity is subject to threats posed directly by climate change on vulnerable/endangered species (including endemic species with a limited range and opportunities for migration) that may be lost forever (Bulgaria's 8th National communication, 2022).

- **Disruption of species lifecycles and phenological phases.** Climate change can affect the life cycles and breeding periods of species, within ecosystems, to affect populations and processes in the ecosystem (food chains and competition for resources), including by invasion of invasive species which compete with native species and replace them from traditional niches, therefore, changing the ecosystem's integrity (Bulgaria's 8th National communication, 2022).
- **Deterioration of habitats.** The possible consequence of climate change is the deterioration of habitats in the categories of critically endangered, endangered, vulnerable, and nearly threatened as included in the Red Data Book of the Republic of Bulgaria, Habitats (BAS 2011). In particular, high-altitude habitats are vulnerable to these changes (Bulgaria's 8th National communication, 2022).
- **Impacts on the provision of ecosystems services.** A key risk is the regime shifts in the long term that may occur in the provision of ecosystem services (Bulgaria's 8th National communication, 2022).
- **The most vulnerable ecosystems** are the southern border forestry area as well as the other lowland areas of the country. The inland wetlands ecosystems, heathland and shrub ecosystems (especially in the alpine zone in mountains), and coastal zone ecosystems are also the most sensitive to climate change (Bulgaria's 8th National communication, 2022).

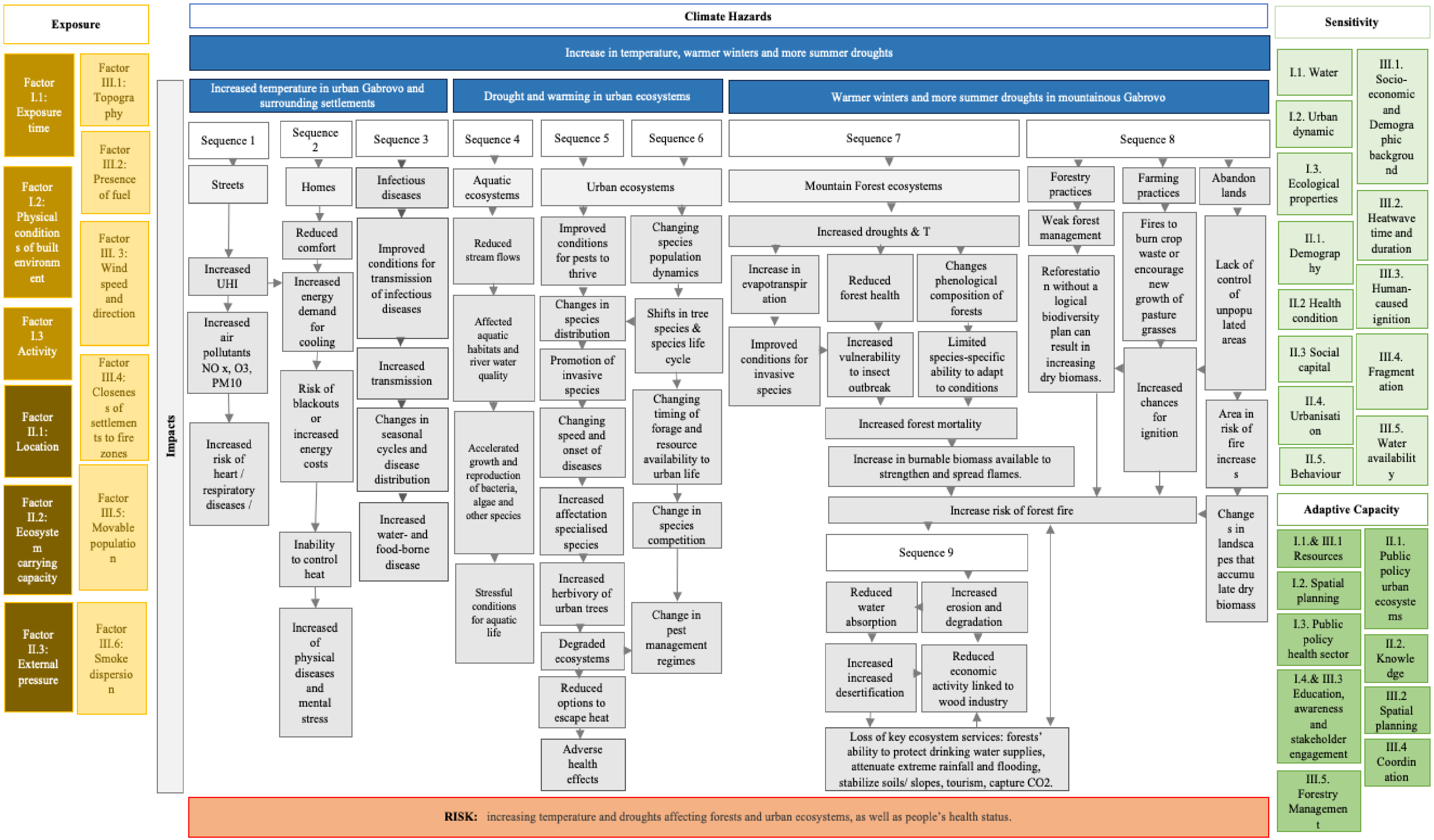
IV. Impacts

The impacts provoked by the increase in temperature and droughts affecting forests, urban ecosystems and people's health status in the Gabrovo region is connected through nine sequences of impacting factors:

- Sequence 1. Increase of air pollution
- Sequence 2. Impact of high temperatures at people's homes
- Sequence 3: Transmission of various infectious diseases
- Sequence 4: Drought and urban heat on aquatic ecosystems
- Sequence 5: Ecosystem degradation
- Sequence 6: Urban heat on population dynamics and forage availability
- Sequence 7. Increased drought and temperature inducing wildfires.
- Sequence 8. Forestry, farming, and social practices inducing wildfires.
- Sequence 9. Socio-economic and ecological impacts resulting from wildfires.

