# Revision and update of the national strategy on adaptation to climate change in Slovakia

## Deliverable 2.3: Climate Risk and Vulnerability Assessment Slovakia

**Technical Support Instrument**
*Supporting reforms in 27 Member States*

**Funded by the European Union**

MINISTRY
OF ENVIRONMENT
OF THE SLOVAK REPUBLIC

The project is funded by the European Union via the Technical Support Instrument, managed by the European Commission Directorate-General for Structural Reform Support.

This report has been delivered in February 2024, under the EC Contract No REFORM/2021/OP/0006 Lot 1 - TSIC-RoC-20036. It has been delivered as part of the project “Revision and update of the national strategy on adaptation to climate change in Cyprus and Slovakia”.

**Directorate-General for Structural Reform Support**
REFORM@ec.europa.eu
+32 2 299 11 11 (Commission switchboard)
European Commission
Rue de la Loi 170 / Wetstraat 170
1049 Brussels, Belgium

**Contract details**

DG REFORM

Revision and update of the national strategy on adaptation to climate change in Cyprus and Slovakia

Reference Number:  REFORM/2021/OP/0006 Lot 1 - TSIC-RoC-20036

**Presented by**

Trinomics B.V.

Mauritsweg 44

3012 JV Rotterdam

The Netherlands

**Contact person**

Mr. Matthew Smith

T: +31 (0)6 1292 9246

E: matthew.smith@trinomics.eu

**Date:** 24th March 2024

**Authors:** Klaus Schneeberger, Franziska Allerberger, Elsa Ventruba, Kathrin Schwab, Caroline Scholl-Poensgen (alpS Consult); Mgr. Jozef Pecho, Mgr. Marcel Garaj, PhD (*Slovenský hydrometeorologický ústav* - SHMÚ); Tatiana Cuervo Blanco, Peter Janoska, Ajla Kospo, Liza Leimane, Petra Remeta, Shashwati Shankar, Matthew Smith (Trinomics); Thomas Dworak (Fresh Thoughts Consulting); Andrej Steiner, Michal Schvalb (KRI)

**Acknowledgements:**. The team would also like to thank all stakeholders that participated in the various workshops, interviews and events held throughout the process of developing this report, your contributions were highly valuable appreciated. The team would also like to express special thanks to the Slovak Hydrometeorological Institute (SHMÚ) for their assistance. The cooperation and SHMÚ's work in preparing scenarios, data, and analyses (geospatial, statistical, etc.) were fundamental to the assessments, data, and maps presented in this report. Without this contribution, this report would not have been possible.

Rotterdam, 15/10/2024

REFORM/2021/OP/0006 Lot 1 - TSIC-RoC-20036

# Revision and update of the national strategy on adaptation to climate change in Cyprus and Slovakia

## Deliverable 2.3:
## Assessment report on climate risks and vulnerabilities (Slovakia)

In association with:

Table of Contents

## List of Abbreviations

| | |
|---|---|
| CIC | *Climate Impact Chain* |
| CRVA | *Climate Risk and Vulnerability Assessment* |
| CSRD | *Corporate Sustainability Reporting Directive* |
| DMOs | *Destination Management Organizations* |
| ECB | *European Central Bank* |
| EUCRA | *European Climate Risk Assessment, European Climate Risk Assessment* |
| ICT | *Information and Communication Technology* |
| IMF | *International Monetary Fund* |
| IPCC | *Intergovernmental Panel on Climate Change* |
| NAP | *National Adaptation Plan* |
| NAS | *National Adaptation Strategy* |
| NBS | *National Bank of Slovakia* |
| NECP | *National Energy and Climate Plan* |
| NEHAP V | *New Action Plan for the Environment and Health of the Inhabitants of the Slovak Republic* |
| SAV | *Slovak Academy of Sciences* |
| SMEs | *small and medium-sized enterprises* |
| SSCRI | *Soil Science and Conservation Research Institute* |
| UHI | *Urban Heat Island* |

# Executive Summary

*Introduction*

Climate change is recognised as decisive, urgent and complex challenge of the 21st century, potentially leading to irreversible effects. Already today, climate change induced impacts pose a major threat to people and nature and adverse consequences are not distributed equally across regions and communities. Both ambitious climate change mitigation and adaptation are key to ensure a climate resilient development at global, national, regional and local level as best as possible (EEA, 2024b; IPCC, 2022f).

Against this background, the project *Revision and update of the national strategy on adaptation to climate change in Cyprus and Slovakia*, funded by the European Commission, aims at supporting both Member States to address climate change related challenges and to implement necessary adaptation steps. The present report was prepared under Deliverable 2.3 (D2.3) and comprises the **Climate Risk and Vulnerability Assessment (CRVA)** for the Slovak Republic. The CRVA serves as essential foundation for the technical note on the draft National Adaptation Strategy (NAS), National Adaptation Plan (NAP) and roadmap towards implementation (D2.4). The results of the CRVA can be understood as business-as-usual scenario, i.e. if no further adaptation measures are implemented.

The CRVA includes an analysis of past and potential future climate of Slovakia and follows a sectoral approach for the assessment of climate impacts in terms of exposure and sensitivity. As displayed in Figure 1, a total number of 15 sectors are addressed. Climate impacts of high priority were identified and assessed in more detail focusing on the urgency to act and adaptive capacity (i.e. governance framework and financial capabilities). The assessment of climate impacts served as basis for the derivation of key sectoral risks and strategic directions.

*Figure 1: 15 sectors assessed in course of the Climate Vulnerability and Risk Assessment.*

In course of the process, climate impact chains were developed which provide an overview of key results, including climate impacts, key risks, strategic directions as well as other aspects such as exposed subsystems and non-climatic risk drivers. Most importantly, the climate impact chains also contain information on interlinkages to other sectors, highlighting that a climate change adaptation strategy requires cross-sectoral thinking. Against this background, the report also outlines important information on transboundary, cascading and emerging risks, highlighting the relevance of thinking beyond national borders and of considering single risks as being closely entangled. The report is complemented by an outline of limitations of the CRVA, including uncertainties and knowledge gaps, as well as an explanatory note on megatrends potentially influencing the vulnerability to climate change. Furthermore, dedicated chapters on urban areas and social vulnerabilities in the context of climate change are used to provide further insights into these two cross-cutting issues.

A unique characteristic of the CRVA is its participatory approach. This overall process allowed relevant stakeholders to be involved in the most crucial parts of the CRVA. Two in-person workshops were organised, focusing on the assessment of a) climate impacts as well as b) key risks and strategic directions. The selection and invitation of stakeholders was done in close cooperation with the Ministry of Environment and local partners of the consortium.

### *Climate change in Slovakia*

In Slovakia, there has been a uniform **warming trend in annual air temperatures**, despite the complex climate conditions due to a multitude of influences and varied landscape topography (Labudová et al., 2015; Labudová et al., 2024). The data reveal an increase of approximately 2 °C in mean temperature since 1881, resulting in an average increase of approximately 0.15 °C per decade (Gera et al., 2017; UNFCCC, 2023). In recent decades, specifically from 2001 to 2022, Slovakia has seen a notable increase in extreme maximum and minimum daily air temperatures, with a sharp rise in the frequency of heat waves. Since 1991, the number of warmer years has significantly risen, particularly highlighted by the record average annual temperature of 12.4°C in Hurbanovo for the years 2018 and 2019 (UNFCCC, 2023). The rise in summer days (temperatures reaching 25°C or higher) and tropical days (temperatures of 30°C or higher) has been striking since the last decade of the 20th century (Labudová et al., 2015). Dry periods, characterised by a lack of precipitation, have become more common, leading to more frequent and severe soil droughts due to generally warmer conditions (UNFCCC, 2023). Seasonal differences of temperature increases are also observed, showing the largest temperature increases in January and the summer months. Between 1961–1990 and 1991–2020, January temperatures rose by more than 1.2°C, while June and July recorded increases of 1.6°C, and August over 1.8°C. With respect to past developments, research indicates that seasonal temperature changes (Labudová et al., 2024).

Unlike temperature trends, **precipitation** patterns in Slovakia are less pronounced due to their complex spatial and temporal distribution. The most noticeable difference in monthly precipitation totals between reference periods occur primarily in July. Extreme weather events from the Mediterranean in summer during the late 20th and early 21st centuries have resulted in substantial rainfall and flooding, notably in the years 1997, 1998, 1999, 2001, 2004, and 2005. The region's topography interacts with these weather systems, influencing precipitation trends (Labudová et al., 2024). However, the existing network of meteorological stations may not fully capture the spatial variability of precipitation patterns and the air masses delivering precipitation records of meteorological stations varies depending on their location and the influence of air masses delivering precipitation, which results in potentially contrasting trends within the same country. In Slovakia, the most substantial increases in precipitation were recorded at higher altitudes (Gera et al., 2017; Labudová et al., 2024; Lapin, 2021). This trend has intensified in recent years, with the 2024 floods, the worst in 30 years, driven by extreme rainfall, further demonstrating the increasing severity of such events (DW, 2024).

Since the 1980s, Slovakia has experienced frequent **hydrological droughts**. As the impact of climatic factors, particularly precipitation and potential evapotranspiration, on drought conditions has become more pronounced since 2000 (Fendeková, 2018b), the country has encountered three significant drought events of Pan-European scale in recent years. Analysis of the droughts in 2003, 2012 and 2015 revealed that while these years shared similar weather conditions, the effects varied significantly across the twelve river basins assessed. The 2003 drought was moderately severe in terms of duration and precipitation deficit, while the 2012 and 2015 droughts were relatively mild in terms of return period (Fendeková, 2018b).

The increase in occurrence of drought events also adversely affects **groundwater**, which constitutes the primarily source of drinking water in Slovakia. Since 1991, the intensity of negative changes in groundwater resources has markedly increased and reductions in groundwater reached 25% in the most affected areas and up to 35% in local spots, resulting in an estimated total decrease of 250,000 $m^3/km^2$. In total, at least 70% of Slovakia had experienced declines in groundwater levels by 2009. However, studies reveal regional differences and indicate that the groundwater increased moderately in south-eastern Slovakia and the central Váh River Basin. In fact, frequent extended drought periods reduce usable water resources and highlight the vulnerability of Slovakia's water systems to climate change.

Slovakia is projected to experience significant changes in temperature and precipitation in both the near and far future. Assessments for two future timeframes and scenarios were compiled, an optimistic and a pessimistic scenario for both the near (2021-2050) and far future (2071-2100), respectively. The optimistic scenario describes a future where climate mitigation efforts limit global warming (RCP4.5), whereas the pessimistic scenario describes a business-as-usual scenario without any mitigation efforts (RCP8.5). The data shows a clear trend of rising temperatures and an increase in extremely hot days across Slovakia, with more significant changes under higher emissions scenarios. Climate projections indicate that by 2071-2100 the annual mean temperature for selected cities in Slovakia is expected to rise by approximately 1.2 to 3.4 °C compared to the reference period of 1991-2020, depending on the region and the climate change scenario (RCP4.5 or RCP8.5). Additionally, heatwaves and the frequency of days with maximum temperatures exceeding 30 °C are projected to rise by the century's end. Over the past twenty years, there has been a decline in heating degree days (HDDs) and an increase in cooling degree days (CDDs)[1], reflecting changing energy needs (IEA, 2022).

According to analysed data provided and processed by the Slovak Hydrometeorological Institute, Slovakia is expected to experience moderate increases in mean annual air temperature in °C and tropical days (maximum temperatures reaching at least 30°C) in the near future (2021-2050) and significant increases in the far future (2071-2100) under the RCP4.5 scenario. Specifically, as indicated in the data presented in the tables below, the number of tropical days is expected to rise, highlighting a concerning trend. In contrast, the RCP8.5 scenario predicts substantial increases in mean annual air temperature and tropical days for both periods. Both scenarios foresee a significant rise in the number of tropical days (days with maximum temperatures above 30°C).

Precipitation patterns are expected to show strong variability in the future. Climate projections suggest up to a 30 % increase in annual precipitation by 2075 compared to 1961-1990, with significant seasonal and geographical variations. However, this increase is expected to vary by season and region, with winter experiencing a more substantial rise compared to summer, and the northern regions seeing a greater increase than the southern area. These changes in precipitation may increase the country's exposure to both heavy rainfall events and droughts[2]. These projections come with a high degree of uncertainty, particularly for precipitation, which is inherently more difficult to model compared to temperature (IEA, 2022). Rainfall patterns are anticipated to become more variable, with longer periods of dry conditions interspersed with more intense, short-duration rain events. By the end of the century, precipitation totals across most of Slovakia are projected to increase with potential rises of up to 10 % under RCP4.5 and up to 15 % under RCP8.5 compared to the 1981-2010 period. This corresponds to an annual increase of 50 to 70 mm for RCP4.5 and 100 to 120 mm for RCP8.5. Increases in rainfall intensities are expected to be approximately +5% to +8% for RCP2.6 from 2021-2050, +3% to +5% from 2051-2100, and up to +35% for RCP8.5 by the end of the century. Stronger storms are also anticipated, with more frequent high wind gusts and larger hail (UNFCCC, 2023).

The frequency of **extreme storm**-related phenomena, such as wind gusts exceeding 25 m/s and hail events with hailstones measuring 2-5 cm in diameter, is projected to increase significantly; by 2100, high wind gusts could see a 20-80% rise in occurrence, while hail events with hailstones up to 5 cm could increase by 40-150%, depending on the chosen emission scenario. Additionally, during dry and windy spells, wind erosion is expected to affect exposed areas (UNFCCC, 2023).

---

[1] Degree days are calculated based on the assumption that outdoor temperatures around 18.3°C (65°F) indicate that heating or cooling is not needed for comfort. Degree days measure the difference between the daily mean temperature (the average of the daily high and low temperatures) and 18.3°C. If the mean temperature is above 18.3°C, the result is termed Cooling Degree Days (CDDs), obtained by subtracting 18.3°C from the mean. Conversely, if the mean temperature falls below 18.3°C, the outcome is known as Heating Degree Days (HDDs), calculated by subtracting the mean from 18.3°C (National Weather Service, n.d.).

[2] Additionally, the decrease in snow cover may lead to reduced groundwater recharge, as less snowmelt during the winter months will result in more precipitation running off rather than replenishing aquifers.

*Risk assessment – overview of results*

Based on the climate impact assessment workshops, expert knowledge and scientific literature, climate impact chains were developed, reflecting the current climate impact situation and considering climate impacts of high priority, the exposed subsystems (e. g. urban ecosystems, international supply chains, freshwater systems, companies & operating sites; subsystems vary depending on the sector) and non-climatic risk drivers. These compiled impact chains served as a basis for discussions in the participatory process for deriving key risks. Key risks are characterised by their longevity, their duration of necessary time for adaptation options to fulfil their impact and their wide-ranging effects and consequences, possibly rippling through ecological, economic and societal levels (EEA, 2024b; GIZ, 2023; IPCC, 2022c).

During the climate impact assessment workshops, discussions were held in breakout groups, where the results of prior working steps have been reflected, and sector-based key risks were formulated and agreed on. The key risks reflect the exposure, sensitivity, adaptive capacity and urgency to act, presenting the current rating of climate impacts within each sector and condensing the knowledge collected in prior working steps into a current risk landscape. Hence, the current risk assessment was derived for each key risk. These assessments were further linked with climate data under two scenarios: optimistic (RCP4.5) and pessimistic (RCP8.5), spanning the near future (2021–2050) and far future (2071–2100). In addition, the temporal dynamics (e. g. acute or slow onset events) as well as potential spatial variabilities (e. g. some regions might be affected more than others; hence local, regional or national occurrence are differentiated) are also considered. The risk is classified in four categories, i.e. *low*, *medium*, *high* and *very high*.

The risk assessment represents a business-as-usual scenario, i.e. consequences to be expected if no adaptation measures are implemented. The current and future risk landscape of Slovakia shows that severe adverse impacts have to be expected if no or only insufficient action is taken as the levels of nearly every identified key risk reach *high* to *very high* levels in the far future at the latest. In the near future, apart from two exceptions in the Tourism sector, key risks reach *medium* to *high* levels. As such, the assessment highlights the urgent need for both extensive mitigation and adaptation efforts to prepare for the challenges in the far future, emphasising that the time to act is now to avoid escalating costs, irreversible damage, and lost opportunities to strengthen resilience and to reduce vulnerability and thus consequently minimise risks effectively. With regard to potential financial burdens, it should be noted that risk of costs of inaction due to insufficient mitigation and adaptation to climate change (KR-FI-3) is already rated as *high*. A comprehensive list of all identified risks can be found in the respective sectorial chapters. Each key risk has a code to link it to the respective sector and support its quick identification.

In eight of the 15 sectors assessed, the key risks identified have already a *high* risk level and are expected to become more severe in the coming decades. These key risks are related to malfunctioning water management systems in agriculture (KR-A-3), loss of biodiversity and habitats (KR-B-1), damage to and loss of people, livelihoods and (critical) infrastructure, in particular due to extreme events such as heat, drought and floods (KR-DRM-1, KR-DRM-2, KR-WM-1, K-SP-1, KR-TIB-2), loss of ecosystem service provision provided by forests (KR-FO-1) and adverse effects due to inadequate forest management (KR-FO-2).

Most importantly, the key risk of rising costs of inaction in terms of adaptation and mitigation (KR-FI-3; currently and in the near future rated as *high* and *very high* in the far future) draws attention to the fact that urgent action is needed to tackle (severe) climate change induced impacts. This becomes even more important as there is an increasing risk of rising insurance costs and potentially insurable climate impacts (KR-FI-1; currently and in the near future rated as *high* and *very high* in the far future).

Apart from some exceptions, all key risks reach *high* or *very high* levels in the far future (2071-2100) either only under a pessimistic or under both an optimistic and pessimistic scenario. Extreme events such as heat waves, droughts, pluvial and fluvial flooding as well as forest- and wildfires play an essential role in shaping the risk landscape of Slovakia. With respect to heat, in particular urban areas face major risks due to the urban heat island effect, resulting in heat stress for inhabitants and increased energy demands for cooling of buildings and transport infrastructure (KR-SP-1, KR-H-1, KR-TIB-2). Associated heat waves and droughts pose major threats to biodiversity and terrestrial and aquatic ecosystems (KR-FO-1; currently and in the near future rated as *high* and *very high* in the far future), potentially leading to a *very high* risk of decreased food security and lack of food (KR-A-4) in the far future under a pessimistic scenario. Likewise, extreme events such as floods and wildfires do not only adversely affect people and lead to major destructions of infrastructure and buildings, but might also result in a risk to cultural heritage, i.e. historical, archaeological, cultural and natural heritage sites and landscapes might get damaged (KR-CH-1; currently and in the near future *medium* risk, *high* risk in the far future) and are one factor affecting soil erosion (KR-GES-1; currently rated as *medium*, *high* in the near future and *very high* in the far future under a pessimistic scenario). Adverse consequences must also be expected for the Tourism sector as impacts of such events can lead to limited accessibility of attractions (KR-T-3; currently and in the near future *medium* risk, *high* risk in the far future). In addition, there is an increasing risk of insufficient water supply, malfunctioning wastewater and sewage systems (KR-WM-2, KR-WM-3; currently rated as *medium*, *high* in the near future and *very high* in the far future under a pessimistic scenario) as well as decreasing groundwater availability and quality (KR-GES-2; currently and in the near future rated as *medium* and *very high* in the far future under a pessimistic scenario). With regard to spatial planning, a risk of long-lasting maladaptation and lock-ins is expected if no respective measures are taken, meaning that the risk is rated as *medium* for the near future and *high* in the far future under both scenarios (KR-SP-2).

In addition to sectoral key risks, transboundary, cascading as well as newly and emerging risks have to be considered, underlining the complex interconnectedness going beyond the Slovak Republic.

**Transboundary risks**, that can lead to both positive and negative effects, can be defined as those risks induced by climate change that cross national borders, moving from one country to its immediate neighbour as well as leaping across entire regions and continents, transmitting risks to countries and people thousands of kilometres away from the initial point of impact (Anisimov and Magnan, 2023). Potential transboundary risks affecting Slovakia can be associated with the energy supply and trade as well as the water resources and river basin management. Regarding the latter, disputes over water management and allocation among countries sharing these resources have to be expected as climate change affects precipitation patterns and leads to an increased frequency of droughts, potentially resulting in adverse effects on water availability and quality.

**Cascading risk** emerges from the interconnectedness of systems and their elements, when interactions of individual risks result in cascades of failures (UNDRR and UNU-EHS, 2022). Examples of relevant cascading risks for Slovakia are related to water stress/scarcity and urban heat islands. Urban heat, amplified by a heightened frequency of heat waves, can lead to increased energy demands for cooling, straining the power grid, potentially resulting in power outages, and adversely affecting inhabitants. Water stress and water scarcity are related to multiple aspects such as irrigation needs, decreasing crop yields and productivity, negative impacts on livelihoods of farmers, higher food prices and reduced food security and adverse effects on public health due to waterborne diseases, all of which are connected in a complex interplay of potential domino effects.

**Emerging risks** from climate change encompass a broad range of threats that are increasingly recognised as critical to understand and manage the global climate crisis and the responses to it. They may be new or familiar risks that become apparent in emerging circumstances and may not be fully understood or assessed but nevertheless pose a threat to human security (International Risk Governance Council (IRGC), 2010; IPCC, 2014). Emerging risks often arise from feedback processes between climatic changes, human mitigation and adaptation interventions, and processes in natural systems which can threaten human security, leading to unexpected, severe consequences (IPCC, 2014). Slovakia is exposed to several emerging risks, ranging from an increased frequency of extreme weather events, impacts on human health and critical infrastructure, limited water availability to shifting energy consumption patterns, economic impacts e. g. affecting agriculture and tourism and loss of biodiversity.

Knowledge gaps and uncertainties further add to the complexity of the Slovak risk landscape. For instance, tipping dynamics of the global climate system might result in unprecedented severe impacts, calling for an even stronger and faster implementation of mitigation and adaptation measures (Lenton et al., 2023). In addition, data and knowledge gaps as well as limitations have been identified in course of the project (e. g. a lack of investigation and monitoring of underground water quality, lack of data concerning effects of the extension of the vegetation period, weak crisis management in the ICT sector), based on the expertise of involved stakeholders, highlighting the need for further investigations and actions to address these limitations.

In addition, social vulnerabilities and inequalities in the context of climate change are other aspects of major concern and should be addressed in both adaptation and mitigation, ensuring, among other things, a socially just adaptation (Breil et al., 2018; IPCC, 2023b).

### *Concluding remarks & summary of key messages*

This risk assessment underscores the escalating consequences of inaction with key risks expected to intensify significantly under a business-as-usual trajectory. Without adaptation (along with mitigation efforts), the risks of irreversible damage, soaring costs, and missed opportunities for resilience will rise. Extreme weather, biodiversity loss, resource scarcity, and economic strain collectively emphasise the need for immediate measures to address these challenges.

### Key messages

1 In eight of the 15 sectors assessed, at least one key risk identified already has a *high* risk level.

2 All key risks reach *medium* or *high* levels in the near future (2021-2050), with one exception in the Tourism sector.

3 With only some exceptions, all key risks reach *high* or *very high* levels in the far future (2071-2100), either under a pessimistic scenario only or under both an optimistic (RCP4.5) and pessimistic scenario (RCP8.5).

4 Extreme events such as heat waves, droughts, pluvial and fluvial flooding as well as forest- and wildfires play an essential role in shaping the risk landscape of Slovakia.

5 Rising costs of inaction (mitigation and adaptation) and insurance costs (including potentially insurable climate impacts) have to be expected.

6 There are no substantial opportunities from a business-as-usual approach, i.e. if no further adaptation measures are implemented.

7 Climate change and its impacts are strongly intertwined with security issues.

8 Climate change adaptation and mitigation should acknowledge the complex interplay of social, economic, environmental and cultural dimensions and processes within and across regions and countries. This requires a cross-sectoral, holistic and forward-looking way of thinking and acting.

# 1 Introduction

Climate risk and vulnerability assessments (CRVA) provide the basis for decision making, highlighting the vulnerabilities and adaptive capacities of systems in order to effectively plan adaptation measures. Based on scientific literature, and climate data and projections, a holistic picture is drawn, presenting a risk landscape comprised of climatic parameters, socio-economic and other underlying systemic factors. Through the evaluation and assessment of risk-drivers, i.e. climate-related hazards, exposure, vulnerability, key risks and strategic directions are identified, serving as entry points for targeted climate change adaptation (GIZ, 2023). The whole process is strongly dependent on stakeholder participation and local expert knowledge, which is a key pillar of the assessment alongside data- and science-based knowledge.

This report presents the results of the CRVA of Slovakia. As shown in Figure 2, the assessment comprises several steps that are based on both literature and data analysis as well as participatory workshops with selected local stakeholders. In addition to a detailed analysis of sector-specific climate impacts, key risks, strategic directions, potential knowledge gaps and limitations, cross-sectoral interdependencies and connections as well as transboundary, cascading and emerging risks for Slovakia are incorporated in the assessment results.

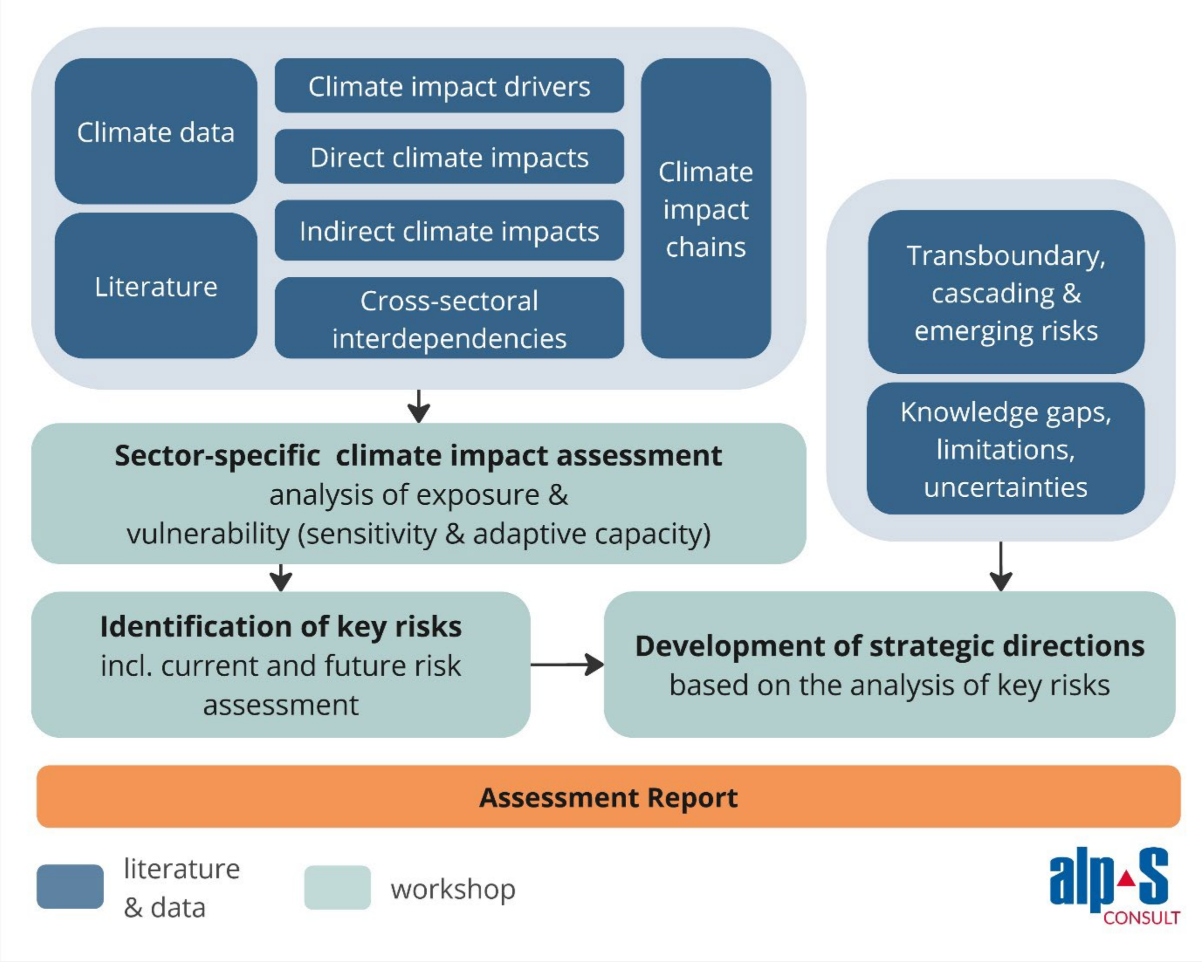


*Figure 2: Flow chart of the work process for the Climate Risk and Vulnerability Assessment*

A detailed description of the methodological approach is provided in Annex A: Additional information on methodological design. It is based on current scientific and key literature as well as reports recently published that are of considerable importance in the context of the European Union in general and to the beneficiary of the assessment in particular.

This central literature includes:

- IPCC 6th Assessment Report (IPCC, 2022g)
- Climate Risk Sourcebook (GIZ, 2023)
- Manual to climate risk assessment (published under the EU Mission on Adaptation to Climate Change) (Smithers and Dworak, 2023)
- European Climate Risk Assessment (EUCRA; EEA, 2024b).

## 1.1 Purpose of this project

At the end of 2023, the European Commission launched the technical support project "**Revision and update of the National Strategy on Adaptation to Climate Change in Cyprus and Slovakia**". The consortium of international and local experts – Trinomics, AARC, alpS Consult, Fresh Thoughts and KRI – has been commissioned to carry out this work, and the project is being implemented in close coordination and agreement with the Ministry of Environment of the Slovak Republic.

Following the first phase of the project, in which the project partners Trinomics and KRI analysed the state of play in the country, by evaluating policy and governance frameworks, progress in implementing adaptation measures and key actors, and conducting scoping interviews with local experts, the present report supplements this work by providing a CRVA. The analysis focusses on the assessment of:

- **exposure**[3] **and sensitivity**
- **climate impacts of high priority**
- **adaptive capacity** (i.e. governance framework and financial capabilities)
- **urgency to act**

of relevant climate impacts in 15 sectors in Slovakia. These were selected based on key sectors that are traditionally considered in the field of climate change adaptation and relevant in the context of Slovakia. They are aligned with existing adaptation efforts, policy documents and strategies in Slovakia and based on the scoping interviews conducted in Deliverable 2.2 (D2.2).

This draft report summarises relevant background information with respect to Slovakia and the methodological approach. Besides, the 15 sectors are defined and their relevance against the background of climate change are described. For each sector, already accomplished work and workshop results of

---

[3] A slightly different understanding of exposure than that used by IPCC is used in this project and report. Further information and explanation are provided in Appendix A.

the Climate Impact Assessment are outlined. More precisely, this includes an assessment of identified climate impacts in terms of exposure and sensitivity. For climate impacts considered a high priority also, the urgency to act and the adaptive capacity (i. e. governance framework and financial capabilities) are assessed.

Next steps following the impact analysis to a comprehensive risk assessment include

- a detailed risk assessment of climate impacts of high priority,
- the identification of key risks, and
- the identification of strategic directions.

## 1.2 Reading guide

The report comprises six main chapters and three annexes, synthesising information gathered from extensive literature analysis and stakeholder consultation. The main body of the report, delineated in Chapter 3, includes the most relevant information for the impact and risk analysis in Slovakia. This assessment is supplemented by dedicated chapters on urban areas, social vulnerabilities and inequalities, transboundary, cascading and emerging risks as well as limitations in particular with respect to knowledge gaps and uncertainties.

**Chapter 1** introduces the reader to the methodological design of the CRVA and the outline of the project. Annex A provides a more in-depth description of the methodology and further background information.

**Chapter 2** describes past and future climate developments in Slovakia and the effects of climate change on temperature, precipitation, and wind, among others. Annex B provides additional graphs supplementing the climate data provided in Chapter 2 as well as underlying information for the CRVA regarding the nature and environment as well as socio-economic data of Slovakia.

**Chapter 3** presents the overall results of the various steps taken within the CRVA. Using a sectoral approach, it covers 15 sectors in total. Each chapter focuses on one sector and includes a general description of the sector, recent socio-economic developments and relevant climate impacts observed in Slovakia, or, where necessary, at EU level. Differences between the respective sectoral descriptions may exist depending on data and availability of relevant publications. Further information on global and EU level developments can be found in Annex C. The chapter then moves on to the outcomes of the first workshop and the climate impact assessments. Results of the climate risk assessment, including a presentation of respective key risks and strategic directions as well as visualisations of sector specific climate impact chains were finalised and added after the second stakeholder workshop, held in September 2024. Detailed information on the climate impacts assessed per sector is provided in Annex C.

**Chapter 4** outlines major aspects relevant with regard to urban areas.

**Chapter 5** deals with social vulnerabilities in the context of climate change.

**Chapter 6** summarises limitations as well as uncertainties and knowledge gaps both in terms of content and methodology.

**Chapter 7** addresses potential opportunities arising from a business-as-usual scenario and from the implementation of climate change adaptation measures. In addition, megatrends and their potential impacts on the vulnerability to climate change are outlined.

# 2 Current & Future Climate

The Slovak Republic is a landlocked country in Central Europe with a temperate climate, featuring four distinct seasons and relatively even precipitation throughout the year (UNFCCC, 2023; World Bank Group, 2021). Slovakia's topography is characterised by its mountainous northern regions, primarily the Carpathians and the Ore Mountains, which transition into fertile lowlands in the south and east, including the Danube, Tisa and Hornad river valleys. This diverse landscape supports a variety of ecosystems and is vital for the country's agricultural activities. Approximately 60% of Slovakia's surface is situated above 300 meters, with elevations such as Gerlach Peak at 2 655 meters, while more than 95% of the territory is drained by the Danube River. The presence of large water dams and smaller reservoirs further enhances the agricultural potential of the region, making it a significant area for both ecological diversity and farming (UNFCCC, 2008).

The country's complex landscape contributes to diverse climate conditions even within small areas. Notable climate contrasts exist between the north and south, with colder conditions prevailing in the north and warmer climates in the south. The climate exhibits significant regional variation: the western region is more influenced by oceanic climate characteristics, while the eastern region has more continental characteristics. The Mediterranean climate mainly affects the southern central region, leading to higher precipitation in autumn (World Bank Group, 2021).

The land use in Slovakia is characterised by forested areas covering around 55% (26 803 km$^2$) of the total land area, agricultural soil at approximately 38% (18 385 km$^2$), built-up areas slightly below 5% (2 296 km$^2$), and water bodies accounting for 1.9% (Copernicus, 2019). The country faces various climate change hazards and impact-drivers, including extreme weather events like increased precipitation and temperature, which heighten the risk of flooding and impact critical economic sectors such as agriculture (World Bank Group, 2021).

In recent decades, specifically from 2001 to 2022, Slovakia has also seen a notable increase in extreme maximum and minimum daily air temperatures, with a sharp rise in the frequency of heat waves. Dry periods, characterised by a lack of precipitation, have become more common, leading to more frequent and severe soil droughts due to generally warmer conditions (UNFCCC, 2023). Looking ahead, future climate projections suggest significant warming, with mean annual temperatures rising by 2.0-3.0°C by 2050 and up to 6.0°C by 2100 under high emissions scenarios (RCP 8.5) (IPCC, 2021b).

## 2.1 Climate Past

### *Temperature*

Climate conditions in Slovakia are notably complex due to a mix of oceanic influence in the west and continental characteristics in the east, along with temperature differences between the northern and southern regions. Despite these regional variations, there has been a uniform upward trend in annual air temperatures (Labudová et al., 2015; Labudová et al., 2024). The data reveal an increase of approximately 2 °C in mean temperature since 1881, resulting in an average increase of approximately 0.15 °C per decade (Gera et al., 2017; UNFCCC, 2023).

Between 1980 and 2021, the average annual temperature rise was more substantial than the overall increase recorded between 1881 and 2021 (UNFCCC, 2023). From 2000 to 2020, the country experienced an average temperature rise of 0.06 °C per year, significantly outpacing the global average of 0.03 °C per year (IEA, 2022). Between 2001 and 2021, the frequency of days with mean temperature exceeding 27 °C increased fivefold compared to the period from 1951 to 1960, while the number of days with mean temperatures below 5 °C decreased by half (IEA, 2022; UNFCCC, 2023). A clear warming trend is evident from January to August, with significant temperature increases observed during these months (Gera et al., 2017).

Since 1991, the number of warmer years has significantly risen, particularly highlighted by the record average annual temperature of 12.43°C in Hurbanovo for the years 2018 and 2019 (UNFCCC, 2023). The rise in summer days (temperatures reaching 25°C or higher) and tropical days (temperatures of 30°C or higher) has been striking since the last decade of the 20th century, especially in May, where maximum temperatures above 25°C have been recorded on more than half of the days in several years since 1991—a stark contrast to the period from 1931 to 1990, when such events were rare (Labudová et al., 2015).

The largest temperature increases were observed in January and the summer months. Between 1961–1990 and 1991–2020, January temperatures rose by more than 1.2°C, while June and July recorded increases of 1.6°C, and August over 1.8°C. In contrast, between the earlier reference periods of 1931–1960 and 1961–1990, the summer months and September actually experienced slight temperature decreases of 0.1 to 0.7°C. Spring and autumn months, however, saw only minor changes, particularly in April, May and October (Labudová et al., 2024).

Seasonal temperature trends mirror these changes, with summer temperatures rising by as much as 2.0°C, while autumn showed a more moderate increase of up to 1.0°C. April stands out among spring months with the fastest warming trend. The rise in temperature is primarily concentrated in the warm half of the year (April–September), while in the cold half (October–March), only January and November show rapid increases. Seasonal temperature changes between 1931–1960 and 1961–1990 were less significant, with summer showing a slight decrease and winter a modest increase at all observation stations since 1931 (Labudová et al., 2024).

In recent decades, temperature changes in spring and autumn, particularly in September and October, have been relatively smaller compared to other months. The rise in spring temperatures is largely due to the decreasing number of snow-covered days and reduced snow cover in March, which accelerates surface warming, especially in both lowland and mountainous areas. Additionally, increased sunlight exposure from reduced cloud cover and lower soil moisture during droughts has further contributed to spring warming. Since the 1990s, May has also experienced more frequent tropical heat events (Tmax ≥ 30°C), with episodic heat waves now emerging as early as the end of April and early May (Labudová et al., 2024).

The summer of 2024 is marked as the warmest in Slovakia since at least 1931, with a predicted average air temperature of 20.7°C. This is almost 0.5°C higher than the previous record set in 2022, indicating a significant increase (Slovak Hydrometeorological Institute). This summer marks the third time since 2019 that air temperatures have exceeded 20°C. June 2024 was the 6th warmest on record, with an average temperature of 19.1°C, and the highest temperature recorded this summer reached 38.3°C in Mužli on August 14, 2024, which is about 2°C lower than the record highs of over 40°C in southern Slovakia during 2007 and 2013 (Slovak Hydrometeorological Institute). Sunshine hours in June and August have generally been close to the 1991-2020 average, with June recording between 220 to 280 hours, while July experienced longer durations, averaging between 250 and 350 hours (Slovak Hydrometeorological Institute). The effect of snow cover on spring warming is evident, as the lack of snow speeds up the warming process in both lowland and mountainous areas. In high mountainous regions, recent years have shown a more significant warming trend compared to the lowlands, indicating that temperature increases in these areas have lagged since the 1990s. This pattern suggests that warming starts at the surface and then moves upward through atmospheric processes. Initially, record high temperatures were mainly observed in southwestern Slovakia, but they have recently shifted to northern and eastern regions, reflecting a more widespread impact of the warming trend across the country (Labudová et al., 2015).

### *Water*

Unlike temperature trends, precipitation patterns in Slovakia are less pronounced due to their complex spatial and temporal distribution. The most noticeable difference in monthly precipitation totals between reference periods occur primarily in July. Extreme weather events from the Mediterranean in July during the late 20th and early 21st centuries have resulted in substantial rainfall and flooding, notably in the years 1997, 1998, 1999, 2001, 2004 and 2005. The region's topography interacts with these weather systems, influencing precipitation trends (Labudová et al., 2024).

In the 1990s and 2000s, Slovakia experienced several severe precipitation events that led to significant floodings. These events were likely influenced by an increase in the spatial extent and intensity of rainstorms, which contributed to flash floods. The growing frequency and intensity of such storms underscore the complex relationship between changing precipitation patterns and extreme weather conditions (Labudová et al., 2015). However, the existing network of meteorological stations may not fully capture the spatial variability of precipitation patterns with variations due to location and the influence of air masses, which results in potentially contrasting trends within the same country. In Slovakia, the most substantial increases in precipitation were recorded at higher altitudes (Gera et al., 2017; Labudová et al., 2015; Lapin, 2021). This trend has intensified in recent years, with the 2024 floods, the worst in 30 years, driven by extreme rainfall, further demonstrating the increasing severity of such events (DW, 2024).

Atmospheric precipitation varied significantly across the summer months in 2024. In June, precipitation levels in Slovakia were well above the average, ranging from 75% to 175% of the 1991-2020 normal in most areas, with some local spots reaching up to 300% due to storms. In contrast, July saw precipitation levels drop to 10% to 75% of the normal across much of the country, with the lowest amounts recorded in the southern Danube Plain. This deficit continued into August, with precipitation ranging between 15% and 40% of the normal, particularly low in the southern parts of central Slovakia and in the Záhorie, and Považie regions. Heavy storms, especially in June, contributed to localised downpours, adding to the overall precipitation of the summer. These storms created significant spatial and temporal variability in rainfall. However, the persistent heat waves exacerbated soil drought, reminiscent of the conditions in 2022 and partly in 2023. The troubling trend of recurring heat waves and drought each year, becoming more pronounced, poses increasing risks to natural ecosystems (Slovak Hydrometeorological Institute).

Research from the late 1990s projected a considerable decline in runoff during the spring and summer months, with northern Slovakia expected to experience a 20-25% decrease and southern regions facing reductions of 30-40%, potentially up to 60%, decrease in spring and summer runoff. In contrast, winter runoff was anticipated to rise significantly, with increases of 20% in the north and 40% in the south. Additionally, spring yields were forecasted to decrease by 10-60%, depending on the region (Zeleňáková and Fendeková, 2019). Historical climate scenarios reveal an increase in runoff during colder months and a loss of winter precipitation stored as snow. Warmer months, however, have seen decreased soil moisture and groundwater runoff, along with increased surface runoff during intense rainfall, which worsens soil erosion and silting of water reservoirs. Moreover, extended drought periods have become more frequent, reducing usable water resources and highlighting the vulnerability of Slovakia's water systems to climate change (UNFCCC, 2023).

Since the 1980s, Slovakia has experienced frequent hydrological droughts. In the 21st century, the country has encountered three significant drought events of Pan-European scale. The impact of climatic factors, particularly precipitation and potential evapotranspiration, on drought conditions has become more pronounced since 2000 (Fendeková, 2018b). Analysis of the droughts in 2003, 2012 and 2015 revealed that while these years shared similar weather conditions, the effects varied significantly across the twelve river basins assessed. The 2003 drought was moderately severe in terms of duration and precipitation deficit, while the 2012 and 2015 droughts were relatively mild in terms of return period (Fendeková, 2018b).

According to Fendeková (2018b), the 2003 and 2012 droughts were more similar to each other than the 2015 drought. The 2015 drought resembled the average drought parameters from the reference period of 1981–2010, although there were exceptions. For instance, the Kysuca River saw its most extreme drought parameters in 2015. The variability in drought impacts across Slovakia, even over short distances, underscores the climate heterogeneity even over short distances such as altitude-related variations in air temperature and precipitation, geomorphological and geological conditions which have an effect on wetness preconditions in river basins (Fendeková, 2018b).

In Slovakia, groundwater serves primarily as a source of drinking water. However, the increasing frequency of droughts, largely attributed to climate change, poses a significant threat to these vital resources. Since 1991, the intensity of negative changes in groundwater resources has markedly increased, with reductions reaching 25% in the most affected areas and up to 35% in local spots, resulting in an estimated total decrease of 250,000 m³/km² (Fendeková, 2018a). By 2009, it was noted that at least 70% of Slovakia had experienced declines in groundwater levels, particularly in the southern and central regions. Despite these challenges, some areas, such as southeastern Slovakia (including the Eastern Slovakian Lowland and Košice basin) and the central Váh River Basin, have seen a moderate increase in groundwater levels. Additionally, baseflow drought studies have been conducted in several river sub-basins, including the upper Torysa, upper Nitra, and Topľa River Basins, which have included comparative research on streamflow and groundwater drought in the Topľa River Basin (Fendeková, 2018a; Zeleňáková and Fendeková, 2019).

### *Other*

Čimo et al. (2020b) examined the effects of climate change on the length of the vegetation period in Slovakia from 1961 to 2010, focusing on species such as *Capsicum annuum* (bell pepper), *Brassica oleracea var. capitata* (cabbage) and *Beta vulgaris subsp. vulgaris* (beetroot). The analysis revealed that while the overall vegetation periods for these crops remained relatively stable, minor variations were observed due to temperature fluctuations. For instance, *Capsicum annuum* showed a slight increase in the vegetation period by about five days in southern regions, reaching up to 175-180 days from 2001 to 2020. Conversely, both *Brassica oleracea* and *Beta vulgaris* experienced a reduction in their vegetation periods during the colder decade of 1971–1980, but their overall durations remained consistent at 215-220 days and did not show significant changes from 1961 to 2020. Notably, the boundary of the long vegetation period zone shifted from southeast to southwest Slovakia between the periods of 1961–1970 and 2001–2010.

## 2.2 Climate Future

The future extent of climate change, projected through to 2100, will largely hinge on greenhouse gas emissions and their atmospheric concentrations. This is reflected in the predictions of global climate models (GCMs) and regional climate models (RCMs), which use various emission scenarios such as the Representative Concentration Pathways (RCPs), ranging from RCP2.6 to RCP8.5, and the more recent Shared Socioeconomic Pathways (SSPs), ranging from SSP1-2.6 to SSP5-8.5 (UNFCCC, 2023).

Global and regional climate models are crucial for understanding and forecasting climate changes throughout the 21st century. While GCMs are continually improved, their spatial resolution tends to be relatively broad. To address this limitation, regional climate models use dynamical downscaling to refine GCM outputs, providing detailed projections for smaller, localised areas with higher spatial and temporal resolution (UNFCCC, 2023).

Europe is experiencing the fastest rate of warming among the continents; since the 1980s, its temperature increase has been approximately doubled compared to the global average, with 2023 and 2024 being the warmest years on record over more than 100 000 years (Copernicus, 2025; EEA, 2024b).

As shown in Table 2 and Table 4 below, Slovakia is projected to experience significant temperature and precipitation increases in both the near and far future.

The tables below summarise the results of two different scenarios: a moderate scenario (RCP-4.5), where emissions are expected to peak in about around 2040, and a high-emissions scenario (RCP-8.5) in which emissions continue to rise throughout the century. Figure 3 and Figure 4 show changes in mean annual air temperature in °C, and mean annual precipitation in mm against the reference period 1991-2020 (Slovak Hydrometeorological Institute). Colour codes, used in Tables 2 to 7, provide an overview over the expected indicator changes. Table 1 provides the qualitative description of the colour codes used in the indicator tables.

*Table 1: Qualitative description of colour coding for indicator changes provided in Tables 2 – 7.*

| Qualitative description of indicator change | | |
|---|---|---|
| Large | Medium | Small |
| Change is > 2 °C | Change is 1.5-2 °C | Change is < 1.5 °C |
| Change is > 10 days | Change is 5-10 days | Change is < 5 days |
| Change is > 75 % | Change is 25-75 % | Change is < 25 % |
| Change is > 80 mm | Change is 40-80 mm | Change is < 40 mm |

The data show a clear trend of rising temperatures and an increase in extremely hot days across Slovakia, with more significant changes under higher emissions scenarios, underscoring the urgent need for adaptation to address heat impacts. Additionally, there is a noticeable increase in heavy rain days at both city and regional levels, with more pronounced changes projected under the higher emissions scenario, highlighting the need for improved flood management and adaptation strategies.

### *Temperature*

Climate projections by the Slovak Hydrometeorological Institute indicate that by 2071-2100 (Table 2), the annual mean temperature for selected cities in Slovakia is expected to rise by approximately 1.2 to 3.4 °C compared to the reference period of 1991-2020, depending on the city and the climate change scenario (RCP4.5 or RCP8.5). This increase in temperature is anticipated to impact energy consumption patterns, leading to higher demands for cooling and lower requirements for heating. The warming is expected to be relatively consistent across the country, whereby scenario results show more pronounced levels of warming for southern and western parts of Slovakia. Additionally, heatwaves and the frequency of days with maximum temperatures exceeding 30 °C are projected to rise by the century's end. Over the past twenty years, there has been a decline in heating degree days (HDDs) and an increase in cooling degree days (CDDs)[4], reflecting changing energy needs (IEA, 2022).

Under the RCP4.5 scenario, Slovakia is expected to experience moderate increases in mean annual air temperature in °C and tropical days (maximum temperatures reaching at least 30°C) in the near future (2021-2050) and significant increases in the far future (2071-2100). Specifically, as indicated in the data presented in the tables below, the number of tropical days is expected to rise, highlighting a concerning trend. In contrast, the RCP8.5 scenario predicts substantial increases in mean annual air temperature and tropical days for both periods. Both scenarios foresee a significant rise in the number of tropical days (days with maximum temperatures above 30°C).

---

[4] Degree days are calculated based on the assumption that outdoor temperatures around 18.3°C (65°F) indicate that heating or cooling is not needed for comfort. Degree days measure the difference between the daily mean temperature (the average of the daily high and low temperatures) and 18.3°C. If the mean temperature is above 18.3°C, the result is termed Cooling Degree Days (CDDs), obtained by subtracting 18.3°C from the mean. Conversely, if the mean temperature falls below 18.3°C, the outcome is known as Heating Degree Days (HDDs), calculated by subtracting the mean from 18.3°C (National Weather Service, n.d.).

Climate models forecast that by 2030, southern Slovakia could see an increase in the annual average air temperature of 0.7-0.9 °C (compared to 1991-2020 period). By 2050, this rise is expected to reach 2.0-3.0 °C, and by 2100, temperatures could increase by 3.5-6.0 °C, depending on the RCP scenario. Minimum temperatures are anticipated to rise more rapidly than maximum temperatures, potentially increasing by 6.0 to 10.0 °C for minimums and 2.0 to 5.0 °C for maximums by 2100. This pattern may lead to a reduced daily temperature range. While there are no major expected changes in the annual temperature pattern, autumn is projected to warm more slowly compared to other seasons. By 2100, summer temperatures are expected to rise by 1.5 to 4.0 °C and winter temperatures by 2.5 to 5.0 °C (UNFCCC, 2023).

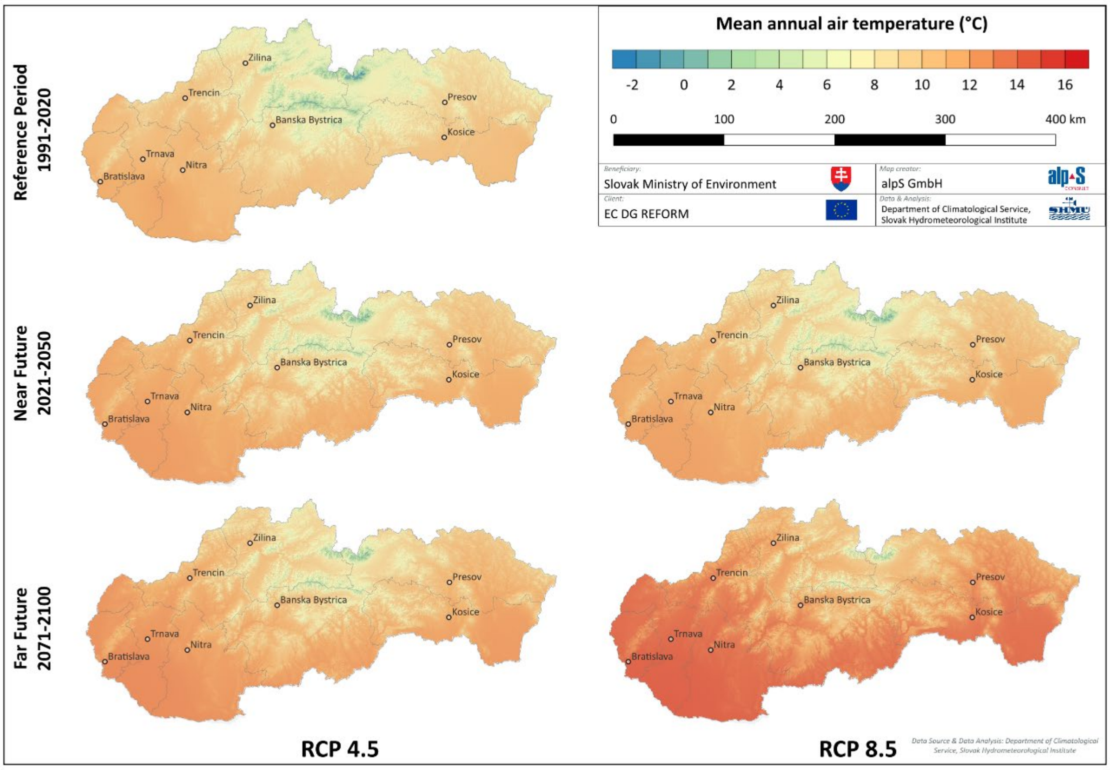


*Figure 3: Mean annual air temperature in °C; scenarios for the near (2021-2050) and far (2071-2100) future under RCP4.5 and RCP8.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

By 2050, there will be an expected increase in the number of summer and tropical days, along with a decrease in frost and ice days. Heat waves are expected to become more frequent, longer, and more intense, potentially beginning as early as May and extending through mid-September. The occurrence of heat waves similar to those in 2003, 2007, or 2015 could increase by 3 to 5 times around 2050 (UNFCCC, 2023).

According to Table 2 below, mean annual temperatures are projected to increase in all cities, with more significant rises expected under the high emissions scenario (RCP 8.5). For instance, Bratislava's temperature could rise by up to 2.8°C by 2100 the far future under RCP 8.5, compared to the reference period (1991-2020). The number of tropical days is also projected to increase, with a more substantial rise under the high emissions scenario. Bratislava could experience an increase of up to 30.5 tropical days by 2100 under RCP 8.5, compared to the reference period 1991-2020.

*Table 2: Changes in mean annual air temperature in °C and tropical days (maximum temperatures reaching at least 30°C) in days for regional capitals of Slovakia for the near (2021-2050) and far (2071-2100) future under RCP 4.5 and RCP8.5 are shown. The colour coding is explained in Table 1. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

|  |  |  | Absolut changes to reference period 1991-2020 |  |  |  |
|---|---|---|---|---|---|---|
|  |  | Ref. Period 1991-2020 | Near Future 2021-2050 |  | Far Future 2071-2100 |  |
| Indicator | City |  | RCP4.5 | RCP8.5 | RCP4.5 | RCP8.5 |
| Temperature [°C] | Bratislava | 10,9 | 0,6 | 0,3 | 1,3 | 2,8 |
|  | Trnava | 10,5 | 1,0 | 0,8 | 1,6 | 3,2 |
|  | Nitra | 10,7 | 0,8 | 0,6 | 1,3 | 3,0 |
|  | Trencin | 10,0 | 0,7 | 0,6 | 1,2 | 2,9 |
|  | Banska Bystrica | 9,1 | 1,0 | 0,9 | 1,5 | 3,2 |
|  | Zilina | 8,8 | 0,9 | 0,8 | 1,3 | 2,9 |
|  | Presov | 9,0 | 1,2 | 1,2 | 1,7 | 3,4 |
|  | Kosice | 9,8 | 0,9 | 0,9 | 1,5 | 3,2 |
| Tropical days [Days] | Bratislava | 25,8 | 6,1 | 5,8 | 11,1 | 30,5 |
|  | Trnava | 23,3 | 5,3 | 5,2 | 10,4 | 30,3 |
|  | Nitra | 27,8 | 6,3 | 6,8 | 12,5 | 31,7 |
|  | Trencin | 21,3 | 4,8 | 5,2 | 10,0 | 28,6 |
|  | Banska Bystrica | 14,0 | 3,9 | 4,2 | 9,7 | 27,1 |
|  | Zilina | 15,1 | 4,6 | 4,4 | 8,3 | 24,2 |
|  | Presov | 13,4 | 3,2 | 3,9 | 9,2 | 26,9 |
|  | Kosice | 16,3 | 3,3 | 4,8 | 10,8 | 29,5 |

*Table 3: Changes in mean annual air temperature in °C and tropical days (maximum temperatures reaching at least 30°C) in days for regions of Slovakia for the near (2021-2050) and far (2071-2100) future under RCP4.5 and RCP8.5 are shown. The colour coding is explained in Table 1. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

| | | | Absolut changes to reference period 1991-2020 | | | |
|---|---|---|---|---|---|---|
| | | Ref. Period 1991-2020 | Near Future 2021-2050 | | Far Future 2071-2100 | |
| Indicator | Region | | RCP4.5 | RCP8.5 | RCP4.5 | RCP8.5 |
| Temperature [°C] | Bratislavsky kraj | 10,4 | 0,9 | 0,6 | 1,5 | 3,1 |
| | Trnavsky kraj | 10,5 | 0,9 | 0,7 | 1,5 | 3,1 |
| | Nitriansky kraj | 10,6 | 0,7 | 0,5 | 1,2 | 3,0 |
| | Trenciansky kraj | 9,0 | 0,7 | 0,6 | 1,2 | 2,9 |
| | Banskobystricky kraj | 8,3 | 1,0 | 1,0 | 1,6 | 3,3 |
| | Zilinsky kraj | 6,4 | 1,1 | 1,0 | 1,6 | 3,3 |
| | Presovsky kraj | 7,3 | 1,3 | 1,3 | 1,8 | 3,5 |
| | Kosicky kraj | 9,0 | 0,9 | 0,9 | 1,5 | 3,2 |
| Tropical days [Days] | Bratislavsky kraj | 18,1 | 4,9 | 4,5 | 8,8 | 27,2 |
| | Trnavsky kraj | 25,7 | 5,6 | 5,8 | 11,0 | 30,5 |
| | Nitriansky kraj | 28,0 | 6,0 | 6,5 | 12,4 | 32,1 |
| | Trenciansky kraj | 19,1 | 4,6 | 4,8 | 8,8 | 25,2 |
| | Banskobystricky kraj | 17,1 | 4,4 | 4,9 | 9,4 | 25,5 |
| | Zilinsky kraj | 7,5 | 3,2 | 3,1 | 5,5 | 17,5 |
| | Presovsky kraj | 10,8 | 2,8 | 3,7 | 7,4 | 20,9 |
| | Kosicky kraj | 17,9 | 3,7 | 5,1 | 10,1 | 26,6 |

### *Water*

Precipitation patterns are expected to show strong variability in the future. Climate projections suggest up to a 30 % increase in annual precipitation by 2075 compared to 1961-1990, with significant seasonal and geographical variations. However, this increase is expected to vary by season and region, with winter experiencing a more substantial rise compared to summer, and the northern regions seeing a greater increase than the southern area. These changes in precipitation may increase the country's exposure to both heavy rainfall events and droughts[5]. These projections come with a high degree of uncertainty, particularly for precipitation, which is inherently more difficult to model compared to temperature (IEA, 2022). Rainfall patterns are anticipated to become more variable, with longer periods of dryness interspersed with more intense, short-duration rain events. By the end of the century, precipitation totals across most of Slovakia are projected to increase with potential rises of up to 10 % under RCP4.5 and up to 15 % under RCP8.5 compared to the 1981-2010 period. This corresponds to an annual increase of 50 to 70 mm for RCP4.5 and 100 to 120 mm for RCP8.5. While winter and autumn precipitation are expected to grow, spring and summer rainfall may decline, potentially worsening the precipitation balance and increasing drought frequency, particularly in southern Slovakia. Additionally, sultry days are likely to increase due to higher atmospheric moisture and warm, dry conditions are expected to arrive earlier in the spring (UNFCCC, 2023). As shown in Table 4 below, across the cities of Slovakia, the frequency of heavy rain days is projected to increase significantly in both the near and far future (2021-2050 and 2071-2100, respectively) with a more substantial rise under the high emissions scenario (RCP8.5). Nitra and Trnava are anticipated to experience the most significant relative increases, particularly in the far future. At the regional scale, depicted in Table 5, heavy rain days are also projected to increase significantly. The highest increases are expected in Zilinsky kraj, both in the near and far future, with substantial rises in other regions as well. Climate change will cause a general decline in precipitation across the country. Though both areas will experience reductions, the north will still receive relatively more rainfall. This spatial disparity in precipitation is expected to persist over time (future water resource planning and management (Štefunková et al., 2013).

Studies conducted after 2010 indicate that winter and early spring runoff would likely increase while summer runoff would decline, with southern Slovakia particularly susceptible to reductions of up to 67 % by 2075 (Zeleňáková and Fendeková, 2019). Projected changes in the seasonal distribution of average monthly river discharges suggest that all studied river basins could become more prone to drought during the summer and early autumn. During these months, when water demand is high for irrigation, domestic and industrial use, and tourism, river discharges may decrease due to climate change. The intensity of these changes is expected to grow as we approach 2070–2100. Therefore, a continued decline in the usable water resources is anticipated, which will need to be considered in future water resource planning and management (Štefunková et al., 2013).

---

[5] Additionally, the decrease in snow cover may lead to reduced groundwater recharge, as less snowmelt during the winter months will result in more precipitation running off rather than replenishing aquifers.

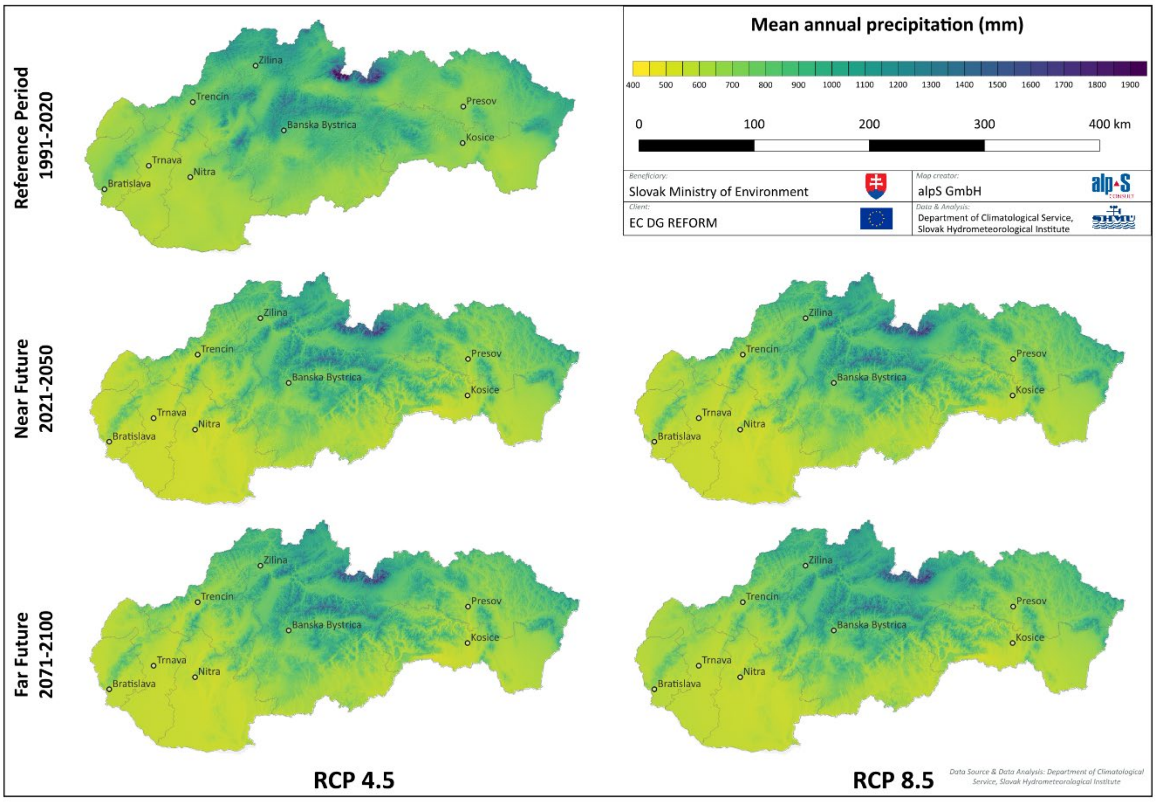


*Figure 4: Mean annual precipitation in mm for Slovakia; scenarios for the near (2021-2050) and far (2071-2100) future under RCP4.5 and RCP8.5 are shown, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

*Table 4: Changes in mean annual heavy rain days (more than 40 mm precipitation) in percent for regional capitals of Slovakia; scenarios for the near (2021-2050) and far (2071-2100) future under RCP 4.5 and RCP 8.5 are shown. The colour coding is explained in Table 1. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

| | | | Relative changes to reference period 1991-2020 in % | | | |
|---|---|---|---|---|---|---|
| | | Ref. Period 1991-2020 | Near Future 2021-2050 | | Far Future 2071-2100 | |
| Indicator | City | | RCP4.5 | RCP8.5 | RCP4.5 | RCP8.5 |
| Heavy rain [Days] | Bratislava | 0,82 | 11 | 15 | 23 | 59 |
| | Trnava | 0,54 | 57 | 57 | 72 | 126 |
| | Nitra | 0,52 | 63 | 63 | 79 | 135 |
| | Trencin | 0,79 | 19 | 23 | 32 | 68 |
| | Banska Bystrica | 1,24 | -10 | -5 | 0 | 23 |
| | Zilina | 0,67 | 61 | 70 | 81 | 122 |
| | Presov | 0,70 | 47 | 54 | 64 | 107 |
| | Kosice | 0,74 | 32 | 38 | 47 | 88 |

*Table 5: Changes in mean annual heavy rain days (more than 40 mm precipitation) in percent for regions of Slovakia; scenarios for the near (2021-2050) and far (2071-2100) future under RCP4.5 and RCP8.5 are shown. The colour coding is explained in Table 1. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

| | | | Relative changes to reference period 1991-2020 in % | | | |
|---|---|---|---|---|---|---|
| | | Ref. Period 1991-2020 | Near Future 2021-2050 | | Far Future 2071-2100 | |
| Indicator | Region | | RCP4.5 | RCP8.5 | RCP4.5 | RCP8.5 |
| Heavy rain [Days] | Bratislavsky kraj | 0.76 | 22 | 25 | 36 | 74 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Trnavsky kraj | 0.60 | 47 | 50 | 63 | 112 |
| | Nitriansky kraj | 0.56 | 59 | 63 | 77 | 129 |
| | Trenciansky kraj | 0.76 | 55 | 67 | 74 | 111 |
| | Banskobystricky kraj | 0.85 | 53 | 68 | 73 | 105 |
| | Zilinsky kraj | 0.87 | 83 | 106 | 108 | 138 |
| | Presovsky kraj | 0.93 | 47 | 63 | 68 | 97 |
| | Kosicky kraj | 0.81 | 44 | 56 | 62 | 98 |

An important index for understanding water stress in ecosystems and agricultural areas is the Annual Climate Water Index (KUZ), measuring the balance between the potential for water to evaporate and be transpired by plants (evapotranspiration) and the amount of precipitation received. A positive KUZ indicates a water deficit (more evapotranspiration than precipitation), while a negative value suggests a water surplus. This index is crucial for understanding water stress in ecosystems and agricultural areas. As shown in

Table 6, the annual KUZ absolute changes on city level (i.e. regional capitals) become higher in course of the 21st century, whereby the greatest changes are to be expected in the far future (2071-2100) under a RCP8.5 scenario. On regional level (Table 7), changes are less pronounced. The most significant changes are estimated for Trnavsky kraj, Nitriansky kraj and Trenciansky kraj in the far future under a RCP8.5 scenario, indicating that these areas are expected to experience a more pronounced water deficit due to higher positive KUZ values.

*Table 6: Changes in mean annual Climate Water Index (KUZ) in mm for regional capitals of Slovakia; scenarios for the near (2021-2050) and far (2071-2100) future under RCP4.5 and RCP8.5 are shown. The colour coding is explained in Table 1. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

| | | | Absolute changes to reference period 1991-2020 in mm | | | |
|---|---|---|---|---|---|---|
| | | Ref. Period 1991-2020 | Near Future 2021-2050 | | Far Future 2071-2100 | |
| Indicator | City | | RCP4.5 | RCP8.5 | RCP4.5 | RCP8.5 |
| Climate water index [mm] (KUZ) | Bratislava | 200 | 5 | 20 | -5 | 81 |
| | Trnava | 200 | 39 | 47 | 26 | 111 |
| | Nitra | 200 | 65 | 63 | 53 | 126 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Trencin | 100 | 29 | 18 | 15 | 60 |
| | Banska Bystrica | -100 | 65 | 35 | 47 | 83 |
| | Zilina | -150 | 70 | 52 | 51 | 52 |
| | Presov | 50 | 21 | 8 | 8 | 60 |
| | Kosice | 150 | 12 | 19 | 2 | 63 |

*Table 7: Changes in mean annual Climate water index (KUZ) in mm, scenarios for the near and far future under RCP4.5 and RCP8.5 are shown for regions of Slovakia. The colour coding is explained in Table 1. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

| | | | Absolute changes to reference period 1991-2020 in mm | | | |
|---|---|---|---|---|---|---|
| | | Ref. Period 1991-2020 | Near Future 2021-2050 | | Far Future 2071-2100 | |
| Indicator | Region | | RCP4.5 | RCP8.5 | RCP4.5 | RCP8.5 |
| Climate water index [mm] (KUZ) | Bratislavsky kraj | 176 | 5 | -9 | 18 | 75 |
| | Trnavsky kraj | 180 | 30 | 16 | 35 | 95 |
| | Nitriansky kraj | 176 | 40 | 28 | 38 | 95 |
| | Trenciansky kraj | -70 | 59 | 42 | 41 | 81 |
| | Banskobystricky kraj | -63 | -12 | -29 | -28 | 26 |
| | Zilinsky kraj | -331 | -11 | -34 | -43 | -24 |
| | Presovsky kraj | -171 | -19 | -35 | -45 | -6 |
| | Kosicky kraj | 9 | 0 | -11 | -4 | 43 |

### *Wind*

Stronger and more intense storms are anticipated to occur more frequently as air temperatures and humidity levels rise. The frequency of extreme storm-related phenomena, such as wind gusts exceeding 25 m/s and hail events with hailstones measuring 2-5 cm in diameter, is projected to increase significantly; by 2100, high wind gusts could see a 20-80% rise in occurrence, while hail events with hailstones up to 5 cm could increase by 40-150%, depending on the chosen emission scenario. Additionally, during dry and windy spells, wind erosion is expected to affect exposed areas. Torrential rains are likely to cause increased water erosion, exacerbated by the growing intensity and frequency of these events and the diminished anti-erosion effects of crop vegetation, leading to more instances of gully erosion. Shallow soils, particularly in mountainous regions, are considered especially vulnerable to these changes (UNFCCC, 2023).

### *Extreme weather events*

Models predict that torrential and intense short-term rainfall events will become more frequent and severe. For example, increases in rainfall intensities are expected to be approximately +5 to +8% for RCP2.6 from 2021-2050, +3 to +5% from 2051-2100, and up to +35% for RCP8.5 by the end of the century. Stronger storms are also anticipated, with more frequent high wind gusts and larger hail (UNFCCC, 2023).

### *Other*

Projections indicate that climate change will lead to a longer vegetation period for various crops in Slovakia. For *Capsicum annuum*, the growing season is expected to extend by about 5 days to approximately 185 days by 2041–2050, with further increases expected to reach 195 days by 2100. This marks a significant rise of 15–20 days compared to the 1961–2000 average and a 30–35-day increase compared to the coldest decade from 1971–1980. Similarly, the vegetation period for *Brassica oleracea var. capitata* is projected to extend to 220–225 days by 2041–2050 but then decline to 195 days by 2091–2100, representing a 15–20 day increase from 1961–2000 and a 35–40 day increase from 1971–1980. For *Beta vulgaris subsp. vulgaris*, the growing period is forecasted to increase to 175–180 days by 2041–2050 and to 190 days by 2091–2100, resulting in a 25–30-day extension compared to 1971–1980 (Čimo et al., 2020b).

In the broader context of climate change effects, Škvarenina et al. (2004) analysed potential impacts on water balance across different vegetation types in the West Carpathians of Slovakia. By 2075, rising temperatures are expected to enhance potential evapotranspiration while simultaneously decreasing precipitation and humidity, resulting in significant water deficits—ranging from 200-400 mm in lower vegetation stages and 50-150 mm in middle stages. This scenario could favour drought-resistant species and broadleaved trees, although it may also lead to reduced coverage of spruce trees. Higher elevations might experience a water surplus, potentially benefiting wood production, although this advantage could be mitigated by adverse factors like windstorms and pests. As such, adaptation strategies will be crucial, including updated agricultural practices and improved water management in horticulture to cope with these climatic changes.

# 3 Climate Risk and Vulnerability Analysis

Europe is considered to be severely affected by climate change due to faster warming than on global average, having reached 2.1 °C mean temperature increase relative to pre-industrial levels on a 10-year average, compared to 1.2 °C mean temperature increase on global level (EEA, 2024b). The years 2023 and 2024 were yet other record-breaking years in terms of temperature and have shown by example the exacerbating effects of climate change(Copernicus, 2025; EEA, 2024b).

These rising temperatures are associated with a range of climate impacts that affect biophysical and socio-economic systems. Climate change impacts on different scales have been observed in all parts of Europe. Southern regions are likely to be most severely affected, facing increasing water demand and decreasing precipitation, droughts and increase in fire risk, among others (IPCC, 2022d). In terms of risk, national, regional and local characteristics distinguish exposure, vulnerability and adaptive capacity, however, key risks have been identified by the IPCC (IPCC, 2022d) and in more detail by the first European Climate Risk Assessment (EUCRA; EEA, 2024b). Key risks identified by the IPCC (2022d) for Europe are described in the box below (Table 8). The assessment of climate impacts within the EUCRA has backed these findings, highlighting prolonged heatwaves and changing precipitation patterns. Particularly southern regions and low-lying coastal areas are risk hot spots, with increasing impacts from heat and droughts on agriculture and crop production and fire-induced risks to the built environment, to humans and to biodiversity.

*Table 8: Key climate risks for Europe based on IPCC (2022d) and EEA (2024b).*

Key Risks for Europe

The IPCC report for Europe (2022d) has identified four key risks: heat, agriculture, water scarcity and flooding. While most risks are assessed as moderate until up to 1.5 °C warming, their severity increases substantially with every increment of warming.

*Heat*. The increasing frequency, intensity and duration of heat extremes and increasing mean temperatures influence human health, morbidity and mortality as well as productivity. Terrestrial and marine heat waves cause losses in biodiversity and species extinction, and reduces ecosystem service provision, especially in Southern Europe and the Mediterranean.

*Agriculture*. Heat also affects agricultural production and crop yields, especially compounding with dry conditions or extreme weather, leading to reduced crop quality and quantity as well as shifts in agricultural zones and desertification.

*Water Scarcity*. Risks related to water scarcity are already persistent in Southern Europe and are projected to increase in Western and Central Europe too. Water scarcity is closely connected to multiple other sectors, causing cascading impacts well beyond the scope of water availability and precipitation alone, as agriculture, ecology, energy supply and industries are negatively influenced. Droughts are projected to become more persistent, making water scarcity more widespread and severe, especially at 3 °C global warming level and beyond.

*Flooding*. Coastal, pluvial and fluvial flooding depend on regional spatial contexts and topography. As sea levels rise, so does human exposure in coastal areas, due to the amount of people and assets present. In parallel, inland pluvial flooding is considered a key risk in Europe due to the extent of exposed settlements and the limited adaptation options in urban areas.

Similarly, key risks for Europe were identified by the European Climate Risk Assessment (EUCRA) for five clusters, i.e. ecosystems, food, health, infrastructure and economy & finance (EEA, 2024b):

*Ecosystems*. Marine and terrestrial ecosystems are put under severe pressure by climate change by climate impacts such as droughts, wildfires and changing precipitation patters, leading to degradation and biodiversity loss. At the same time, non-climatic risk drivers (e.g. pollution by industries) further intensify these effects. Climate risks to ecosystems differ depending on the region, species and habitats affected. The assessment shows that more or even urgent need to take action exists to tackle identified risks.

*Food*. Droughts, crop failures, heavy rain or pests and diseases, among others, are relevant for current and future risks to crop production and food security. The current risk is already substantial or critical and will increase within the 21st century. As food security in Europe is also linked to international supply chains, food production and associated challenges due to climate change in other geographical regions have to be taken into account as well.

*Health*. The urgency to take action is highest for heat and wildfires, in particular in South Europe. Other relevant climate-induced impacts result from increased vector- and water-borne diseases due to rising temperatures and extreme events such as droughts and floods. Climate risks in the health cluster are highest for vulnerable groups (e.g. older people, children and people with disabilities).

*Infrastructure*. Pluvial, fluvial and coastal flooding already lead to severe impacts on infrastructure and the associated risk will increase throughout the century. Disruptions of supply with critical resources such as water and energy have to be expected. Likewise, transportation on both land and water is facing severe climate risks, whereby the extend of direct and cascading impacts is significantly uncertain.

*Economy & finance*. Climate-related impacts such as extreme events also affect the stability of financial markets and the economies of the EU Member States. Already nowadays, the EU solidarity fund faces tremendous challenges due to the costly consequences of floods and wildfires. Supply chain disruptions pose risks to businesses and these can be amplified by non-climatic risk drivers such as critical geopolitical circumstances.

The EEA report also incorporates priority fields of action for all five clusters on European level to address current and expected future climate risks.

The major climate risks identified in the EUCRA (Table 8) further emphasise the urgency to act to overcome several already severe risks (EEA, 2024b). These risks are characterised by their longevity, the time needed for adaptation options to fulfil their impact and their wide-ranging effects and consequences, possibly rippling through ecological, economic and societal levels (GIZ, 2023). Addressing current and future climate risks, assessing the exposure and vulnerability as well as potential hazards, forms the basis of a well-informed CRVA. As such assessments, when applied to different scales, uncover risks relevant on national, regional or even local levels, the EU has incorporated risk and impact analysis in the EU Climate Adaptation Strategy, aiming to improve knowledge about relevant climate impacts to enhance targeted and systemic adaptation based on well-informed decision-making, by providing common rules for data collection and monitoring on different scales (European Commission, 2021b).

The following chapters present the assessment of climate impacts, key risks and the development of strategic directions for Slovakia. The methodology and the understanding of terms, such as hazard, climate impact, key risks are explained in Annex A: Additional information on methodological design.

## 3.1 Agriculture

The sector **Agriculture** encompasses the cultivation of crops (cereal, fruit, citrus, vegetables, olives, wine, etc.) and production of animal products such as dairy, meat and others. It includes issues of food security and safety for humans as well as animal health and welfare. Spatially, it covers all agriculturally used land, greenhouses, pastures and spaces for animal husbandry and livestock farming (FAO, 2021).

According to the Ministry of Agriculture and Rural Development of the Slovak Republic (2020c), the natural conditions in Slovakia for agricultural production are manifold and differ depending on the region in terms of soil fertility, energy input and rainfall. For instance, regions with the most fertile soils, mainly used for maize (*Zea mays*) and rapeseed (*Brassica napus*) production, face unfavourable conditions concerning water availability in particular during the summer months due to a lack of rainfall. To compensate for this water shortage, irrigation is installed on approximately 300 thousand hectares (Ministry of Agriculture and Rural Development of the Slovak Republic, 2020c), as of 31 December 2022 a total area of 318,28 ha, whereby the system is functional on 53,675 ha and partly functional on 86,699 ha (Ministry of Agriculture and Rural Development of the Slovak Republic, 2023). In contrast, soils in regions such as the Eastern Carpathian are less fertile, but water availability is rather given.

The three most important crops grown in Slovakia (as of 2020) are winter wheat (approx. 350-660 thousand ha; 26 % of arable land), spring barley (approx. 200 thousand ha; 14 % of arable land) and maize (approx. 140 thousand ha; 10.2 % of arable land). Other crops of greater significance are oilseed rapes. Less important or declining are field and fruit vegetables, and root crops such as sugar beet and potatoes, whereby the latter was known as a traditional Slovakian crop and its agricultural production is now concentrated in the lowlands instead of areas in higher altitude. Viticulture only plays a minor role on a national level but should not be neglected regarding its historical and cultural relevance for certain regions such as the Small-Carpathians the Tokai and Hont region (Ministry of Agriculture and Rural Development of the Slovak Republic, 2020a, 2020c). Partially, organic agriculture practices are used in Slovakia, whereby their beginning dates back to 1991. Nowadays, the area used for organic agriculture comprises approximately 65 388 ha and a total number of 131 registered entities. Most of them are located in mountain and sub-montane regions (Ministry of Agriculture and Rural Development of the Slovak Republic, 2024b). Furthermore, the animal production sector can be considered important in Slovakia, in particular regarding the cultural value of beef cattle and sheep breeding in the past, present and, potentially, in the future (Ministry of Agriculture and Rural Development of the Slovak Republic, 2020b, 2020d, 2024a). The sector itself is highly subsidised, mostly through funds provided by the European Union (72%) (Ministry of Agriculture and Rural Development of the Slovak Republic, 2020b). Despite this financial support, the sector has faced various challenges. For instance, the milk/dairy production sector has undergone three crises in the last ten years (as of 2023) and is therefore weakened, also in financial terms. In general, the number of farm animals (cattle, dairy cows) shows a declining trend from 2010-2020 (Kapsdorferova et al., 2023).