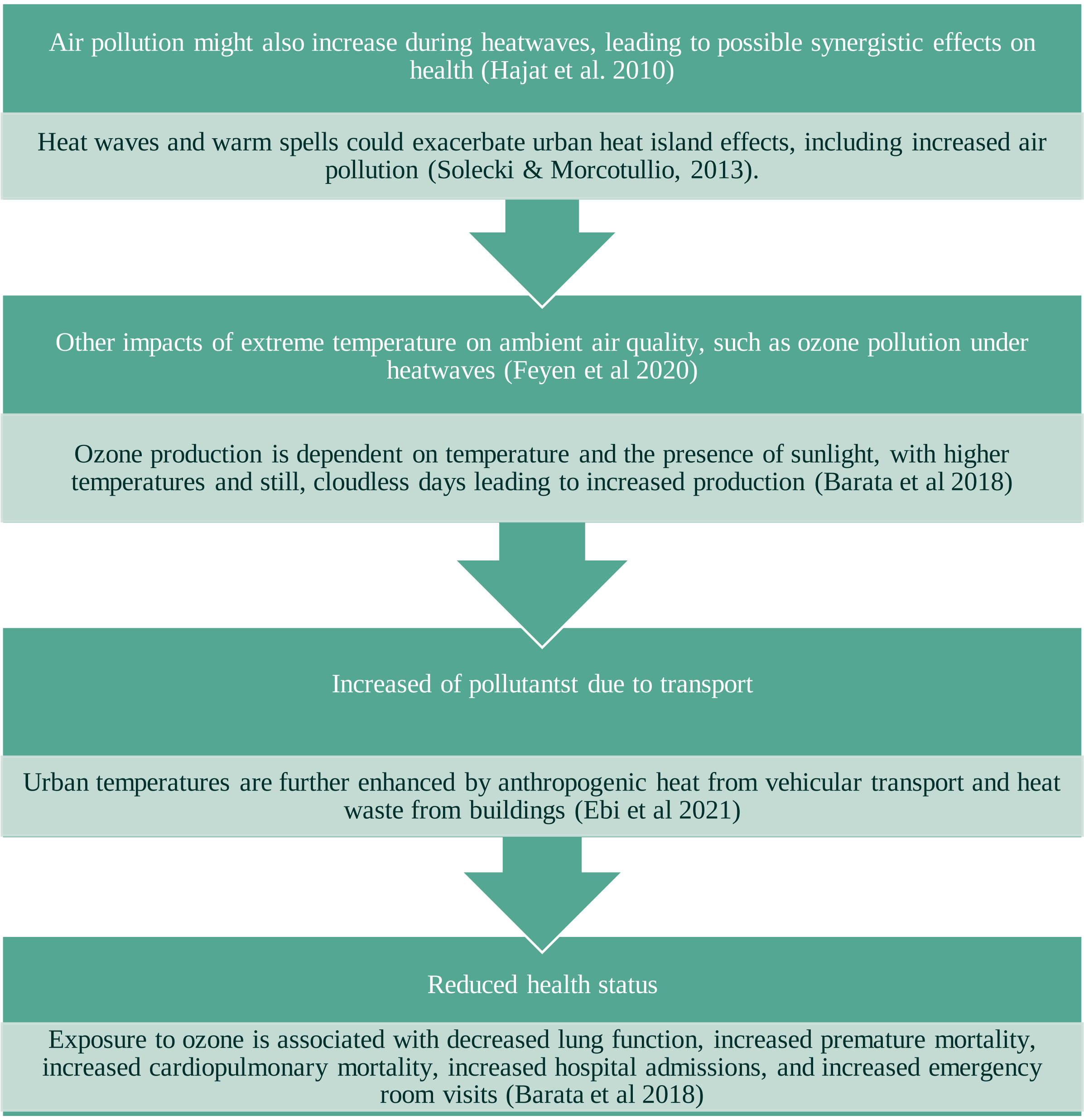
The full climate impact chain is presented below in figure 3.

Figure 3: Climate Impact Chain for the region of Gabrovo



Sequence 1. Increase of air pollution

In the first sequence of impacts proposed, the focus is on the increase of air pollution as provoked by urban warming and related health effects.



Sequence 2. Impact of high temperatures at people's homes

In the first sequence, the focus is on people's health being affected by the increased temperatures in their private households.

Generation of Urban Heat Islands

One consequence of urban development is the urban heat island (temperature difference between inside the city and outside it) that results in cities being, on average, warmer than adjacent rural landscapes (Ebi et al 2021)

Difficulties to escape heat at night time

The urban heat island is amplified at night when stored daytime heat is emitted and intensified with increasing city size and population density (Ebi et al 2021)

Increasing energy demand threatens cooling devises

Urban heat island can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning (Richter 2015).

An approach focusing on air conditioning as a preventive measure for reducing heat-related morbidity and mortality is vulnerable to failure when the underlying infrastructure – the electrical grid – weakens or fails during a summer heat wave (Barata et al).

Increased affectation to vulnerable groups

Hot weather and heat extremes are associated with increased emergency room visits and hospital admittance, increased deaths from cardiorespiratory and other diseases, mental health issues, adverse pregnancy and birth outcomes, and increased health-care costs (Ebi et al 2021).

In Europe, population exposure to heatwaves increased by 57% on average in 2010–19 compared with 2000–09, and by more than 250% in some regions, putting older people, young children, people with underlying chronic health conditions, and people who do not have adequate access to health care at high risk of heat-related morbidity and mortality (van Daalen et al. 2023)

Worsening living conditions and increased mental stress

Sequence 3: Transmission of various infectious diseases

In the third sequence of impacts proposed, the focus is on the shifting the environmental suitability for the transmission of various infectious diseases due to extreme temperatures.

Changing environmental conditions shift the environmental suitability for the **transmission of various infectious diseases**.

An increasing percentage of coastal waters in Europe are showing suitable conditions for the transmission of pathogenic non-*cholerae Vibrio*, the climatic suitability for the transmission of dengue increased by 30% in the past decade compared with the 1950s, and the environmental risk of West Nile virus outbreaks increased by 149% in southern Europe and 163% in central and eastern Europe in 1986–2020 compared with 1951–85. West Nile virus has emerged in the Americas and expanded in Europe, where it is becoming a public health concern (Hajat et al. 2010).

↓

Increased transmission

Vector-borne disease incidence is influenced by temperature and precipitation, which can affect the range, prevalence, and reproductive cycle of disease vectors, among other determinants (Hajat et al, 2010).