Various climate-induced impacts on the agricultural sector are relevant in Slovakia. Generally speaking, temperature and moisture related changes can affect pest and weed occurrence, properties of soils, wintering conditions and the phenology (Šiška and Nejedlik, 2013). For instance, research indicates changes in agroclimatic indices such as temperatures during the growing season (Kišš et al., 2023) and a prolongation of the vegetation period, meaning that the onset in spring is earlier and the overall duration is extended in autumn (Čimo et al., 2020a; Čimo et al., 2020b; Kišš et al., 2022a; Šiška and Nejedlik, 2013; Varga, 2021). However, the length of the vegetation period varies depending on the species (Čimo et al., 2020b) and even though such a prolongation could be considered as positive, aspects such as a decrease in water availability, along with an increasing need for irrigation, among others, might limit agricultural production. Hence, the time span during which additional artificial water supply is necessary is expected to expand (Bárek et al., 2009; Čimo et al., 2020a; Kišš et al., 2022a; Šiška and Nejedlik, 2013). Kišš et al. (2022b) show a decline in precipitation in April (statistically significant), leading to deceasing soil moisture and restricting growth of agricultural plants (Kišš et al., 2022b). Against this background, Bárek et al. (2009) already called for an improvement of water management planning and control. At the same time, other extreme weather events such as heavy precipitation can also affect agricultural production and the distribution of products (Devot et al., 2023; EEA, 2024b). In this context, heavy precipitation is one of the most important factors inducing soil erosion. Research on future levels of rainfall erosivity indicates that in particular river basis regions in central Europe are susceptible to increasing rates of such water-induced erosion (Uber et al., 2024). According to

Petrikovičová et al. (2020), erosion caused by water affects roughly 37 % of the area used for agriculture in Slovakia and is among the most relevant erosion processes. Another major concern in the agricultural sector are droughts (Crocetti et al., 2020; Labudová et al., 2017; Šiška and Nejedlik, 2013). In their analysis based on a comparison of two reference periods (i.e. 1961-1990 and 1991-2020), Labudová et al. (2024) found, among others, that droughts tend to last longer and observed a shift of major drought seasons from autumn/winter to spring/summer month. In the last two decades, three severe European drought events also affected Slovakia, i.e. in 2003, 2012 and 2015 (Fendeková et al., 2018). 2024 is yet another year of extreme drought events, whereby for instance nearly a third of the county was affected by severe soil drought in August (Interreg Central Europe, 2024). Additionally, heat waves already occur more frequently (Varga, 2021). Such heat events can also lead to heat stress for animals. For instance, research conducted in dairy cattle farms in Slovakia indicate that dairy cows spent less time in milking boxes and milking time was reduced as well (Boďo et al., 2022). The Agriculture sector has many interlinkages with others, for instance with Biodiversity & Ecosystems. In this context, Tomka et al. (2022) note that applying cross-sectorial approaches can lead to an increased awareness that biodiversity of agricultural landscapes is also part of biodiversity in general.

Agriculture is among the sectors already addressed in the updated National Adaptation Strategy (NAS; Ministry of Environment of the Slovak Republic (2014), (2018a)) and the National Action Plan (NAP; Ministry of Environment of the Slovak Republic (2021b)). Besides that, several sector-specific plans are available. Among the major gaps identified is a lack of available monitoring data to evaluate the progress of adaptation efforts and measures[6].

### 3.1.1 Climate Impact Assessment

The workshop assessment indicates that climate impacts in the nexus of water availability, demand and usage, as well as heat-, pest-, and natural hazard-related aspects, are of particular importance. With respect to natural hazards, an increased natural hazard potential associated with increased insurance costs is rated highest of all climate impacts, as one has to expect higher operating costs and damages in the agricultural sector. This is mirrored by the consequences of yield loss due to extreme events associated with a high urgency to act.

The relevance of heat and drought is reflected by several climate impacts of high priority, namely an increase in drought stress for plants and animals as well as an increase in water scarcity and an increasing need for irrigation. Most importantly, a low adaptive capacity with regard to water scarcity, both in terms of governance framework and financial capabilities, underlines the need to take urgent action. Among other things, this is reflected by a growing need to implement measures for capturing and storing precipitation water, with an emphasis on the rainy winter season, when there is no snow and moisture is not deposited in the deeper layers of the soil, augmenting a dry spring. Medium-sized reservoirs evenly distributed across the country are considered a solution by workshop participants, including the possibility of revitalising historical reservoirs.

As an increase in pests and harmful organisms in plants and animals is associated with high levels of exposure and sensitivity, the use of pesticides and their effectiveness in relation to climate change need to be considered. For instance, extreme drought or rain events may limit conventional farming practices, e. g. by reducing the effectiveness of pesticides.

In addition, it should be noted that especially wild pollinators are deemed relevant with respect to an increasing desynchronisation of pollinator-plant phenology, whereby the role of honeybees is less important.

---

[6] Information based on assessment conducted within the scope of this project/Deliverable 2.2.

Table 9 below presents the results from the participatory climate impact assessments, which were conducted in June 2024. The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C. Definitions of key terms used are provided in Annex A.

*Table 9: Presentation of the results of the climate impact assessment for the sector Agriculture. Impacts of high priority are highlighted in **bold**. The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).*

| Agriculture | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| Biophysical | | | | | |
| **increase in drought stress for plants** | **very high** | **High** | **medium** | **medium** | **high** |
| **increase in heat stress for animals** | **high** | **High** | **medium** | **medium** | **medium** |
| **increase in pests & harmful organisms in plants & animals** | **high** | **High** | **medium** | **medium** | **medium** |
| **increase in water scarcity** | **high** | **High** | **low** | **low** | **high** |
| increase in soil erosion (drought, heavy precipitation, wind) | medium | very high | - | - | - |
| decrease of soil fertility, structure and stability | medium | High | - | - | - |
| extension of vegetation period | very high | Medium | - | - | - |
| decrease in nutrient availability due to water shortages | high | Medium | - | - | - |
| spread and proliferation of invasive plants and animals | high | Medium | - | - | - |
| increased desynchronisation of pollinator-plant phenology | high | Medium | - | - | - |
| increase in plant growth (increase of $CO_2$ availability) | medium | Medium | - | - | - |
| shift of cultivation areas | medium | Medium | - | - | - |

| | | | | | |
|---|---|---|---|---|---|
| Agriculture | | | | | |
| reduction of biodiversity in agricultural landscapes | low | Medium | - | - | - |
| increasing soil salinisation | high | Low | - | - | - |
| changes in winter conditions (absence of snow cover & periods of frost) | high | Low | - | - | - |
| socio-economic | | | | | |
| increased natural hazard potential (increased insurance costs) | very high | very high | medium | medium | medium |
| pesticide use and its effectiveness in relation to climate change | high | High | medium | medium | medium |
| yield loss due to extreme events | high | very high | medium | medium | high |
| increasing need for irrigation | high | High | low | low | high |
| increasing yields in grassland agriculture | medium | Medium | - | - | - |
| decrease in the quality of certain crops | low | Medium | - | - | - |
| increase in cooling requirements for horticultural crops | medium | Medium | - | - | - |
| yield increase in arable farming | high | Medium | - | - | - |
| decrease in yield potential (complete change or loss of production of agricultural crops) | high | Medium | - | - | - |

### 3.1.2 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of four key risks (KR) for the sector Agriculture (A) displayed in Table 10. KR-A-1 (*Risk of loss of agricultural land*) is related to climate impacts such as increase in soil erosion (drought, heavy precipitation, wind), decrease of soil fertility, structure and stability, shift of cultivation areas and increasing soil salinisation. The current climate risk is rated as '*low*', associated with a rather *medium* rating of exposure and sensitivity. In the course of the 21st century, the risk rises and is rated *high* for the far future (2071-2100) assuming a pessimistic climate scenario. Several climate impacts are relevant for KR-A-2 (*Risk of malfunctioning and failure of water management systems in agriculture*), i.e. increased natural hazard potential (increased insurance costs, e.g. caused by damages by hail), yield loss due to extreme events, increase in drought stress for plants, increase in heat stress for animals, decrease in yield potential (complete change or loss of production of agricultural crops), increase in pests & harmful organisms in plants &

animals, pesticide use and its effectiveness in relation to climate change. The increase in natural hazards was mentioned by participants as going beyond all other factors, hence it is mentioned explicitly. Similarly, pests and harmful diseases played a certain role in the discussion, also with regard to the use of pesticides. Considering these aspects, the current risk is rated as medium and rises in the coming decades up to a *very high* risk level at the end of the century (pessimistic scenario).

The third key risk (KR-A-3, *Risk of malfunctioning and failure of water management systems in agriculture*) was highlighted by stakeholders in particular since climate impacts such as water scarcity, increasing need for irrigation and increase in drought stress for plants are among those rated as highest compared to others. The spatial variability reflects the fact that water scarcity differs from region to region. Current risk is rated as *high* due to *low* to *medium* adaptive capacity and *medium* to *high* urgency to act. This is reflected by the perception of involved stakeholders that the agricultural sector is not very well adapted to climate change. There is an existential lack of irrigation systems due to insufficient investments, resulting in the necessity to take into account destroyed irrigation systems requiring renewal and the need for implementing functioning water capture and storage systems. This is the case for the most productive parts of Slovakia in the lowlands in the southwest and southeast. The sector is also lagging behind in terms of implementing various policies and directives into practice, including measures to prevent erosion and the installation of water-retention measures. The *Risk of decreased food security & lack of food* is closely related to the malfunctioning of the water management and irrigation system, resulting in a similar current and future risk rating.

*Table 10: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Agriculture (KR-A) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-A-1<br>Risk of loss of agricultural land | low | medium | medium | medium | high | slow onset | regional |
| KR-A-2<br>Risk of loss of livelihoods and income from agriculture due to increase in costs, impacts of extreme events and pests/harmful organisms | medium | high | high | high | very high | slow onset<br>acute | regional |
| KR-A-3<br>Risk of malfunctioning and failure of water management systems in agriculture | high | high | high | very high | very high | acute | local<br>regional |

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-A-4<br>Risk of decreased food security & lack of food | medium | high | high | high | very high | slow onset<br>acute | regional<br>national |

The strategic directions listed below do not only reflect the key risks, but also the specific objectives as mentioned in the current NAP of the Slovak Republic (Ministry of Environment of the Slovak Republic, 2021a)[7]. Sustainable and adapted practices particularly draw attention to KR-A-2, KR-A-3 and KR-A4. Explicitly incorporating governance frameworks as one essential part of the strategic directions takes into account a *low* to *medium* adaptive capacity of relevant climate impacts in this respect.

### Strategic Directions – Agriculture

| | |
|---|---|
| SD-A-1 | Agricultural land in Slovakia including soils and its biodiversity is valued and protected. Related practices are adapted to EU-level and national governance frameworks and policies are implemented to prevent degradation (e.g. soil erosion). (NAP 2.1, 2.2, 2.3, 2.6) |
| SD-A-2 | Agricultural crop production and livestock farming practices are sustainable and adapted to changing climatic conditions (i.e. climate-smart) and nutrient runoff is reduced by increased fertilisers efficiency. Investments are made to ensure climate-resilient irrigation and water-retention systems. Farmers and other agriculture-related businesses are aware of climate-related risks and hazards and have sufficient know-how to mitigate and react to them, including nature-based solutions. (NAP 2.1, 2.4, 2.5) |
| SD-A-3 | People in Slovakia have access to sufficient regional, high-quality food and agricultural products, the production of which is supported through govern- |

---

[7] The number code of specific objectives of the current NAP associated with certain strategic objectives are listed in brackets.

## 3.2 Biodiversity & Ecosystems

**Biodiversity** circumscribes“ ‘the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems’” (IPCC, 2021a). This encompasses three levels of biodiversity as defined by the Convention on Biological Diversity: species, ecosystems and genetic diversity.

**Ecosystems** are defined as ‘a functional unit consisting of living organisms, their non-living environment and the interactions within and between them.’ (IPCC, 2021a).

In Slovakia, the Act No. 543/2002 Coll. Nature and Landscape Protection (in force since 2003) is the most relevant legal document to safeguard landscapes and nature within the country (ECOLEX, n. d; Slovak Museum of Nature Protection and Speleology, 2017; Štátna ochrana prírody Slovenskej republiky, n. d.). With respect to large scale protected areas, a total of nine national parks and 14 protected landscape areas can be found in Slovakia (Slovak Museum of Nature Protection and Speleology, 2017; Štátna ochrana prírody Slovenskej republiky, 2024). In addition to this nationally regulated protection areas, the Slovak Republic has recognised 41 protected bird areas, comprising 26.2% of the country under the umbrella of the European Natura 2000 areas (Ministry of the Environment of the Slovak Republic, n. d.). Recently, on 1st January 2024, a regulation establishing a list of areas of European importance came into force. The 644 areas listed in this regulation encompass approximately 13 % of the Slovakian territory (Ministry of Environment of the Slovak Republic, s. a.). Small-scale protected areas comprise Protected Sites, Nature Reserves, National Natural Reserves, Natural Monuments and National Natural Monuments (Parks.it, n. d; Štátna ochrana prírody Slovenskej republiky, n. d.). In Slovakia, there are more than 1000 such small-scale protected areas (Parks.it, n. d.). According to the updated version of the Slovakian biotope catalogue, 116 out of 178 biotope areas are of European and 30 of national importance (Štátna ochrana prírody Slovenskej republiky, 2023). Among the most frequently occurring biotopes are non-forest areas, in particular low-land as well as foothill meadows. Regarding forest biotopes, the most prevalent are Carpathian oak-hornbeam forests, flowering beech and fir-beech forests (Štátna ochrana prírody Slovenskej republiky, 2023). Research indicates that the highest number of species can be found in seminatural grassland, whereby alkaline soils (i.e. base-rich soils) provide favourable conditions for species-rich grasslands and forests. Such regions include volcanic and limestone areas in central Slovakia as well as the flysch zones. Similarly, the species-richest areas of non-forest vegetation are meadows (base-rich), grasslands, mesic meadows as well as sub-Alpine grasslands and also partly wet meadows (Pullaiah, 2018). A more in-depth and recent classification as well as an analysis of ecosystems in Slovakia can be found in Černecký et al. (2023) where the authors provide a detailed map of ecosystems, including metadata such as status and spatial distribution. A synthesis of Slovakian Ecosystem Services can be found in Mederly and Černecký (2020), highlighting the necessity for implementing protective measures and the importance of key ecosystems such as large forest and (sub-) mountain regions within the country. Furthermore, as the assessment in D2.2 outlines, the sector is also among the ones particularly addressed in the NAP and the protection of Biodiversity is part of several key policy documents of the Slovak Republic. For instance, a new National Biodiversity Strategy and Action Plan 2030 was developed following recent agreements on European and global level, i.e. EU Biodiversity Strategy 2030 and Kunming-Montreal Global Biodiversity Framework 2030 (European Commission, 2020)[8].

Next to the above-mentioned protected areas based on national and European regulation schemes, also UNESCO Biosphere reserves are established in Slovakia, i.e. Slovak Karst, Poľana, the Eastern Carpathian Biosphere Reserve and the Tatra region, whereby the latter is not limited to the Slovak Republic (State Nature Protection of the Slovak Republic, 2024).

This underlines the importance of biodiversity and ecosystems in Slovakia, which is underpinned by the fact that several parts of the country are home to endemic species. For instance, more than 100

---

[8] Information based on assessment conducted within the scope of this project/Deliverable 2.2.

endemic species can be found in the Carpathians (e. g. in the lakes of the Tatra Mountains) and the Slovakian Karst regions. In particular, the Tatra region without any connection to other territories is unique in terms of flora and fauna. High differences in altitude, a huge geological variety and a diverse spectrum of soil and moisture conditions are among the key enabling aspects for this uniqueness (Oscar et al., 2011). These mountain ranges are the last refuge for endangered plant species such as *Carex rupestris*, underlining the ecological significance of the region and highlighting the problem of shrinking habitats (Svitková et al., 2019).

Against this background, multiple impacts of climate change on ecosystems and biodiversity have to be considered in Slovakia as well. They include, but are not limited to, shifting vegetation zones and phenological phases, fragmentation of habitats, biodiversity loss as well as spring frosts, increased intensity of fires and forest pests. With respect to the loss of biodiversity, species extinction is to be expected, and on the other hand, certain species might migrate to Slovak territory (Považan and Blaško, 2023).

In general, addressing biodiversity and ecosystem related challenges is of particular importance as biodiversity is still degrading in the EU and efforts taken lag behind the goals as set in the EU Biodiversity Strategy (EEA, 2020b; European Commission, 2020).

### 3.2.1 Climate Impact Assessment

The workshop on climate impacts highlighted several critical concerns for biodiversity and ecosystems. The increase in species extinction and loss of biodiversity, affecting genetic diversity, species diversity, ecosystem functions and soil biodiversity, is driven by both climate change and human activities degrading habitats. Habitat loss due to degradation, influenced by both human activity and climate change, as well as legislative challenges, remains a significant issue.

The change in species composition due to temperature shifts and altered conditions are likely to result in the survival of fewer current species and increased migration of fauna and flora, emphasising the need for enhanced landscape connectivity and assisted species migration discussions. Examples of changes in species composition might increase deer population leading to heightened forest damage. It was noted that shifts of such population dynamics may be caused by climatic or non-climatic circumstances or by a combination of both, highlighting the complex interplay of different factors. The extension of the vegetation period has unclear effects on ecosystems, with insufficient national or international data.

The increase in water temperatures in watercourses, correlated with more days of low water discharge, is an underestimated impact. Small changes in temperature significantly affect aquatic organisms, underscoring the need for more data on these consequences also for Slovakia. Capturing and retaining water is crucial for Slovakia to increase soil moisture and maintain underground water reserves, addressing the rising number of low water discharge days. The change in the seasonal distribution of precipitation, attributed solely to climate change, poses challenges as the implementation of nature-based solutions and water retention measures is lagging.

The adaptive capacity for the prioritised impacts was mostly rated *low*, mainly for financial capabilities, to medium, mainly for governance frameworks. This is concomitant with a *high* urgency to act, primarily for the increase in species extinction and loss of biodiversity and habitats, as well as changes in water availability and seasonal distribution of precipitation.

Table 11 presents the results from the participatory climate impact assessments, conducted in June 2024. The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C in the Biodiversity & Ecosystems. Definitions of key terms used are provided in Annex A.

*Table 11: Presentation of the results of the climate impact assessment for the sector Biodiversity & Ecosystems. Impacts of high priority are highlighted in **bold**. The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).*

| Biodiversity & Ecosystems | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| Biophysical | | | | | |
| **increase in species extinction/loss of biodiversity** | **very high** | **very high** | **medium** | **Low** | **high** |
| **loss of habitats** | **very high** | **high** | **medium** | **Low** | **high** |
| **spread and proliferation of invasive plants and animals** | **high** | **very high** | **high** | **medium** | **medium** |
| **increase in pests & harmful organisms in plants & animals** | **high** | **very high** | **medium** | **Low** | **medium** |
| **change in water availability** | **high** | **high** | **medium** | **medium** | **high** |
| **increase in water temperatures (standing waters)** | **high** | **high** | **low** | **Low** | **low** |
| **change in the seasonal distribution of precipitation** | **high** | **high** | **medium** | **Low** | **high** |
| **change in species composition** | **high** | **high** | **medium** | **Low** | **medium** |
| extension of vegetation period | very high | medium | - | - | - |
| increase in water temperatures (watercourses) | high | medium | - | - | - |
| increased desynchronization of pollinator-plant phenology | high | medium | - | - | - |
| increasing threat to wetland habitats (peatlands, bogs, fens) | high | medium | - | - | - |
| increase of days with low water discharge | high | medium | - | - | - |
| shift of habitats | high | low | - | - | - |

| Biodiversity & Ecosystems | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| lowering of the groundwater level | medium | medium | - | - | - |
| changed reproductive behaviour | medium | medium | - | - | - |
| degradation of water quality | medium | medium | - | - | - |
| increased disturbance and loss of aquatic habitats | medium | medium | - | - | - |
| changed biological interaction | medium | medium | - | - | - |
| increase in habitat fragmentation | medium | low | - | - | - |
| Increase in desynchronisation of predator-prey relationship | low | medium | - | - | - |
| increased algae bloom | low | low | - | - | - |
| increase in nutrient pollution in water bodies | low | low | - | - | - |

### 3.2.1 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of two key risks (KR) for the sector Biodiversity & Ecosystems (B), displayed in Table 12. Key risk KR-B-1 (*Risk of loss of biodiversity and habitats (terrestrial & aquatic)*) is connected to climate impacts such as increase in species extinction/loss of biodiversity and loss of habitats. The exposure for both is considered as *very high;* governance frameworks exist, but not comprehensively and financial capabilities are insufficient (rated as *low*), resulting in a *high* urgency to act. Besides, involved stakeholders highlighted that KR-B-1 is further exacerbated by unfavourable legislation and harmful human practices[9]. Other relevant climate impacts are the spread of invasive species and hence, the change in species composition, driven not only by climate change but also human activities e. g. landscape fragmentation, tourism, forestry, agricultural practices etc. Such a loss of biodiversity as well as landscape and ecosystem degradation foster the loss of ecosystem service (ESS) provision (KR-B-2; *Risk of decreasing ecosystem service provision from terrestrial and aquatic ecosystems*). For instance, flood protection in terms of water retention is adversely affected by climate change, which is in turn necessary for retaining water for dry

---

[9] No further details were provided concerning the highlighted shortcomings.

periods and days with low water discharge in order to stabilise ecosystems and soil functions (supporting and regulating ESS). For both risks, the risk level increases throughout the century, resulting in risks rated as *high* or *very high* (respectively) for the far future.

*Table 12: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Biodiversity & Ecosystems (KR-B) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-B-1<br>Risk of loss of biodiversity and habitats (terrestrial & aquatic) | high | high | high | very high | very high | slow onset | local<br>regional<br>national |
| KR-B-2<br>Risk of decreasing ecosystem service provision from terrestrial and aquatic ecosystems | medium | high | high | high | very high | slow onset | regional<br>local |

The strategic directions consider several specific objectives of the current NAP (Ministry of Environment of the Slovak Republic, 2021a)[10] and are embedded in EU-level laws such as the EU Biodiversity Strategy for 2030 (European Commission, 2020) and the EU Nature Restoration Law (EU Commission, 2024). In addition, the strategic directions address current limitations e.g., regarding insufficient governance frameworks and draw attention to the fact that biodiversity and its protection is a pertinent issue in other sectors such as Agriculture and Forestry, underlying the necessity for cross-sectoral approaches to tackle climate-related risks.

---

[10] The number code of specific objectives of the current NAP associated with certain strategic objectives are listed in brackets.

### Strategic Directions – Biodiversity & Ecosystems

| | |
|---|---|
| SD-B-1 | The value of a rich biodiversity of ecosystems, species, genes and soils is recognised as an important parameter to foster resilience against climate change. Effective and targeted legislative frameworks support the preservation and protection of sensitive ecosystems, with special consideration of sustainable use of agricultural land and forests. (NAP: 4.2, 4.3, 4.4, 4.5) |
| SD-B-2 | Management practices in agriculture, fishery, forestry and other related fields are adapted with the objective of ensuring the optimal provision of ecosystem services from terrestrial and aquatic ecosystems. Relevant information and awareness-raising initiatives support practitioners in adapting their activities and increasing their sustainability. (NAP: 4.1, 4.6, 4.7) |
| SD-B-3 | The connectivity of terrestrial ecosystems is ensured and ecologically relevant areas are mapped and protected. |

## 3.3 Cultural Heritage

The sector **Cultural Heritage** includes two types of artefacts, 1) physical or tangible artefacts, assets and spaces like architecture, monuments, sites, landscapes, parks, gardens, artwork, other archives and 2) other expressions of human creativity that are intangible like traditions, practices and knowledge. Cultural heritage can be public or private as well as digitised and analogue. Both tangible and intangible cultural heritage may hold the potential to support the implementation of adaptation measures (European Commission, 2024b; UNESCO Institute of Statistics, 2024).

In Slovakia, there are eight sites recognised as UNESCO World Heritage Sites, six of them are considered cultural and two as natural heritage sites. The cultural heritage sites comprise the Bardejov Town Conservation Reserve, the frontiers of the Roman Empire (Danube Limes, western segment), the historic town of Banská Štiavnica and the technical monuments in its vicinity, Levoča, Spišský Hrad and the associated cultural monuments, Vlkolínec and the wooden churches of the Slovak part of the Carpathian Mountain area. The ancient and primeval beech forests of the Carpathians as well as the caves of Aggtelek Karst and Slovak Karst are recognised natural heritage sites (UNESCO, 2024b). In addition, twelve sites are listed as tentative (UNESCO, 2024a).

With respect to natural cultural heritage sites, trees are considered as heritage objects (Supuka et al., 2015) and foresters are seen as a crucial stakeholder group safeguarding forests and thereby contributing to heritage protection in Slovakia (Miľanová, 2018). Štrba et al. (2022) use the term 'geoheritage' to draw attention to the fact that the geological environment is considered as cultural heritage as well, not least because humans are still shaping these landscapes. In addition, as vine growing is the most ancient form of specialised agricultural production in Slovakia, it is also part of the country's cultural heritage (Slobodová Nováková, 2019). Likewise, beekeeping has a longstanding tradition and is of importance not only on a local/regional or national scale, but also globally (Macko, 2021). Next to these aspects, the various mills (Glaser-Opitz et al., 2012) and castles (Vlcko et al., 2009) that can be found in Slovakia's landscape are considered as cultural heritage sites and 'artifacts' of former industry and ways of living. Slovakian folk art is yet another part of the nation's cultural heritage (Jaďuďová, 2019).

All the above mentioned, but not all-encompassing, examples show how rich and manifold cultural heritage is in Slovakia and in consideration of the outlined aspects regarding heritage and climate change they underline the importance of addressing climate related impacts in this sector. For instance, the city of Bratislava participates in the EU-funded project ARCH, aiming to support urban areas in taking measures to protect cultural heritage from adverse climate change impacts (ARCH Research Project, n. d.). In case of Bratislava, pluvial flooding poses a major risk to the historical centre. The ruin of Devín Castle, located only a few kilometres away from the city centre, is affected by solid-mass related movements as the cliff is eroding. This process is triggered by temperature variability, changing freeze and thaw cycles, and increasing humidity levels due to climate change. A total collapse of the castle into the Danube River has to be considered as a worst-case scenario, whereby the access to the castle area itself may have to be restricted already at an earlier stage (Lückenrath et al., 2021; Pauditšová et al., 2020). The described temperature-related deformations and destructions were also found relevant by Vlcko et al. (2009) for other medieval castles in Slovakia. Climate impacts to nature-related cultural heritage sites are comparable to those described in the other respective sectorial chapters (e.g. Biodiversity & Ecosystems, Geological Environment & Soil).

Against the background of climate change related indices, such as increases in the number of floods, it has to be expected that also other heritage sites in Slovakia face challenges due to climate change. For instance, the Flood Directive (Act No. 7/2010 Coll) also considers cultural heritage as relevant with respect to flood risk management. However, to the best of the knowledge of the authors, apart from projects such as ARCH and the cited literature, there is still limited research particularly focussing on the interplay of climate change and cultural heritage in Slovakia. This is mirrored in the conclusion of the assessment carried out in Deliverable 2.2 stating that actions in the NAP cannot be directly implemented in the context of cultural heritage[11].

### 3.3.1 Climate Impact Assessment

According to the workshop participants, it is important to consider that climate impacts on cultural heritage also incorporate natural cultural heritage, such as biodiversity. Since natural heritage currently receives less attention than heritage sites such as buildings, accounting for this differentiated view becomes even more important. With regard to natural cultural heritage, climate impacts such as indigenous pathogens/emergence of new pathogens, as well as vegetation damage and loss of biodiversity, are relevant. When assessing damage to vegetation, one must consider the health status of vegetation, especially trees. In addition, changing climatic conditions can lead to the disappearance of traditional and local varieties of fruits and herbs, with invasive plants putting additional pressure on this type of flora. Consequently, such a loss of biodiversity can influence not only the production of traditional products but also the appearance of the cultural landscape or the original woody composition of historical parks and gardens. Hence, the authenticity and historical substance of landscapes can be lost due to climate change. Against the background of the abovementioned aspects, it becomes apparent how strongly intertwined cultural and natural cultural heritage are.

The rating of certain climate impacts as high priority, such as the increase in maintenance needs and flood events, is mirrored in several aspects to be considered. Firstly, permanent maintenance, including the conduction of care and implementation of respective monitoring measures, is crucial for the appropriate prevention of climate-related threats. For instance, irreversible damage can be avoided by the timely detection and repair of malfunctions, damage to human-made or natural objects. Besides that, the necessity for conducting maintenance and evaluation work for each monument or building must be taken into account. Already established risk assessments used in the construction sector can serve as a foundation for assessing historical buildings/objects accordingly.

Secondly, with respect to extreme weather events such as floods, landslides or fires, a functioning infrastructure with sufficient capacity is important (e.g. water drainage, availability of rescue equipment, fire extinguishing). The need for maintenance in the context of fires can be illustrated by the burning down of the Krásna Hôrka castle. In this case, the fire spread through the whole building complex due

---

[11] Information based on assessment conducted within the scope of this project/Deliverable 2.2.

to extensive vegetation growth leading to overgrowth in the immediate vicinity of the castle in combination with human carelessness and drought.

In general, the more in-depth assessment of climate impacts of high priority shows a *high* urgency to take action. Most importantly in this regard, adaptive capacity, both in terms of governance framework and financial capabilities, is estimated to be rather low, except for impacts associated with insufficient soil moisture and biological, chemical and physical weathering/decomposition processes.

Table 13 presents results from the participatory climate impact assessments, conducted in June 2024. The assessment of adaptive capacity and urgency to act was conducted for climate impacts of high priority. However, this more in-depth assessment might not have been possible entirely due to time constraints and intense discussions at the workshop (see Annex A: Additional information on methodological design Box 1). The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector Cultural Heritage. Definitions of key terms used are provided in Annex A.

*Table 13: Presentation of the results of the climate impact assessment for the sector Cultural Heritage. Impacts of high priority are highlighted in* ***bold****. The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).*

| Cultural Heritage | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| biophysical | | | | | |
| **increase in floods (pluvial, fluvial)** | **high** | **high** | **low** | **low** | **high** |
| **increase in forest & wildfires** | **medium** | **high** | **medium** | **medium** | **high** |
| **increase in speed of many chemical reactions** | **high** | **medium** | **low** | **low** | **high** |
| **increase in erosion (soil, surfaces/materials)** | **high** | **high** | **low** | **low** | **high** |
| **increase in insufficient soil moisture** | **high** | **medium** | **high** | **high** | **high** |
| **increase in indigenous pathogens/emergence of new pathogens** | **high** | **high** | **medium** | **medium** | **high** |
| **increase in biological, chemical & physical weathering/decomposition** | **medium** | **high** | **high** | **high** | **high** |
| increase in vegetation damage (e.g. damage to forests, branch breakage) | medium | medium | - | - | - |

| Cultural Heritage | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| increase in biological, mircobiological & botanical growth & decay | medium | high | - | - | - |
| increase in species extinction/loss of biodiversity | low | low | - | - | - |
| increase in subsidence of building foundations | medium | medium | - | - | - |
| increase in disturbance of stratigraphical sequences & changes in soil structure | low | low | - | - | - |
| increase in UV/IR radiation | medium | low | - | - | - |
| socio-economic | | | | | |
| increase in damage to buildings/building materials, facades & coatings (e.g. monuments) | medium | high | medium | low | high |
| increase in damage to historical gardens, parcs & landscapes | high | high | low | low | high |
| increase in maintenance needs | very high | very high | - | - | - |
| increase in biological & chemical damage of assets, collections & archives (e.g. papers, textiles, photographs, wood, metal) | low | medium | - | - | - |
| increase in damage to/loss of archaeological sites (underground/above-ground) | low | medium | | | |
| prohibition of access to certain areas | low | medium | - | - | - |
| increase in effort, controls & time needed at construction | *[not discussed & no feedback received]* | | | | |
| loss of authenticity & historical substance | low | medium | - | - | - |

### 3.3.2 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed one key risk (KR) for the sector Cultural Heritage (CH), displayed in Table 14. The described risk of loss sites (historical, archaeological, cultural and natural) and landscapes values, traditional practices and authenticity in this key risk is associated with climate impacts such as increase in floods (pluvial, fluvial), increase in forest- & wild fires, increase in erosion (soil, surfaces/materials), increase in damage to buildings/building materials, facades & coatings (e. g. monuments), increase in vegetation damage (e. g. damage to forests, branch breakage). As it is expected that these impacts become more severe during the 21st century, the risk is rated as *high* for both scenarios for the far future.

*Table 14: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Cultural Heritage (KR-CH) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-CH-1<br>Risk of loss of historical, archaeological, cultural and natural sites, landscapes values, traditional practices and authenticity | medium | medium | medium | high | high | slow onset | national<br>regional<br>local |

The strategic directions listed below highlight the need for preventive measures and the importance to differentiate between a) tangible/intangible and b) natural and cultural heritage. Both aspects have been underlined by stakeholders to be of particular importance. Similarly, the necessity for implementing effective governance frameworks is explicitly mentioned as the assessment shows that there are currently major gaps, i.e. adaptive capacity in this regard ranges rather between *low* to *medium*, partly associated with a *high* urgency to act.

### Strategic Directions – Cultural Heritage

| | |
|---|---|
| SD-CH-1 | Tangible cultural goods like buildings, museums, archives, etc. are protected and preserved through regular, preventive maintenance and climate-adapted servicing ensuring a sufficient level of resilience. |
| SD-CH-2 | Intangible cultural heritage and associated practices and traditions are secured and well promoted to support local identity. |
| SD-CH-3 | Tangible natural heritage are mapped, linked to landscape management and sufficiently protected, considering climate-change related, destructive impacts. |
| SD-CH-4 | Effective governance frameworks, aligned with propositions/policies by the European Union and international organisations like UNESCO, are implemented. |

## 3.4 Disaster Risk Management, Civil Protection & Critical Infrastructure

**Disaster Risk Management (DRM)** is defined as "processes for designing, implementing and evaluating strategies, policies and measures to improve the understanding of current and future disaster risk, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, prevention and protection, response and recovery practices, with the explicit purpose of increasing human security, well-being, quality of life and sustainable development" (IPCC, 2022c) .

While there is no official definition of **Civil Protection**, it can be understood as the protection of people, the environment and property against both natural and man-made disasters. This involves planning, preparation and response activities, including deployment of forces and equipment as appropriate.

In Europe, **Critical Infrastructure** is defined by the European Union legislation (European Commission, 2022b) as "an asset, a facility, equipment, a network or a system, or a part of an asset, a facility, equipment, a network or a system, which is necessary for the provision of an essential service".

Climate change has been identified as a safety risk by the Slovak government in their risk management planning documents. The two underlying goals of risk management in Slovakia are the prevention of losses and harms, including the integration of mitigation measures into activities, and modernisation of crisis communication and situational awareness (strategic foresight). It is recognised as a cross-cutting topic in the Slovakian NAP, stressing the need to strengthen civil protection systems and modernising early warning and notification systems.

Climate change will increase risks to citizens and critical infrastructure, and there is some uncertainty about the shape impacts will take or where they will physically take place. The climate-related disasters with the highest risk factor were floods and subsequent landslides, heavy snowfalls, extreme storms and wildfires[12]. Droughts and water scarcity were also considered significant risks, and in 2018, an Action Plan to Address the Impacts of Drought and Water Scarcity was adopted to prevent and mitigate such risks specifically (Ministry of Environment of the Slovak Republic, 2018b). Additionally, crisis plans on flooding ("flood plan") are commonly prepared to handle flood risk on the local level. An analysis of possible risks and potential emergencies is carried out regularly; however, while such assessments exist on the national and regional level, they are lacking on the local level. Based on these assessments, the government develops annual plans in the field of civil protection, including a National (Security) Risk Management Strategy that describes the main risks and hazards (Slovak Republic, 2021). An additional measure that has been included is the mapping of risks and establishing of recommendations for a sound framework approach to critical infrastructure protection.

Civil protection has been established with the aim of protecting lives, health and property. The basis for civil protection is the Act on Civil Protection of the Population in 1994. The crisis management system, which is a part of civil protection, is divided geographically – each level of public administration plays a part (European Commission, 2019). The Ministry of Interior is responsible for overseeing the system and cooperates with other institutions to do so. Additionally, it is also the main authority responsible for risk management and response. It is expected that disaster risk management, civil protection and critical infrastructure protection processes will continue to be a priority.

---

[12] These disasters were identified in a 2011 report on climate change impacts, vulnerabilities and adaptation, which assessed how climate change will impact Slovakia. The report analysed impacts in eight key sectors. The report was used as input for the First National Adaptation Strategy of 2014.

The Critical Infrastructure Act of 2011 nationally regulates critical infrastructure, including outlining the process of determining critical infrastructure, establishing obligations for its protection and liability for breach of obligations. Critical infrastructure is also identified in other strategic and action policy documents, such as the Security Strategy of Slovakia and the National Programme for the Protection and Defence of Critical Infrastructure. The Critical Infrastructure Act and its Annex identify nine main sectors, within which sub-sectors are included:  transport, electronic communications, energy sector, post office, industry, ICT, water and atmosphere, health and finance (Santusová and Jakubík, 2020).

### 3.4.1 Climate Impact Assessment

For the whole sector, the Ministry of the Interior of the Slovak Republic plays a key role, according to workshop participants. This is reflected in the Ministry's new law on critical infrastructure, aiming to keep the Slovak Republic vigilant and adaptive within current geopolitical contexts. The proposal also reflects European Union legislation. The material is in abbreviated inter-ministerial comment proceedings.[13] In addition, it will be necessary to propose new and adjust existing laws related to crisis management and civil protection.

With regard to climate impacts of high priority, the increase in (extreme) weather events and associated impacts such as damage from pluvial flooding on low-lying infrastructure or more generally speaking, damage to critical infrastructure, have to be particularly considered. According to the Civil Protection Information Service, floods make up approximately 45% of natural events. In addition, experts stated that prevention against impacts induced by landslides and mudslides is currently neglected in Slovakia, whereby necessary clean-up work after such events takes a long time. Besides, it should be noted that the specific list of critical infrastructure objects is subject to secrecy. The urgency to act for all prioritised climate impacts ranges between *medium* to *high*. However, it should be taken into account that the concrete level of both the urgency to act and adaptive capacity might vary depending on the specific part of the sector under consideration.

Table 15 presents the results from the participatory climate impact assessments, conducted in June 2024. The assessment of adaptive capacity and urgency to act was conducted for climate impacts of high priority. However, this more in-depth assessment might not have been possible entirely, due to time constraints and intense discussions at the workshop (see Annex A: Additional information on methodological design Box 1). The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector Disaster Risk Management, Civil Protection & Critical Infrastructure. Definitions of key terms used are provided in Annex A.

---

[13] Government bill on critical infrastructure and amendment to certain acts, National Council of the Slovak Republic, 2024. Zákony : Vyhľadávanie v návrhoch zákonov : Detaily návrhu zákona - Národná rada Slovenskej republiky

*Table 15: Presentation of the results of the climate impact assessment for the sector Disaster Risk Management, Civil Protection & Critical Infrastructure. Impacts of high priority are highlighted in **bold**. The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).*

| Disaster Risk Management, Civil Protection & Critical Infrastructure | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| Biophysical | | | | | |
| **increase in forest & wildfires** | **high** | **medium** | **medium** | **medium** | **medium** |
| **change in seasonal distribution of precipitation** | **very high** | **medium** | **low** | **medium** | **high** |
| **increase in flood events (pluvial, fluvial)** | **very high** | **medium** | **medium** | **low** | **high** |
| **increase in extreme events** | **very high** | **very high** | **medium** | **medium** | **high** |
| increase in landslides & mudslides | medium | medium | - | - | - |
| increase in erosion (soil, surfaces/materials) | medium | medium | - | - | - |
| socio-economic | | | | | |
| **increase in damage to critical infrastructure** | **very high** | **very high** | **medium** | **medium** | **high** |
| **changes in the availability & quality/reliability of services (direct/indirect disruption from weather events)** | **high** | **high** | **medium** | **medium** | **medium** |
| **increase in expenditures & costs for maintenance** | **high** | **high** | **low** | **medium** | **high** |
| **increasing damage from pluvial flooding of low-lying infrastructure** | **very high** | **high** | **medium** | **medium** | **medium** |
| **increase in heat load** | **very high** | **high** | **medium** | **medium** | **high** |
| **decrease in accessibility of central & critical infrastructures** | **high** | **high** | - | - | - |
| increased risk for employees | high | high | - | - | - |

| Disaster Risk Management, Civil Protection & Critical Infrastructure | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| increased corrosion due to higher humidity levels | low | low | - | - | - |
| changing demands for emergency operations (equipment, training) | high | medium | - | - | - |

### 3.4.1 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of three key risks (KR) for the sector Disaster Risk Management, Civil Protection & Critical Infrastructure (DRM), displayed in Table 16. The risk of widespread disruptions (KR-DRM-1) is associated with various climate impacts such as increase in forest- & wildfires, change in seasonal distribution of precipitation, increase in flood events (pluvial, fluvial), increase in extreme events, increase in damage to critical infrastructure or decrease in accessibility of central & critical infrastructures. The current risk rating as *high* reflects the exposure and sensitivity ratings of relevant impacts mostly ranging between *high* and *very high*. Besides, participants noted that e.g. prevention against consequences of landslides and mudslides are currently neglected and is subject to further improvements. The second key risk (KR-DRM-2) reflects expected climate change induced increases in expenditures and costs for maintenance, e.g. caused by damage due to floods, and changing demands for emergency operations in terms of equipment and training. The third key risk focuses on individuals and communities adversely affected by increasing impacts of climate extremes, whereby particularly vulnerable groups are prone to such negative consequences. The current risk rating as *high* reflects that relevant climate impacts are among those listed as high priority. Besides, participants noted that there is a need for a more sophisticated crisis management. Against the background of expected changes of relevant climate indices (Chapter 2.2), the risk is rated as *very high* considering a pessimistic scenario for the far future for all three identified key risks.

*Table 16: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Disaster Risk Management, Civil Protection, Critical Infrastructure (KR-DRM) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-DRM-1<br>Risk of widespread disruptions of (critical) infrastructure & services due extreme events (e.g. forest & wildfire and flood events (pluvial, fluvial) | high | high | high | high | very high | acute | local<br>regional |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| KR-DRM-2<br>Risk of increasing costs for maintenance, provisions and emergencies | medium | high | high | high | very high | slow on-set | national |
| KR-DRM-3<br>Risk to communities prone to increasing frequency and intensity of natural disasters (vulnerable to different extreme events, including impacts on human health) | high | high | high | high | very high | acute<br>slow on-set | local<br>regional |

The strategic directions reflect the need for a stronger, more sophisticated legislation e.g. with respect to crisis management and take note of the fact that a new version of the law on critical infrastructure was presented by the Ministry of the Interior. In addition, the adaptive capacity in terms of governance framework for climate impacts of high priority were rated between *low* to *medium* and the at same time urgency to act ranges between *medium* to *high*.

### Strategic Directions – Disaster Risk Management, Civil Protection & Critical Infrastructure

| | |
|---|---|
| SD-DRM-1 | Critical infrastructure, civil protection and disaster risk management are in place, reflecting relevant laws of the European Union and account for climate change impacts and associated risks to ensure a resilient Slovak Republic. |
| SD-DRM-2 | Effective preventive and emergency measures are implemented at all levels of governance to ensure resilience of communities, settlements and critical infrastructure against natural disasters. Current emergency response systems are evaluated and adapted where necessary to ensure readiness in extreme events even under altered conditions, including ensuring sufficient funding and provision of technical sources. |

## 3.5 Economy & Industry

The **Economy & Industry** sector encompasses heavy industries such as steel, aluminium, paper, chemicals and cement as well as light industry, in accordance with the sectorial definition used by the International Energy Agency (IEA, 2023a). In this context, light industry includes a diverse range of sub-sectors including food processing, textiles, and the manufacturing of consumer goods, vehicles and machinery (IEA, 2023b).

In this summary, the Economy & Industry sector excludes agricultural (including aquacultural) activities, tourism, and services related to the Information and Communication Technology (ICT) industry, as these are covered by other specific sectors detailed in other chapters.

Slovakia's economy is heavily industrialised, with industry contributing 22.2% to GDP in 2021, surpassing the EU average of 18% (Ministry of Environment of the Slovak Republic, 2023). Notably, the production of means of transport stands out, generating 34.7% of total revenues from industry production in 2021. Within this sector, the automotive industry in 2020 accounted for 12% of GDP, employed around 245 thousand workers and played a pivotal role in exports and total industry revenues, solidifying Slovakia's position as the world leader in car production per capita (Ministry of Environment of the Slovak Republic, 2023). Given the disruptions climate change poses to global value chains, it is imperative for Slovakia to adapt accordingly.

The NAS recognises the vulnerability of Slovakian businesses to the impacts of climate change, particularly in the industry and energy sectors. The NAS 2018 identifies various risks, including those to the continuity of operations, the occurrence of major industrial accidents, and threats to human health and safety. Additionally, businesses in Slovakia are increasingly aware of the risks associated with extreme weather events, as indicated by surveys conducted by industry associations (Ministry of Environment of the Slovak Republic, 2018a).

Despite the industry's prominence in the NAS (under area Energy, Industry and other business areas), the NAP features only one directly applicable measure (measure 7.3) aimed at supporting businesses, with no explicit measures addressing the industry. It acknowledges the risks that water scarcity and emergencies pose to businesses and emphasises the need to view adaptation not just as a cost but also as an opportunity for a more resource-efficient economy and the development of the domestic business sector, particularly small and medium-sized enterprises (SMEs). Among others, the plan proposes promoting a voluntary public-private partnership for waste data exchange and enhancing cooperation with other Member States, cities, and industries, and the promotion of new products and services for climate change adaptation, leveraging an emerging market.

Slovakia lacks a detailed assessment of climate impacts on its industry sector and there is no dedicated sectorial strategy enabling adaptation. However, various examples illustrate that given its industrial structure, the Slovak economy is highly exposed, particularly in terms of supply chain disruptions. According to the International Monetary Fund (IMF), Slovakia is among the most highly integrated countries in the EU into Global Value Chains (GVCs), relying extensively on foreign intermediate inputs. Furthermore, the Slovak industrial sector predominantly participates in downstream stages of production, exposing it to disruptions in upstream suppliers (IMF, 2022). Particularly, the automotive sector has encountered significant obstacles due to supply shortages, leading to a pronounced contraction in motor vehicle production in 2021 because of global bottlenecks in semiconductor supply. In the second half of 2021, Slovakia's manufacturing output could have been 15 % higher in the absence of supply bottlenecks and 60 % of the increase in manufacturing producer price inflation during that period could have been avoided (IMF, 2022).

### 3.5.1 Climate Impact Assessment

The workshop on climate impacts in Slovakia identified several priorities for the Economy & Industry sector. Primarily the increase in flood events and low water levels in summer poses significant risks. Low water levels reduce the availability of water for industrial purposes, necessitating adaptations in water management practices. In this context, an increase in physical asset degradation from frequent changes in weather conditions or outright damage to buildings and industrial infrastructure has to be considered as well.

Decarbonisation efforts and changing consumption patterns are expected to alter electricity and power demand, requiring the energy sector to adapt to new demands and integrate renewable energy sources. The rise in extreme events and exposure to natural hazards underscores the importance of existing strict regulations that enforce preventive measures for businesses. These regulations are crucial for enhancing resilience and mitigating the impacts of natural disasters on industrial operations and infrastructure. For specific categories of workers, in particular those exposed to heat, a change in work times is expected, potentially resulting in an increase in production downtime. There is also a need for additional protective measures against potential blackouts of industries as such events can pose huge risks in terms of civil protection. To ensure sufficient and effective implementation of disaster risk management in companies, skilled workers who are equipped with the necessary knowledge and competences are required.

On the positive side, challenges resulting from climate change-related impacts are driving product and process innovation within the sector, offering opportunities to respond to impacts within this and other sectors. The corresponding governance framework is currently rated as medium, with low financial capabilities, highlighting the additional efforts necessary to utilise the innovative potential.

While there has been a considerable increase in extreme events, the exposure of businesses to natural hazards remained less prominent. Particularly the increase in low water levels in summer shows a high urgency to act, combined with a low current adaptive capacity, calling for targeted actions to support businesses and industry dependent on water.

Table 17 presents the results from the participatory climate impact assessments, conducted in June 2024. The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C in the sector Economy & Industry. Definitions of key terms used are provided in Annex A.

*Table 17: Presentation of the results of the climate impact assessment for the sector Economy & Industry. Impacts of high priority are highlighted in **bold**. The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).*

| Economy & Industry | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| Biophysical | | | | | |
| increase in flood events (pluvial, fluvial) | very high | high | medium | medium | low |
| increase in low water levels in summer | high | high | low | low | high |
| increase in extreme events | high | medium | - | - | - |

| Economy & Industry | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| increase in heat stress | high | medium | - | - | - |
| socio-economic | | | | | |
| increase in product & process innovation | high | high | medium | low | medium |
| change in electricity & peak power demand | low | low | - | - | - |
| increase in insurance costs | low | low | - | - | - |
| impairment of transport infrastructure | medium | low | - | - | - |
| increase in exposure to natural hazards | low | medium | - | - | - |
| change in the availability of raw materials & primary products | very low | high | - | - | - |
| increased risk to supply chains | low | high | - | - | - |
| increase in production downtime | low | high | - | - | - |
| increase in cooling requirements (server rooms, storage, premises) | low | low | - | - | - |
| increase in material stress | low | high | - | - | - |
| increase in costs along value chain (e.g. energy/water costs for production) | medium | high | - | - | - |

### 3.5.2 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of three key risks (KR) for the sector Economy & Industry (EI) displayed in Table 18. The *Risk to businesses and industries due to extreme events (floods, droughts)* (KR-EI-1) is related to climate impacts such as increase in extreme events, e.g. floods (pluvial/fluvial; *low* urgency to act, as governance frameworks and financial support exist) as well as loss of water levels in summer and droughts (*low* adaptive capacity and *high* urgency to act). Both affect the water availability for industrial purposes, whereby strict regulations ensure that businesses take preventive measures against extreme events. However, increased occurrence in the future may result in a heightened risk in the long-term. Businesses in other locations might be impacted by climate hazards as well, jeopardizing supply chain stability. Different businesses and industries have alternating vulnerabilities, potentially making an in-depth, focussed assessment necessary to gain further understanding of the respective business- and industry-related climate risks, considering their particular vulnerability. Such detailed assessments become even more important as the risk is expected to increase in the coming decades, resulting in a *high* risk rating for both scenarios by the end of the century.

The second risk (KR-EI-2) deals with process and product innovations, highlighting the necessity to leverage such innovations by financial funding schemes and by implementing respective governance frameworks. As these innovations and niche developments are already emerging internationally, attention has to be paid nationally to ensure proactive and long-term competitiveness. As a functioning labour market is a prerequisite for the financial sector, the key risk addressing potential loss of jobs and lack of skilled workers (KR-EI-3) is linked to the Finance sector. It was noted by stakeholders that it is becoming increasingly challenging for certain industries (especially critical heavy industries and primary manufacturing) to secure the requisite expertise in disaster risk management and civil protection, largely due to a general scarcity of labour, a skills mismatch, a decline in the number of graduates in the sector, demographic shifts, and other factors. A deficiency in human capital that impairs the effective implementation of disaster risk management plans will directly impact the ability of industries to manage climate risks. In view of the climate impact assessment carried out, risk ratings range between low to medium and become more pronounced in the course of the 21st century. Since climate extremes are expected to increase and become more severe, the risk to businesses caused by climate extremes is rated as *high* for the far future for both scenarios.

*Table 18: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Economy & Industry (KR-EI) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-EI-1<br>Risk to businesses and industries due to extreme events (floods, droughts) | low | medium | medium | high | high | acute | national<br>regional<br>local |
| KR-EI-2<br>Risk of missed opportunities and unutilised innovation potential | medium | medium | medium | medium | medium | slow onset | national |
| KR-EI-3<br>Risk of loss of jobs and lack of skilled workers | low | medium | medium | medium | medium | slow onset | national |

The strategic directions draw attention to the required regulations and frameworks to tackle climate extremes such as floods and droughts and are partly related to the current NAP (Ministry of Environment of the Slovak Republic, 2021a)[14]. Additionally, the second and third strategic direction (SD-EI-2 and SD-EI-3) are directly related to the key risks addressing innovation potentials and adequately equipped workers, highlighting the need for awareness raising and providing relevant information.

## Strategic Directions – Economy & Industry

| | |
|---|---|
| SD-EI-1 | Existing regulations and frameworks enforcing protective measures in companies against extreme events like floods and droughts and businesses are continuously adapted to changing climate risks and altered empirical values. |
| SD-EI-2 | Industries are aware of relevant climate impacts that affect them and have the capabilities to manage them effectively, including enhanced resilience of supply chains. Further support to businesses such as additional financial resources or relevant information to assess their individual risk due to climate change is provided. (NAP: 7.3) |
| SD-EI-3 | Innovative concepts and niche business developments supporting climate change adaptation objectives are supported financially and through enabling policies. (NAP: 7.3) |

---

[14] The number code of specific objectives of the current NAP associated with certain strategic objectives are listed in brackets.

## 3.6 Energy

The **Energy** sector is responsible for providing many of our basic needs, such as electricity for lighting, heating that keeps homes warm and the fuel that powers transportation. Generally, the Energy sector is involved in the extraction, production, refining and distribution of primary energy sources (Cheng et al., 2022). The Energy sector comprises major energy demand sub-sectors, including industry, residential, commercial, transport and agriculture, and the energy supply sub-sectors, including resource extraction, conversion and delivery of energy products (EEA, 2024b).

Energy is a critical focus of Slovakia's climate change adaptation strategy. The NAS recommends measures to enhance the resilience of the energy sector, such as constructing new electricity lines and equipment, renovating outdated infrastructure and protecting energy systems against floods (Esser et al., 2018; Ministry of Environment of the Slovak Republic, 2021a). While Slovakia's energy policies address climate concerns, they primarily emphasise climate change mitigation over adaptation and resilience (IEA, 2022). Slovakia has started work on changing its energy architecture, the core objectives of which are energy self-sufficiency, diversification of the energy mix, and increasing electricity generation using low-carbon technologies (Kochanek, 2021).

The Slovak Republic maintains a balanced energy mix, with its gross inland energy consumption in 2020 comprising natural gas (24.9 %), nuclear energy (24.0 %), oil (22.7 %), coal (13.7 %) and renewable sources, including hydropower (14.7 %) (UNFCCC, 2023). In 2021, fossil fuels comprised 64 % of Slovakia's gross available energy (Eurostat, 2024). According to the draft updated National Energy and Climate Plan (NECP), this proportion is anticipated to fall to 54 % by 2030 and further decrease to 48 % by 2040 (European Commission, 2023d). In 2023, Slovakia expanded its nuclear capacity by connecting the Mochovce-3 nuclear power plant to the grid and adding a new reactor. This reactor achieved full power in September 2023, enhancing the share of nuclear power to approximately 60 % of Slovakia's electricity generation, thus contributing to one of the lowest-emission energy mixes in the EU (Enerdata, 2023; European Commission, 2024a; IEA, 2022; UNFCCC, 2023).

The production of biofuels and bio-waste has significantly replaced coal in heat and energy production, contributing to Slovakia's relatively high energy self-sufficiency. Slovakia has ceased hard coal mining, now fully importing it primarily from Russia and Ukraine. Lignite, however, was a significant hydrocarbon, with domestic reserves totalling 83 million tonnes. Lignite mining in Slovakia, characterised by underground extraction due to the country's specific geological conditions, faced higher production costs compared to neighbouring countries. (Kochanek, 2021).

In line with Slovakia's coal phase-out strategy[15], lignite mining ceased in December 2023[16]. Lignite mining was previously supported to ensure the operation of lignite plants for energy security. This support was provided as a temporary subsidy to electricity generators, compensating for non-economic baseload power generation for security of supply. The last coal-fired power plant in Slovakia was also phased out in December 2023, having remained operational to maintain regional energy security until a key power connector was completed in 2023[17].

Total energy consumption per capita is 10 % above the EU average in 2022 (Enerdata, 2023). Heating and cooling account for nearly 86 % of Slovakia's residential final energy consumption, with renewables contributing a share of 20 %. According to the draft of the updated NECP, the renewable energy's share in the heating and cooling sector is expected to reach 28.3 % by 2030 (European Commission, 2023d).

---

[15] Press release: State aid for closing mines on the upper Nitra, April 2022. Available at : https://www.hbp.sk/index.php/sk/Aktuality-2.

[16] https://www1.pluska.sk/regiony/takto-vyzera-smutok-banikov-slzy-poslednou-vytazenou-tonou-uhlia

[17] https://www.seas.sk/novinky/novaky-koniec-uhlia-na-slovensku/

Slovakia has made notable strides towards achieving the EU's 2030 energy efficiency targets. In 2022, its primary energy consumption was 15.5 million tonnes of oil equivalent (Mtoe), a reduction of 5.8 % compared to 2021 and 5.3 % compared to 2012. Final energy consumption marked a 6.9 % decrease from 2021 and a 2.8 % decrease from 2012 (European Commission, 2024a). The high energy intensity in Slovakia is largely due to the industrial sector, which has much higher energy demand and emissions compared to other IEA countries (Esser et al., 2018). Over the past year, the industrial sector showed the best results with a 12.4 % reduction in final energy consumption, while the transport sector performed the worst, with a 3.4 % increase in final energy consumption (European Commission, 2024a).

Between 1881 and 2016, the Slovak Republic's average annual temperature increased by almost 2°C, with a more noticeable increase in recent decades. This warming trend is expected to alter energy demand patterns, increasing the need for cooling and decreasing the need for heating (IEA, 2022). Although Slovakia is not often affected by cyclones, windstorms and thunderstorms can still significantly impact its energy system (IEA, 2022). The country is already experiencing electricity disruptions due to storms, exemplified by the March 2019 storm Eberhard, which caused power outages for 17 000 households in the central region and nearly 9 000 in eastern Slovakia (IEA, 2022).

Slovakia is increasingly feeling the effects of climate change, with more frequent floods and droughts. An increase in the number of floods is anticipated to have a high impact on energy infrastructure, operations and resources. The southern region is experiencing gradual desertification and a reduction in usable water sources. By 2030, freshwater runoff is expected to decrease by 29 % in the lowlands and by 35 % in southern central Slovakia (Esser et al., 2018). Extreme weather events, floods, heatwaves or drought could impact demand and supply for the energy system and reduce nuclear power production due to a lack of cooling water (European Commission, 2023d). To address these challenges, it is crucial to enhance the safety of power plants and ensure their resilience against extreme weather conditions (Ministry of Environment of the Slovak Republic, 2014).

The specific risks and vulnerabilities of the energy and business sectors mentioned in Slovakia's reporting on adaptation are not covered in the NAP (European Commission, 2023b). The draft updated NECP lacks adequate information on water and the resilience of energy systems to both structural and seasonal water scarcity. Since Slovakia relies significantly on nuclear power, the drought and heat can affect energy production (European Commission, 2023d). The NAS acknowledges that both conceptual and legislative frameworks for adaptation need an integrated approach, encompassing all relevant areas for adaptation, including energy (OECD, 2023).

The updated NAS highlights 13 key areas, including energy, and recommends adaptation measures to be integrated into sectoral strategies and action plans. For the energy sectors, the government expresses three primary concerns. First is the effect of climate change on electricity and heat supply and demand due to the higher energy demand for air conditioning in the summer and reduced power consumption in the winter due to milder weather. Second, the government projects that extreme weather could raise the incidence of blackouts by 10 to 20 % by 2050 compared to the reference period of 2000-2010 and suggests improving the power plants and distribution grids. Third, prolonged dry periods could intensify the competition for water between agricultural irrigation and nuclear power plants (IEA, 2018).

The government's main adaptation strategies for the energy sector include:

- Enhancing overall energy efficiency, for instance, through energy labelling for appliances and promoting smart energy consumption that accounts for seasonal variations.
- Strengthening safety measures at power facilities and preparing precautionary arrangements to ensure reliable system operation during extreme weather events (IEA, 2018).

### 3.6.1 Climate Impact Assessment

The assessment in the Energy sector shows that a total of five climate impacts are rated as high priority. These include not only alterations in the biophysical environment such as increasing number of flood events or changes of seasonal precipitation patterns, but also damages to infrastructure relevant to ensuring energy supply. For instance, an increase in damage to high-voltage lines is expected, rated with a *high* level of exposure and sensitivity. It should be noted that such impairments can affect all lines. Concerning energy generation from hydropower, the concrete impacts of climate change may vary from facility to facility, i.e. how severely a hydropower plant is affected by changes in runoff regimes depends on the specific facility. Other impacts relevant for hydropower generation are increasing bed load in watercourses as well as the increase of days with low water discharge, with both factors being closely connected.

As already discussed in other chapters, heat during summer months is one of the key climate impacts. This is also relevant for the Energy sector as cooling demand and requirements for electricity grids are expected to increase. Such an increase in energy and cooling demand is particularly relevant for the production of nuclear energy. In Slovakia, nuclear energy is still among the key energy sources and faces increased risk due to climate change. In light of the developments in the field of small modular reactors (SMRs) in Slovakia and neighbouring countries, it is likely that the proliferation of a localised form of nuclear energy production will increase. This may result in an expansion of the associated risks, which may become more geographically widespread as the number of SMRs rises.

In general, collecting and analysing hydrometeorological data to monitor the electricity generation potential from hydropower is a key factor in better understanding the impact of climate change on the sector.

Table 19 presents the results from the participatory climate impact assessments, which were conducted in June 2024. The assessment of adaptive capacity and urgency to act was conducted for climate impacts of high priority. However, this more in-depth assessment might not have been possible entirely, due to time constraints and intense discussions at the workshop (see Annex A: Additional information on methodological design Box 1). The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector Energy. Definitions of key terms used are provided in Annex A.

*Table 19: Presentation of the results of the climate impact assessment for the sector Energy. Impacts of high priority are highlighted in* ***bold.*** *The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).*

| Energy | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| biophysical | | | | | |
| increase in the number of floods | high | high | - | - | - |
| increase in bed load of watercourses | medium | high | low | low | high |
| change in seasonal distribution of precipitation | very high | medium | - | - | - |
| increase in extreme events | high | medium | - | - | - |

| Energy | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| loss of snow cover & precipitation buffering effect in spring | high | low | - | - | - |
| increase of days with low water discharge | high | low | - | - | - |
| increase in insolation | medium | low | - | - | - |
| change in the runoff regime | high | low | - | - | - |
| socio-economic | | | | | |
| impairment of the energy supply | medium | very high | high | medium | medium |
| increase in damage to high-voltage lines | high | high | high | medium | medium |
| impairment of electricity generation from biomass | high | medium | high | medium | medium |
| increase in cooling demand & requirements for electricity grids | high | medium | - | - | - |
| change in electricity and peak electricity demand | medium | medium | - | - | - |
| improved conditions for power generation from PV and solar thermal energy | medium | medium | - | - | - |
| increase in risk of failure of the electric system | medium | high | - | - | - |
| increase in damage caused by high wind | high | low | - | - | - |

### 3.6.2 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of two key risks (KR) for the sector Energy (E), displayed in Table 20. The key risk of *failure and impairment of energy production, supply and disruption of infrastructure due to extreme events* is associated with several climate impacts listed as high priority such as increase in the number of floods, impairment of the energy supply, increase in damage to high-voltage lines. Other climate impacts are also of relevance (e.g. increase in risk of failure of the electric system, increase in extreme events). It is expected that the current risk increases and is rated as *high* (optimistic scenario) to *very high* (pessimistic scenario) for the far future. Energy production of renewables is subject to fluctuations and disruptions e.g. due to extreme events (unreliability). Furthermore, Slovakia is still depended on imports of coal, gas and oil and these imports might be subject to global market dynamics. At the same time, energy generation from nuclear power plants plays a major role in the energy mix of Slovakia, potentially cushioning the effects of these fluctuations. However, it is up to further discussions if nuclear energy can be considered as sustainable and to what extend this kind of energy production is increasing the climate risk. The installation of more small and medium sized power plants across regions within Slovakia and in neighbouring countries in combination e.g. with increasing cooling demands due to warmer summer months has to be considered in this context.

*Table 20: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Energy (KR-E) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-E-1<br>Risk of failure and impairment of energy production, supply and disruption of infrastructure due to extreme events | medium | medium | medium | high | very high | acute | regional<br>national |
| KR-E-2<br>Risk of fluctuations in energy production | low | medium | medium | medium | medium | slow onset | national |

The strategic directions identified draw attention to the fact that renewables are crucial for climate mitigation (SD-E-1). In parallel, the use of renewable energy is, albeit dependent on natural systems like wind, sunlight and water, is less affected by heat waves and droughts, which in turn have adverse consequences for transport and cooling of nuclear power plants. Consequently, SD-E-2 and SD-E-3 highlight that climate change impacts lead to the necessity to adapt energy/electricity infrastructure in order to ensure reliable and resilient energy supply. Apart from transforming the energy supply to a system ideally fully based on renewables, raising awareness for sufficiency (i.e. decrease energy demand and usage in total) is another crucial aspect at the interface of climate change adaptation and mitigation.

### Strategic Directions – Energy

| | |
|---|---|
| SD-E-1 | Security of supply from an optimally structured energy and electricity system is ensured, including an expansion of PV-, solar-, wind- and water-based sources, and considering the role of energy supply at the interface of climate mitigation and adaptation. |
| SD-E-2 | Energy and electricity infrastructure (from production to distribution to the end-user) is adapted to changing climatic conditions, e.g. increased risk of grid failure. |
| SD-E-3 | The capacity of the energy and electricity system is sufficient to meet potentially changing demands (e. g. increased cooling requirements). Technical innovations ensure that these demands are covered as efficient as possible. |
| SD-E-4 | Awareness raising of the Slovak society with respect to the supply with and demand of energy in the context of climate change ensures energy sufficiency as crucial pillar next to efficiency. |

## 3.7 Finance

The **financial sector** is a section of the economy including firms and institutions that provide financial services to commercial and retail customers. This sector comprises a broad range of industries such as banks, investment companies, insurance companies, and real estate firms (Kenton, 2021).

The financial system channels funds from those who are net savers (i.e. who spend less than their income) to those who are net spenders (who spend more than their income) (European Central Bank, n.d.).

According to the latest 2024 European Climate Risk Assessment (ECRA), European financial systems face significant risks from climate change impacts, with current assessments underestimating the full extent of these risks, both domestically and globally (EEA, 2024b). EU Member States' public finances are vulnerable, with costly climate extremes leading to reduced tax revenues, increased government spending, other fiscal challenges, and solidarity funds strained due to oversubscription from events like wildfires in recent years. Risks to property and insurance markets could also be substantial with potentially increasing insurance costs, widening protection gaps and exacerbating vulnerability among disadvantaged groups (EEA, 2024b). A recent review of the empirical literature on how climate change affects banks concluded that there is a common trend of not fully recognising the risks of climate change, indicating that banks might not be accurately measuring these risks (Bandt et al., 2023). Undervaluing climate risk has shown to be a particular concern for longer-term investors and sectors including insurance, pension funds, infrastructure and agriculture (UNDRR, 2021).

In Slovakia, the financial sector is aware of the risks posed by climate change and is taking proactive measures to prepare and mitigate its impacts. Notably, the priorities of the National Bank of Slovakia (NBS) align closely with those of the European Central Bank (ECB) 's Single Supervisory Mechanism (with one of the priorities focused on intensifying efforts to tackle the impacts of climate change) (Národná Banka Slovenska, 2022). The NBS underscored its commitment to addressing climate-related challenges by publishing its climate pledge committing to deepening its understanding of how climate change affects financial stability and the broader economy (Národná Banka Slovenska, 2021). Furthermore, the NBS is actively working to raise awareness of climate-related risks among financial institutions, establish clear supervisory expectations and standardised disclosure practices and develop robust risk assessment frameworks (Národná Banka Slovenska, 2021). Importantly, the NBS has also begun collaborating with the ECB and other euro area national central banks on developing experimental climate change-related indicators.

The Slovak Academy of Sciences (SAV) has also highlighted the significant impact of climate change on the financial sector with rising costs, particularly in insurance against natural disasters, straining state budgets and threatening financial stability (Slovenská Akadémia Vied, 2021). As emphasised by the SAV, international monetary and economic institutions are urged to redirect public investments with estimates suggesting that individual states may need to allocate 0.5-2 % of GDP annually for climate-related expenses. In contrast, in 2019, research and development expenditures in Slovakia were at 0.83 % of GDP (Slovenská Akadémia Vied, 2021).

### 3.7.1 Climate Impact Assessment

The abovementioned climate risks posed to the financial sector are well-reflected in the climate impact assessment. For instance, the only identified biophysical climate impact, i.e. increase in extreme events, is estimated to be *very high* or *high* in terms of exposure and sensitivity, leading to a high urgency to take actions accordingly. An optimistic perspective is that workshop participants estimate the financial capacity to be enough to handle this challenge effectively. At the same time, extreme events and their impacts are strongly linked to insurance. In Slovakia, inhabitants do not pay for technical risk insurance. Likewise, property insurance is not mandatory and rising insurance premiums might result in the fact that individuals do not get insurances anymore. In particular against the background of unprecedented levels of global warming, the question arises whether associated climate-related risks will be insurable. This is also mirrored by increasing financial needs for adaptation and mitigation measures associated with *very high* levels of exposure and sensitivity pointing to a *high* urgency to act. Furthermore, experts stressed that, insurance policies might not have a national focus, given that branches of insurance companies in Slovakia are subsidiaries of multinational corporations. For other climate impacts such as the increase in probability of default and loss of asset value affecting financial institutions, tightening financial conditions as well as liquidity and operational risk, the assessment indicates rather *very low* to *medium* levels of exposure and sensitivity.

Besides this, in the context of potentially changing requirements for prudential frameworks, there is a need to consider that financial institutions will also be affected by new EU regulations that enter into force in 2024. For example, the EU Corporate Sustainability Reporting Directive (CSRD) which came into force on January 5, 2023. This regulation requires that businesses operating in the EU – including qualifying third-country subsidiaries – disclose information about their environmental, social and governance impacts and how these aspects affect their business.

Table 21 presents the results from the participatory climate impact assessments, conducted in June 2024. The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector Finance. Definitions of key terms used are provided in Annex A.

*Table 21: Presentation of the results of the climate impact assessment for the sector Finance. Impacts of high priority are highlighted in* ***bold****. The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).*

| Finance | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| biophysical | | | | | |
| increase in extreme events | very high | high | medium | high | high |
| socio-economic | | | | | |
| increase in insurance costs | high | high | low | low | high |
| change in requirements for prudential frameworks (need to incorporating climate-related risks) | high | high | medium | high | medium |
| increase in financial needs for adaptation and mitigation measures | very high | very high | medium | high | high |
| decrease in public finances (e.g. tax revenues, increased government expenditures, lower credit rating) | high | medium | - | - | - |
| increase in insurance premia & widening of existing protection gap | high | low | - | - | - |

| Finance | | | | | |
|---|---|---|---|---|---|
| increase in probability of default and loss of asset value affecting financial institutions | low | low | - | - | - |
| increase in tighter financial conditions | very low | low | - | - | - |
| increase in liquidity risk | low | low | - | - | - |
| increase in operational risk (damage to offices and/or data centres) | low | low | - | - | - |
| increase in demand for insurances | low | medium | - | - | - |

### 3.7.2 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of three key risks (KR) for the sector Finance (FI), displayed in Table 22. Concerning KR-FI-1 (*Risk of fiscal and individual financial instability and instability of bank portfolios due to climate-related events, in particular extreme weather events*), climate impacts such as a decrease in public finances and an increase in extreme events are of relevance. Therefore, extreme events were the identified biophysical climate impact and rated as *very high* and *high* respectively with respect to exposure and sensitivity. The current high urgency to act highlights the need to implement measures, in particular as the risk becomes more severe and is rated as *high* for the future (optimistic and pessimistic scenario). Insurances and associated costs play a major role in the financial sector and the respective climate impact is rated as high priority one (*high* exposure and sensitivity), along with a *high* urgency to act and a *low* adaptive capacity. Therefore, the current risk rating is already assumed to be *high* and *very high* for both scenarios in the far future, considering adverse effects of potentially unprecedented levels of global warming. The *Risk of rising costs of inaction due to insufficient mitigation and adaptation to climate change* (KR-FI-3) is directly related to the climate impact of increasing financial needs for adaptation and mitigation measures which was rated as highest (*very high* exposure and sensitivity), associated with a *high* urgency to act. The current risk rating as *high* reflects this assessment and also the fact that this risk is related to all other risks/climate impacts as adaptation and mitigation are key to avoid unprecedented and potentially irreversible climate change impacts.

*Table 22: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Finance (KR-F) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-FI-1<br>Risk of fiscal and individual financial instability and instability of bank portfolios due to climate-related events, in particular extreme weather events | low | medium | medium | high | high | slow onset | national |
| KR-FI-2<br>Risk of increase in insurance costs and uninsurable climate impacts potentially leading to a loss of risk transfer possibilities | high | high | high | very high | very high | slow onset | national |
| KR-FI-3<br>Risk of rising costs of inaction due to insufficient mitigation and adaptation to climate change | high | high | high | very high | very high | slow onset | national |

Awareness-raising and building up required knowledge and competencies can contribute to a 'transformation' of the Finance sector towards climate resilience (SD-FI-1, SD-FI-2). This is particularly important as, according to workshop participants, climate change impacts will reach levels that are uninsurable, potentially leading to a lack of risk transfer. SD-FI-3 draws attention to this risk and highlights that insurance for both technical and property assets is crucial (currently, property insurance is not mandatory in Slovakia). This also refers to the insurance of agricultural property.

## Strategic Directions – Finance

| | |
|---|---|
| SD-FI-1 | Sufficient funding of adaptation and mitigation measures ensures a climate-resilient Slovak society. Climate adaptation-related financial needs in other government sectors/ministries are known and funding is allocated appropriately. The governmental body is aware of the resulting effects like reduced availability of funds in other fields of action. Funding opportunities from competitive EU programmes available to support climate change adaptation efforts at all levels are additionally used. |
| SD-FI-2 | Public finances allocation is prudent and under transparent public scrutiny. In their operations, public and financial institutions take into account climate change related risks such as the potential lack of risk transfer (uninsurable climate impacts), have sufficient knowledge concerning climate change related impacts on the financial sector and act accordingly. EU-level obligations, e.g. the EU Taxonomy, are implemented. |
| SD-FI-3 | Schemes and obligations for technical and property insurance are enforced and adapted to climate change and potentially unprecedented climate-related impacts. |

## 3.8 Forestry

The sector **Forestry** encompasses ecosystems covered mainly by tree species, but also non-forest woodland and associated ecosystem elements such as other species and soils. The sector also includes forest products such as wood and processed wood by-products. Within the sector, the human role describes the management of forests and woodlands as well as the economic valuation of forests and their products and services (European Commission, 2021c).

With a forest cover of more than 40 %, Slovakia comes 11th in the ranking of 50 European countries regarding their respective forest cover area (Gubka et al., 2013). In 2017, approximately 41.1 % of Slovakia was categorised as forest ecosystems, out of which 40 to 45 % are seminatural (Izakovičová et al., 2017). From 1950 to 2013, Slovakia's forest landcover had increased about 9 % (Gubka et al., 2013). The relatively high proportion of forest on non-forest land can be attributed to the country's considerable decline of agricultural land. While the tree species composition varies, deciduous trees make the larger share in comparison to coniferous trees and the most prevalent type of forest ecosystems is the medio-European neutrophile beech (*Fagus*) forest (Černecký et al., 2020). The most abundant tree species include European beech (*Fagus sylvatica L.*; 32.7 %), Norway spruce (*Picea abies L.*; 27.5 %), oak (*Quercus sp.*; 11.3 %) as well as Scotch pine (*Pinus sylvestris L.*; 7.8 %) and white fir (*Abies alba L.*; 4.6 %) (Izakovičová et al., 2017).

While the current bioclimatic conditions for Slovakian forests can be described as cool, mountainous-temperate and moderately humid, changes due to climate change are expected to affect lowland and mountain regions dramatically. Risk factors for forest growth are abiotic aspects such as heatwaves, droughts, storms and forest fires but also biotic factors like pathogens and pests, all of which greatly affect forest management in negative ways (Council Directive, 2008; Korená Hillayová et al., 2021). Even though rising temperatures, changing precipitation patterns and higher probabilities of severe droughts fuel the risk of wildfires, they occur mostly as a consequence of human activity and are not the most common cause of forest damage in Slovakia (Korená Hillayová et al., 2021). Statistical data shows that fires were responsible for a tree cover loss of 1.74 kha from 2001 to 2023, representing a share of 0.71 % of the total tree cover loss of 242 kha (Global forest watch, 2024).

When looking at future climate projections, models and scenarios predict the emergence of warm-temperate zones with xerothermic forests in the southern regions of Slovakia. Alpine communities, on the other hand, are expected to go extinct and be substituted by bioclimatic conditions of subalpine, very humid mountainous forests (Minďáš, 2005). Furthermore, climate change will quite possibly lead to an upward shift of the tree line to the present subalpine zone. This is also the zone with the most observed change in tree, shrub and herbaceous species diversity, being affected by anthropogenic factors such as ecosystem management as well as natural disturbances through wind and snow patterns or insects (Mindas and Škvareninová, 2016). Especially spruce stands are damaged frequently due to harmful agents like bark beetle outbreaks whose dynamics are intertwined with factors like droughts, storms and other stressors and thus progressively replaced by beech and maple (Gubka et al., 2013; Považan and Blaško, 2023). In mixed forests, mainly conifers are predicted to gradually fall out and to be superseded by oak, maple, ash, elm and agate (Považan and Blaško, 2023). Models for water balance changes under future climate conditions show that the spruce and mountain pine vegetation seem to be sufficiently supplied by precipitation water, while other vegetation zones will be characterised by a deepening deficiency of water balance in the vegetation period, shifting more importance to water supply in the winter season (Minďáš, 2005).

Generally, the formerly intense use of forests in Slovakia for agricultural purposes, metallurgy, as well as mining related forestry explains the country's high yet still growing forest areas. Researchers strongly suggest that non-productive functions of ecosystems like soil and water protection should be promoted and protected more rather than solely focussing on timber production and other economic use of forest (Gubka et al., 2013).

### 3.8.1 Climate Impact Assessment

As the assessment based on the stakeholder workshop shows, a significant amount of climate impacts is rated as high priority. The relevance of forests results from a diverse spectrum of functions they provide, yet climate change puts increasing pressure on forests and deteriorates functions provided by these ecosystems. Among other things, forests are of utmost importance for capturing water as they have high retaining capacities. Thus, forests can play a major role in tackling climate impacts such as increasing droughts or floods and in the protection of soils (e.g., soil fertility is negatively impacted by droughts). At the same time, extreme weather events such as storms can severely impact the quality of the protective function of forests, and large-scale disturbances are expected to increase. Besides, impacts such as the prolongation of the vegetation period can lead to an insufficient regeneration of certain species (e.g., deciduous trees) due to the shorter winter season and a lack of snow cover.

The effects of climate change in general and of drought stress in particular strongly depend on the tree species composition and are also influenced by other factors such as the functional complexity of ecosystems and affected species. Already today, spruce trees are those most severely affected by heat-induced stress. Climate change has led to a gradual shift of spruce trees out of the ecological optimum of their environmental conditions in some localities.

Similarly, tree species such as beech and oak are already under pressure locally. Cases of collapses of such populations, e. g. recorded in Hungary, are indicating that similar breakdowns have to be expected in the future in Slovakia as well. Generally, single-species forests are more affected by climate change. Furthermore, native tree species are affected by the spread of invasive plants and animals as well as pests and harmful organisms. Thus, some species are already experiencing a dramatic decline. Since 2004, fungus *Chalara fraxinea* decimated slender ash wood populations and elm has constantly been damaged by the fungus *Ophiostoma sp.* since the 1950s. In addition, invasive plants are increasingly relevant. The appearance of new species spreading through the natural movement of pests or transfer with goods, tourism and trade is difficult to forecast, underlining the challenging character of this significant problem, currently not being addressed adequately. At the same time, changes in species composition might also be caused intentionally by assisted migration as one way for adaption.

Forest- and wildfires are also among the climate impacts of high priority. In Slovakia, measures to support biodiversity, such as leaving dead matter in forests, increase the chances of severe and extensive fires – this shows a potential conflict between biodiversity protection and wildfire prevention. Most importantly, it should be noted that forests are not sufficiently accessible for fire trucks via fire roads and climate change accelerates the extent, intensity, and occurrence of fires. At the same time, the vast majority of fires is caused by human activity, e.g., due to burning residues after mining, barbecuing, or throwing away cigarette butts. Hence, the disrespectful behaviour of tourists can be relevant, particularly due to the rising number of tourists, as people increasingly seek relief from summer heat and heat stress, seeking cool places. Hence, it is assumed by involved stakeholders that the increase in heat waves occurrence will very likely lead to higher movement of people in the forests.

Forest fires are a good example highlighting the complex interplay of climate change itself and other human-induced consequences. The expert discussions during the assessment revealed that it can be difficult to clearly estimate - and without long-term studies nearly impossible - to what extent climate change adversely affects forests and to what extent inappropriate forest management is the reason for damage and deterioration of the state of these ecosystems (e. g. with respect to increasing pests and harmful organisms or the endangerment of the protective function of forests). Long-term studies comparing nature reserves and intensively managed forests could address this issue, but it was stated that such studies are rather rare in Slovakia. Inappropriate forest management can be associated with aspects such as delayed implementation of measures because of time-consuming public procurement procedures, an increase in areas with no management, or removal of humus during harvesting. The question of the interrelation of human-made climate change impacts and other aspects influenced by human actions indicates the complex interplay of both.

Regarding yield, the shortening of the rotation period and increased biomass production, several aspects must be considered. Firstly, the amount of yield, whether decreasing or increasing, is also influenced by non-climatic factors such as the quality of wood raw material and rising afforestation costs. Secondly, the effect of increased $CO_2$ availability leading to increased biomass production is assumed to be only temporarily effective. Thirdly, with the shortening of the rotation period, it should be noted that wood processing procedures are also changing in general, i.e., younger trees are being felled. In this context, it should be noted that forests could be damaged and destroyed by extreme events such as storms, pest infestations, or fires before they reach the harvest season.