Transmission season for dengue combining information on temperature, rainfall, mosquito abundance, and human population density in the period 1986–2020 has increased by 17·3% in Europe compared with 1951–1985. This pattern is also observed for chikungunya and Zika virus. The greatest upward shift in transmission season is observed in central eastern Europe, with a gain of about 0,2 suitable months for dengue (van Daalen et al 2023).

Dengue fever transmitters, the Aedes aegypti mosquito, can be easily found in regions of tropical and subtropical climate, having an ideal temperature of transmission of between 23°C and 27°C, although temperatures from 18°C can also trigger its transmission (Barata et al 2018)

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Changes in seasonal cycle and spatial distribution of vector-borne diseases

Climate change may lead to changes in the seasonal cycle and spatial distribution of some vector-borne diseases... it is also possible that optimal temperature conditions for certain vector species will be exceeded and thus potentially reduce the risk of infection, particularly under high warming scenarios (Barata et al 2018)

Warmer temperatures are also shifting flowering seasons of several allergenic tree species, with birch, olive, and alder seasons beginning 10–20 days earlier than 41 years ago, affecting the health of around 40% of the population in Europe who have pollen allergies (van Daalen et al 2023)

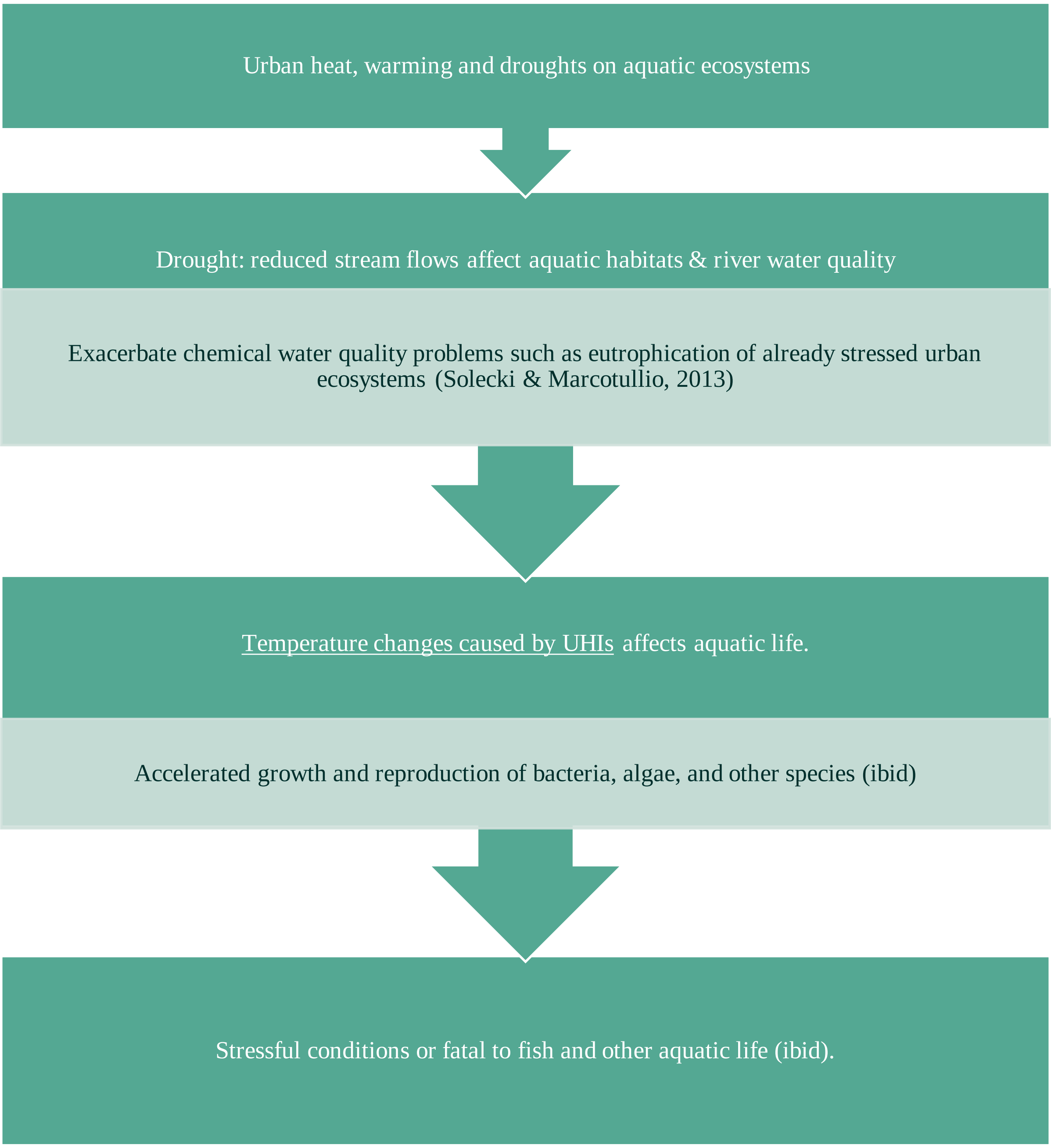
↓

Increased water- and Food-Borne Disease

Humans can be exposed to water- and food-borne pathogens through a variety of routes, including via the ingestion of polluted drinking water, consumption of contaminated food, inhalation of aerosols containing bacteria, and by direct contact with recreational or floodwaters. A number of pathogens that cause water- and food-borne illnesses in humans are sensitive to climate parameters, including increased temperature, changing precipitation patterns, extreme precipitation events, and associated changes in seasonal patterns in the hydrological cycle (Romanello, 2023).

Sequence 4: Drought and urban heat on aquatic ecosystems

In the fourth sequence of impacts proposed, the focus is on the degradation of aquatic habitats provoked by urban heat, warming and droughts.



Sequence 5: Ecosystem degradation

In the fifth sequence of impacts proposed, the focus is on the degradation of urban ecosystems due to extreme temperatures and drought, which reduces green spaces in the city.

Urban heat and warming

Climate change is already impacting urban biodiversity and ecosystems (Rosenzweig et al. 2015). The combination of climate change and urbanization (i.e., increased patch fragmentation and diversity), is expected to heighten the vulnerability of biodiversity hotspots, urban species, and essential ecosystem services (Luck & Wu, 2002)

Better conditions for pests

Changing climate may also affect the introduction of new species in urban ecosystems by reducing noninvasive and native species while favoring weedy and urban-adapted species (Rosenzweig et al. 2015).

Winter warming and absence of cold waves will benefit certain species of insect pests and diseases that are sensitive to prolonged periods of cold (Solecki and Marcotullio 2013).

Changes in species distribution and promotion of invasive species

Ultimately, changes in species distributions are expected to modify the ecological interaction networks in cities and have the potential to promote invasive species, which could accelerate the loss of urban biodiversity (Kendal et al., 2012)

Changing speed and onset of diseases

Climate shifts can adjust the speed of onset of emerging diseases and other pathogens and alien/invasive species entering the extended regions around cities (Solecki and Marcotullio 2013).

Increased affectation on specialised species

Species that are highly specialized and heat sensitive may be threatened with local extinction driven also by an inability to move to new areas as urban development expands (Rosenzweig et al. 2015).

Increased herbivory of urban trees

Urban trees could face greater herbivory in the future as a consequence of the increased fitness of some herbivorous arthropods under warming scenarios. However, more research is needed to generalize these results to more urban areas (Rosenzweig et al. 2015).

Degrarded ecosystems

As a result of the interconnectedness between ecosystem well-being and ecosystem services, growing ecological stress diminishes the quality and quantity of ecological services (Cairns and Pratt, 1995).

Reduced options to escape heat

Sequence 6: Urban heat on population dynamics and forage availability

In the sixth sequence of impacts proposed, the focus is on the changing population dynamics and forage availability provoked by extreme heat. Literature supporting the statements as well as suggestions connecting the cause-effect relationship are presented in figure 7, below.

Extreme heat affects species dynamics

Changing population dynamics

The UHI effect in cities can change the reproductive and population dynamics of animals (Rosenzweig et al. 2015)

Insect life cycles and migration patterns have been well-documented, with changes in the life cycle of certain insects having already occurred in response to urban warming (Parmesan, 2006; Parmesan and Yohe 2003).

Change resource availability

Climate shifts will impact the resources available to urban wildlife including insects, birds, and other larger animals by changing the quantity, quality, and timing of forage for animals (Solecki and Marcotullio 2013).

Forest tree species shifts, such as the decline in one species to be replaced by another better suited to the likely warming and moisture-limiting climate-, could result in an important loss of forage for one or more animal species (Solecki and Marcotullio 2013).

Changes in species competition and pest management regimes

The shifts in forage and in species composition will result in changes in species competition and pest management regimes (Ibid).

Sequence 7. Increased drought and temperature inducing wildfires.

Increased drought and temperature

Increased evaporation rates caused by high temperatures, in association with drought, will exacerbate plant stress, yield reduction, fire risks, and depletion of surface and groundwater resources (Gowda et al. 2018)

Elevated temperatures play a critical role in increasing the rate of drought onset, overall drought intensity, and drought impact through altered water availability and demand (Gowda et al. 2018).

Drought, coupled with extreme heat and low humidity, can increase the risk of wildfire (IPCC, 2012).

↓

Changes in the composition of forests

Observed and future responses of forests to climate change include changes in growth rates, phenology, composition of animal and plant communities, increased fire and storm damage, and increased insect and pathogen damage (Kovaks et al. 2014).

↓

Improved conditions for invasive species

Increasing temperatures promote an increased spread of invasive or encroaching species, which exacerbate wild- fire risks (Gowda et al. 2018)

The combination of different vegetation stressors such as high temperatures, droughts and windstorms in homogeneous forests increases the probability of bark beetle outbreaks at landscape scales (Raffa et al. 2008 in Chuvieco et al. 2023)

Periods of drought could change the composition of producers in the terrestrial ecosystems causing changes in their functioning and resulting in reduced provision of ecosystem services (B8NC, 2022).

↓

Increasing fire risk caused by forest plagues

Seidl et al. (2014) estimated that climate change will increase the damage from windstorms, bark beetle (*Ips typographus*) attacks, and wildfires up to +0.91× 106 m3 of timber per year until 2030. However, in the last decades, massive bark beetle outbreaks and wildfires have already occurred at an un- precedented scale and in unusual regions (Seidl et al 2014, Lausch et al. 2013 in Chuvieco et al 2023).

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Increased tree mortality and burnable biomass

In the last 30 years, tree canopy mortality has doubled in European temperate forests because of natural disturbances, land-use change, and especially because of an intensified wood extraction from naturally disturbed areas where trees were dying (Seidl. et al 2014 in Chuvieco et al. 2023).

Sequence 8. Forestry, farming, and social practices inducing wildfires.

Poor forestry practices

Combined with a lack of forest management and the surge in dry biomass due to human activity being abandoned, fires can spread uncontrollably, reaching urban areas and homes without mandatory preventive plans (Greenpeace, 2023).

Wildfire is a natural process of many landscapes, having a crucial role in nutrient cycling, habitat creation and maintenance, and natural succession of plant communities. Blind wildfire suppression without understanding these ecological aspects has led to unintended and often adverse consequences, including the accumulation of inflammable biomass and the disruption of natural re regimes (Eftychidis et al. 2023)

↓

Wrong reforestation techniques

Reforestation activities including mixed plantings of conifers (black pine, maritime pine, and Cedrus spp.) can further agravate the risk of wildfires (Alemeida et al. 2023)

↓

Changes in landscape accumulates burnable biomass

Humans have an indirect effect on fire via land cover change, particularly abandonment (reduction), through fragmentation (increase in land use intensity) and permanent agriculture which impact fire propagation (Chuvieco et al. 2023).

Fires spread fastest in areas where there is little to no human presence to control them (Greenpeace, 2023).