Table 23 presents the results from the participatory climate impact assessments, which were conducted in June 2024. The assessment of adaptive capacity and urgency to act was conducted for climate impacts of high priority. However, this more in-depth assessment might not have been possible entirely, due to time constraints and intense discussions at the workshop (see Annex A: Additional information on methodological design Box 1). The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector Forestry. Definitions of key terms used are provided in Annex A.

*Table 23: Presentation of the results of the climate impact assessment for the sector Forestry. Impacts of high priority are highlighted in* ***bold****.*

| Forestry | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| biophysical | | | | | |
| **increase in abiotic forest damage** | **very high** | **very high** | **-** | **-** | **-** |
| **shift of habitats/vegetation zones** | **very high** | **high** | **-** | **-** | **-** |
| **increase in drought stress** | **very high** | **high** | **-** | **-** | **-** |
| **increase in pests & harmful organisms** | **high** | **high** | **-** | **-** | **-** |
| **changes in population dynamics of pests** | **high** | **high** | **-** | **-** | **-** |
| **reduction of water retention capacity** | **high** | **high** | **-** | **-** | **-** |
| **increase in large-scale disturbances of ecosystems (especially in forest areas due to extreme events)** | **high** | **high** | **-** | **-** | **-** |
| **increase in forest and wild fires** | **medium** | **high** | **-** | **-** | **-** |
| extension of vegetation period | high | medium | - | - | - |

| Forestry | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| decrease in water availability during vegetation period | high | medium | - | - | - |
| decrease in soil fertility (droughts) | high | medium | - | - | - |
| change in tree species composition | high | medium | - | - | - |
| increase in soil erosion, soil degradation | medium | medium | - | - | - |
| increase in biomass production (increased $CO_2$ availability) | medium | medium | - | - | - |
| decrease of climatically suitable areas for key forest species | high | low | - | - | - |
| spread and proliferation of invasive plants and animals | medium | low | - | - | - |
| lowering of groundwater level | medium | low | - | - | - |
| shift of timberline | medium | low | - | - | - |
| socio-economic | | | | | |
| **damage to/losses of forest** | **high** | **high** | **-** | **-** | **-** |
| **decrease in provision of ecosystem services** | **high** | **high** | **-** | **-** | **-** |
| increase of yield | medium | high | - | - | - |
| endangerment of the protective function of forests | medium | high | - | - | - |
| decrease in yield | high | medium | - | - | - |
| shortening of the rotation period | high | low | - | - | - |

### 3.8.2 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of three key risks (KR) for the sector Forestry (FO), displayed in Table 24. Several climate change impacts associated with degradation and disturbances of forests put forest ecosystems services under pressure (KR-FO-1). As these climate impacts are among those considered as high priority (e.g. increase in drought stress, increase in pests & harmful organisms, increase in large-scale disturbances of ecosystems due to extreme events, increase in forest- and wildfires), the current risk is rated as *high* and as *very high* for the far future (optimistic and pessimistic scenario). At the workshops as well as in course of the feedback phase, sector experts stated that forest management also plays a key role to ensure healthy forests. Inadequate forest management as such is already considered as being problematic, and climate change leads to an additional pressure (KR-FO-1). Given that such deficient management was already a reason of concern among the stakeholder group, the current risk assessment is rated as *high*. In view of the above-mentioned factors, the *Risk of loss of economic viability of forestry* is expected to increase in the next decade, resulting in a *high* risk by the end of the century.

*Table 24: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Forestry (KR-FO) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-FO-1<br>Risk of loss of ecosystem services provided by forests (e.g. water regulation, carbon sequestration) due to forest degradation and forest disturbances | high | high | high | very high | very high | slow onset | regional<br>local |
| KR-FO-2<br>Risk of inadequate forest management (e.g. due to lack of knowledge and insufficient flexibility of legislation), in particular under changing climate conditions | high | high | high | high | high | acute<br>slow onset | regional<br>local |
| KR-FO-3<br>Risk of loss of economic viability of forestry | low | medium | medium | medium | high | slow onset | regional |

The derived strategic directions are associated with several specific objectives listed in the current NAP (Ministry of Environment of the Slovak Republic, 2021a)[18], i.e. there is a dedicated chapter on 'adapted forestry'. These objectives are specifically both directly and indirectly related to the identified key risks.

### Strategic Directions – Forestry

| | |
|---|---|
| SD-FO-1 | Sufficient and effective measures are implemented to ensure climate-resilient forests and their associated ecosystem services, including monitoring, restoration and protection. (NAP: 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 4.3, 4.5, 4.7) |
| SD-FO-2 | Provisioning forest ecosystem services (including sustainable timber production) are appropriately supported as a tool to mitigate climate change. |

---

[18] The number code of specific objectives of the current NAP associated with certain strategic objectives are listed in brackets.

## 3.9 Geological Environment & Soil

The **Geological Environment** focuses on the diverse geological structures of Earth, particularly rocks and the processes by which they change over time. Expertise on the geological environment is crucial in assessing and managing climate-related hazards. The **Soil** sector plays a cross-sectoral role, with strong overlaps with Agriculture, Forestry, Biodiversity & Ecosystems. As a vital component of natural capital, soil hosts rich biodiversity and provides critical ecosystem services, such as food production, water purification, groundwater formation and carbon storage, amongst other services (EEA, 2024d).

Slovakia has two biogeographic regions: the Carpathian Mountains (to the North) and the Pannonian Lowlands (to the South). This allows for a diversified landscape and rich diversity of flora and fauna. The Pannonian zone is more fertile and thus, important for regional livelihoods, due to a high agricultural productivity. Mountain landscapes occupy the largest proportion of Slovakia (53 % of the land area), while 29 % of the land area are lowlands (Izakovičová et al., 2022). Agricultural land covers 48.4 % of Slovakia, dominated by arable land, while forests cover around 40 % of Slovakia – it is thus among the most forested countries in Europe. Slovakia also has a dense river network, with most of the watershed draining via the Danube into the Black Sea. The relatively large reserves of groundwater are unevenly distributed across the country (Izakovičová et al., 2022).

Changes in the geological environment and soil are intricately connected to other natural processes: As oceans are warming due to climate change, the amount of water evaporating increases, impacting the intensity and frequency of precipitation. Heavy precipitation can lead to waterlogging or flooding in areas with reduced runoff possibilities. This, particularly combined with soil erosion, can lead to flash floods that can affect drinking water quality as sources are contaminated by debris or waste carried by the flash flood. Additionally, heavy precipitation can lead to landslides and erosion, making land-use changes necessary. Soil erosion, especially from water, is a particular problem in the mountainous areas of Slovakia, affecting fertile agricultural land. As a result, the reduced soil profile leads to a loss of organic matter and nutrients, exacerbating a deterioration in all soil properties and structures (Sobocká, 2017). Acidification of soil can also be considered a relevant threat. Soil moisture in Slovakia is likely to decrease, particularly as reduced water availability may arise due to increases in temperatures. A lowering of the groundwater table, combined with reduced surface flows, may lead to hydrogeological droughts.

In Slovakia, the National Agricultural and Food Center and the State Geological Institute of Dionýz Štúr are the primary institutions relevant to the present sector. The National Agricultural and Food Center conducts research on soil and water resources, agriculture and rural development, particularly through the Soil Science and Conservation Research Institute (SSCRI). The State Geological Institute of Dionýz Štúr provides geological research and has created an information system in geology. Regarding soil protection, both the Ministry of Agriculture and Rural Development and the Ministry of Environment hold responsibility. Importantly, all EU policies relating to soil have also been transposed into national legislation and a separate legal document on protection and use of agricultural land is available. For instance, within the frame of the environment monitoring system, there is a soil monitoring programme in Slovakia called 'Čiastkový monitorovací systém Pôda'[19]. While Slovakia does have targets for all soil challenges within the monitoring system, in most documents these targets are not quantified, limiting their effectiveness (Sviček et al., 2022). Additionally, research has shown that management practices identified by stakeholders in Slovakia quite often differ from management practices that are identified in policy documents (Sviček et al., 2022). Alignment between the two should occur, in order to effectively address soil challenges.

---

[19] http://www.podnemapy.sk/portal/prave_menu/cms_p/cms_p.aspx

According to the NAP, Slovakia aims to protect soil under the specific objective 2 on 'sustainable agriculture'. Soil protection measures are focused on increasing water retention in soil, minimising wind and water erosion of soil, as well as implementing soil conservation measures.

### 3.9.1 Climate Impact Assessment

The workshop on climate impacts in Slovakia highlighted several critical issues for the Geological Environment & Soil sector. One of the highest priorities is the extension of the vegetation period, although data on this is lacking (see Chapter 3.2). The increase in landslides and mudslides is another significant concern, with climate change identified as a major contributing factor. In Slovakia, slope deformations affect 5.25 % of the territory, largely due to fluctuations in the groundwater level. These fluctuations in groundwater levels exhibit a strong regional character, particularly impacting the flysch mountains.

Additionally, the lowering of the groundwater table and changes in groundwater quality are concerning. Processes like evapotranspiration and other biogeochemical changes, influenced by increased groundwater temperatures, affect underground water quality. However, there is limited investigation and monitoring of groundwater quality in Slovakia, making it difficult to evaluate the impacts of climate change and human activity on pollution levels. Extreme climate events, such as floods, further compromise groundwater quality, affecting its usability for drinking water supply.

Other important impacts include increases in soil erosion and overall changes in water availability, which lead to decreased soil water retention capacity and desiccation of soils. This necessitates in reducing soil compaction, e.g. in agriculture. Although soil salinisation, initially combined with desiccation of soils, was discarded, it remains relevant due to increased evapotranspiration and its impact on soil ecosystem services (see Chapter 3.1).

Table 25 presents the results from the participatory climate impact assessments, conducted in June 2024. The assessment of adaptive capacity and urgency to act was conducted for climate impacts of high priority. However, this more in-depth assessment might not have been possible entirely, due to time constraints and intense discussions at the workshop (see Annex A: Additional information on methodological design Box 1). The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C in the sector Geological Environment & Soil. Definitions of key terms used are provided in Annex A.

*Table 25: Presentation of the results of the climate impact assessment for the sector Geological Environment & Soil. Impacts of high priority are highlighted in **bold**. The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).*

| Geological Environment & Soil | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| biophysical | | | | | |
| extension of the vegetation period | very high | very high | low | - | medium |
| increase of landslides and mudslides | high | high | low | - | medium |

| Geological Environment & Soil | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| fluctuation/lowering of the groundwater level | high | high | low | - | high |
| change in groundwater quality | high | high | - | - | - |
| increase in soil erosion | high | high | low | - | high |
| change in water availability | high | medium | low | - | high |
| decrease in soil water retention capacity | medium | high | - | - | - |
| decrease in nutrient availability due to water shortages | medium | high | - | - | - |
| desiccation of soil | medium | high | - | - | - |
| degradation of humus | medium | medium | - | - | - |
| decrease in soil biodiversity | medium | medium | - | - | - |
| acceleration of conversion processes | medium | medium | - | - | - |
| change in soil water balance | medium | medium | - | - | - |
| increase in forest and wild fires | medium | medium | - | - | - |
| change in soil organic matter content and stocks | medium | low | - | - | - |
| decrease of soil fertility, structure and stability | low | medium | - | - | - |
| soil compaction | low | medium | - | - | - |
| changes in the valley shape/certain areas | low | low | - | - | - |

### 3.9.2 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of two key risks (KR) for the sector Geological Environment & Soil (GES), displayed in Table 26. Extreme events (mainly droughts, landslides and mudslides, with *medium* to *high* urgency and governance frameworks rated as *low*) are among those climate impacts associated with the key risk *soil degradation, including erosion*. As such events are expected to increase in terms of frequency and intensity, the risk becomes more severe and is rated a *high* (optimistic scenario) and *very high* (pessimistic scenario) for the far future. The regional distribution and occurrence depend on the bedrock and topography, among others. The risk of decreasing groundwater availability and quality is associated with climate impacts such as fluctuation/lowering of the groundwater level and change in groundwater quality, impacted by changes in precipitation patterns, droughts/heat waves as well as an overall rise in temperature. The regional distribution of both risks depends on the bedrock and topography, among others.

*Table 26: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Geological Environment & Soil (KR-GES) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-GES-1<br>Risk of soil degradation, including erosion | medium | high | high | high | very high | slow onset acute | regional |
| KR-GES-2<br>Risk of decreasing groundwater availability and quality | medium | medium | medium | high | high | slow onset | regional |

The strategic directions focus on the resilience of soil and its capacity to provide ecosystem services, highlighting the necessity to work across sectors and are related to some specific objectives of the current NAP (Ministry of Environment of the Slovak Republic, 2021a)[20]. Currently underestimated hazards (landslides/mudslides) are addressed as well, considering the importance of comprehensive mappings to assess risks.

---

[20] The number code of specific objectives of the current NAP associated with certain strategic objectives are listed in brackets.

## Strategic Directions – Geological Environment & Soil

| | |
|---|---|
| SD-GES-1 | The ecosystem service provision of soils is secured through sustainable management practices, especially considering agriculture, forest soils and urban soils, to protect water retention capacity and limit excess surface runoff, reduce evapotranspiration and thus improve the overall soil water balance. (NAP 2.1, 2.2, 7.1) |
| SD-GES-2 | Areas at risk for landslides and mudslides are mapped, considering future climate developments and their relevance for hazard and risk maps. |

## 3.10 Health

**Health** is defined by the World Health Organization as ‘a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity’ (IPCC, 2022c). Thus, the three components of ‘health’ that are assessed for climate risks and vulnerabilities are physical health, mental health and general well-being. Key predictors of well-being used by the IPCC include annual income, access to food and water, healthy environment and access to green spaces (IPCC, 2022c). Although usually assessed separately, physical health, mental health and well-being are inter-connected – any type of health problem can reduce overall well-being and vice versa.

Climate change has a significant impact on health in Slovakia. Rising temperatures affect the transmission and spread of vector-borne diseases, likely worsening over time. Adverse impacts on mental and psychosocial health are expected, as well as increases in noncommunicable diseases, zoonoses, heat-related illnesses, respiratory diseases and malnutrition, among others. (World Health Organization (WHO), 2022). To illustrate, the WHO showed that under a high emissions scenario (RCP 8.5), additional deaths per warm season are projected to rise to 1 276 in 2071–2099, whereas a reduction in emissions (in accordance with RCP4.5) could lower this number to 517 during the same period[21] Similarly, the number of cases of tick-borne encephalitis and waterborne diseases (including hepatitis and diarrhoea) in Slovakia is expected to increase as a result of climate change (World Health Organization (WHO), 2022).[22] Another indirect consequence of climate change on health originates from potentially changing ultraviolet radiation which plays an important role in the development of skin cancer, cataracts and other eye diseases, and suppresses the immune system (Government of the Slovak Republic, 2019). Furthermore, a recent OECD study identified high-risk areas in Slovakia prone to extreme events with health implications: southern districts like Bratislava, Rimavská Sobota, and Lučenec are among the regions facing the highest risks caused by extreme heat risks due to projected scenarios and limited healthcare access. In the southwest, including Bratislava and Žitný ostrov, droughts threaten water supply and agriculture. Northern districts like Tvrdošín and Dolný Kubín will be prone to extreme precipitation and landslides (OECD, 2023).

To mitigate these effects, the Action Plan for the Environment and Health of the Inhabitants of the Slovak Republic (NEHAP V.) focuses on minimising environmental health risks, such as air and water pollution and climate change. NEHAP V includes activities like monitoring vector-borne diseases, tick prevention campaigns, and improving information services on allergenic particles (Government of the Slovak Republic, 2019).

Response options to decrease the impacts of climate change on human health, well-being and health systems include i) reducing exposure to climate-related hazards; ii) reducing vulnerability to such hazards, and iii) strengthening health system responses to future risks.

### 3.10.1 Climate Impact Assessment

The workshop on climate impacts identified several issues for the health sector. The highest priority is the increase in heat stress, which is associated with a rise in illnesses, mortality, and morbidity during

---

[21] In comparison, if temperatures remain unchanged, about 250 heat-related deaths would occur in Slovakia during the same period (2017-2019). (World Health Organization 2022). RCP stands for 'Representative Concentration Pathway', consisting of a set of scenarios used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) that include time series of emissions and concentrations of greenhouse gases (GHGs), aerosols, and land use changes.

[22] Ticks in Slovakia are spreading to higher altitudes and are active for longer periods due to milder winters, increasing the risk of tick-borne encephalitis outbreaks. (World Health Organization 2022)

heat waves, resulting particularly in increased numbers of heat strokes, heart attacks and collapses due to heat.

There is also an increase in newly emerging diseases. Vector-borne diseases are on the rise, with 10 out of 60 mosquito species in Slovakia now being invasive and transmitting such diseases. The resistance of mosquitoes to insecticide treatment is increasing, this issue is receiving insufficient attention and research, according to experts. Furthermore, ticks remain active during winter due to higher temperatures; however, vaccination against tick-borne diseases is well-accepted, despite the declining popularity of vaccination post-COVID. Food diseases are becoming more common, primarily due to reduced food quality from higher pest numbers in agriculture and increased pesticide use.

The spread of invasive plants and animals also contributes to health risks, with invasive vegetation increasing allergen concentrations and insects posing threats as disease vectors. Due to changes in pollination, pollen load and allergenicity, exacerbated by the extended pollen season and shorter and milder winters, allergies are increasing.

Extreme weather events affect groundwater levels, leading to fluctuations impacting the availability and quality of drinking water, especially during floods. This issue is particularly severe in villages where households use questionable well water to save money. Marginalised Roma communities are particularly at risk due to lower water network connections.

Lastly, the reduction in work performance is linked to increasing numbers of hot days and nights, affecting physical health, psychological well-being and productivity. Mental health issues, including anxiety and depression, are rising, particularly among younger generations, due to concerns about climate change and inadequate solutions. Changes in individual behaviour, such as increased outdoor activities, also raise the risk of skin cancer due to higher exposure to sunlight and UV radiation.

Table 27 presents the results from the participatory climate impact assessments, conducted in June 2024. The assessment of adaptive capacity and urgency to act was conducted for climate impacts of high priority. However, this more in-depth assessment might not have been possible entirely, due to time constraints and intense discussions at the workshop (see Annex A: Additional information on methodological design Box 1). The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector Health. Definitions of key terms used are provided in Annex A.

*Table 27: Presentation of the results of the climate impact assessment for the sector Health. Impacts of high priority are highlighted in* ***bold***.

| Health | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| biophysical | | | | | |
| increase in heat stress | very high | very high | - | - | - |
| increase in vector-borne diseases | high | very high | - | - | - |

| Health | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| increase in water temperatures | high | high | - | - | - |
| increase in summer & tropical days/nights | very high | medium | - | - | - |
| increase in urban heat island effect | high | high | - | - | - |
| change in pollination, pollen load & pollen allergenicity | high | high | - | - | - |
| spread and proliferation of invasive plants & animals | high | high | - | - | - |
| increased exposure to (new) pathogens | high | high | - | - | - |
| increase in extreme events | very high | medium | - | - | - |
| increase in food diseases | very high | high | - | - | - |
| increase in polluted water & food | high | medium | | | |
| increase in air pollutants | low | low | - | - | - |
| socio-economic | | | | | |
| increase in mortality & morbidity during heat waves | very high | very high | - | - | - |
| increase in illnesses due to heat waves | very high | very high | - | - | - |
| increase in newly emerging diseases | very high | high | - | - | - |
| reduction in work & performance capacity | very high | high | - | - | - |
| increase in allergies | high | high | - | - | - |
| mental health and well-being | very high | medium | - | - | - |

| Health | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| change in behaviour | high | medium | - | - | - |
| degradation of drinking water quality | medium | medium | - | - | - |
| increase in probability of injuries & accidents | medium | medium | - | - | - |
| increased risk of skin cancer | high | low | - | - | - |

### 3.10.1 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of four key risks (KR) for the sector Health (H), displayed in Table 27. KR-H-1 draws attention to (extreme) heat as one major risk to human health, associated with six prioritised climate impacts, i.e. increase in summer days and tropical nights, especially in urban and built-up areas/increases in UHI, overall increase in heat stress and increases in illnesses, morbidity and mortality during heat waves resulting from heat strokes, heart attacks and collapses. As mean temperatures will increase and extreme heat events are expected to become severe and frequent, the risk for the near future is rated as *high* and *very high* for the far future (optimistic and pessimistic scenario).

Health is also affected by an increase in air-, insect-, water-and food-borne diseases, pathogens and allergens (KR-H-2), exacerbated by shifting spatial distributions of invasive plants and animals, altering ecosystems and species composition and agricultural practices, i.e. higher use of pesticides.

Various climate impacts have adverse effects on water quality and availability, i.e. increase in water temperatures, degradation of drinking water quality (exposure and sensitivity currently rated as *medium*), increases in water demand expected due to increasing air temperatures and heat extremes but also increases in extreme events (mainly flood events). This results in a risk of insufficient access public water infrastructure (KR-H-3), currently rated as *low* but becoming more acute in the future (rated as *medium* for the near future and as *high* for the far future).

Key risk KR-H-4 results from decreased work performance and productivity (*very high* exposure and *high* sensitivity) due to increases in heat extremes. Likewise, increases in psychological disorders like depression and anxiety due to climate change and insufficient responses and solutions are also of relevance. Further impacts resulting from behavioural changes and individual responses to climate extremes might generate shifts in revenues as everyday practices are altered, e.g. regarding choice of travel destination and leisure activities or technical appliances (i.e. air conditioning, etc.).

*Table 28: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Health (KR-H) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-H-1<br>Risk to human health from extreme heat events and overall increase in heat | medium | high | high | very high | very high | slow onset<br>acute | national<br>regional |
| KR-H-2<br>Risk of increases in air-, insect-, water-and food-borne diseases, pathogens and allergens | medium | medium | medium | high | very high | slow onset<br>acute | national<br>regional |
| KR-H-3<br>Risk of a lack for access to public water infrastructure | low | medium | medium | high | high | slow onset | local<br>regional |
| KR-H-4<br>Risk of health-related increases in economic losses and burdens | medium | high | high | high | very high | slow onset | national |

The strategic directions take up specific objectives defined in the current NAP (Ministry of Environment of the Slovak Republic, 2021a)[23]. To enhance the resilience of the healthcare system, aspects such as providing relevant information, ensuring sufficient financial, infrastructural and human resources as well as raising awareness are considered to be key. Disadvantaged groups are particularly mentioned as they are more vulnerable than other population groups.

---

[23] The number code of specific objectives of the current NAP associated with certain strategic objectives are listed in brackets.

### Strategic Directions – Health

| | |
|---|---|
| SD-H-1 | Slovakian healthcare infrastructure is adapted to changing demands and climate risks resulting from heat waves and diseases. Sufficient capacities are available, i.e. training, infrastructure, energy, human and financial resources, complemented by available information for the general public and sufficient accessibility to healthcare infrastructure, both specifically for vulnerable groups and including mental health. Protection through state and emergency mechanisms is ensured. (NAP: 5.1, 5.2, 5.3, 5.4, 5.6, 7.5) |
| SD-H-2 | The resilience of the population (especially disadvantaged groups) is strongly supported. People are aware of health risks, including mental health, due to heat and risks resulting from air-, food-, water- or vector-borne diseases. |
| SD-H-3 | The sanitation system is adapted to changing water availability and demand and increasing climate risks such as extreme events. |
| SD-H-4 | Safe water supply is ensured and water networks are further expanded. |

## 3.11 Hydrological Regime & Water Resource Management

The sector **Hydrological Regime & Water Resource Management** addresses freshwater systems and their management including drinking water, irrigation water and wastewater. Water resources are directly linked to climate change as the hydrological cycle is highly dependent on climatic factors. Changes in rainfall patterns, and temperature have implications on the availability of surface and subsurface water, as volume and timing of precipitation, as well as evaporation are driving factors of the water balance (World Bank Group, 2022).

Water resource management in Slovakia is based on water availability which is driven by non-stationary meteorological, climatological and hydrological processes. Thereby, infrastructural measures such as water reservoirs have already been used in the past to deal with seasonal to perennial precipitation variations. Successful future management of water resources involves knowledge on hydrological extremes such as floods and droughts (Negm and Zeleňáková, 2019).

Considering the hydrological input, mean annual precipitation has been increasing in general, but very slightly on a national level; a regime shift (i. e. the timing and spatial distribution of precipitation e.g. on a monthly or seasonal basis) is more pronounced. However, in the period 1981-2013 for instance, decreasing trends in mean precipitation were detected in December months in the northern area of Slovakia, whereas the central and southern areas showed increasing trends. At the same time, most of the analysed stations revealed increasing summer precipitation trends (Zeleňáková et al., 2017).

The hydrological regime, or river regime, is not only influenced by changes in precipitation, but also by land-use and land-use changes. Particularly, forests play a significant role in surface runoff and river discharge. The subsequent occurrence of high flow conditions and floods therefore depends on spatial-temporal differences and variabilities. Flood generation processes in mountain regions are therefore influenced by forest disturbances such as windstorms or by increased forest growth, restoring the water retention capacity. A case study in two small river basins in the Low Tatras shows an increase in extreme discharges in the future, as water retention capacity decreases (Danáčová et al., 2020). An increase in winter runoff is also expected for various mountain catchments as a result of more rainfall and less snowfall as well as earlier snowmelt (Rončák et al., 2019). High flow hydrological simulation results (100-year flood) for eleven medium-sized to large basins indicate an increase (>+5 %) for seven basins, a decrease (<-5 %) for three basins and for one basin no change for the analysed future period (Kopáčiková et al., 2020). Hlavčová et al. (2015) studied the increase in extreme 5-day precipitation totals in medium-sized to large Central Slovakian mountain basins based on the reference period 1981-2010. The results indicate a median change (model ensemble) in the maximum mean daily discharges ranging from 16–28% for 2025, 15–24% for 2050 and 28–49% for 2075. The assumptions can be subsumed in two central findings: 1) More frequent occurrence of dry periods prior to significant 5-day precipitation events will lead to amplified floods, and 2) extreme precipitation events can be even more significant due to more intense thunderstorms.

In parallel, the occurrence of low flow conditions and droughts in Slovakia are also dependent on region and season. A case study in a large catchment (Laborec River) in eastern Slovakia reveals the highest number of low flow days in August and September during the observation period 1980-2019 and highlights potential impacts on water supply, agriculture and energy production during summer and autumn within this area (Kubiak-Wójcicka et al., 2021). Future changes in low flow are shown exemplary in various catchment studies in the Low and High Tatras. A significant temperature increase and a slight precipitation decrease in the far future (2071-2100) under a moderate to high emission scenario will lead to an increase in evapotranspiration, a decrease in water yield and a shift in runoff timing. Therefore, a maximum decline in runoff will occur during summer alongside with significant changes in the hydrological regime. Consequently, this also has impacts on ecosystems and biodiversity, through e. g shifts in species composition (see Chapter 3.2; Becokova et al., 2009; Rončák et al., 2019).

### 3.11.1 Climate Impact Assessment

Several high-priority issues were identified for the Hydrological Regime & Water Resource Management sector. The increase in extreme events, particularly pluvial and flash floods, and the resulting damages are of significant concern. There is also a critical reduction in the yield of drinking water from springs and a general decrease in the availability and supply of drinking water. This issue is arising on the national level and is prominent in regions such as the south, east and Záhorie. During droughts (e.g. in 2024), municipalities in these regions had to prohibit the use of public water supplies for anything other than personal hygiene, drinking and cooking. Some municipalities have already had to import drinking water by tankers during dry seasons in the last five years. Concomitant with decreases in water availability, though currently not rated as a high priority, are increasing water demands for private use, irrigation, agriculture and businesses.

Another significant problem is the changed seasonal distribution of precipitation and runoff patterns, with increased winter and spring runoff and decreased summer and autumn runoff. This affects sewer systems, treatment plants and energy production based on hydropower. Water conservation efforts and the interest in retaining water within the country have led to sewers struggling with waste dilution during droughts. Additionally, during short-term heavy rains, wastewater treatment plants must process larger volumes of wastewater than designed for and simultaneously remove increased amounts of more hormone-based pharmaceuticals and microplastics. This overload during such extreme events might be caused, among others, by the fact that there is only one sewage system for both rainwater and sewage water.

Table 29 presents the results from the participatory climate impact assessments, which were conducted in June 2024. However, this more in-depth assessment might not have been possible entirely, due to time constraints and intense discussions at the workshop (see Annex A: Additional information on methodological design Box 1). The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector Hydrological Regime & Water Resource Management. Definitions of key terms used are provided in Annex A.

*Table 29: Presentation of the results of the climate impact assessment for the sector Hydrological Regime & Water Resource Management. Impacts of high priority are highlighted in **bold**.*

| Hydrological Regime & Water Resource Management | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| Biophysical | | | | | |
| **increase in extreme events** | **very high** | **very high** | - | - | - |
| **reduction of yield of drinking water springs** | **very high** | **high** | - | - | - |
| **increase in winter & spring runoff** | **very high** | **high** | - | - | - |
| **decrease in summer & autumn runoff** | **very high** | **high** | - | - | - |
| **change in seasonal distribution of precipitation** | **very high** | **high** | - | - | - |
| increase of days with low water discharge | high | medium | - | - | - |
| increase in pluvial floods | medium | high | - | - | - |
| increase in fluvial floods | medium | high | - | - | - |
| decrease in snow precipitation & snow cover | high | very low | - | - | - |
| increase in water temperatures (watercourses) | medium | medium | - | - | - |
| increase in water temperatures (standing waters) | medium | medium | - | - | - |
| increase in water temperatures (groundwater/springs) | low | medium | - | - | - |
| socio-economic | | | | | |
| **increase in damage due to extreme events** | **high** | **very high** | - | - | - |

| Hydrological Regime & Water Resource Management | | | | | |
|---|---|---|---|---|---|
| sewer system collapses and sewage treatment plant collapses | medium | high | - | - | - |
| decrease in the availability of drinking water supply | high | medium | - | - | - |
| increase in water demand (agriculture, industry, private households) | high | medium | - | - | - |
| increase in irrigation demand | high | low | - | - | - |

### 3.11.1 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of four key risks (KR) for the sector Hydrological Regime & Water Resource Management (WM), displayed in Table 30. The identified key risks address potentially adverse effects related to floods (KR-WM-1), water supply and availability (KR-WM-1, KR-WM-4), and wastewater (KR-WM-3). There is also a risk of damage to infrastructure due to extreme flood events, expected to increase under climate change conditions, as well as due to changed seasonal distribution of precipitation. Areas that are currently not affected by such events might be in the future, resulting in a heightened risk (*very high* for both scenarios in the far future). Therefore, regulating ecosystem services have to be considered, i.e. (natural or nature-based) flood protection and water retention.

*Table 30: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Hydrological Regime & Water Resource Management (KR-WM) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-WM-1<br>Risk to population and infrastructure from flooding | high | high | high | very high | very high | acute<br>slow onset | national<br>regional |
| KR-WM-2<br>Risk of unreliable water supply | medium | high | high | high | very high | slow onset | regional |
| KR-WM-3<br>Risk to wastewater infrastructure and sewage systems | medium | high | high | high | very high | slow onset<br>acute | regional<br>local |
| KR-WM-4<br>Risk of decreasing groundwater availability and quality | medium | medium | medium | high | high | slow onset | regional |

Already in the current NAP (Ministry of Environment of the Slovak Republic, 2021a), specific objectives address the protection of health and life of people and animals from climate-related extreme events[24]. According to the strategic directions derived in course of the risk assessment process, nature-based solutions and ensuring healthy ecosystems and soils are essential building blocks for enhancing resilience. In addition, adapting water and wastewater infrastructure to changing climatic conditions and implementing sufficient and effective measures concerning water management can also contribute to a more resilient, climate-adapted Slovak Society.

---

[24] The number code of specific objectives of the current NAP associated with certain strategic objectives are listed in brackets.

### Strategic Directions – Hydrological Regime & Water Resource Management

| | |
|---|---|
| SD-WM-1 | Health and life of people, properties and animals are protected from pluvial and fluvial flood events. (NAP: 1.2, 1.4) |
| SD-WM-2 | Nature-based water retention measures support infrastructural flood protection (e.g. sponge city approaches) and are themselves supported by healthy and resilient ecosystems and soils. (NAP: 1.1, 1.4, 1.7) |
| SD-WM-3 | Water and wastewater infrastructure is fixed, maintained and adapted to changing climatic conditions (e.g. heat, aridity, floods) to secure a reliable supply of safe water. |
| SD-WM-4 | Sufficient and effective measures are implemented to ensure climate-resilient water management, including reuse, allocation and monitoring of water resources. |

## 3.12 Information and Communication Technology

An **information and communication technology (ICT)** system comprises integrated networks, systems and components that enable the transmission, receipt, capture, storage and manipulation of information by users on and across electronic devices (Fu et al., 2016).

The state of Information and Communication Technology (ICT) in Slovakia reflects a mix of growing infrastructure, increasing digital literacy and active participation in European digital initiatives. Slovakia has made significant progress in developing its ICT sector, driven by investments in broadband infrastructure, e-government services and the digital economy. The country has also been working on improving its cybersecurity framework and enhancing ICT education and skills among its population (European Commission, 2022a).

Climate change poses significant challenges for the ICT sector, categorised into acute events and chronic stresses. Acute events, such as floods, hurricanes and heatwaves, are short-lived but can severely damage ICT infrastructure by destroying physical assets. In contrast, chronic stresses result from gradual climate changes, including temperature extremes and humidity, leading to asset degradation, more frequent failures and shorter lifespans, with significant financial implications due to the need for frequent upgrades and replacements. Data centres, which use substantial amounts of water for cooling, are particularly vulnerable. A third type of stress, termed 'chronic crisis,' combines elements of both acute and chronic stresses, such as prolonged flooding. Despite these challenges, the ICT sector is naturally decentralised and modular, providing it with a high degree of climate resilience. Redundant systems and diverse service providers enhance this resilience, though the increasing reliance on centralised cloud computing could reduce it in the future (European Environment Agency (EEA), s. a.).

The NAS of Slovakia does not explicitly refer to ICT adaptation, but it includes several measures where ICT tools are utilised for adaptation in other sectors. It identified five cross-cutting actions, including the establishment of a national information system for the provision of climate information, which falls under the responsibility of the Ministry of Environment of the Slovak Republic. These actions are supported by 18 specific tasks focused on seven core areas, including technical, economic and social measures (UNFCCC, 2023).

A significant challenge in supporting the business environment's adaptation to climate change lies in the management of electricity consumption patterns. This includes accommodating new climate-friendly technologies such as smart grids. According to Taneja and Mandys (2024), electricity consumption in Slovakia has declined resulting from greater ICT investments. Promoting the broader adoption of smart concepts in the energy sector is crucial, as awareness of these benefits is currently insufficient in Slovakia. While some smart concepts, like electromobility and smart cities, are already in place, others, such as smart grids, smart homes, and smart buildings, need further development. In the tourism sector, ensuring the security of critical infrastructure requires linking early warning and agro-meteorological information systems as well as creating comprehensive information systems for weather alerts, flood risks, and fire warnings (UNFCCC, 2023).

In the draft updated NECP, Slovakia references the EU Action Plan on Digitalising the Energy System, highlighting the need for modernising and digitalising its transmission system and regional distribution networks. A key investment of EUR 133 million, as outlined in Slovakia's RRP and REPowerEU chapter, supports the creation of a digital data platform for tracking the energy performance of buildings. Progress in this area includes the ACON project, a collaboration with Czechia, aimed at digitalising Slovakia's distribution system and providing innovative technological solutions to network users (European Commission, 2023d). The Recovery and Resilience Plan – REPowerEU investments will focus on modernising and digitalising the transmission system and regional distribution networks. The investment aims to develop the transmission system to provide sufficient capacity for connecting additional renewable energy sources (RES) to the grid and for importing RES-generated electricity from abroad. The US company Westinghouse Electric Sweden AB and French company Framatome have been chosen as alternative suppliers for VVER 440 nuclear fuel for Slovak Power Plants. In June 2023, Slovak elektrárne and Framatome signed a Memorandum of Understanding to develop long-term partnerships in areas like digital security and cybersecurity for nuclear plant operations in Slovakia (Ministry of Economy of the Slovak Republic, 2023).

Furthermore, Slovakia plans to prioritise the digitalisation and automation of transport to develop intelligent transport systems, as well as to enhance digital security and cybersecurity of nuclear power plants. However, the draft updated NECP does not establish specific quantitative targets for the digitalisation of its energy system (European Commission, 2023d).

Additionally, it is important to note that the project team gathered valuable insights from experts in the ICT sector during stakeholder workshops focused on sectoral climate risk assessments. The feedback received during these workshops revealed a clear consensus that, due to the fast-evolving nature of the ICT sector and its relatively short equipment replacement cycles, the introduction of technical adaptation measures is less critical for this sector compared to other infrastructure sectors. Typically, ICT infrastructure requires replacement when performance issues are identified, and during these replacement cycles, new and enhanced climate adaptation features are often incorporated. Stakeholders emphasized, however, that it is crucial to regulate the ICT sector, given the significant involvement of private entities in the sector's activities. Moreover, there was a strong sentiment among participants that ICT plays a dual role in climate adaptation: (1) ICT must adapt to climate change to ensure functionality under varying climate conditions, and (2) ICT can also contribute substantially to climate change adaptation efforts. Various examples were shared during the workshop, including the use of remote sensors for monitoring road bridges and heat and fire sensors for communication towers, among other applications.

### 3.12.1 Climate Impact Assessment

A relevant aspect to be highlighted in ICT is that the state's crisis management of the Slovak Republic in this sector is rather weak, indicating a need for improvement. This identified gap is mirrored in the climate impact assessments, as the adaptive capacity in terms of governance framework is estimated to be *low* and rated as *medium* for only two climate impacts of high priority. Against this background, the necessity for raising awareness of climate change-related impacts on IT and its infrastructure becomes even more important. At the same time, progress and innovation processes within the ICT sector are fast and currently allow for a timely response to damage caused by climate impacts. For instance, devices are being made more robust and durable. Furthermore, an increasing need to measure several parameters can steer process or product innovations, respectively, leading to technological developments. In this regard, ICT can support the monitoring of climate impacts, with the increased usage of mobile infrastructure such as drones expected to enhance resilience. Another highly relevant aspect to consider in the context of the Slovak Republic is that the country's ICT infrastructure is mostly privately owned, meaning that the state itself is not the primary entity responsible for taking respective measures. However, given the aforementioned crisis management deficit, dealing with climate change-induced consequences might become even more challenging.

Among the climate impacts rated as high priority is the increase in heat load, making cooling of ICT infrastructure and facilities such as data centres, heat pumps or solar panels necessary to prevent overheating.

Table 31 presents the results from the participatory climate impact assessments, conducted in June 2024. The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector. Definitions of key terms used are provided in Annex A Information & Communication Technology.

*Table 31: Presentation of the results of the climate impact assessment for the sector Information & Communication Technology. Impacts of high priority are highlighted in **bold**. The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).*

| Information & Communication Technology | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| biophysical | | | | | |
| increase in forest and wildfires | high | high | low | medium | low |
| increase in heat load | high | high | low | medium | low |
| increase in erosion (soil, surfaces/materials) | high | high | low | medium | low |
| increase in extreme events | high | high | low | medium | low |
| socio-economic | | | | | |
| increase in damage to critical infrastructure | very high | very high | low | medium | medium |
| changes in the availability and quality/reliability of services (direct/indirect disruption from weather events) | high | high | medium | medium | medium |
| increasing demand for ICT services responding to climate risks | very high | high | low | medium | low |
| increasing damage from pluvial flooding of low-lying infrastructure | high | high | low | high | medium |
| increased impacts on infrastructure from extreme events | high | very high | medium | medium | low |
| increased corrosion due to higher humidity levels | medium | medium | - | - | - |
| increase in personnel stress | high | medium | - | - | - |
| changed health and safety requirements for employees | high | medium | - | - | - |

| Information & Communication Technology | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| increase in expenditures and costs for maintenance | low | very high | - | - | - |
| increase in frequency of failure and shortening of life spans | low | very high | - | - | - |
| increased water usage for on-site cooling (e. g. data centres) | high | low | - | - | - |
| increasing material stress and asset degradation from chronic changes in climate variables | low | low | - | - | - |

### 3.12.2 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed one key risks (KR) for the sector Information & Communication Technology (ICT), displayed in Table 32. Damage to ICT infrastructure and the associated risk can be a result of several factors such as extreme events and changes in the availability and quality/reliability of services (direct/indirect disruption from weather events). Relevant climate impacts for the identified key risk are all among those rated as high priority. As the urgency to act is rated mostly as *low*, partly as *medium*, the current risk is estimated to be *medium* and increasing throughout the next decades, resulting in a *very high* risk at the end of the century (pessimistic scenario).

*Table 32: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Information & Communication Technology (KR-ICT) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-ICT-1<br>Risk of damage to ICT infrastructure and widespread disruptions of ICT services e.g. due to extreme events | medium | medium | medium | high | very high | acute<br>slow onset | local<br>regional |

Given that the adaptive capacity in terms of governance frameworks is mostly rated as *low*, SD-ICT-1 aims at directly addressing this issue. It also highlights the need to incorporate some kind of regulation for privately owned ICT infrastructure as most of it is owned privately in Slovakia. SD-ICT-2 not only underlines the necessity for adaptation, but also takes into account the role ICT can play with respect to a green transformation. SD-ICT-3 is associated with the identified need for raising awareness of ICT operators for climate impacts.