When the land is no longer used, fragmentation decreases while fuel connectivity increases and thus the fuel horizontal and vertical continuity, leading to fire risk increments. (Chuvieco et al. 2023)

Climatological changes interact with trends of agricultural abandonment, particularly in the South of Europe, as many areas experience a rural exodus. Therefore, these areas face new and heightened risks as landscapes shift from managed, mosaic types with ample variation in fuel density and distribution, to more pyrologically homogenous land covers of even-aged stands with dense, continuous understories (Sil et al. 2019 in Chuvieco et al. 2023)

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Increase in burnable biomass

In Southern Europe, fire frequency and wildfire extent significantly increased after the 1970s compared with previous decades as a result of fuel accumulation, climate change and extreme weather events (Kovaks et al. 2014)

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Many references acknowledge that humans are behind most fire ignitions (90% according to FAO), (Chuvieco et al. 2023)

Humans have an indirect effect on fire via land cover change, particularly through fragmentation (increase in land use intensity) and permanent agriculture which impact fire propagation (Chuvieco et al. 2023)

Sequence 9. Socio-economic and ecological impacts

Increased desertification

The impacts of climatic change on water systems include an overall decrease in aquifer infiltration and recharge, as a result of decreased rainfall and higher evapotranspiration; as well as the amplification of the desertification due to water deficits and soil changes (Ministry of Environment and Energy, 2022).

Soil degradation is already intense in parts of the Mediterranean and Central-Eastern Europe and, together with prolonged drought periods and fires, is already contributing to an increased risk of desertification (Kovaks et al. 2014)

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Increased risk of fire

Increased probabilities of large fires and other disturbances such as windthrows, damages from wet snow and ice, attacks from insects. This is potentially the most important factor for forests given the fact that natural disturbances often lead to dramatic changes in forest structure and environment (B8NC, 2022).

↓

Changing forest composition

While in natural conditions, such temporal dynamics in forest composition and structure are often a part of the overall forest dynamics, new climatic conditions may lead to completely different species compositions and, therefore, ecosystems over a relatively short time period (B8NC, 2022).

↓

Loss of ecosystem services further affecting economic activity

Wildfires are one of the critical factors affecting global ecosystems and societies, impacting atmospheric composition, vegetation succession, soil erosion and runoff, and societal values (resources and assets) (Chuvieco et al. 2023).

The ecosystem services most commonly affected by fire are timber supply, carbon sequestration and storage, pastures... and recreation (Martino et al. 2022 in Chuvieco et al. 2023)

In Bulgaria, In economic terms, the annual contribution by forestry, logging, and furniture production is approximately €500 million (EUROSTAT and European Sector Monitor of Wood Processing and Furniture Industry). About 43,000 people are employed in the forestry sector and in some rural areas, it is the main driver of economic output (B8NC, 2022).

There is already evidence of impacts on the forestry sector in Bulgaria from climate events. In future these could contribute to very high economic losses, degradation of the ability of forests to sequester carbon and affect the quality of life in Bulgaria by reducing the delivery of valued ecosystem services (B8NC, 2022).

According to one study, wood growth could be reduced by 3.5 million m3 per year (Kostov and Raffailova 2009). This is equivalent to 42 percent of the annual harvest and would have a devastating effect on the primary production of forest products and the rural economy. Impact of a similar scale could be expected on the forests' ability to protect drinking water supplies, attenuate extreme rainfall and flooding, stabilize vulnerable soils and slopes, facilitate a growing recreation and tourism sector, capture carbon, and support a rich resource of natural biodiversity (B8NC, 2022).

V. Exposure

I. People's health in urban settings

Factor 1: Exposure time

- Overall, the number of hours of risk per person is increasing across all European regions. In southern Europe, the number of hours with heat-related health risks during medium-intensity activities (e.g., football or tennis) increased relatively by 106% between 1990 and 2020 and increased to 429 hours per person in 2020. For strenuous activities (e.g., mountain biking), there was a relative increase of 77% in southern Europe, leading to 627 hours at risk per person in 2020 (van Daalen et al. 2022).
- Equipment operators and road builders can be exposed to hight temperatures for long periods (maintenance and building staff working in hot weather may experience intense fatigue) (Jacobs et al. 2014).
- People at bus stops exposed for long time periods (waiting at unsheltered transit stations during peak hours can lead to severe heat stress (Slavich et al. 2022).
- The timing of exposure, encompassing distinct exposures during daytime and nighttime, gives rise to varied risks among different demographic groups. As highlighted in the workshop session, individuals may have access to cooler environments, such as shopping centres or swimming pools during the day. Conversely, during the night, individuals are often confined to their residences, occasionally lacking the necessary cooling amenities for comfort. This situation may pose additional challenges for individuals living alone and facing mobility issues, particularly the elderly.

Factor 2: Physical conditions of built environment

- Urban environment and building structure play a vital role in determining the vulnerability of urban populations to heat stress, such as access to vegetation and green space, development intensity, living on a high floor of multi-storey buildings, building materials, land cover and housing density (Puntub et al 2022).
- High building density and a lack of urban green and water spaces determine the adverse bioclimatic evaluation of urban environments (Richter 2015).
- Urban temperatures are enhanced by anthropogenic heat from vehicular transport, heat emitted from building energy waste (Ebi et al 2021).
- Urban heat island can cause significant negative environmental and economic impacts such as affecting human thermal comfort, air quality and energy use due to the increased use of air conditioning, inducing also earlier spring-time flowering in urbanized areas compared to surrounding rural areas (Richter 2015).

Factor 3: Nature of activity (indoor – outdoor activity and timing of activity)

- Heat exposure in sport events: In 2019, examples of heat-related disruptions to major sporting events include the Women's Fédération Internationale de Football Association (FIFA) World Cup in France, the Australian Open tennis tournament in Melbourne, VIC, Australia, the Olympic test triathlon event in Tokyo, Japan, the World Track and Field

Championships in Doha, Qatar, and the New York City Triathlon, NY, USA; each had either interrupted or postponed competition due to the anticipated high risk of exertional heat illness in competitors (Ebi et al. 2021).

- Projections suggest that by 2085, very few major cities will be able to host the summer Olympic games due to heat-related risks for athletes. Heat-related concerns could be even greater for the Paralympic games because they will involve more vulnerable populations (Ebi et al 2021).
- For outdoor workers, high metabolic heat production associated with occupational tasks combined with high ambient and radiant heat, low air flow, and sometimes high humidity, add to human heat strain (Ebi et al 2021)
- Cyclists exposed to dehydration and heat strokes (pedestrians and cyclists might also suffer from heat stress and health problems, potentially shifting to public transit or avoiding travel if they can't use a private vehicle (Jaroszweski et al. 2014).