### Strategic Directions – Information & Communication Technology

| | |
|---|---|
| SD-ICT-1 | Sufficient governance frameworks are implemented on a national scale to ensure state-wide effective crisis management, i.e. ICT infrastructure breakdowns, including regulations for privately owned ICT infrastructure. |
| SD-ICT-2 | ICT infrastructure is adapted to climate-related impacts, taking into account the need for a green transformation. |
| SD-ICT-3 | Sufficient and effective awareness raising measures are implemented with respect to climate-related impacts on the ICT sector, in particular on IT infrastructure. |

## 3.13 Spatial Planning

**Spatial Planning** is understood as the public task of coordinating the demands for the use of space, with the view of influencing the future distribution of activities (Danielzyk and Münter, 2018; UNECE, 2008). It aims to create a rational territorial organisation, that balances demand for development with the need to protect the environment and achieve development objectives. Thus, an interdisciplinary approach is required to balance competing demands for land use. Structures created through spatial planning transcend political and administrative boundaries.

In recent years the Slovakian government has started to recognise the importance of coherent spatial planning policy. Since a few years, Spatial Planning has a growing importance in Slovakia's development, which is enhanced through the establishment of the Authority for Spatial Planning and Construction in 2022 (Authority for Spatial Planning and Construction, s. a.). This authority operates as the central state administration body for spatial planning supervision (except for ecological aspects), construction and expropriation. Additional institutions involved in spatial planning and implementation of adaptation actions across the sector are the Ministry of the Environment of the Slovak Republic and the Ministry of Transport.

The establishment of Authority for Spatial Planning and Construction was accompanied by an update of the spatial planning laws in 2022. Local governments still retain main competence over spatial planning, and at the same time the government, through the new authority, is revising and updating planning rules, as well as reviewing spatial planning methodologies (Authority for Spatial Planning and Construction, s. a.). The revised Spatial Planning Act tries to motivate municipalities to engage in spatial planning as currently more than half of the municipalities in Slovakia do not have a spatial plan – this makes sustainable development of cities, villages or regions difficult (Authority for Spatial Planning and Construction, s. a.). In addition to spatial planning laws, the Concept of Urban Development of the Slovak Republic until 2030 is a key policy document (Ministry of Transport and Construction of the Slovak Republic, 2019b). It emphasises the importance of applying a systematic approach to climate change adaptation in urban areas, and to do so, recommends several requirements that should be taken into account during spatial planning to systematically integrate adaptation measures into spatial planning documents.

Just over half of Slovakia's population lives in cities (World Bank, 2018), which are particularly affected by climate change.

Addressing the effects of climate change including its risks and impacts in urban areas in particular is crucial. According to the NAS (Ministry of Environment of the Slovak Republic, 2018a), an increase in the number of tropical days and heat waves, uneven distribution of precipitation and more frequent extreme precipitation leading to flash floods or mud floods as well as more frequent droughts are among the expected impacts.

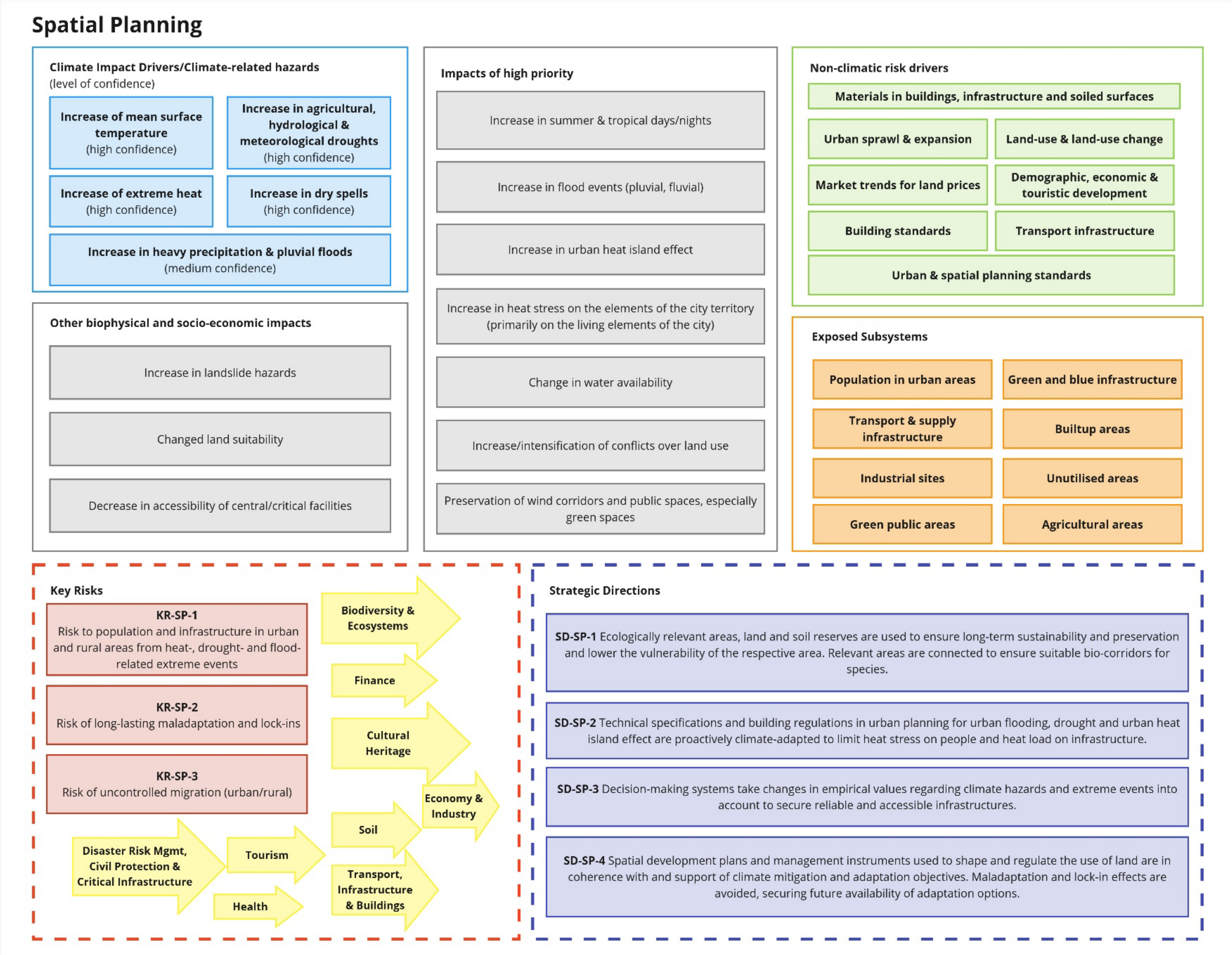
The NAS proposes several adaptation measures for municipalities to address these risks. Some measures suggested are the use of green spaces, and the development of green and blue infrastructure. Green spaces can mitigate the urban heat island (UHI) effect, while providing additional benefits to biodiversity (Froese and Schilling, 2019). In line with the NAS, the NAP has a specific objective for the built environment to contribute to the creation of a sound legislative, institutional, and financial environment for systematic and comprehensive action by local governments.

### 3.13.1 Climate Impact Assessment

The workshop highlighted several key priorities for the Spatial Planning sector coming from various other sectors due to the cross-cutting nature of spatial planning. The primary concerns are the impacts in cities of the increase in summer and tropical days and nights, the intensification of UHI effects and the overall rise in heat stress for both people and other living organisms. Increased heat loads on buildings and infrastructure were also considered, such as the electricity grid and energy supply, leading to thermal stress, structural failures due to overheating, and road and track surface failures, though expert opinions differed on the relevance.

Another significant issue is the rise in flood events, both pluvial and fluvial, and changes in water availability. Conflicts over land use are intensifying as different interest groups, such as building developers, have varying ideas about the use of undeveloped urban areas. This has a strong link to the preservation of wind corridors and public spaces, especially green areas, which are under increasing pressure and require more regulation. Other impacts include the rise in landslide hazards, which also connect to the soil sector and may lead to altered hazard classifications in geological risk maps. Additionally, there is a change in land suitability and decreased accessibility to central or critical infrastructures due to climate change-induced disruptions, such as extreme weather events.

Table 33 (below Figure 51) presents the results from the participatory climate impact assessments, conducted in June 2024. The assessment of adaptive capacity and urgency to act was conducted for climate impacts of high priority. However, this more in-depth assessment might not have been possible entirely, due to time constraints and intense discussions at the workshop (see Annex A: Additional information on methodological design Box 1). The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector.



**Spatial Planning**

**Climate Impact Drivers/Climate-related hazards**
(level of confidence)

- **Increase of mean surface temperature** (high confidence)
- **Increase in agricultural, hydrological & meteorological droughts** (high confidence)
- **Increase of extreme heat** (high confidence)
- **Increase in dry spells** (high confidence)
- **Increase in heavy precipitation & pluvial floods** (medium confidence)

**Other biophysical and socio-economic impacts**

- Increase in landslide hazards
- Changed land suitability
- Decrease in accessibility of central/critical facilities

**Impacts of high priority**

- Increase in summer & tropical days/nights
- Increase in flood events (pluvial, fluvial)
- Increase in urban heat island effect
- Increase in heat stress on the elements of the city territory (primarily on the living elements of the city)
- Change in water availability
- Increase/intensification of conflicts over land use
- Preservation of wind corridors and public spaces, especially green spaces

**Non-climatic risk drivers**

- **Materials in buildings, infrastructure and soiled surfaces**
- **Urban sprawl & expansion**
- **Land-use & land-use change**
- **Market trends for land prices**
- **Demographic, economic & touristic development**
- **Building standards**
- **Transport infrastructure**
- **Urban & spatial planning standards**

**Exposed Subsystems**

- **Population in urban areas**
- **Green and blue infrastructure**
- **Transport & supply infrastructure**
- **Builtup areas**
- **Industrial sites**
- **Unutilised areas**
- **Green public areas**
- **Agricultural areas**

**Key Risks**

**KR-SP-1**
Risk to population and infrastructure in urban and rural areas from heat-, drought- and flood-related extreme events

**KR-SP-2**
Risk of long-lasting maladaptation and lock-ins

**KR-SP-3**
Risk of uncontrolled migration (urban/rural)

**Strategic Directions**

**SD-SP-1** Ecologically relevant areas, land and soil reserves are used to ensure long-term sustainability and preservation and lower the vulnerability of the respective area. Relevant areas are connected to ensure suitable bio-corridors for species.

**SD-SP-2** Technical specifications and building regulations in urban planning for urban flooding, drought and urban heat island effect are proactively climate-adapted to limit heat stress on people and heat load on infrastructure.

**SD-SP-3** Decision-making systems take changes in empirical values regarding climate hazards and extreme events into account to secure reliable and accessible infrastructures.

**SD-SP-4** Spatial development plans and management instruments used to shape and regulate the use of land are in coherence with and support of climate mitigation and adaptation objectives. Maladaptation and lock-in effects are avoided, securing future availability of adaptation options.

Figure 52: Climate impacts for the sector **Spatial Planning** arranged in a matrix with respect to their sensitivity and exposure.

*Table 33: Presentation of the results of the climate impact assessment for the sector Spatial Planning. Impacts of high priority are highlighted in* ***bold****.*

| Spatial Planning | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| Biophysical | | | | | |
| **increase in summer & tropical days/nights** | **very high** | **very high** | **-** | **-** | **-** |
| **increase in flood events (pluvial, fluvial)** | **very high** | **high** | **-** | **-** | **-** |
| **increase in urban heat island effect** | **high** | **high** | **-** | **-** | **-** |
| **increase in heat stress on the elements of the city territory (primarily on the living elements of the city)** | **high** | **high** | **-** | **-** | **-** |
| **change in water availability** | **high** | **high** | **-** | **-** | **-** |
| increase in landslide hazards | medium | high | - | - | - |
| socio-economic | | | | | |
| **increase/intensification of conflicts over land use** | **high** | **high** | **-** | **-** | **-** |
| **preservation of wind corridors and public spaces, especially green spaces** | **high** | **high** | **-** | **-** | **-** |
| changed land suitability | medium | high | - | - | - |
| decrease in accessibility of central/critical facilities | medium | high | - | - | - |

### 3.13.1 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of three key risks (KR) for the sector Spatial Planning (SP), displayed in Table 34.

KR-SP-1 is related to several climate impacts such as increase in heat stress on people and living organisms, heat load on infrastructure due to increase in summer days and tropical nights as well as heat waves, with these impacts being especially higher in urban environments compared to rural areas. Other extreme events such as floods and landslides can potentially lead to disruptions of critical transport infrastructure and limit the accessibility of critical facilities such as hospitals. During dry spells and heat waves, the population can also be adversely affected by changes in water availability. The current risk is already at a *high* level, considering the mostly *high* to *very high* ratings of exposure and sensitivity of relevant climate impacts. The exposure is expected to increase throughout the century due to ongoing urbanisation as well as increases in heat and heat extremes exacerbating the risk, especially in the far future under both scenarios.

An increase of conflicts over land uses and the necessity to preserve wind corridors and green spaces in urban centres can be considered as non-climatic risk drivers, leading to an additional pressure. Such land-use conflicts emphasise the crucial role of spatial planning in both climate change mitigation and adaptation, including the reduction of risk due to extreme events (KR-SP-2). If maladaptation is not avoided and lock-ins, e.g. resulting from the longevity of build structures, risk is expected to increase. Thus, spatial planning has to be viewed as a cross-sectorial theme, being key for achieving adaptation goals in other sectors.

The third key risk draws attention to migration dynamics in the context of urbanisation processes, i.e. people moving from rural to urban areas and vice versa. In this regard, it should be noted that involuntary migration due to climate change is also among the key risks of the global risk assessment provided by the Wold Economic Forum (World Economic Forum (WEF), 2024).

*Table 34: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Spatial Planning (KR-SP) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-SP-1<br>Risk to population and infrastructure in urban and rural areas from heat-, drought- and flood-related extreme events | high | high | high | high | very high | acute<br>slow onset | regional<br>local |
| KR-SP-2<br>Risk of long-lasting maladaptation and lock-ins | low | medium | medium | high | high | slow onset | national<br>regional |
| KR-SP-3<br>Risk of uncontrolled migration (urban/rural) | low | medium | medium | high | high | slow onset | Regional |

The strategic directions listed below for the sector Spatial Planning reflect specific objectives of the NAP currently in place (Ministry of Environment of the Slovak Republic, 2021a)[25]. The directions do not only consider the natural environment (e.g. using ecologically relevant areas, land and soil reserves are used to ensure long-term sustainability and to reduce vulnerability), but also address the necessity to implement respective measure in terms of technical specifications and building regulations to tackle flood and heat events. This is done by future-orientated decision-making approaches which consider changes of empirical values. Most importantly, stakeholders drew attention to the fact that the Spatial Development Concept of Slovakia is binding (current plan from 2001, with an updated version from 2010). A new Spatial Development Concept, whereby climate adaptation is included as a key principle, is in preparation and will be approved by the government until 31st March 2027.

Strategic Directions – Spatial Planning

| | |
|---|---|
| SD-SP-1 | Ecologically relevant areas, land and soil reserves are used to ensure long-term sustainability and preservation and lower the vulnerability of the respective area. Relevant areas are connected to ensure suitable bio-corridors for species. |
| SD-SP-2 | Technical specifications and building regulations in urban planning for urban flooding, drought and urban heat island effect are proactively climate-adapted to limit heat stress on people and heat load on infrastructure. (NAP: 6.1, 6.2, 6.3, 6.4, 7.2) |
| SD-SP-3 | Decision-making systems take changes in empirical values regarding climate hazards and extreme events into account to secure reliable and accessible infrastructure. (NAP: 6.2, 6.3, 6.4, 7.2) |
| SD-SP-4 | Spatial development plans and management instruments used to shape and regulate the use of land are in coherence with and support of climate mitigation and adaptation objectives. Maladaptation and lock-in effects are avoided, securing future availability of adaptation options. (NAP: 6.1, 6.2, 6.3, 6.4, 7.2) |

---

[25] The number code of specific objectives of the current NAP associated with certain strategic objectives are listed in brackets.

## 3.14 Tourism

**Tourism** includes all activities of incoming travellers who visit a place for less than one year for leisure, business or other personal purposes. This includes tourism behaviour and patterns, tourist activities and the use of local infrastructure (e. g. recreational areas and parks, beaches, etc.) by daily visitors and overnight guests. Furthermore, it encompasses the recreation activities of local inhabitants. The sector is highly interconnected with, and dependent on, the development of many other fields of action and the state of natural areas.

In 2019, Slovakia recorded a total of 5.6 million tourists. It has experienced a major growth in the number of tourists within the last years (Figure 5) (World Data, 2024a). Even though Slovakia is not very well known on international level yet, an increasing interest and potential for touristic growth has been observed within the last years. A potential boost in rural tourism is expected due to the country's picturesque landscapes, traditional villages and other features such as attractive natural sights. Hence, the sector is becoming increasingly important for Slovakia's economy (Čuka and Šenková, 2017; OECD iLibrary, 2024; Štefko et al., 2018). The future projections for the tourism sector expect an annual growth rate of 3.2 %, which would result in a market volume of € 1 609m by 2028 (OECD iLibrary, 2024; statista, 2024; World Data, 2024a).

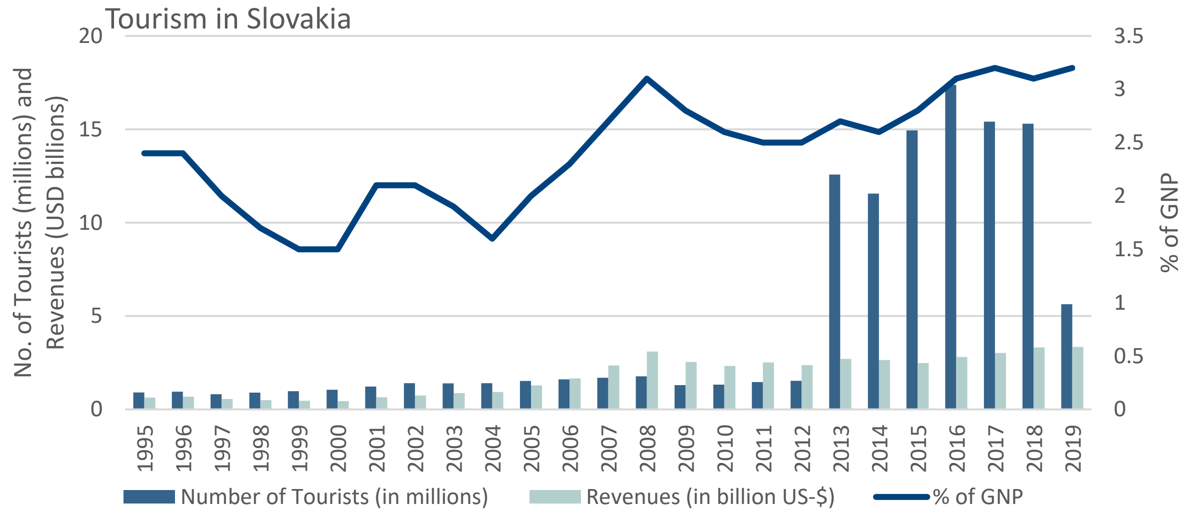


*Figure 5: Tourism in Slovakia. Left axis: No. of tourists (in millions) and revenues in billion US-$; right axis: % of GNP. Data source World Data (2024a).*

Latest data from 2021 showed a decline, heavily influenced by the COVID-19 pandemic and lockdowns, this showed that domestic tourists make up a large share of the sector with accommodation providers registering 2.1 million domestic tourists in comparison to 576 000 international guests in 2021 (OECD iLibrary, 2024). In the same year, tourism in Slovakia accounted for roughly 1 % of the GDP, which was equal to about 1.2 billion USD, a significant decline from the 2019 values. Within the tourism sector, package holidays make up the largest market with an expected volume of US$ 735m in 2024 (statista, 2024; World Data, 2024a).

The Ministry of Sport and Tourism holds the main responsibility in tourism governance and funding. It is divided into different departments and working groups covering fields like national tourism policy or integration cooperation. Multiple organisations play a role in the sector: the departments of international relations and marketing, destination management as well as state tourism policy on the national level as well as departments of self-governing regions and the Regional Destination Management Organizations (DMOs) on regional level. Local stakeholders are comprised of the departments of Municipalities, Local DMOs and the tourism-related services and industries, tourism associations and non-profit-organizations. In response to the consequences of the COVID-19 pandemic on the tourism sector in Slovakia, the national council launched a Tourism Support Act in November 2022 to tackle and mitigate the crisis. A framework of state aid schemes was developed to maintain employment and compensate fixed costs to ensure the competitiveness of tourism businesses. According to the Slovakian Minister of Transport, Andrej Doležal, one of the most important and closest partners and countries for inbound tourism is the Czech Republic, with the majority of Czech visitors considering Slovakia as a 'domestic holiday destination'.

Since a great part of Slovakia has favourable natural, cultural and historical conditions for tourism development like protected areas, UNESCO World Heritage cultural memories, waterfalls, mineral swimming pools, etc., tourism should be considered a key sector for regional development. The country can be divided into different regions with varying characteristics concerning main tourist attractions with the majority of tourists staying in the Bratislava and Zilina regions (OECD iLibrary, 2024; Štefko et al., 2018).

The region around the capital Bratislava is surrounded by cultural and historical monuments such as numerous castles, international cycling routes and art galleries. Furthermore, wine routes, lakes and aqua parks add to the activities in this region. Košice the second biggest town of Slovakia, provides cultural and historical monuments as well well and also shows a history of successful city promotion activities (Štefko et al., 2018; The Slovak Spectator, 2024). The area around Trnava is characterised by towns with historical centres and monuments, benefitting from spas, thermal swimming pools and watermills nearby. The so-called Trencin Region was named after the Trencin Castle and holds many historic monuments like the Bojnice Chateau or the ruins of Beckov Castle as well as mineral and thermal springs. The Nitra region around Slovakia's oldest town holds ancient churches and the Zilina region has cultural and historical monuments, spas, ski centres and aqua parks. The Banska Bystrica region is known for its UNESCO monuments and ski resorts, while the region around Prešov is mostly visited for the Tatra National Park. One inherent part of the Slovakian tourism sector is the wellness and spa industry dating back to the Romans. While spas were historically mainly used for medical purposes, the present form of spa tourism is focussing on wellness developed after the 1990s. Today, the Slovak Republic is one of the most advanced countries in the European spa industry, where a significant share of tourist overnight stays and revenues are related to the wellness and spa sector. In 2016, there were 29 spa places in 23 spa resorts and 31 spa companies in Slovakia, according to the Ministry of Health and the Association of Slovak Baths.

Another part of tourism is comprised of skiing as a recreational sport with more than 100 ski resorts in Slovakia, mainly in the northern and central mountain areas. Since the majority of Slovakian ski resorts lie below an altitude of 1 000m, they are highly vulnerable to climate change.

### 3.14.1 Climate Impact Assessment

The workshop highlighted several critical impacts of climate change on Slovakia's tourism sector, focusing particularly on winter tourism and the adaptive strategies required to mitigate these impacts. A significant concern is the decrease in snow precipitation and snow reliability during winter, threatening winter tourism revenue and employment. This, as well as the shortening of winter seasons, will necessitate changes in tourism products and services. Ski slopes may rely on artificial snowmaking, albeit potentially for shorter periods. At higher altitudes (above 2000 meters on northern slopes), snow storage from previous seasons might be possible, requiring substantial funding. The lack of snow could lead to fewer winter holiday tourists, who may prefer destinations like the Alps, Dolomites, or Bulgarian mountains, forcing Slovak winter recreation centres to diversify their offers to remain competitive. The adaptive capacity for addressing these issues is medium, supported by appropriate governance frameworks and financial resources. However, the urgency to act is medium to high as rising temperatures already impact snow conditions, affecting winter tourism activities. To adapt, tourism services must focus on alternative activities and services that cater to visitors, leveraging existing infrastructure, entrepreneurial innovation, financial resources, and subsidies. State authorities should support the transformation of tourism services through advertising, marketing, and financial aid. Investments are crucial for this transformation.

An increase in the number of extreme weather events poses additional challenges, with significant negative effects on touristic activities and visitor safety. These events can damage infrastructure, restrict visitor movement and necessitate costly repairs and rebuilding. The presence of bears in tourist areas, including urban settings, further reduces visitor well-being and safety.

Additionally, there is an increasing demand for cooling solutions in summer, such as water mists and drinking fountains, particularly in southern regions. These measures are essential for health, benefiting both residents and visitors.

Conflicts over water use, essential for tourism facilities and services, are expected both during dry spells in summer and for technical snowmaking in winter. Water-dependent tourism providers, wellness centres and other water-dependent activities will be particularly affected.

Heat waves may have mixed impacts, benefiting water parks and pools while exacerbating UHI effects in cities. Solutions like green and blue infrastructure are being implemented to mitigate these effects, particularly for vulnerable groups.

Finally, exposure and sensitivity to other risks like increases in forest and wildfire as well as reduced water availability are *medium*. However, increased awareness-raising regarding forest management and wildfire prevention, water conservation, and sustainability in general is suggested. Increasing visitors' economic, financial and environmental awareness is crucial for sustainable tourism development.

Table 35 presents the results from the participatory climate impact assessments, conducted in June 2024. The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector Tourism. Definitions of key terms used are provided in Annex A: Additional information on methodological design.

Table 35 (see below): Presentation of the results of the climate impact assessment for the sector Tourism. Climate impacts of high priority are highlighted in **bold**. The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).

| Tourism | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| biophysical | | | | | |
| decrease in natural snow reliability | very high | very high | medium | medium/high | medium/ high |
| decrease in snow precipitation in winter | very high | very high | medium | high | medium/ high |
| increase in extreme events | high | high | medium | high | medium/<br>high |
| increase in heat waves | medium | very high | - | - | - |
| increase in urban heat island effect | medium | medium | - | - | - |
| increase in forest and wildfires | medium | medium | - | - | - |
| change in water availability | medium | medium | - | - | - |
| decrease in water quality | medium | medium | - | - | - |
| socio-economic | | | | | |
| decrease in winter holiday tourists | high | high | medium | high | medium/<br>high |
| increase in demand for cooling in summer | high | high | medium | medium | medium |
| negative influence of extreme weather events on tourism activities | high | high | medium | medium | high |
| increase in conflicts over water-use (tourists, agriculture, local population) | high | high | medium | medium/high | medium |
| increase in negative impacts on safety of tourists | high | high | medium | medium/high | medium |

| | | | | | |
|---|---|---|---|---|---|
| shortening of winter season & disturbance of conditions for winter leisure activities | high | medium | - | - | - |
| increase in summer holiday tourists | medium | medium | - | - | - |
| extension/shift of the touristic season | medium | medium | - | - | - |

### 3.14.1 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of three key risks (KR) for the sector Tourism (T), displayed in Table 36.

The *Risk of decreasing tourism competitiveness due to increasing costs for tourism providers* (KR-T-1) is related to increases in conflicts over water use (tourists, agriculture, local population), changes in water availability, increase in demand for cooling in summer, shortening of winter season and disturbance of conditions for winter leisure activities. In particular, water is considered as an urgent issue by involved stakeholders.

The second key risk (KR-T-2) highlights that Slovakia or various regions of Slovakia might have to deal with newly emerging, competitive destinations at international and national level.

Climate impacts such as increase in extreme events, increase in heat waves, increase in urban heat island effect, decrease in water quality, increase in negative impacts on safety of tourists are associated with KR-T-3 (*Risk of loss of touristic attractiveness, key sources & limited accessibility of tourist attractions due to extreme heat and damage induced by other extreme events (floods, storms, fires)*).

Except for KR-T-2 (low for all time horizons), the associated risks are expected to become more severe throughout the century for both scenarios.

Besides, various connections to certain key risks of the sectors Agriculture, Biodiversity & Ecosystems, Hydrological Regime & Water Resource Management and Forestry have been identified by involved stakeholders[26]. For instance, risks resulting from a loss of biodiversity (KR-B-1), degrading ecosystem services (KR-B-2) or inadequate forest management (KR-FO-2) as well the risk due to floods (KR-W-3) are considered as relevant

*Table 36: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Tourism (KR-T) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | | Near Future (2021-2050) | Far Future (2071-2100) | | |
|---|---|---|---|---|---|

---

[26] Please note: Workshop participants were not explicitly asked to identify interrelations with key risks of other sectors.

|  | Current Risk Assessment | Optimistic | Pessimistic | Optimistic | Pessimistic | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| KR-T-1<br>Risk of decreasing tourism competitiveness due to increasing costs for tourism providers (adaptation, energy, water, labour etc.) | medium | high | high | high | high | slow onset | regional<br>national |
| KR-T-2<br>Risk of newly emerging, competing destinations at national and international level | low | low | low | low | low | slow onset | regional<br>national |
| KR-T-3<br>Risk of loss of touristic attractiveness, key sources & limited accessibility of tourist attractions due to extreme heat and damage induced by other extreme events (floods, storms, fires) | medium | medium | medium | high | high | acute | local<br>regional |

Climate change requires a diversification and adaptation of tourism offers and destinations to ensure competitiveness and climate resilience. According to the identified strategic directions, sustainable tourism associated with a high quality and a climate-friendly life play a key role in this context. Besides, SD-T-1 is directly associated with one specific objectives of the current NAP (Ministry of Environment of the Slovak Republic, 2021a).[27] In the course of the workshop, stakeholders identified a broad range of connections with strategic directions of other.[28] These include all strategic directions of the Biodiversity & Ecosystem (SD-B-1 to SD-B-3) sector and three of the Agriculture sector (SD-A-1 to SD-A-3). SD-FO-1 aiming at ensuring climate-resilient forests, SD-WM-1 addressing the protection against floods and SD-GES-1 focusing on securing ecosystem service provision of soils were explicitly mentioned as well, underling the complex interconnectedness.

---

[27] The number code of specific objectives of the current NAP associated with certain strategic objectives are listed in brackets.

[28] Please note: Workshop participants were not explicitly asked to identify interrelations with strategic directions of other sectors.

## Strategic Directions – Tourism

| | |
|---|---|
| SD-T-1 | Tourism offers are diversified to meet emerging markets and demands and to ensure competitiveness of destinations. (NAP 7.4) |
| SD-T-2 | Tourism is effectively managed based on partnership and data to support sustainability by key resources, including measures in visitor management, adaptation to changing climatic conditions (e. g. cool attractions for extreme heat) and implementation of preventive measures against natural hazards. |
| SD-T-3 | Tourism is sustainable, adapted to climate change and contributes to high quality, climate-friendly life in destinations and supports resilience in changing conditions. |

## 3.15 Transport, Infrastructure & Buildings

The **infrastructure** sector is defined as the basic equipment, utilities, productive enterprises, installations and services essential for the development, operation and growth of a city or nation (IPCC, 2023c). It comprises public and private physical structures such as roads, railways, bridges, tunnels, water supply systems, sewers, electrical grids and telecommunications. Infrastructure also includes green and blue infrastructure, such as sports grounds, parks and water treatment facilities. It corresponds to the built environment, representing everything people live in and around. The transport and buildings sectors are subsystems of the infrastructure sector (Boyle, 2024; EEA, 2024b; Markard, 2011).

The **transport** sector represents companies that provide services to move people or goods and construct and maintain transportation infrastructure. It includes road, rail, and marine transport, logistics, airlines and the corresponding infrastructure. (Hayes, 2021).

The **buildings** sector represents an industry associated with erecting, renovating, repairing, maintaining or altering and completing buildings. This includes residential, commercial, institutional and public buildings (EEA, 2024b; International Energy Agency (IEA), n. d.).

A wide range of climate change risks can impact infrastructures: heat waves, uneven distribution of precipitation or more frequent extreme precipitation causing flash floods and mudflows or other extreme weather situations. Impacts might be exacerbated by the age and condition of existing infrastructure, e.g. old sewage systems not being able to accommodate extreme precipitation levels and thus causing damages to transport infrastructure and impair traffic flow. In general, impacts vary depending upon the geographical location and type of infrastructure. The Slovakian government supports climate resilience of all types of infrastructure, which is promoted by adaptation measures in the NAP, for example, by supporting climate change impact assessment methodologies in preparing and appraising of infrastructure plans/projects.

Impacts on transport infrastructure in particular can be immediate and intense, leading to delayed transport times for goods and increased travel times, as well as increased likelihood of damage to transport infrastructure. Adaptation measures should therefore be considered already in the planning processes, and investments in the sector should ensure climate resilience. To this end, Slovakia developed the guideline 'Methodological Handbook on Assessing Climate Change Impacts on Major Transport Projects' to aid in the assessment of climate change on major projects in the transport sector (Správa, 2017). The transport sector's strategic documents are starting to address climate risks and potential impacts. The NAS stated that transport sector adaptation measures would be implemented through the Operational Programme Integrated Infrastructure (OPII) for the 2014-2020 programming period. Currently, the NAP does not explicitly mention specific objectives for the transport sector; nonetheless, the Programme Slovakia for the 2021-2027 programming period also includes objectives and activities to address climate change impacts. If such activities will include infrastructure projects, they will have to be climate-proofed in accordance with the Technical guidance on the climate proofing of infrastructure.

The climate risks to the infrastructure, buildings and transport sectors are recognised in Slovakia, as adaptation measures are included in both the NAS and NAP. As mentioned in Chapter 3.4, Slovakia does not yet have a coherent approach to critical infrastructure protection. Neither the NAS nor the NAP directly address the infrastructure or building sectors. At the same time, the NAP acknowledges, that the way to manage climate risks in infrastructure and related sectors, is through prevention, protection and management as a whole. Additionally, there are adaptation measures included in the built environment, which cover the transport and infrastructure sector to some extent.

### 3.15.1 Climate Impact Assessment

The workshop results emphasise that the significant challenges posed are increasing heat, including the UHI effect, hot days, tropical nights and heat stress. The adaptive capacity to address these heat-related impacts is generally *low*, underscoring the *high* urgency to adapt infrastructure to climate change. This necessitates increased shading and the adaptation of buildings to maintain comfortable indoor temperatures and humidity levels during summer. Financial capabilities to address these needs are *high*, reducing the urgency to *medium*. However, there is a lack of effective governance frameworks to support building adaptations and shading is lacking. There is also an increasing requirement for cooling in public transport, which ties into climate mitigation efforts.

Additionally, the frequency of extreme weather events is leading to greater wind and water erosion, as well as an increase in land and mudslides, which damage infrastructure, buildings and transport facilities. Excess runoff during heavy rainfall and low water levels during dry spells challenge existing sewage systems and wastewater treatment plants, which are often not adapted to these more extreme flow rates. This highlights the urgent need for infrastructure improvements to manage these changing conditions.

Table 37 presents the results from the participatory climate impact assessments, conducted in June 2024. The assessment of adaptive capacity and urgency to act was conducted for climate impacts of high priority. However, this more in-depth assessment might not have been possible entirely, due to time constraints and intense discussions at the workshop (see Annex A: Additional information on methodological design Box 1). The digitised workshop materials and descriptions of the individual climate impacts can be found in Annex C: Climate Impacts & Assessments in the sector Transport, Infrastructure & Buildings. Definitions of key terms used are provided in Annex A: Additional information on methodological design.

*Table 37: Presentation of the results of the climate impact assessment for the sector Transport, Infrastructure & Buildings. Impacts of high priority are highlighted in* ***bold****. The colours used correspond to the ratings (adaptive capacity: green=high, yellow=medium, red=low; urgency to act: green=low, yellow=medium, red=high).*

| Transport, Infrastructure & Buildings | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| biophysical | | | | | |
| increase in urban heat island effect | very high | very high | low | low | high |
| changes in indoor temperature and humidity | very high | high | low | high | medium |
| increase of landslides and mudslides | medium | very high | low | low | medium |
| increase in summer/tropical days & nights | high | high | low | low | high |

| Transport, Infrastructure & Buildings | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| increase in erosion (soil, surfaces/materials) | high | high | low | low | high |
| increase in extreme events | medium | high | - | - | - |
| lowering of groundwater table | medium | high | - | - | - |
| increase in flood events (pluvial, fluvial) | medium | medium | - | - | - |
| extension of the vegetation period | high | low | - | - | - |
| increase of days with low water discharge | medium | high | - | - | - |
| ground subsidence | low | medium | - | - | - |
| socio-economic | | | | | |
| increase of cooling requirements in buildings | high | very high | medium | high | medium |
| increase for cooling requirements in public transport | high | very high | low | low | high |
| increase in need for realignment of sewage system & sewage treatment plants | very high | high | medium | medium | high |
| increased need to adapt building planning & building services to summer heat | high | medium | low | low | high |
| undersized retention basins | very high | high | low | medium | medium |
| increase in the need for shading | high | high | low | low | high |
| increase in heat stress | very high | high | low | low | high |
| increase in exposure to natural hazards | low | high | - | - | - |

| Transport, Infrastructure & Buildings | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| lower heating demand in winter | medium | low | - | - | - |
| increase in damage to buildings | medium | high | - | - | - |
| increase in secondary damage due to natural hazards (e.g. mould formation) | low | high | - | - | - |
| reduced stability of ground-rooted infrastructure (subsidence) | low | medium | - | - | - |
| increase in expenditures and costs for maintenance | medium | high | - | - | - |
| increased insurance costs | low | low | - | - | - |
| increase in endangerment of supply chains | medium | high | - | - | - |
| limited navigability | low | medium | - | - | - |
| destabilisation & destruction of road/rail routes/airport infrastructure | medium | high | - | - | - |
| increase in damage to vehicles and transport facilities | medium | high | - | - | - |
| increase in probability of accidents (road, rail, waterways, flights) | medium | high | - | - | - |

### 3.15.1 Climate Risk Assessment

The participatory and expert-based climate risk assessment revealed a total number of two key risks (KR) for the sector Transport, Infrastructure & Buildings (KR-TIB), displayed in Table 38.

Climate impacts such as undersized retention basins, increase in flood events (pluvial, fluvial) and increase in exposure to natural hazards are associated with KR-TIB-1, highlighting the risk of potential damage to infrastructure and buildings. In the course of the workshops and feedback process attention was drawn to the fact that pluvial floods are particularly relevant and that the consequences of mudslides and landslides are currently neglected. It is expected that the risk, currently rated as *medium*, will increase through the century, reaching a *very high* level by the end of the century under a pessimistic scenario. Heat related climate impacts are among the ones considered as high priority, rating *high* to *very high* exposure and sensitivity. The assessment also reveals a lack of adaptive capacity, whereby the urgency to act is considered to be *medium* to *high*. Hence, the current risk is already rated as *high* and *very high* for both scenarios in the far future.

*Table 38: Assessment of identified key risks including their temporal dynamics and spatial variability in the sector Transport, Infrastructure & Buildings (KR-TIB) for two future time horizons (each for an optimistic (RCP4.5) and pessimistic scenario (RCP8.5)).*

| Key Risk | Current Risk Assessment | Near Future (2021-2050) | | Far Future (2071-2100) | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-TIB-1<br>Risk of damage to infrastructure and buildings e.g. due to landslides/mudslides & pluvial floods and loss of livelihoods | medium | high | high | high | very high | acute | national |
| KR-TIB-2<br>Risk to human comfort and health due to increased heat in urban centres and buildings | high | high | high | very high | very high | acute | regional |

The strategic directions listed below reflect the necessity for governance frameworks and sufficient financial capabilities (currently *low* adaptive capacity) and adaptation needs with respect to most relevant climate impacts. They also consider specific objectives of the current NAP (Ministry of Environment of the Slovak Republic, 2021a)[29].

---

[29] The number code of specific objectives of the current NAP associated with certain strategic objectives are listed in brackets.

## Strategic Directions – Transport, Infrastructure & Buildings

| | |
|---|---|
| SD-TIB-1 | Effective governance frameworks are implemented and sufficient funds are made available to ensure a climate-resilient adaptation of transport, infrastructure and buildings to climate change. (NAP: 6.1, 6.2, 6.5, 7.2) |
| SD-TIB-2 | Transport, infrastructure and buildings are adapted to climatic conditions such as increased heat and natural disasters such as floods, land- or mudslides (e. g. through used materials and technology). (NAP: 7.2) |

## 3.16 Transboundary, cascading & emerging risks

The way in which climate change impacts affect a particular community or ecosystem depends on local conditions and societal characteristics. This local nature of vulnerabilities has led to the prevailing approach of framing climate risks from a local perspective and consequently considering adaptation measures from the same perspective as well (Berninger et al., 2022). Changes in climate, however, will have repercussions for all biophysical systems, through which the impacts of climate change will permeate all facets of society, the economy and environment. These impacts do not stop at national borders, so considering them only from a local perspective may lead to gaps in the robustness and comprehensiveness of adaptation plans and ultimately less resilient responses to climate change (Carter et al., 2021).

Awareness of the significance of transboundary climate risks is increasing, alongside an expanding body of knowledge; however, this remains a developing research field with ongoing advancements in conceptual and empirical understanding, further complicated by the frequent emergence of new climate risks. Moreover, this research field has yet to agree on a common terminology, which adds a layer of complexity in understanding its current state of play (Harris et al., 2022). Practically, the terms 'transboundary', 'transnational', 'cross-border', 'cascading', 'indirect' and 'systemic', amongst others, are used interchangeably to refer to climate risks transcending national borders (Berninger et al., 2022).

In the following chapters we discuss transboundary, cascading and emerging climate risk, and present how they could evolve in Slovakia. Considering the issue with the terminology elaborated above, we provide a few clarifications to facilitate understanding of the following sections. In this report, we primarily use the term 'transboundary' when referring to these risks, as well as distinguish the term 'cascade' to denote a specific type of risk (as explained further in text). In examining transboundary risks within the context of the Republic of Slovakia, our approach adheres to the sovereignty and independence of European Union member states. This implies that transboundary impacts are not assessed in relation to the EU border. Essentially, this means that an impact in Slovakia resulting from a climate event in, for example, Poland (an EU member state), would be treated similarly to an event occurring in, say, Brazil – both are regarded as transboundary.

### 3.16.1 Transboundary risks

Transboundary climate risks can be defined as those risks induced by climate change that cross national borders, moving from one country to its immediate neighbour as well as leaping across entire regions and continents, transmitting risks to countries and people thousands of kilometres away from the initial point of impact (Anisimov and Magnan, 2023). These risks can be brought about by both the adverse effect of climate change impacts and the adverse effects of adaptation measures that cross borders (Harris et al., 2022). The risks can, however, lead to both positive and negative consequences across borders (Anisimov and Magnan, 2023).

The cross-border nature of transboundary climate risks can manifest in numerous analytical challenges defined by high levels of connectivity, major uncertainties and non-linear cause-effect relationships (Harris et al., 2022). Conceptualising an analytical framework to assess transboundary risks can be done from three distinct perspectives, as highlighted by (Harris et al., 2022): i) by nature of risk; ii) by mode of transmission; and iii) by public policy domain the risks belong to. Existing literature indicates the mode of transmission as most explored and explained approach to understanding transboundary risks, especially in the framework proposed by (Carter et al., 2021).

The assessment framework based on the mode of transmission focuses on how a climate impact occurring at a given location may be transmitted across borders, potentially presenting a risk to a region of interest that is remote from the initial impact, which may require a response from actors in that region (Carter et al., 2021). It identifies a climate trigger, either a short-period weather shock or slow onset changes, leading to an initial impact that propagates through an impact transmission system.

According to Carter et al. (2021) there are seven pathways for the cross-border transmission of climate risks categories (Figure 6).

- Trade: import and export of goods and services, as well as transport and processing sites;
- Finance: flow of capital and other assets, such as foreign investment and remittances;
- People: tourism, migration or forced displacement;
- Psychological: perception and communication of climate risks and opportunities, especially as delivered by the media;
- Geopolitical: impacts on international relations, resource access and strategies;
- Biophysical: shared ecosystems and resources, such as mountain ranges and river basins;
- Infrastructure: transport and telecommunications links.

The transmitted aggregate impact – recipient risk – may necessitate responses to mitigate damage or harness benefits. Propagation of transboundary risks through a system occurs by moving from one system component to the other; this movement can also be escalating – amplified in each system component compared to the previous one or diminishing – reduced in each system component compared to the previous one (Talebian et al., 2023). Spatial complexity can occur if these risks are propagated via system components located in more than one country. Responses, part of the response transmission system, can be reactive or anticipatory, targeting the initial impact, its transmission, or recipient risk indirectly. A central premise of this framework is that the frequency and/or magnitude of the climate trigger can be linked to and is liable to be altered by a changing climate.

*Figure 6: Pathways for cross-border transmission of climate risks. Source: Carter et al. (2021).*

*Illustrative examples of transboundary climate risks*

Some examples of transboundary risks are presented below, based on the key transboundary risks indicated in the 2023 Global Transboundary Climate Risk Report (Anisimov and Magnan, 2023):

- Agriculture and food security risk: Climate trigger for this risk is a severe drought that reduces water availability for irrigation in a major food producing region, leading to reduced agricultural yields. This reduction in availability leads to export restrictions and price increase on global market to prevent food insecurity at home. The transmission pathway of this risk is primarily through trade.

Transboundary impact: Export restrictions disrupt supply chains and increased prices affect the quantities that can be procured by importing countries, leading to food insecurity and higher food prices, impacting on the cost of living.

- Human health – infectious diseases risk: Climate trigger for this risk can be found in changes in temperature, precipitation patterns and humidity levels that create favourable conditions for the proliferation of disease vectors such as mosquitoes, ticks and rodents. Warmer temperatures and altered precipitation patterns lead to expanded habitats and increased populations of vectors. These diseases spread to new regions previously unaffected by these vectors, fast-tracked by travel and tourism. The main transmission pathway of this risk is people.

  Transboundary impact: Increased illness reduces workforce productivity and caregiving capacity, while local and regional healthcare systems become overwhelmed by a surge in infectious disease cases.

- Shared natural resources – water risk: Climate change leads to altered weather patterns, resulting in significant increase in extreme precipitation events (frequency and intensity). The climate trigger of extreme rainfall causes rivers to overflow, leading to widespread flooding across multiple countries sharing the river basin. The main transmission pathway of this risk is biophysical.

  Transboundary impact: Flooding damages critical infrastructure like roads, bridges, and buildings, and causes temporary displacement of populations from affected areas.

### *Slovakia’s exposure to transboundary risks*[30]

Possible transboundary risks in Slovakia include:

- Agriculture and Food Security: Slovakia imports a wide range of fresh food products, including various fruits and vegetables, primarily from southern EU countries such as Spain, Italy, and Greece. Key imports, according to the European Commission Directorate-General for Agriculture and Rural Development (DG AGRI) ‘s Agri-food data portal, include tomatoes, lettuces, leafy greens, citrus fruits, seasonal fruits, and olives. However, these imports are increasingly at risk due to climate-related factors. Southern Europe, the source of much of Slovakia's imported produce, has been facing rising temperatures, prolonged droughts, and extreme heatwaves. These climatic shifts have led to reduced yields, both in terms of quantity and quality, affecting agricultural output. Consequently, this results in less produce available for export, threatening the stability of agricultural supply chains and potentially causing shortages and price hikes in Slovakia, as an importing country. These amplify and add to the risks identified in the agriculture sector assessment in 3.1.

- Energy Supply and Trade: Slovakia is integrated into a regional energy network, and it imports a lot of its electricity from the Czech Republic. In 2022, Slovakia imported electricity worth approximately $1.85 billion from the Czech Republic[31]. Among various climate risks for the energy sector outlined by the Strategy on Adaptation to Climate Change of the Czech Republic from

---

[30] No prioritisation was done for this set of climate impacts and the risks were not discussed during the sectoral and strategic workshops. Therefore, the risks identified for the country do not reflect a prioritisation based on stakeholder consultation, but are the result of the researchers' opinion of what might be relevant given the socio-economic context in Slovakia and taking into account the results of the sector-specific risk and vulnerability assessment.

[31] Electricity in Slovakia | The Observatory of Economic Complexity

2021, are also infrastructure damage (including on power generation facilities, and transmission grid) and transmission system malfunctions caused by climate-related risks, such as floods, heavy snowfall, and extreme winds. Disruptions in electricity generation or transmission in the Czech Republic due to extreme weather events could impact Slovakia's electricity imports. These amplify and add to the risks identified in the Energy sector assessment in 3.6.

- **Water Resources and River Basin Management:** Slovakia shares river basins like the Danube with neighbouring countries. Changes in precipitation patterns and increased frequency of extreme weather events (e.g., floods, droughts) could affect water availability and quality. This could lead to disputes over water management and allocation among countries sharing these resources. These amplify and add to the risks identified in the Hydrological regime and water resource management assessment in 3.11.

### 3.16.2 Cascading risks

Climate change can lead to an impact that reverberates as a ripple effect through more than one sector, aggregating or shifting risks across systems of a different nature. These risks can be called cascading risks (Anisimov and Magnan, 2023). Cascading climate risks can originate and be transmitted within one border or can be brought about by an initially transboundary risk. In the latter case, we can then consider cascade risks as a sub-type of transboundary climate risks.

Cascading risk emerges from the interconnectedness of systems and their elements, when interactions of individual risks result in cascades of failures (UNDRR and UNU-EHS, 2022). Propagation of cascading risks across systems is dynamically complex. It can occur as transmission of risks at multiple systems components caused in multiple different locations before converging to affect a recipient (compound) or originate amplifying feedback loop between multiple system components (Carter et al., 2021). When such propagation is characterised by high spatial (i.e., multiple countries) and dynamic (i.e., multiple sectors) complexity, then these risks can be classified as systemic (Talebian et al., 2023). Usually, cascading risks are associated with disasters, leading to negative outcomes.

*Illustrative examples of cascading climate risks*

Using the same examples of transboundary risks (based on Anisimov and Magnan (2023)), we expand on their initial transboundary impacts to illustrate how they could develop into cascading risks:

- **Agriculture and food security risk:** Climate trigger for this risk is a severe drought that reduces water availability for irrigation in a major food producing region, leading to reduced agricultural yields. This reduction in availability leads to export restrictions and price increase on global market to prevent food insecurity at home. The transmission pathway of this risk is primarily through trade.

  **Cascading impact:** Initial transboundary impacts in importing countries (food insecurity, higher food prices) resulting in higher living costs, lead to increased malnutrition and health issues in low-income households, social unrest and potential migration to more affluent regions.

- **Human health – infectious diseases risk:** The climate trigger for this risk can be found in changes in temperature, precipitation patterns and humidity levels that create favourable conditions for the proliferation of disease vectors such as mosquitoes, ticks and rodents. Warmer temperatures and altered precipitation patterns lead to expanded habitats and increased populations of vectors. These diseases spread to new regions previously unaffected by these vectors, fast-tracked by travel and tourism. Main transmission pathway of this risk is people.

  **Cascading impact:** Increased demand for medical supplies, vaccines, and healthcare professionals, burdens public health systems and expenditures, while travel and trade restrictions disrupt economies, disproportionately affecting vulnerable populations and straining social cohesion, hindering educational attainment and economic development, and exacerbating global inequality.

- **Shared natural resources – water risk:** Climate change leads to altered weather patterns, resulting in significantly increased precipitation. The climate trigger of excessive rainfall causes rivers to overflow, leading to widespread flooding across multiple countries sharing the river basin. Main transmission pathway of this risk is biophysical.

  **Cascading impact:** Flooding disrupts transportation, communication, and utilities, inundates agricultural lands causing food shortages and economic losses, displaces populations leading to refugee flows and health crises, and strains international relations and social tensions due to resource scarcity and disaster response challenges.

*Slovakia's exposure to cascading risks*[32]

An example of possible cascading risk in Slovakia, building on transboundary and emerging risks (see sections above and below), include:

- **Water stress/scarcity**: Transboundary impacts on water availability and quality in shared river basins can significantly affect agriculture, energy, public health, and transportation. Reduced water for irrigation may lower crop yields and agricultural productivity, threatening farmers' livelihoods, raising food prices, and reducing food security. Simultaneously, limited water availability compromises hygiene and sanitation, heightening the risk of waterborne diseases and public health crises. For Slovakia, reduced water levels directly affect energy security by limiting the cooling capacity of power plants, potentially reducing domestic electricity production. This can lead to increased electricity imports, higher costs, and potential disruptions in energy supply, impacting sectors reliant on electricity and overall quality of life. Lower river levels also hinder navigation, disrupting the transportation of critical goods such as natural gas. These cascading effects - economic hardship, food insecurity, and public health challenges - may escalate social tensions as communities compete for increasingly scarce resources.

- **Urban Heat Islands**: Urban areas can experience higher temperatures due to the heat island effect. Increased heatwaves can lead to higher energy demand for cooling, straining the power grid. This can result in power outages and increased vulnerability of populations, particularly the elderly and those with pre-existing health conditions, exacerbating public health issues and economic burdens.

### 3.16.3 Introduction to emerging and newly assessed risks

Emerging risks from climate change encompass a broad range of threats that are increasingly recognised as critical to understanding and managing the global climate crisis and our responses to it. They may be new or familiar risks that become apparent in emerging circumstances and may not be fully understood or assessed, but nevertheless pose a threat to human security (International Risk Governance Council (IRGC), 2010; IPCC, 2014). Emerging risks often arise from feedback processes between climatic changes, human mitigation and adaptation interventions, and processes in natural systems which can threaten human security, leading to unexpected, severe consequences (IPCC, 2014). There may be three categories of emergent risks: (1) significant uncertainty and limited understanding of

---

[32] No prioritisation was done for this set of climate impacts and the risks were not discussed during the sectoral and strategic workshops. Therefore, the risks identified for the country do not reflect a prioritisation based on stakeholder consultation, but are the result of the researchers' opinion of what might be relevant given the socio-economic context in Slovakia and taking into account the results of the sector-specific risk and vulnerability assessment.

potential impacts and their interactions with systems that absorb risks, (2) growing complexity, unforeseen interactions, and interdependent systems, which may result in unpredictable, non-linear effects and outcomes, and (3) shifts in context – such as social and behavioural patterns, organisational structures or environmental conditions which can change the nature and likelihood of impacts (IPCC, 2022c) .

Some examples of emergent risks may include ecosystem service degradation, resource management and health effects. Firstly, in terms of ecosystem service degradation, this can include extinction risks and declines in biodiversity driven by changes in climate, extreme weather events, and increased frequency of wildfires (IPCC, 2014). These changes disrupt ecosystems, threatening biodiversity and the essential services these systems provide, such as pollination, water purification, and carbon sequestration. Secondly, climate change also exacerbates risks involving the management of water, land, and energy. For instance, the water use for various sectors and daily needs can heighten water stress in already arid regions, leading to conflicts over water resources (IPCC, 2014). Furthermore, climate-related extreme events impact water, sanitation, and hygiene services and local water security which makes this interruption to these services an emergent risk (IPCC, 2022c). These interruptions can lead to a higher risk of diarrhoea and other water-related diseases (IPCC, 2022c). Thirdly, the impact of emergent health risks from climate change varies between regions, largely influenced by the adaptive capacity of public health systems. A significant global public health risk is malnutrition, driven by ecological changes and disturbances in food production (IPCC, 2014). Additionally, in densely populated urban areas, extreme heat and air pollution pose severe health risks, particularly for vulnerable populations like the elderly or those suffering from asthma (IPCC, 2014). Another potential emergent risk comes from unintended consequences of climate change mitigation or maladaptation (IPCC, 2022c), such as negative impacts on ecosystems and water availability from increased use of hydropower for the purpose of climate mitigation.

Newly assessed risks are risks that we have only recently been able to assess due to previous lack of evidence. Several emerging risks can be considered as newly assessed risks, such as those including human migration in the context of climate change (IPCC, 2014). Societies are continuously exposed to environmental impacts to which they may be unable to adapt, promoting displacement and migration, while amplifying existing and generating new vulnerabilities, making effective climate adaptation plans essential (IPCC, 2022c). Environmental risks are connected to the risks following critical change to Earth systems (tipping points, see Chapter 6) and may have socioeconomic implications on chronic health conditions, involuntary migration, spreading vector-borne and food-borne diseases and even causing negative economic implications (World Economic Forum (WEF), 2024).

### *Slovakia's exposure to emerging risks*[33]

- **Increased frequency of extreme weather events**: Slovakia is experiencing more frequent and severe weather events such as floods, storms and droughts. These events not only cause direct damage to infrastructure and ecosystems but also lead to secondary impacts such as landslides and soil erosion, particularly in vulnerable mountainous regions (World Bank Group, 2021).

- **Human health impacts/risks:** Ambient air pollution can have direct consequences for health. Fine particles, which penetrate deep into the respiratory tract, subsequently increase mortality from respiratory infections, lung cancer and cardiovascular disease (World Health Organization (WHO), 2022). Climate change may also exacerbate heat stress and may cause dehydration, rash, cramps, heatstroke, heat exhaustion and death (World Health Organization (WHO),

---

[33] No prioritisation was done for this set of climate impacts and the risks were not discussed during the sectoral and strategic workshops. Therefore, the risks identified for the country do not reflect a prioritisation based on stakeholder consultation, but are the result of the researchers' opinion of what might be relevant given the socio-economic context in Slovakia and taking into account the results of the sector-specific risk and vulnerability assessment.

2022). It may also cause changes in the distribution of vector-borne diseases (tick-borne encephalitis (TBE)), as warmer temperatures expand the range of ticks (World Health Organization (WHO), 2022), as well as increase the risk of waterborne diseases in Slovakia, including hepatitis and diarrhoea (World Health Organization (WHO), 2022).

- Critical infrastructure is at increased risk from extreme weather events: Slovakia is particularly vulnerable to impacts of climate change from extreme weather events (World Bank Group, 2021). Floods and landslides can damage physical, social, and ecological infrastructure and disrupt socio-economic, transportation and communication networks (IPCC, 2022c). They also affect water and sanitation infrastructure and services which can cause contamination of water with faecal bacteria from run-off or sewer overflow (World Health Organization (WHO), 2022).

- Water availability: Altered precipitation patterns, leading to periods of drought and reduced water available, will exacerbate water scarcity issues (World Bank Group, 2021; World Health Organization (WHO), 2022). Climate change could, thus, affect drinking water supplies, agriculture, forestry and hydropower, as well as increasing risks to biodiversity and human health (OECD, 2023). Water scarcity could be especially dangerous during heatwaves, which could negatively affect vulnerable populations.

- Energy: Higher temperatures increase the demand for energy, especially for cooling (e.g., in summer), potentially straining the energy supply during peak periods. With the country's peak electricity demand occurring in the winter, this increase in summer demand is projected to flatten Slovak Republic's yearly consumption profile (International Energy Agency (IEA), 2022). At the same time, while demand for cooling will rise, demand for heating may decrease during milder winters. This shift could alter the overall energy consumption patterns and require adjustments in energy production and distribution strategies (International Energy Agency (IEA), 2022).

- Economic impacts:

    - Agricultural changes and productivity: The agricultural sector may suffer due to increased frequency of droughts and heatwaves (OECD, 2023). This can potentially cause issues for food security and the livelihoods of farmers (World Bank Group, 2021), and through (re)emergence of new hazards, and increase in the exposure or the susceptibility to known hazards, can change the levels of micronutrients and macronutrients in food and feed items (World Health Organization (WHO), 2022).

    - Tourism: Winter tourism will be impacted due to rising temperatures causing decreases in snowfall. This could lead to economic losses for businesses and communities dependent on winter tourism (The Slovak Spectator, 2023).

- Biodiversity loss: Climate change can introduce invasive alien species harmful to plant and animal health. It has an impact on the occurrence and toxicity of blooms of potentially toxic marine and freshwater algae and bacteria, on the dominance and persistence of various parasites, fungi, viruses, vectors and invasive species, harmful to plant and animal health (World Health Organization (WHO), 2022). 'Observed or expected impacts on biodiversity include shifts in vegetation zones and species distributions, phenological changes, extinction risk to species with a narrow ecological niche and increased risk of IAS [invasive alien species] and pest outbreaks (e.g. increased range or intensity of bark beetle outbreaks). Montane pine forests, swamps in the foothills and mountains and other aquatic systems are among the most vulnerable ecosystems' (OECD, 2024cf. MoE 2022).

# 4 Urban areas in the context of climate change

Urban areas play a crucial role in the climate change narrative, being responsible for a significant share of GHG emissions, while also acting as essential agents in mitigation and adaptation efforts. The drivers of urban GHG emissions are complex and include population size, income, state of urbanisation and urban form. An increasing global share of emissions can be attributed to urban areas, with the share increasing from about 62 % to 67–72 % between 2015 and 2020 (IPCC, 2022b).

At the same time, climate change is felt even more intensively in urban settings due to the urban morphology as well as high infrastructure and population densities, increasing both exposure and vulnerability to climate impacts (Hobbie and Grimm, 2020; IPCC, 2022b). Therefore, urban areas have to face hazards such as flash/surface flooding, rainstorms, mudslides, heatwaves and droughts and water scarcity, with particularly high vulnerability against heatwaves, droughts and floods (CPD, n. d; EEA, 2024e; Hobbie and Grimm, 2020). These adverse impacts affect human health, livelihoods and key infrastructure in cities, as mortality and morbidity increase and infrastructure can be damaged by extreme weather events, causing secondary damages and high reconstruction costs (Hobbie and Grimm, 2020; IPCC, 2022b, 2022h).

Within the scope of this report, these and other climate change induced impacts are well covered by the impacts and key risks identified for the various sectors. Sectors such as Spatial Planning, Hydrological Regime & Water Resource Management, Transport, Infrastructure & Buildings, Health as well as Disaster Risk Management, Civil Protection & Critical Infrastructure are essential for tackling climate change related impacts on urban areas. For instance, with regard to infrastructure and buildings, the risk of damage caused by floods or landslides/mudslides and the potential loss of livelihoods is of importance (KR-TIB-1). Furthermore, as heat is recognised as one of the most pressing challenges for urban areas, the risk to human comfort and health due to increased heat in urban centres and buildings (KR-TIB-2) has to be addressed. Hence, also the risk to human health from extreme heat events and overall increase in heat (KR-H-1) plays an essential role in shaping urban risk landscapes and underscores the increasing need for cooling in buildings and thus adapting buildings to summer heat. Likewise, shading is required not only for buildings but also other public areas. In addition, all three key risks identified in the realm of disaster risk management are relevant in urban areas. This includes the risk of widespread disruptions of (critical) infrastructure and services due to extreme events (KR-DRM-1), increasing maintenance, provision and emergencies costs (KR-DRM-2) as well as the risk to communities prone to increasing frequency and intensity of natural disasters (vulnerable to different extreme events, including impacts on human health; KR-DRM-3). The mentioned sectorial key risks severe as examples. Other identified and assessed key risks can have severe and adverse consequences on urban areas as there is a concentration of goods, services and people.

In the context of climate change induced impacts and urban areas, it is key to consider different levels of vulnerabilities. Senior citizens, children, those in poor health and economically disadvantaged groups, are consistently among the groups most affected by climate impacts, either immediately during or after extreme weather events or in the long term (Breil et al., 2018).

In larger urban areas in Europe, the sectors to be most impacted are water management, buildings, health and transport. Smaller municipalities have reported impacts in agriculture and forestry, environment and biodiversity, and civil protection and emergency sectors (EEA, 2024e).

More than half of Slovakia's population currently lives in urban areas (approx. 54 %). A total number of 141 towns and cities exists, with Bratislava and Košice being the biggest ones (Ministry of Transport and Construction of the Slovak Republic, 2019a; Univerzita Komenského v Bratislave, 2021). Climate change induced impacts such as extreme events are also of relevance in these urban areas. For instance, projected increasing numbers of tropical days and the occurrence of heat waves in summer put Slovak cities and towns under pressure and further investigations and implementation of measures are needed. In particular against this background, urban green areas are of importance, providing benefits in terms of health and well-being (e.g. improvement of mental health, decrease of adverse consequences from chronic diseases, lowering temperatures, improving air quality) (EEA, 2020a, 2022; WHO, 2016). The EEA highlights that such green spaces are particularly relevant for vulnerable groups such as children and elderly people as staying in these areas enhances their physical and mental health and provides an environment for supporting social well-being (EEA, 2020a, 2022). Besides, urban green spaces are important for biodiversity and associated functions (Copernicus, n. d.). Benefits from other functions and services provided by green spaces to the city's population (i.e. aesthetic and psychological functions  need to be taken into account in addition to their climate adaptation benefits. Pauditsova and Reháčková (2006). A total number of 58 functions of green areas in Bratislava have been identified (Belčáková et al., 2019). The aspects outlined indicate that greenery planning can be considered as an important part of spatial planning. However, research not only shows that such planning is insufficiently implemented, but also stresses that there is a lack of green area mappings in Slovakia (e.g. see for Bratislava Belčáková et al. (2019) and Belčáková et al. (2022)) For the city of Bratislava, Reháčková and Pauditšová (2004) provided a mapping of green urban areas, indicating that forests, forest parks, private and cottage gardens as well as allotments are the most important green spaces, all of them differently distributed across the city's territory.

With regard to climate change adaptation, many possible adaptation pathways are known. For instance, the IPCC differentiates three main adaptation realms, i.e. social infrastructure, nature-based solutions and grey/physical infrastructure (IPCC, 2022b). Likewise, in the current NAP of the Slovak Republic (Ministry of Environment of the Slovak Republic, 2021a), infrastructure has been divided between grey, green and blue to help to devise climate change adaptation solutions for infrastructure. However, only a modestly growing number[34] of Slovak cities have developed climate change adaptation strategies/policies. A serious challenge to climate resilience is the insufficient and non-systematic implementation of the urban adaptation process. Assessment of local adaptation plans in section 2.4 of D2.2 and stakeholder engagement identified the following causes of this situation:

- Limited ability to incorporate climate risks or climate goals into the city's decision-making or planning processes. Local adaptation strategies provide inadequate assessment of spatial, sector-specific and multi-dimensional climate risk assessment (D2.2. of this project).

- Most representatives of the cities (mayors, council members, employees of the city office) do not consider climate change to be of city priority importance because they do not realise/do not attribute all its economic, social and environmental cascading consequences and the associated enormous damages.

- Lack of tools and evaluation mechanisms to assess how vulnerability might change with implementation of local level adaptation measures, such as urban planning or construction permitting procedures.

- The Spatial Planning Act 88 contains adaptation measures at the regional level, which are cascaded down to the zone plan and are adopted in the form of generally binding regulation. The feedback loop from zone level to the regional level is however equally important for climate adaptation and should be formally put in place.

Within the scope of this project, D2.4 will include certain measures for adaptation on a sectoral level.

---

[34] Out of 39 cities with populations over 20,000 in Slovakia, only 17 have developed adaptation strategies. Moreover, only 9 towns that are not a regional capital have developed a strategy, indicating a particular lack of strategies for small and medium-sized cities. This indicates a considerable gap that needs addressing to guide the remaining cities in the adaptation process effectively (see report provided in D2.2 in course of the project).

# 5 Social vulnerabilities in the context of climate change

Climate change impacts are not distributed equally within and between countries as well as different generations. Concepts such as climate justice draw attention to the fact that, globally, countries that contributed the least to global warming are affected most by its impacts (IPCC, 2022f, 2023b; MRFCJ, 2022; Porter et al., 2020). Similarly, intergenerational equity describes the disproportionate consequence of climate change felt by past, current and future generations (IPCC, 2022f, 2023b; Parsons et al., 2024). Incorporating an intergenerational perspective in the context of tackling climate change is key, as disadvantaged groups are already affected more than others by climate change induced impacts (Islam and Winkel, 2017). Based on a literature review, Breil et al. (2018) listed older people, children, women, people with low incomes, poor health or insufficient social networks, tenants and illiterate groups as disadvantaged. Others are ethnic and racial minorities, migrants, people with disabilities and homeless people (Breil et al., 2018). Factors influencing the level of affectedness include physiological aspects and different biological preconditions, limitations due to a lack of available resources, mobility restrictions and lack of participation options in political decision-making processes (Breil et al., 2018). Already poor health conditions may be exacerbated by access limitations to health infrastructure (e. g. due to extreme events). Lacking financial resources may further reduce the adaptive and coping capacity of disadvantaged people (Breil et al., 2018).

The reasons provided can be linked directly to certain sectors. For instance, disadvantaged groups are often disproportionally prone to and affected by extreme events such as floods or heat waves (Breil et al., 2018; McDermott, 2022), relevant for the Disaster Risk Management, Civil Protection & Critical Infrastructure sector. Hence, two identified key risks in the context of disaster risk management address the necessity to pay special attention to disadvantaged groups, i.e. the risk of widespread disruptions of (critical) infrastructure and services due extreme events (e.g. forest and wildfires and flood events (pluvial, fluvial) (KR-DRM-1)) as well as the risk to communities prone to increasing frequency and intensity of natural disasters (vulnerable to different extreme events, including impacts on human health) (KR-DRM-3). Limited financial capabilities e. g. of low-income groups (Breil et al., 2018) are relevant in the sectors Finance or Health. As disadvantaged groups often live in areas prone to e. g. floods or landslides or that are highly affected by urban heat island effect with limited access to green spaces, the sector Spatial Planning gains importance when considering a socially just adaptation. These aspects are particularly reflected by the risk to population and infrastructure in urban and rural areas from heat-, drought- and flood-related extreme events (KR-SP-1). In addition, most vulnerable groups might be disproportionally adversely affected by risks such as decreasing ecosystem service provision from terrestrial and aquatic ecosystems, including forests (KR-B-2; KR-FO-1). Furthermore, the housing standards of disadvantaged groups tend to be lower, making overheating in summer months particularly problematic (Breil et al., 2018), relating to the Transport, Infrastructure & Building sector in general and to the risk to human comfort and health due to increased heat in urban centres as well as buildings (KR-TIB-2). Maladaptation may further increase such inequalities (IPCC, 2022g). In this regard, the Agenda 2030 of the United Nations (UN, 2015) is a key document as one goal (i.e. Sustainable Development Goal (SDG) 10) is dedicated to reduce inequalities (UN, n. d.) and the concept of leaving no one behind (LNOB) is anchored in the Agenda as well.

Slovakia has committed to achieve both the SDGs and dedicated a chapter to LNOB in its 2nd voluntary report to the UN (Ministry of Investments, Regional Development and Informatization of the Slovak Republic, 2023). This commitment by the Slovak Republic underlines the necessity and obligation to consider social vulnerabilities and inequalities in the context of climate change. In Slovakia, Roma are one of the population communities being particularly marginalised and vulnerable (European Union, 2020; Minority Rights Group, 2023). According to official statistics (Census 2011), roughly 2% of the Slovak population is part of the Roma community, however, it is assumed that the actual number is higher, ranging between 7% to 11% (Minority Rights Group, 2023). With respect to climate change impacts, a report prepared by the Institute of Environmental Policy concludes that Roma communities are particularly prone to adverse consequences. These climate-change induced negative impacts include a high risk due to heavy rain and floods as well as limited access to appropriate heat protection, whereby poor and insufficient infrastructural and housing conditions are among the factors influencing the risk (Institute for Environmental Policy, 2023).

It is important to understand underlying perspectives for social vulnerability (Breil et al., 2018), which, in this report, follows the IPCC risk and vulnerability concept. Social vulnerability is *'a state resulting from interaction of socio-economic and environmental characteristics, such as personal sensitivity, economic deprivation or housing conditions, affecting how prone to harm from climate-related events people and communities are'* (Breil et al., 2018). Against this background, adaptation to climate change has to take into account social vulnerabilities and associated possibilities to adapt to and cope with climate-related impacts. Both procedural justice, with its focus on fair participation in decision making processes, and distributive justice, dealing with the distribution of benefits and adverse effects of climate change among groups and individuals, are relevant (Breil et al., 2018). A socially just adaptation can therefore be understood as *'a set of policies and actions responding to current climate variability and anticipating the future climate change and its impacts designed to ensure that neither the impact of climate change nor the policies and actions themselves exacerbate existing or create new inequalities across different groups.'* (Breil et al., 2018; cf Climate Just 2014). In alignment with the commitments by the Slovak Republic to the achievement of the SDGs and the LNOB concept, this understanding of a socially just adaptation will be considered in the identification of adaptation options.

# 6 Limitations: Knowledge Gaps & Uncertainty

The risk and vulnerability assessment provided in this report has certain limitations, mostly due to knowledge gaps and uncertainties both in terms of methodology and content. It is crucial to take into account these limitations when interpreting the assessment results and before using them in further work. This chapter outlines both content-related as well as methodological limitations, while it should be noted that there are also interlinkages.

In the Climate Risk Sourcebook (GIZ, 2023), the five most relevant sources of uncertainties related to a Climate Risk Assessment are differentiated and displayed in Table 39.

*Table 39: Sources of uncertainty in Climate Risk Assessments (CRA) according to GIZ (2023).*

| Key sources of uncertainty in Climate Risk Assessment (CRA) | |
|---|---|
| Uncertainty source | Description |
| Climate data and models | Climate observations might be sparse or incomplete. Climate models have high uncertainties specifically when it comes to precipitation-related factors and climate extremes. |
| Lack of understanding of processes related to adverse consequences | For complex impacts, knowledge of the mechanisms underlying climate risks may not be well understood. |
| Socio-economic factors | CRAs also need to consider the potential impacts of socio-economic factors such as population growth, urbanisation, and land-use change that may influence vulnerability and exposure to climate risks. |
| Lack of local knowledge | Even if the evidence for certain climate risks may be high at the global level, a lack of data and knowledge at the regional to local level leads to large uncertainties. |

Climate data and model constraints, potentially underestimating global warming and associated risks (see e.g. Spratt and Dunlop (2018), and the lack of understanding of processes related to negative consequences are of particular importance against the background of complex, non-linear dynamics of the Earth climate system as these go along with multi-faceted interlinkages unfolding across various spatial-temporal scales (Galaz, 2019; Ratter, 2012). This can be illustrated by tipping systems and associated tipping points, i.e. critical thresholds. The recently published Global Tipping Points Report underlines that tipping points in the earth system are arguably the biggest risk we face in a changing world, because they can lead to profound damages that are abrupt or irreversible – or both. The level of global warming that could trigger known climate tipping points is uncertain; there is little assessment of tipping point impacts and even less consideration of who or what is most vulnerable to those impacts' (Lenton et al., 2023). There are, among other things, several essential aspects to be considered in this context:

- Impacts and challenges associated with these tipping dynamics 'pose threats of a magnitude never faced by humanity' (Lenton et al., 2023).
- Crossing such tipping points becomes very likely – already at current levels of global warming. (Lenton et al., 2023).

- The effects are expected to have severe consequences for the functioning of our whole society, i.e. socially, politically and economically, and potentially exceeding coping abilities of societies (Lenton et al., 2023).
- Tipping points are among those aspects being currently underestimated scientifically and politically in terms of (global) risk management and there is a necessity to prepare for potential unprecedented severe consequences by implementing respective adaptation and loss-and-damage governance frameworks on a global level (Lenton et al., 2023; Spratt and Dunlop, 2018).

Within the scope of this report, extreme risks because of tipping dynamics could only be partially covered due to the inherent uncertainties of those and the lack of knowledge on potential impacts on country-level. Likewise, the available climate data for the present report provided and processed by the Slovak Hydrometeorological Institute might not fully account for the accelerated warming dynamics in recent years. However, the risk assessment notably for the far future and under the assumption of a high emission scenario shows how risks might increase. Socio-economic factors relevant for understanding the 'bigger picture' and as source of uncertainty are addressed in the assessment by incorporating non-climatic risk drivers in the sectoral climate impact chains. The report also provides detailed sectoral assessments complemented by visualising cross-sectorial interlinkages in a generic way and including them in the respective climate impact chains. However, an in-depth analysis of interlinkages was beyond the scope of this deliverable.

On a country level, the work carried out within the course of this deliverable also revealed specific data/knowledge gaps and uncertainties for Slovakia which have been identified by involved stakeholders. Therefore, the limitations listed below for some sectors do not exclude the possibility that there are also further uncertainties/knowledge gaps in other sectors.

*Biodiversity & Ecosystems*

According to involved stakeholders, national data regarding the effects of extension of vegetation period on ecosystems and biodiversity is missing. There is also a lack with respect to climate change induced impacts on water-living organisms due to higher temperatures of watercourses.

*Finance*

As noted in the chapters dedicated to the Finance sector, there is uncertainty on the extent to which climate risks and their consequences remain insurable at all.

*Forestry*

It is not always possible to clearly determine to what extent forests are adversely affected by either deficient forest management, climate change or the combination of both. Likewise, stakeholders consider it difficult to forecast the appearance of new pest species spread through natural movement transferred with goods, tourism or trade. There is also a complex interplay of various processes (e.g. soil fertility) with respect to an increase in biomass production that are directly or indirectly affected by climate change. Given the inadequate accessibility of forests by forest roads for fire trucks, one option might be to restrict human movement and activities within these forests. However, there are certain reservation, e.g. to what extend such rules would be followed by potential visitors and generally questioning the idea of restricting access to forests. Specific evaluations of the associated risk, preferably with an automated system, should be done and research is needed to test the functionality in practice of such systems. Besides, stakeholders perceive a deficit in terms of research and data explicitly considering Slovakian circumstances. For instance, in Slovakia particularly spruce forests are adversely affected by climate change, leading to further impacts on biodiversity, timber supply and carbon balance. The adaptive capacity and urgency to act have not been assessed in the workshops and might need further investigation to identify the best adaptation options and effectively plan measures.

### *Geological Environment & Soil*

In Slovakia, there is a lack of investigation and monitoring of underground water quality according to stakeholders. At present, it is not feasible to assess the consequences and impacts of pollution resulting from human activities, including those associated with climate change. However, the extreme manifestations of climate change are undoubtedly linked to the quality of groundwater. For instance, during floods, the sources cannot be utilised for the provision of drinking water. This phenomenon is particularly related to the climate impact-induced lowering of groundwater levels. Besides, the adaptive capacity in terms of financial capabilities has not been assessed in the workshops and might need further investigation to identify the best adaptation options and effectively plan measures.

### *Health*

A major concern raised in course of the discussions was that healthcare facilities in Slovakia are not prepared for the climate impacts and consequences neither from the point of view of patient nor employee comfort. Besides, adaptive capacity and urgency to act have not been assessed in the workshops and might need further investigation to identify the best adaptation options and effectively plan measures.

### *Hydrological Regime & Water Resource Management*

The adaptive capacity and urgency to act have not been assessed in the workshops and might need further investigation to identify the best adaptation options and effectively plan measures. In addition, the Floods Directive, and to some extent the Water Framework Directive, require the consideration of climate change in the planning process.

### *Information and Communication Technology*

Weak crisis management has been identified as major gap by stakeholders. At the same time, monitoring and gathering of relevant data could be supported by an increase in share of mobile devices such as drones. Involved experts also emphasised the need for awareness raising with regard to climate impacts on IT.

### *Spatial Planning*

The adaptive capacity and urgency to act have not been assessed in the workshops and might need further investigation to identify the best adaptation options and effectively plan measures.

### *Tourism*

There is a need to focus on a sustainable use of resources (water, food, energy, etc.) and thus awareness raising is seen as a necessity.

From a methodological point of view, the approach used for the vulnerability and risk assessment has certain limitations. A key element of the CRVA is the participatory process design meaning that relevant stakeholders and experts were closely involved in several steps of the process. This acknowledges and harnesses their local, and probably tacit, knowledge. Bringing together various stakeholders in workshop settings fosters exchange among them and their institutions. This eases the way for the implementation of measures, addressing cross-sectoral interlinkages and collaboration. At the same time, it should be noted that workshop results feeding into the overall CRVA depend on the experts being present, the way of facilitation by moderators and the discussions arising from these specific constellations, which are in turn influenced by the socio-cultural context of the stakeholders (Wildavsky and Dake, 1990). Against the background of this ‘human factor’, it should be noted that the presented assessment results do not represent an objective truth.

To sum up, it can be stated that there always remains a residual risk due to the complex nature of our world and our limited capacities of anticipatory thinking and grasping complexity in all its forms, cognitive biases and rather linear understanding of processes, among others. Or to put it in other words: we have to account for ‘unknown unknows’ and effects that cannot be grasped with our experiences to date (Pawson et al., 2011; Roe, 2020). In a way, this comes to no surprise. In light of these preconditions, the authors of the report take a precautionary assessment approach to account for these limitations as best as possible.

# 7 Informing policy: in the case of no further adaptation action and the relevance of megatrends

If no further adaptation action is taken in Slovakia, i.e. a business-as-usual scenario, then the risks and impacts identified in the earlier chapters are the most likely expected outcomes. This chapter briefly reviews the potential opportunities arising from such a business-as-usual scenario and the implementation of adaptation measures. This is complemented by outlining potential effects of relevant national, European and global megatrends in the context of climate change.

The sectoral risk assessment describes the consequences of a business-as-usual scenario, i.e. outlines potential effects if no adaptation measures are implemented. The current and future risk landscape of Slovakia shows that severe adverse impacts have to be expected if no or only insufficient action is taken as the levels of nearly every identified key risk reach high to very high levels in the far future at the latest. In addition, the risk of costs of inaction due to insufficient mitigation and adaptation to climate change (KR-FI-3) is already rated as high, underscoring the urgent necessity to address climate impacts and associated risks. This aspect is also mirrored in the results of the assessment of the urgency to act for climate impacts of high priority. With the exception of one sector (ICT), where urgency has been assessed, either all high priority impacts or at least some of them require immediate actions. This is particularly important for sectors facing a limited adaptation capacity, either in terms of insufficient governance frameworks, limited financial capabilities or both (e.g. Agriculture, Biodiversity & Ecosystems, Geological Environment & Soil, Transport, Infrastructure & Buildings).