II. Urban ecosystems

Factor 1: Location (please validate and complement)

Factor 2: Carrying capacity of ecosystems (please validate and complement)

Factor 3: Pressure from external stressors (people, etc.) (please validate and complement)

III. Wildfires

- Exposure indicates the extent to which people, infrastructures and other tangible human assets, as well as ecosystems, could be affected by wildfires (Chuvieco et al. 2023). In instances of fire events, the notion of exposure is broad reaching, given that most regions with combustible vegetation have the potential to experience varying degrees of burning, influenced by factors such as fuel composition and weather conditions (ibid).

Factor 1: Topography

- The terrain shape and morphology have great importance both for fire ignition and behaviour. The former through wind regimes, solar exposure, rainfall and air temperature and humidity distribution, which all impact vegetation distribution and moisture contents (Tymstra et al 2010 and Nyman et al 20915 in Chuvieco et al 2023). Impacts of terrain on fire behaviour include the shape of the terrain and relations to prevailing winds (Chuvieco et al. 2023).
- Fire spread depends on concrete weather, topography, fuel conditions and on fire dynamics (Chuvieco et al. 2023).

Factor 2: Presence of fuel

- Vegetation load, structure, composition and moisture status play a key role in wildfire ignition and spread. Fuels include canopy, shrubs, non-woody vegetation, woody fuels, litter-lichen-moss and ground fuels (Chuvieco et al. 2023).

Factor 3: Wind speed and direction

- Either through windstorms that increase dead tree (and hence increased burnable biomass) wind speed (Seidlk et al. 2014 in Chuvieco et al. 2023), wind plays a key role in wildfire behaviour.

Factor 4: Closeness of settlements to risk-prone areas

- Areas may be exposed directly through contact with the fire front or via flaming embers; or indirectly through the dispersion of smoke, or by fire-caused changes in hydrological cycles or soil erosion (Chuvieco et al. 2023)
- The increased extent of high-severity fire expanding into communities further reduces the capacity to provide other services and puts communities, personnel, and infrastructures at higher risk (Gowda et al. 2018)

Factor 5: Movable population (linked to tourism)

- The actual exposure to fire may change even in short periods of time as a result of weather patterns (e.g., heatwaves, changes in wind conditions that transport smoke in different directions) or population movements (summer holidays) (Chuvieco et al. 2023).

Factor 6: Smoke dispersion

- Areas affected indirectly by the dispersion of smoke (Chuvieco et al. 2023)

Resulting from the previous impact cause-effect relations, the following elements could be identified to be exposed to the effects of increasing temperature and drought in urban settings and forests:

Exposure factor	Association to Impact sequence
I.1	1,2
I.2	1,2,5,6
I.3	1,2
II.1	1,5,6,7,8,9
II.2	4,5,6,7,8
II.3	4,5,6,
III.1	7,8,9
III.2	7,8,9
III.3	7,8,9
III.4	7,8,9
III.5	9

III.6	8,9

VI. Sensitivity

Based on information gathered during the workshop and in the context of previous impact sequences and vulnerability factors identified in the literature, the following sensitivity factors are identified:

I. Urban ecosystems

<u>Factor 1: Water availability for urban ecosystems.</u>

- **Water availability**: The issue of urban water security remains an ongoing challenge, particularly in lower-income countries. Many cities face difficulties in providing essential services to their residents, especially those residing in informal settlements. As cities continue to expand, the demand for limited water resources will grow, and the effects of climate change are poised to exacerbate these challenges in numerous urban areas (Rosenzweig et al. 2015).

<u>Factor 2: Urban dynamics.</u>

- **Rate of urban growth**: Urban ecosystems face unique stressors, leading to heightened exposure to hazards such as high population density, the influence of non-climate-related stressors, and the urban heat island (UHI) phenomenon (Farrell et al., 2015).
- **Expansion of impermeable surfaces**: One of the most significant alterations impacting urban streams is the proliferation of impervious surfaces. This transformation modifies the hydrological dynamics and channels pollutants that accumulate from buildings, roadways, and parking lots into the streams (Grimm, et al. 2008).
- **Rate of water infiltration**. Associated to previous factor.

<u>Factor 3: Ecological properties.</u>

- **Tree species composition** McKinney (2006) notes that certain "urban-adapted" species flourish in urban environments globally, often outcompeting indigenous species and becoming prevalent at local and regional levels. The process of homogenizing terrestrial and aquatic ecosystems through urbanization occurs at varying rates across different geographic regions, influenced by factors such as human population growth and the specific composition of species (Olden, 2006). Additionally, while various ecological and socioeconomic factors impact vegetation in urban areas, a significant portion of non-native invasive species that thrive in cities originate from warmer regions, benefiting from shifting climate conditions (Sukopp & Wurzel, 2003).
- **Tree age composition** (please validate and complement)
- **Plant location** (due to water access. Please validate and complement)

II. People's health in urban settings

Factor 1: Demography

- UHI increases with city size and the number of inhabitants (Richter 2015).
- As urban populations steadily increase, larger numbers of people are at risk of heat stress in the built-up environment of cities (Richter 2015).

Factor 2: Pre-existing health preconditions

- Population exposure to heatwaves increased by 57% on average in 2010–19 compared with 2000–09, and by more than 250% in some regions, putting older people, young children, people with underlying chronic health conditions, at high risk of heat-related morbidity and mortality (van Daalen et al. 2022).
- Future susceptibility likely to be increased with ageing populations, (Hajat et al. 2010).
- Population ageing in Europe is a major demographic trend for the coming decades. It could further increase the effect on human beings of temperature extremes (Feyen et al 2020).
- Adults older than 65 years and infants younger than 1 year, for whom extreme heat can be particularly life-threatening, are now exposed to twice as many heatwave days as they would have experienced in 1986–2005 (Ebi et al. 2021).
- heat- related deaths of people older than 65 years increased by 85% compared with 1990–2000, substantially higher than the 38% increase that would have been expected had temperatures not changed (Hajat et al, 2010).
- Studies consistently show that adults older than 65 years, people with cardiopulmonary and other chronic diseases, and very young children are particularly vulnerable to the effects of heat, irrespective of income level or geo- graphical region (Ebi et al 2021).
- pre-existing physical conditions (such as cardio-vascular and cerebrovascular conditions and diabetes) or those related to mental health (such as depression) potentially leading to mortality and morbidity, age (particularly children and the elderly) (Puntub et al 2022)
- Rates of heat-related mortality and morbidity are high in elderly and chronically ill individuals, particularly those with cardiovascular, respiratory, and renal diseases. People with diabetes, neurological disorders, and psychiatric illnesses might also be at increased risk (Hajat et al, 2010).

Factor 3: Economic status and social capital

- Household income, poverty, unemployment, social isolation, social cohesion, household structure, gender, education attainment, language proficiency, race, house-ownership and more (Puntub et al 2022).
- Social isolation and little mobility were identified as key risk factors during heatwaves. Other contextual risk factors include no access to an air-conditioned environment, living in homes with high thermal mass and little ventilation, and living on the upper floors of high-rise buildings (Hajat et al, 2010).
- People who do not have adequate access to health care at high risk of heat-related morbidity and mortality (van Daalen et al. 2023).
- increased mortality during heat extremes is associated with being confined to bed, living alone, being unable to care for oneself, not leaving the residence to cool down their body temperature, and having a pre-existing mental health condition (Ebi et al 2021).

- The highest risk of death during heatwaves were confinement to bed; pre-existing psychiatric illness; not leaving home every day; and an inability to care for oneself (Hajat et al, 2010).
- Risk of water-borne illness is greater among the poor, infants, elderly, pregnant women, and immune-compromised individuals. Food/ water scarcities impact human health (Barata et al 2018).

Factor 4: Urbanisation

- Increasing urbanisation could amplify the urban heat island effect, which causes urban and metropolitan areas to be significantly warmer than their surrounding rural areas (Feyen et al 2020)
- The combined effects of heatwaves and air pollution might further exacerbate human stress in densely populated areas (Feyen et al 2020)
- Urban areas are vulnerable to the health impacts of climate change due to their high population density, concentration of vulnerable populations, higher temperatures compared to surrounding areas (Barata et al 2018).

Factor 5: Behavioural factors: Use of alcohol and drugs

- The use of alcohol, medications, and illegal narcotics is associated with increased mortality during heat extremes. Many commonly prescribed medications, such as general anticholinergics, antidepressants, and opioids and illegal narcotics such as cocaine, might compromise physiological heat loss responses (Ebi et al 2021)
- The magnitude and pattern of future heat-related morbidity and mortality will depend on climate change and other important factors such as population growth and ageing, urbanisation trends, adaptation efforts, and development choices (Ebi et al 2021).
- Some drugs, notably diuretic, psychotropic, and anticholinergic drugs, have been implicated in increasing the risk of heat-related death or illness (Hajat et al 2010).

III. Wildfires

Factor 1. Socio-economic and demographic background

- Societal vulnerability to wildfires may be understood as both the magnitude of the socio-economic impacts deriving from wildfires, and the inability of local societies to cope with stressors to which they are exposed as a consequence of a wildfire (Chuvieco et al. 2023)
- Regarding the human component in wildfire risk assessment, key aspects relate to social capital in relation to the relationships between communities, their activities to contain fire ignition and spread and their strengths and relations with the current institutional system (Chuvieco et al 2023)

Factor 2. Heatwave time and duration (please validate and complement)

Factor 3. Human-caused ignition

- Population density and aging, proximity to roads and urbanized areas, livestock density and social conflicts have been identified as closely related to human fire ignition (Knorr et al 2016 in Chuvieco et al. 2023)

Factor 4. Fragmentation

- Humans fragment the landscape due to settlements, infrastructure (e.g., roads, powerlines, railroad tracks) which impact fire propagation (Chuvieco et al. 2023)

Factor 5. Drought onset

- Elevated temperatures play a critical role in increasing the rate of drought onset, overall drought intensity, and drought impact through altered water availability and demand (Gowda et al. 2018)

Sensitivity factor	Association to impact sequence
I.1	4,5,6,7,8,9
I.2	1,2,3,4,5,6
I.3	5,6,7
II.1	2,3,5,6
II.2	1,2,3
II.3	2,3
II.4	4,5,6
II.5	2
III.1	1,2,3,8
III.2	1-9
III.3	7,8
III.4	7,8
III.5	7,8,9

VII. Adaptive Capacity

Adaptive capacity is normally determined in terms of knowledge, financial resources, technologies, legislations and infrastructures that enable people to adapt to the effects of climate change.

I. People's health in urban settings

Factor 1. Resources

- Provision of air conditioning, increasing urban vegetation, accessibility to medical services and insurance, and accessibility to nearby public heat refuges as crucial (Puntub 2022)
- Financial options for refurbishment (identified during workshop)

Factor 2. Spatial planning

- Spatial planning influences the spatial configuration, type and degree of development of buildings and land use, as well as landscapes and green spaces (Richter 2015).
- Improved design and insulation of houses, schools and hospitals, sound urban planning (increasing tree and vegetative cover, installing green or reflecting roofs, or using cool pavements) (Feyen et al 2020)
- Building codes (Hajat et al 2010)

Factor 3. Policy public health

- Focus on identifying and informing effective and cost-efficient public health and climate change adaptation and mitigation interventions; on monitoring these interventions to reduce health burdens and inequities; promote and facilitate the active involvement of young people and minoritised groups in identifying health and climate change solutions that minimise or eliminate health inequities (Hajat et al 2010)
- Public health protection measures, with the timely provision of appropriate home-based prevention advice to the general public (Hajat et al 2010).
- Heat health warning systems that trigger community alerts and emergency actions in response to forecasts of adverse weather conditions. Because heat- related illness is largely avoidable, the most crucial point of intervention concerns the use of appropriate prevention strategies by susceptible individuals and their carers. Although such home-based prevention advice already forms an integral part of many heat health warning systems, the extent to which the advice is based on medical evidence is unclear. Knowledge of effective prevention and first-aid treatment, besides an awareness of potential side- effects of prescription drugs during hot weather, is crucial for physicians and pharmacists (Hajat et al 2010).
- Upgrading health infrastructure, improving the capacity of health workforces, enhancing disease surveillance and conducting health-specific vulnerability and risk assessments (United Nations Environment Programme, 2023).
- Multisectorial cooperation (identified during workshop)

Factor 4. Education, awareness, and stakeholder engagement

- Education and awareness raising of potential risk factors and recommended responses (Feyen et al 2020)
- Skill preparation of public officials
- Vector-borne and infectious diseases: Epidemiologists (to identify changes in infection rates), hospitals (to respond to public health emergencies and treat patients), and social

workers and local community members and groups (to help identify vulnerable populations and respond to environmental health needs) (Barata et al 2018)

- Heat-related illnesses (including stroke, respiratory and cardiovascular distress): Local municipalities' decision-makers (to develop and implement heat-health warning and response policies), the media (to alert the public to extreme heat events and locations of cooling centers), and independent power producers and utilities (who provide electricity for cooling and maintain infrastructure) (Barata et al 2018)
- Water quality and water-borne diseases: Emergency preparedness organizations (first responders for flood events), municipal planning departments (to upgrade sewer and drainage systems), and water management departments (to detect changes in water quality)
- Air quality, asthma, allergies: Meteorology services, air quality managers, public health and/or medical schools, NGOs and research scientists (to conduct research on air quality and health impacts), private sectors (who may contribute to GHG emissions but may also produce valuable products, including medications for respiratory distress) (Barata et al 2018)

II. Urban ecosystems

Factor 1: Public policy urban ecosystem

- Conserving, restoring, and expanding urban ecosystems to enhance climate resilience and other co-benefits under mounting climatic and non-climatic stresses of growing urbanization and development processes will require improved urban and regional planning, policy, and governance and multi-sectorial cooperation to protect and manage urban ecosystems and biodiversity (Solecki and Marcotullio, 2013).
- Also, greater coordination and networks among governance structures that manage local ecosystems and urban biodiversity, including cemeteries, golf courses, urban parks, and neighbourhood gardens, would strengthen ecosystem functioning as well as the associated and essential social-ecological engagement (Ernstson et al., 2010).
- The adaptive capacity of species in urban landscapes is a function of ecology, physiology, and genetic diversity (Williams et al., 2008).
- In the context of urban biodiversity and ecosystems, nonhuman actors, behaviour, species interactions, and human–ecological interventions are also important for adaptive capacity. For example, human-induced adaptive capacity could include planting species that are more tolerant of higher temperatures and droughts. Nonhuman-derived adaptive capacity could include natural processes that change ecosystem components rapidly for organisms like insect populations persisting despite changing climate (Rosenzweig et al. 2015)
- Multisectorial cooperation (identified during workshop)

Factor 2: Knowledge about the state and dynamics of urban ecosystems

- The adaptive capacity of species in urban landscapes is a function of ecology, physiology, and genetic diversity (Williams et al., 2008).
- In the context of urban biodiversity and ecosystems, nonhuman actors, behaviour, species interactions, and human–ecological interventions are also important for adaptive capacity. For example, human-induced adaptive capacity could include planting species that are more

tolerant of higher temperatures and droughts. Nonhuman-derived adaptive capacity could include natural processes that change ecosystem components rapidly for organisms like insect populations persisting despite changing climate (Rosenzweig et al. 2015).

- Invasive species may also bring opportunities for climate change adaptation (CCA) if used as an indicator in an early warning mechanism or if they are commercially important and contribute to providing ecosystem services (Bulgaria's 8th National Communication).
- Ecosystem data interoperability between authorities and other actors (Bulgaria's 8th National Communication).
- Targeted collection of folk customs and traditional knowledge (Bulgaria's 8th National Communication).
- Communication and tools for informed prioritization of research and practical action (Bulgaria's 8th National Communication).

III. Wildfires

Factor 1. Public and private resources (please validate & complement)

Factor 2. Spatial planning

- Landscape planning and fuel load management may reduce the risk of wildfires but may be constrained by the higher flammability owing to warmer and drier conditions (Moreira et al., 2011 in Kovaks et al. 2014)
- Strategies to reduce forest mortality include preference of species better adapted to relatively warm environmental conditions (Resco de Dios et al., 2007 in Kovaks et al. 2014)
- The selection of tolerant or resistant families and clones may also reduce the risk of damage by pests and diseases in pure stands (Jactel et al., 2009 in Kovaks et al. 2014)

Factor 3. Education, awareness, and stakeholder engagement (please validate & complement)

Factor 4. Coordination across institutions

- Firefighting in the wildland-urban interface is a complicated issue since it involves citizens/people safety and management, addressing challenges in protecting properties dispersed in forested areas and buildings occluded by flammable vegetation, as well as ensuring evacuation for older people, children, and animals (Almeida et al. 2023).

Factor 5. Forestry management and prevention measures

- As with water resources, forests can adapt through management of forest fires, silvicultural practices, and the conservation of forest genetic resources. Ecological restoration, where required, is another effective adaptation measure that enhances biodiversity and environmental services, increases the potential for carbon sequestration, and promotes economic livelihoods in rural areas (Dasgupta et al. 2014)
- As the climate changes, part of adaptive management may entail modification of existing biodiversity management practices. Manipulating vegetation composition and stand

structure, for example, has been proposed as an adaptation option to wildfires in Canada (Dasgupta et al. 2014)

- Fires spread fastest in areas where there is little to no human presence to control them. There is a need to revitalise the rural environment in a way that encourages people to settle in those areas, mitigating the effects of depopulation due to the concentration of economic opportunities in major cities. A mosaic agroforestry landscape, with activities linked to a primary sector deeply rooted in the territory, is a landscape more resilient against major forest fires, climate change and the loss of biodiversity (and agrodiversity) (Greenpeace, 2023).
- Possible response approaches to the impacts of climate change on forestry include short- and long-term strategies that focus on enhancing ecosystem resistance and resilience and responding to potential limits to carbon accumulation (Millar et al., 2007 in Kovaks et al. 2014)

Adaptive capacity factor	Association to impact sequence
I.1	1-9
I.2	1,2,3,4,5,6
I.3	1,2,3
I.4	1,2,3,8,9
II.1	3,4,5,6
II.2	3,4,5,6
III.1	7,8,9
III.2	7,8,9
III.3	8,9
III.4	7,8,9
III.5	7,8,9

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