In view of this challenging risk landscape, it can be concluded that no substantial opportunities emerge if a business-as-usual approach is followed. This reasoning is further underpinned by recent research findings. For instance, the Earth4All report to the Club of Rome differentiates between two major scenarios, one of them is called ‘too little to late’ and describes the consequences of a business-as-usual future development on global level (Dixson-Declève et al., 2022). If this pathway is followed, ongoing economic growth leads to a further destabilisation of planet Earth, decreasing wellbeing and social cohesion as well as increasing social tensions across scales and regions, whereby also total collapses of societies might occur. Even though the perspective is a global one[35], it has to be expected that Slovakia will be adversely affected by these developments due to the worldwide interconnectedness of both biophysical and societal processes. Furthermore, it should be noted that Slovakia has committed to fulfil global agreements such as the Paris Agreement and the Agenda 2030, requiring strong efforts to deal with global challenges going far beyond a business-as-usual approach, including climate change mitigation and adaptation. Thereby, both climate change mitigation and adaptation come along with benefitting aspects for humans and nature. For instance, the implementation of adaptation measures supports ensuring food security, enhances the resilience of (urban) settlements (e.g. to reduce adverse impacts of floods or other extreme events) and is also associated with benefits for human health and well-being. In the European Climate Risk Assessment, opportunities due to climate change adaptation are outlined for each sectorial cluster addressed in the report (EEA, 2024b). These include, among other things, addressing factors leading to biodiversity loss, developing and implementing flexible adaptation options for climate-resilient flood management or enhancing disaster risk reduction (including early warning and surveillance mechanisms) (EEA, 2024b). It should be noted that there are soft and hard limits to adaptation and that it is crucial to avoid maladaptation as this leads to a worsening of the situation (IPCC, 2022f). Both limits to adaptation and the evidence of already existing maladaptation underscore the necessity to reduce greenhouse gas emissions effectively and

---

[35] Researchers are currently working on country-specific Earth4All-reports. They are already available for Germany, Austria and Kenya. See: https://earth4all.life/publications/

to apply a systemic and forward-looking way of thinking that also takes into account e.g. transboundary, cascading and emerging risk (EEA (2024c), IPCC (2023a); also see Chapter 3.16).

Next to direct climate change induced impacts and risks assessed in the sectoral chapters, there are also other socio-economic developments and megatrends that might influence the vulnerability to climate change. With regard to megatrends, there is no consensus definition and descriptions as well as the list of overreaching developments considered as megatrends vary across academic and non-academic literature (Naughtin et al., 2024). Megatrends can refer to various realms, reaching from societal, economic, technological to environmental, political and cultural spheres, and circumscribes a trend, force or process influencing society or life at rather a large scale (e.g. globally) (Naughtin et al., 2024). According to the European Commission Competence Centre on Foresight, megatrends are understood as ‘long-term driving forces that are observable now and will most likely have significant influence on the future’ (EU Competence Centre on Foresight, 2024). In this vein, several megatrends are differentiated reflecting socio-economic developments, whereby climate change itself is considered as such a large-scale force shaping the future (EU Competence Centre on Foresight, 2024).

In the following, the megatrends expected to play a rather direct role shaping vulnerability associated with climate change are described more in detail. Due to the ‘global’ or ‘large-scale’ character of megatrends, the descriptions are rather generic in nature and have to be seen, among other things, in the context of an increasingly interconnected world and global power dynamics, meaning that the consequences of megatrends unfold across regions and countries.

### Accelerating technological change and hyperconnectivity.

Technological innovations can support decarbonisation of sectors such as agriculture, transportation and industry (EU Competence Centre on Foresight, 2024). This aspect is also reflected in the identified key risk of missed opportunities and unutilised innovation potential (KR-EI-2). At the same time, new technologies such as Artificial Intelligence (AI) can lead to increasing energy demands, potentially undermining mitigation efforts (Cowls et al., 2023; UN-EHS, 2024).

### Aggravating resource scarcity.

Resource scarcity is related to aspects such as human-driven overexploitation of natural resources and the exceedance of planetary boundary thresholds, often at the expense of ecosystems and their vital functions for wellbeing of people (EU Competence Centre on Foresight, 2024). Such a degradation of essential functions might lead to an increasing sensitivity and limit capacities to adapt to changing climate. Key risks such as the loss of ecosystem services provided by terrestrial and aquatic systems, including forests, reflect such adverse consequences due to ecosystem degradation (KR-B-2, KR-FO-1). In the context of resource scarcity, the EU Competence Centre on Foresight (2024) also calls for ensuring intergenerational fairness and global equity to allow a good life for all and thus potentially reducing vulnerability.

### Changing security paradigm.

In the future, a more diverse range of threats is expected, including cyber and hybrid threats, whereby new technologies such as robots or other autonomous systems will be used (EU Competence Centre on Foresight, 2024). Associated conflicts and security crisis might lead to destabilisations of countries and regions, further complicating addressing pressing climate change induced impacts (UNEP, 2024). At the same time, there is scientific evidence that armed conflicts can be amplified due to climate change (Schleussner et al., 2016).

### Continuing urbanisation.

Urbanisation is associated with opportunities for inhabitants such as better access to services and jobs (EU Competence Centre on Foresight, 2024). However, urban areas are affected by environmental degradation and people might face inequalities and health related issues (e.g. caused by urban heat island as outlined in the risk assessment). Hence, the vulnerability of people living in urbanised areas is strongly influenced by the way governments address the challenges that arise there, underscoring the urgent need for climate resilient spatial planning (KR-SP-1 to KR-SP-3).

### Diversification of education and learning.

Aspects such as technological innovation and newly developed pedagogical approaches have strong impacts on education and learning (EU Competence Centre on Foresight, 2024). This can also be seen as a chance to foster awareness raising with respect to climate change by using innovative formats, potentially reducing vulnerability as, for instance, knowledge on how to deal with and prevent adverse effects of climate extremes can increase coping and adaptive capacity of individuals, communities and public institutions responsible for implementing measures. In this context, the identified key risk of lack of skilled workers (KR-EI-3) is relevant.

### Widening inequalities.

Inequalities themselves are strongly related to vulnerability as the most vulnerable groups are disproportionally affected by climate impacts (see Chapter 5). Hence, rising inequalities further increases the vulnerability of affected people.

### Expanding influence of East and South.

In the 21st century, rising economies in the global east and south will influence economic power dynamics. Besides, a more fragmentated globalisation fosters the emergence of a multipolar world, in which global economy is influenced by developments such as regional conflicts (e.g. war in Ukraine) or populist nationalism (EU Competence Centre on Foresight, 2024). Such processes, downscaled to a national level, can have impacts on how countries are able to address climate change impacts (UNEP, 2024).

### Increasing demographic imbalances.

Despite the fact that the global population is currently still growing, the dynamics vary from region to region (EU Competence Centre on Foresight, 2024). As for Slovakia, a demographic shift towards an older society is expected (Hwang and Roehn, 2022). Since elderly people are among the groups most vulnerable to climate change impacts such as heat waves (see Chapter 5), this demographic development has to be considered in adaptation planning.

### Increasing significance of migration.

More complex migration dynamics are observed, associated with significant challenges for regional (e.g. EU level) and global governance of such movements of people (EU Competence Centre on Foresight, 2024). Already back in 2008, the International Organization for Migration (2008) stated that the '[d]evelopment and adaptation policies in potential source countries of forced climate migrants need to focus on reducing people's vulnerability to climate change, moving people away from marginal areas and supporting livelihoods that are more resilient.'

### Shifting health challenges.

Mental and physical wellbeing is influenced by a variety of factors, including environmental ones and access to well-functioning health systems. As outlined in the assessment, identified health related key risks underscore the need to tackle climate change to avoid adverse effects for people, in particular for vulnerable groups.

These megatrends are also reflected in other reports such as Amanatidou et al. (2012) and Považan and Blaško (2023). Amanatidou et al. (2012) have identified a list of 16 so called ‘grand challenges’, whereby some of them overlap with the abovementioned megatrends (e.g. with regard to resource scarcity, education, interconnectivity and multipolarity of the world). Likewise, the megatrends addressed in Považan and Blaško (2023) include aspects such as urbanisation, demographic changes, increasing resource demand and scarcity, hyperconnectivity as well as geopolitical changes.

To conclude, this brief outline of megatrends relevant for EU Member States shows that climate change and ensuring a climate resilient development is strongly intertwined with security issues, both regionally and globally. To put it in other words, ‘[t]here can be no sustainable development without peace and no peace without sustainable development’ (UN, 2015). Following this argumentation, if there is a lack of social cohesion and peace within countries and between them, a sustainable and climate resilient development can be severely hampered or even made impossible. Hence, climate change adaptation and mitigation in Slovakia should acknowledge the complex interplay of social, economic, environmental and cultural dimensions and processes within and across regions and countries (see Chapter 3.16), also reflecting the commitment of the EU to an ambitious and constructive way to tackle global societal challenges.

# Annex A: Additional information on methodological design

The methodological approach used for the assessment is based on frameworks published in recent literature particularly relevant within the European context, namely EEA (2024b), GIZ (2023) and Smithers and Dworak (2023). The phases and steps outlined and used in these documents have been adapted to the specific project context, expected timeline and the project proposal and is displayed in Figure 1. The developed methodological approach was discussed within in the project consortium as well as with the client and beneficiary and jointly agreed upon to use it. Most importantly, these documents were chosen as essential basis due to their practical applicability. The following section outlines key aspects how the frameworks were considered in the present report. Further details are described in the other sections of this Annex.

Based on the 6th IPCC Assessment Report (IPCC, 2022c), the EEA (2024b) and GIZ (2023) put the analysis and identification of (key) climate risk at the centre of their assessment approach. Thus, key risks represent a major result of the present report. Similarly to the proposal in Smithers and Dworak (2023) and as applied in the EEA risk assessment EEA (2024b), for identified climate risks not only an assessment of the current risk was conducted, but also for two different future time horizons (near/far future) and two scenarios (optimistic/pessimistic). Besides the EUCRA report highlights the consideration of financial resources as well as policies and institutions as important aspect of vulnerability (EEA, 2024b). Likewise, financial and institutional resources as well as legal aspects and strategies are listed among the factors influencing the capacity to deal with hazards in GIZ (2023). In the present report, this is reflected by the explicit integration of both as aspects in the assessment of the adaptive capacity. As defined in the 6th IPCC Assessment Report (AR6), climate risks are at the interface of exposure, vulnerability and hazard, whereby a particular attention is given on addressing complexities of climate risks due to factors such as cascading and compound risks. This aspect is captured in a dedicated chapter in this report, i.e. transboundary, cascading and emerging risks. Vulnerability comprises the assessment of adaptive capacity and sensitivity, both assessed in course of sector-specific participatory climate impact workshops. These identified climate impacts reflect the hazard component, whereby biophysical as well as socio-economic impacts were taken into consideration. The IPCC defines exposure as the presence of people, infrastructure, ecosystems, and other assets in places that could be affected by climate hazards (IPCC, 2021a). These facets of exposure are already predominately captured by applying a sectoral approach, as proposed in Smithers and Dworak (2023), i.e. each sector comprises a specific set of elements, entailing that some elements are more relevant in one sector than in another. To allow for a more differentiated perspective, in the present report exposure is understood as the extent to which a respective climate impact within the system is dependent on climate change. While this approach deviates from the IPCC framework, it enables a deeper integration of implicit knowledge—such as perceptions of climate change impacts—with scientific evidence on the actual interactions between climate change and its consequences. By adopting this refined perspective, we enhance the analytical depth of the study and a more nuanced understanding of the interplay between exposure and sensitivity is provided.

The overall process setting followed a participatory approach, allowing stakeholders to become directly involved in the course of the assessment of climate impacts, key risks and strategic directions. While the definitions and the general need for a clear-cut distinction of the concepts “climate impact” and “climate hazard” is recognised, the collaborative nature of the process, which brought together a wide range of stakeholders with different backgrounds and potentially different understandings, meant that a strict separation of the two concepts was not always applied.

The key terms for the present report are described in the box below (EEA, 2024b; GIZ, 2023; IPCC, 2022g; Smithers and Dworak, 2023):

**Adaptive Capacity.** In this report, adaptive capacity describes the *current* ability of systems, institutions, humans and other organisms to adjust to potential damages and climate impacts, to take advantage of opportunities, or to respond to consequences. Adaptive capacity therefore describes the status quo of all presently available adaptation options, including e. g. financial or human resources. The adaptive capacity might differ between risks and sectors (European Environment Agency (EEA), s. a; IPCC, 2021a) and is highly dependent on volatile factors such as political direction, leadership and administrative actions, which decreases the reliability of predictions about its future development. Although the adaptive capacity can adjust and alter flexibly, limits to adaptation might be reached, when a system's needs or an actor's objective cannot be secured from intolerable risks, which threaten 'core social objectives associated with health, welfare security or sustainability' (IPCC, 2022e). Those limits might be soft, when adaptation options exist but are currently not available, or hard, when no adaptive actions are possible or feasible to avoid intolerable risks. Climate change will exacerbate the occurrence of hard limits to adaptation, which have already been reached in some natural ecosystems (IPCC, 2022c). Additionally, not all adaptive measures show an immediate effect. To achieve large-scale adaptation, far-reaching adaptation actions might be necessary, which in turn require longer periods to unfold their full impact. This also encompasses the time needed for preparatory and implementation steps. Examples of sectors with prolonged adaptation times are forestry, the geological environment and soil.

**Climate impact.** A climate impact describes an already observed or possible future, relevant impact of one or more climatic influences on a defined system and/or system components (e. g. livelihoods, social/cultural objects, ecosystems). Climate impacts can be described as consequences or results and can be disadvantageous or advantageous. A climate impact always refers to a specific period. As a rule, the term climate impact is used based on the definition of the IPCC up to the point at which an assessment of the climate risk takes place (GIZ, 2023; Umweltbundesamt (UBA), 2021).

**Climate impact chain.** Climate impact chains (CIC) are used to visualise cause-effect relationships between climate impacts and associated risks as well as cross-sectoral interdependencies (GIZ, 2023). In this report, climate impact chains are structured as the ones developed in the course of the EUCRA (EEA, 2024b), whereby slight adaptations were made.

**Climatic impact driver.** A climatic impact driver describes a changing aspect of the climate system that influences a component of a man-made or natural system. The stronger the climatic influence, the stronger the climate impact tends to be (Umweltbundesamt (UBA), 2021).

**Exposure.** Defined by the IPCC as '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' (IPCC, 2021a). Following the sectoral assessment approach, which focuses on one system (e. g. agriculture) at a time, exposure refers to the extent to which a respective climate impact within the system is dependent on climate change.

**Hazard.** A hazard is defined as the 'potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources' (GIZ, 2023).

**Key risk.** According to the Climate Risk Sourcebook, so-called key risks are defined as having 'potentially severe adverse consequences for humans and social ecological systems resulting from the interaction of climate-related hazards with vulnerabilities of societies and systems exposed' (GIZ, 2023). Contrary to climate risks (see below), key risks have consequences of high magnitude or likelihood, they affect essential systems and functions and might have a critical timing, i. e. severe impacts are already occurring.

**Sensitivity.** Sensitivity is defined as the extent to which a system might be positively or adversely affected by climatic changes and is therefore susceptible to harm. An example might be the demographic age distribution or forest structures (IPCC, 2022e; Umweltbundesamt (UBA), 2021). Factors and indicators determining the sensitivity of a system can be derived from the characteristics and attributes, which make the system susceptible to changing hazards (Deutsches Institut für Normung e. V., 2021).

**Risk.** Risk, or more precisely climate risk refers to the potential for adverse impacts on man-made or natural systems, considering the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise both from the potential impacts of climate change and from human responses to climate change. In connection with the effects of climate change, risks arise from dynamic interactions between climatic influences and the spatial exposure as well as the sensitivity and adaptive capacity of the affected system. The term climate risk is used as soon as the risk is assessed (GIZ, 2023; Umweltbundesamt (UBA), 2021). It has to be noted that the mentioned aspects influencing the risk are subject to spatio-temporal changes and come along with uncertainties (e. g. likelihood of occurrence) (GIZ, 2023).

**Vulnerability.** According to the IPCC, vulnerability is understood as '[t]he 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' (IPCC, 2022a).

## Assessment of climate data and country-specific literature review

Available and relevant climate data was reviewed, assessed and summarised in the process of the CRVA. This was complemented by a literature review, including policy papers, scientific reports and articles. Based on this desk research, a country profile focusing on environmental, demographic, economic as well as infrastructural aspects was derived, and past and future developments of the climate described.

This step also comprised the compilation of relevant and sector-specific climate impacts including their definitions, whereby the sectors were defined in close exchange and in agreement with the client and beneficiary.

## Sector-specific climate impact assessment (workshops)

The overall aim of this step is to conduct a sector-specific climate impact analysis, aiming to assess

a. exposure and sensitivity,
b. climate impacts of high priority,
c. adaptive capacity and
d. urgency to act

of the identified relevant climate impacts. This was done by organising workshops with relevant stakeholders for each sector addressed in the report. In doing so, expert knowledge was fed into the process. This particularly allowed for stakeholder engagement as outlined in the State of Play Report of D2.2. Ahead of the workshops, a webinar was organised to

a. provide background information regarding the project in general and of already accomplished work
b. provide key insights regarding climate change and its impacts on a global and national level
c. explain the methodological approach and how the climate impact assessment is carried out within the scope of the workshop.

The workshops, held in Slovak language, focussed on the

a. assessment of exposure and sensitivity for sector-specific climate impacts and identification of climate impacts of high priority
b. assessment of adaptive capacity and urgency to act in particular for climate impacts of high priority.

The methodological approach used for the assessment is based on frameworks published in recent literature particularly relevant within the European context, namely EEA (2024b), GIZ (2023) and Smithers and Dworak (2023).

In total, 15 workshops were conducted, each addressing one specific sector (Table 40). The identified climate impacts for each sector were discussed in workshops with relevant stakeholders to evaluate exposure and sensitivity, climate impacts of high priority, adaptive capacity and urgency to act.

*Table 40: Schedule of sectorial climate impact assessment workshops.*

| Tuesday, 18th of June | BREAKOUT SESSIONS (IN SLOVAK, IN PERSON) | |
|---|---|---|
| 9:00 – 10:15 | Agriculture | Cultural Heritage |
| 10:30 – 11:45 | Biodiversity & Ecosystems | Information and Communication Technology |
| 13:00 – 14:15 | Forestry | Energy |
| 14:30 – 15:45 | Geological Environment & Soil | Economy & Industry |
| **Wednesday, 19th of June** | **BREAKOUT SESSIONS (IN SLOVAK, IN PERSON)** | |
| 9:00 – 10:15 | Hydrological Regime & Water Resource Management | Transport, Infrastructure & Buildings |
| 10:30 – 11:45 | Health | Disaster Risk Management, Civil Protection & Critical Infrastructure |
| 13:00 – 14:15 | Tourism | Finance |
| 14:30 – 15:45 | Spatial Planning | - |

To assess the exposure and sensitivity a classification based on five scales was used, i.e. *very low*, *low*, *medium*, *high*, *very high*. The definitions for the respective categories of exposure and sensitivity are displayed in Table 41 and Table 42 were derived based on IPCC (2021a), IPCC (2022e), Umweltbundesamt (UBA) (2021) and ISO. Thereby, exposure is understood by the IPCC (2021a) as 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". Following the sectoral assessment approach, which focuses on one system (e. g. agriculture) at a time, exposure refers to the extent to which respective climate impact within the system is dependent on climate change.

*Table 41: Definition of exposure as used within the scope of this project.*

| Exposure to climate change conditions and natural hazards | |
|---|---|
| Rating | Definition |
| Very low | • The climate impact or hazard is only influenced by parameters not related to climatic changes. |

| | |
|---|---|
| Low | • The climate impact or hazard is influenced mostly by parameters not related to climatic changes. |
| Medium | • The climate impact or hazard is equally influenced by both climate-related and non-climate-related parameters. |
| High | • The climate impact or hazard is strongly influenced by parameters related to climatic changes. |
| Very high | • The climate impact or hazard is entirely influenced by parameters related to climatic changes. |

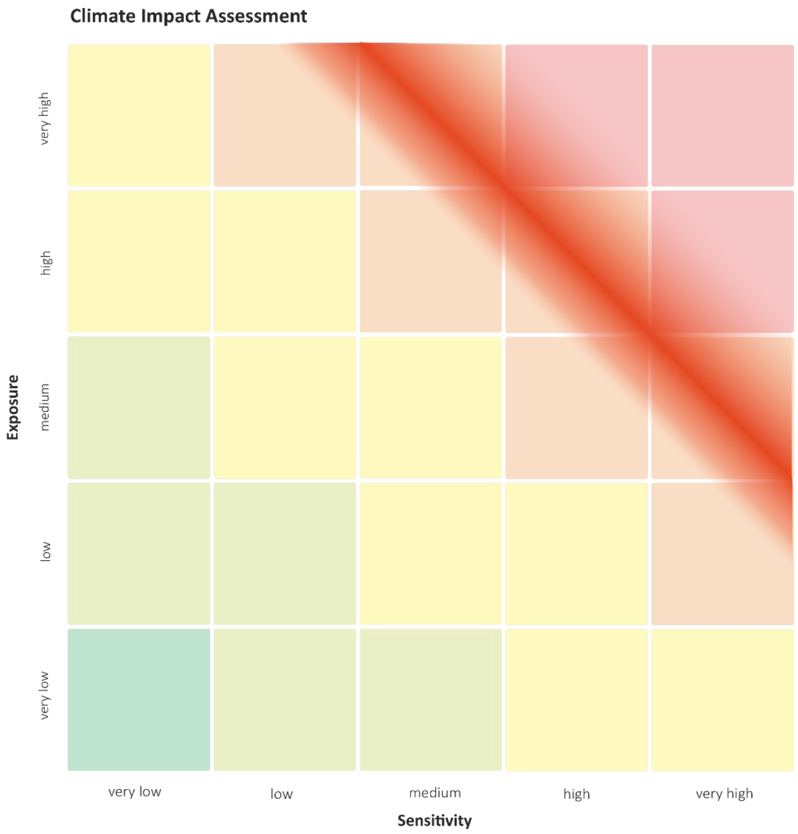
Sensitivity is defined by the IPCC (2021a) as the extent to which a system could be positively or adversely affected by climatic changes and is therefore susceptible to harm. An example might be the demographic age distribution or forest structures.

*Table 42: Definition of sensitivity as used within the scope of this project. Definition based on IPCC (2021a).*

| **Sensitivity** of the system to climatic changes | |
|---|---|
| Rating | Definition |
| Very low | • Very few or no system elements influence, either positively or negatively, the extent of the potential impact |
| Low | • Few system elements influence, either positively or negatively, the extent of the potential impact |
| Medium | • Some system elements influence, either positively or negatively, the extent of the potential impact |
| High | • Many system elements influence, either positively or negatively, the extent of the potential impact |
| Very high | • A high number of system elements influence, either positively or negatively, the extent of the potential impact |

In the workshops, matrices as exemplary shown in Figure 7 were used for each sector to rank the identified climate impacts. Thereby, alpS Consult provided a proposal for the assessment, which was then discussed in the sectorial groups. Changes were made by the workshop participants if necessary. Two types of impact categories were assessed, namely biophysical or direct impacts and socio-economic or indirect impacts. The latter are marked by a yellow frame.

*Figure 7: 25-field matrix template for sectoral climate impact assessments. Climate impacts above the red blurred line are climate impacts of high priority, which are considered for in-depth analysis. Please note that the red line is not a sharp border, but rather serves as an orientation for demarcation.*



For climate impacts of high priority, denoted by the red line, i.e. with high or very high exposure and sensitivity, the adaptive capacity and urgency to act were assessed.

*Box 1: Note regarding ratings of adaptive capacity and urgency to act for climate impacts.*

Please note that for some sectors an in-depth assessment of climate impacts, a detailed assessment of both adaptive capacity and urgency to act was not possible due to time constraints and intensive exchange among participants. As local and sector-specific expertise is crucial for such an assessment, alpS Consult and the international consortium did not complement this information after the workshops based on the feedback provided by singular experts. Besides, in some sectors, ratings for adaptive capacity and urgency to act were made even though they are not climate impacts of high priority according to this definition as workshop participants deemed it necessary to do so.

Within the scope of this project, the adaptive capacity incorporates two sub-categories, namely the governance framework in place and the financial capability. The definitions for the governance framework are based on United Nations Office for Disaster Risk Reduction (UNDRR) (2022), financial capability is defined according to Deutsches Institut für Normung e. V.. As shown in Table 43, the sub-category governance framework asks for making statements about various government instruments like policy instruments, legal frameworks and institutional structures and to what degree they are in place in order to support taking action sufficient action in terms of adaptation. Financial capability explicitly deals with financial resources for identifying, evaluating (cost-benefit rating), implementing and updating adaptation measures and to what extent these resources are available and devoted accordingly.

Both, the adaptive capacity as well as the sensitivity assessed in course of the process comprise the vulnerability.

*Table 43: Definition of adaptive capacity as used within the scope of this project. Adaptive capacity is composed of two factors, i.e. Governance Framework and Financial Capabilities. Defintions based on United Nations Office for Disaster Risk Reduction (UNDRR) (2022) and ISO, 2021.*

| Adaptive Capacity<br>of a system to climatic changes<br>entails two aspects essential for assessing Adaptive Capacity on a national level,<br>i.e. *Governance Framework* and *Financial Capability* | | |
|---|---|---|
| Rating | Definition Governance Framework | Definition Financial Capability |
| Low | No or very little/insufficient government instruments (i.e. policy instruments, legal frameworks, regulations, institutional structures & procedures and resources) are in place, lowering or impeding transparent, inclusive, collective and efficient government responses | No or very little/insufficient financial resources for identifying, evaluating (cost-benefit rating), implementing and updating adaptation measures are available and devoted accordingly |
| Medium | Some/partially sufficient government instruments (i.e. policy instruments, legal frameworks, regulations, institutional structures & procedures and resources) are in place, making transparent, inclusive, collective and efficient government responses partially possible | Some/partially sufficient financial resources for identifying, evaluating (cost-benefit rating), implementing and updating adaptation measures are available and devoted accordingly |
| High | Sufficient government instruments (i.e. policy instruments, legal frameworks, regulations, institutional structures and resources) are in place, enabling transparent, inclusive, collective and efficient government responses | Sufficient financial resources for identifying, evaluating (cost-benefit rating), implementing and updating adaptation measures are available and devoted accordingly |

The urgency to act was also included in the assessment, as it is also part of the climate risk evaluation procedure as proposed in the Climate Risk Sourcebook (GIZ, 2023) and is explicitly addressed in the EUCRA report (EEA, 2024b). Whereas the Climate Risk Source Book does not provide a particular ranking according to which an evaluation could be conducted, the EEA suggests five levels of urgency. These served as the foundation to derive the three levels used within this report. The definition of each level can be found in Table 44.

*Table 44: Definition of adaptive capacity as used within the scope of this project. Definition based on EEA (2024b).*

| Urgency to Act | |
|---|---|
| Rating | Definition |
| Low | • Current implemented and planned adaptation measures, actions and hence policy readiness are appropriate<br>• Continued implementation of planned measures and actions as well as evaluation, monitoring and improvement of existing measures and actions is sufficient |
| Medium | • Current implemented and planned adaptation measures, actions and hence policy readiness are limitedly sufficient<br>• Processes to strengthen adaptation measures and actions have to be initiated based on evidence-based knowledge gathered through research, monitoring or evaluation |
| High | • Current implemented and planned adaptation measures, actions and hence policy readiness are insufficient<br>• New, stronger and/or different adaptation measures and actions have to be implemented |

It should be noted that climate impacts with a high exposure/sensitivity assessment are associated with a greater need for adaptation. Besides, only the current situation with respect to both sub-categories is taken into account.

As a follow-up to the sectoral workshops, minutes covering all assessment results and additional notes (i.e. further information such mentioned by the experts e.g. regarding adaptation measures, regional hot spots) gathered through the discussions were sent to participants who had the possibility to provide feedback.

## Development of sector-specific Climate Impact Chains (CIC)

In this step, sector-specific climate impact chains were elaborated and visualised for each sector assessed in the present report, highlighting the interconnectedness of the different impacts assessed. Non-climatic risk drivers as well as relevant exposed subsystems were collected, drawing a comprehensive and concise picture of the climate impact and risk landscape in the respective sector.

Since different approaches exist for structuring and describing such impact chains, the relevant literature was reviewed to choose the most suitable approach. Among the reports and literature considered are the Climate Risk Sourcebook (GIZ, 2023), the Vulnerability Sourcebook (Fritzsche et al., 2014), climate impact chains developed by the German Federal Environmental Agency (Umweltbundesamt (UBA), 2016) as well as the EUCRA published in 2024 by the EEA (2024b). Based on internal discussions on the advantages and disadvantages of each approach, it was decided in consultation with the beneficiary to develop climate impact chains according to the EEA (2024b). This decision was made for several reasons. Firstly, the structure of the climate impact chains is clear-cut and thus important information can be grasped at first glance making the impact chains easy to understand and to use. Secondly, compared to other approaches, the EEA explicitly considers exposed subsystems. Together with cross-sectoral connections, this supports a systemic and hence more holistic view of climate impacts in a certain sector. Thirdly, and most importantly, the report is the most recent one provided by an institution of the European Union setting important standards for climate risk assessment. In addition to that, the framework and assessment approach used by EUCRA is based on the risk concept of the 6th IPCC Assessment Report (IPCC, 2022a) and relevant ISO standards, i.e. ISO 31000 (ISO, 2018) dealing with risk management and ISO 14091 focusing on adaptation to climate change (ISO, 2021). CIC, depicted in each sector-specific chapter, cover the following aspects: a) climate-related hazards/climate impact drivers, b) non-climatic risk drivers, c) direct and/or indirect climatic impacts, d) exposed subsystems, e) key risks and g) cross-sectoral connections.

Climate-related hazards, or climate impact drivers and non-climatic risk drivers are both broadly understood as risk drivers. Climate-related hazards are defined according to the categories of the EU Taxonomy (European Commission, 2021a), i.e. temperature-related, wind-related, water-related and solid mass-related and aligned with the IPCC WGI Interactive Atlas (2021c) . Non-climatic risk drivers are defined as 'processes and conditions that determine how certain climate-related hazards, individually or in combination, affect a human or ecological system' (EEA, 2024b). They range from environmental stressors to technical, socio-economic factors as well as policy aspects (EEA, 2024b). Direct and/or indirect climate impacts were identified through literature research building the foundation of the later derived key risks. In contrary to the EUCRA report which uses the term 'major climate risk', the term 'key risk' is used, according the Climate Risk Sourcebook, in the present report to describe risks which 'have potentially severe adverse consequences for humans and social ecological [sic!] systems resulting from the interaction of climate-related hazards with vulnerabilities of societies and systems exposed' (GIZ, 2023).

## Assessment of current climate risk (workshop), future climate risk without adaptation and strategic directions

The climate impact assessment served as a basis determining and formulating key climate risks within each sector. They reflect the current climate impact situation, considering climate impacts of high priority, the exposed subsystems, non-climatic risk drivers and recent climate developments. In a first step, all rankings for each climate impact were summarised in a table (see template in Table 45 and sector-specific chapters).

*Table 45: Template to compile all assessed aspects of the climate impacts considered in the analysis, i.e. during the sectoral workshops.*

| Sector | | | | | |
|---|---|---|---|---|---|
| Climate Impact | Exposure | Sensitivity | Adaptive Capacity | | Urgency to act |
| | | | Governance Framework | Financial Capabilities | |
| Climate Impact 1 | | | | | |
| Climate Impact 2 | | | | | |
| Climate Impact 3 | | | | | |

Based on the climate impact assessment and in consideration of prioritised impacts, adaptive capacity and urgency, key risks were prepared by alpS Consult and discussed within a workshop with relevant stakeholders and local experts. Similarly, strategic directions reflecting the risk landscape per sector were discussed in a workshop with the Ministry of Environment and other stakeholders. These strategic directions serve as an essential foundation for D2.4 aiming at deriving recommendations to support the revision and update of the current adaptation strategy.

The assessment of current climate risk is then undertaken for identified key risks which can consist of various climate impacts. The risk classification is based on five scales, i.e. *very low*, *low*, *medium*, *high*, *very high* as defined in Table 46.

*Table 46: Template for key risk assessments currently and in the near and far future.*

| Key Risk | Current Risk Assessment | Near Future | | Far Future | | Temporal Dynamics | Spatial Variability |
|---|---|---|---|---|---|---|---|
| | | Optimistic | Pessimistic | Optimistic | Pessimistic | | |
| KR-xx-1<br>Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumy eirmod | medium | medium | high | high | very high | slow onset | national<br>local |
| KR-xx-2<br>Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumy eirmod | low | medium | medium | medium | high | slow onset | national<br>regional |

The assessment of future climate risk is conducted for each identified key risk. With respect to the time horizon, it is differentiated between the near and far future, i.e. 2021-2050 and 2071-2100. Besides that, two climate scenarios based on the Representative Concentration Pathways (RCP) are taken into account, namely RCP4.5 (optimistic scenario) and RCP8.5 (pessimistic scenario). The risk classification is based on five scales, i.e. *very low*, *low*, *medium*, *high*, *very high*. In addition, the temporal dynamics (e. g. acute or slow onset events) as well as potential spatial variabilities are shown. Temporal dynamics are based on the EU Taxonomy (see German Environment Agency (GEA), 2022), i.e. *slow onset* means that the risk unfolds on longer time scales and is related to 'chronic' climate trends, *acute* means that the risk rather related to urgent climate-related (extreme) events. The spatial variability indicates at which spatial scale the risk is of particular relevance (local = spatially limited / specific local areas or communities; regional = larger areas or communities e.g. at the level of administrative regions; national = relevant at country level). (see German Environment Agency (GEA), 2022)

## Assessment of transboundary, cascading, new and emerging risks, cross-sectoral interdependencies as well as knowledge gaps and uncertainties

The sector-specific analysis is complemented by an exemplary assessment of transboundary, cascading, new and emerging risks. Cross-sectoral interdependencies as well as knowledge gaps and uncertainties are also addressed. Following the workshop on key risks and strategic directions, appropriate risks were exemplarily allocated to the transnational, cascading new or emerging classification to illustrate the topics using a Slovak-specific case.

Any knowledge gaps and uncertainties were collected during the preparation of Deliverable (D2.3) and linked to recent scientific findings, especially regarding tipping points.

# Annex B: Country Profile & further information on climate indicators

## Nature & Environment

Slovakia is located in Central Europe, 19° east of Greenwich and 48° north of the equator. It is a landlocked country bordering Poland, Ukraine, Hungary, Czechia and Austria. Its geographical size covers 49 035 km² with a population of approx. 5.5 million people. Bratislava is the capital city (CIA.gov, 2024). The country features the Carpathian mountain range in the north and central regions, transitioning to the Danube lowlands in the south. The country is well-settled and urbanised. Besides Bratislava, major towns like Banská Bystrica, Košice, Nitra, Prešov and Žilina, each have over 80 000 residents, and serve as regional centres. Numerous small towns, particularly in historic mining areas, are also significant for their mineral and thermal springs, attracting tourists. Slovakia has nearly 2 900 villages, though rural settlements in some mountainous regions are scattered (Carter and Turnock, 2002).

### Geology, Flora and Fauna

The geology of Slovakia is shaped by tectonics, erosion, and sediment deposition. Located in Central Europe, the country is characterised by the Western Carpathians in the north and a Cenozoic basin system in the central and southern regions. The Western Carpathians, part of the larger Alpine orogenic system, were formed by the closure of the Tethys and Alpine oceans during the Mesozoic and Cenozoic eras. This mountain range is divided into three tectonic zones: the Outer, Central, and Inner Western Carpathians. The Outer zone includes the Paleogene to Neogene Carpathian flysch belt in the north. The Central zone, which dominates Slovakia, consists of Late Jurassic to Cretaceous nappe units separated by the Pieniny Klippen Belt and includes the Tatricum, Veporicum, and Gemericum units. The Inner zone in the south is composed of Jurassic accretionary wedges such as the Meliata, Turňa, and Silica nappes. The region also features Upper Cretaceous to Neogene basins and volcanic formations (Lehotský and Boltižiar, 2022).

Around 55% (26 803 km²) of Slovakia`s total area of 48 920 km² is forested, approx. 38 % (18 385 km²) is cropland and slightly below 5 % (2 296 km²) is built-up (status 2019; Copernicus, 2019). In the forests, broad-leaved species are predominant in the lowlands and hills of the south and east. In the central and northern mountains, mixed forests with a dominance of coniferous species are common, particularly featuring spruce, fir and beech (Figure 8).

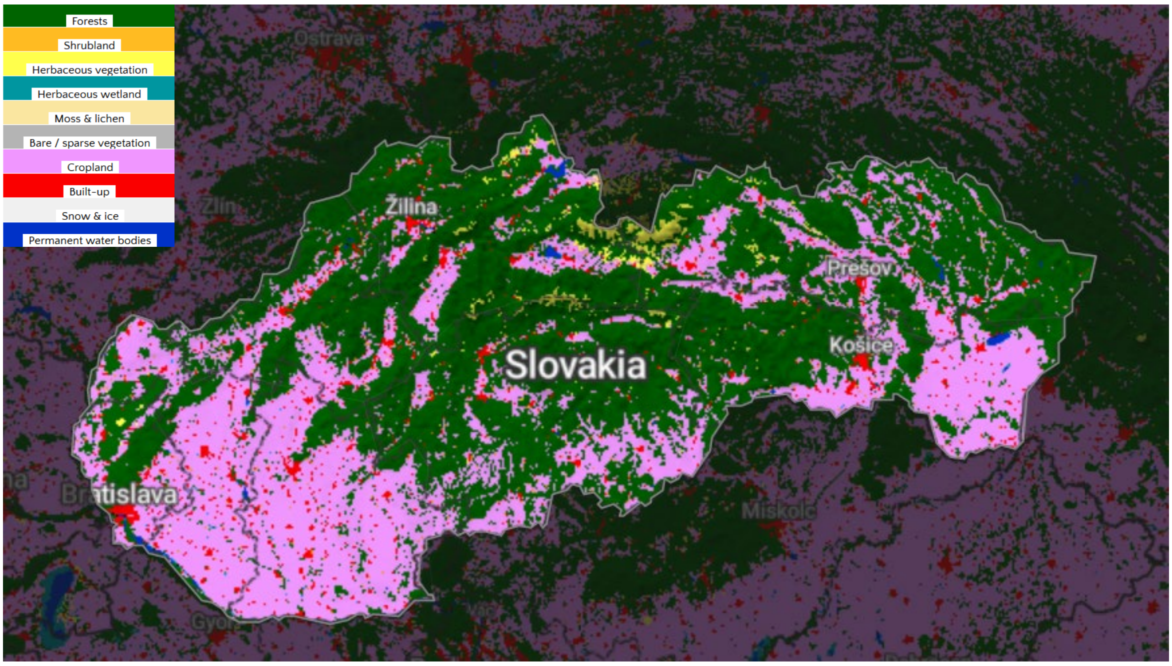


*Figure 8: Land cover of Slovakia (Copernicus, 2019).*

Due to its geographic position between the Carpathian Mountains and the Pannonian lowland areas Slovakia poses a rich diversity of flora and fauna with more than 11 300 plant and 28 800 animal species. Of these, 45 % of fish species, 100 % of amphibian species, 100 % of reptile species, 32 % of bird species and 65 % of mammal species are endangered (Libor et al., 2018; SCBD, n.d.).

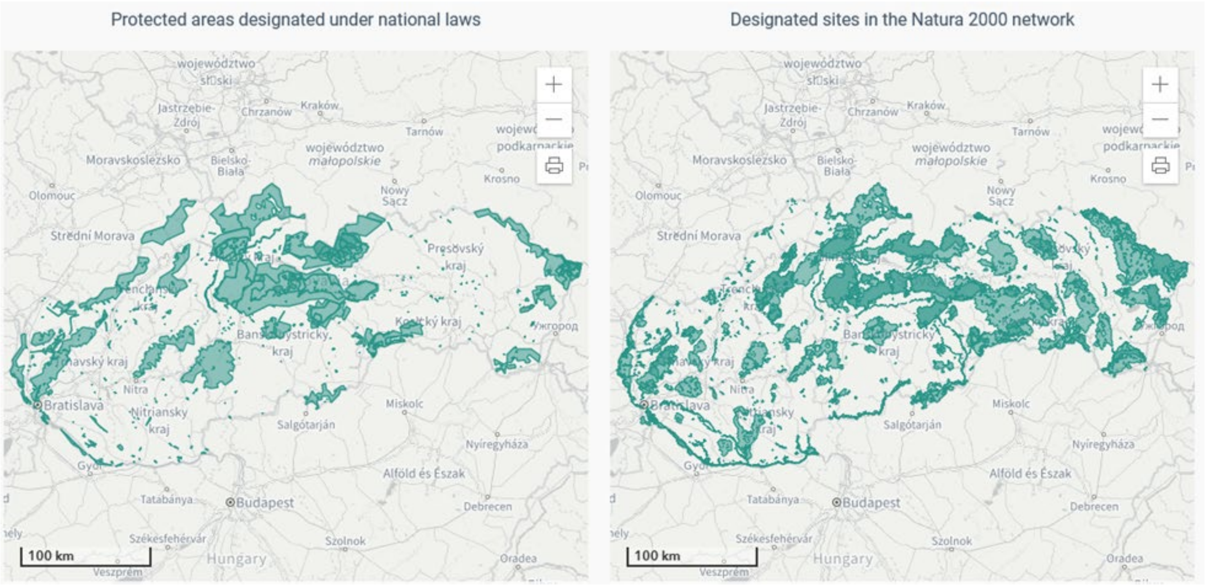
### Protected Areas

Slovakia has more than 3 000 protected areas, of which 2 510 sites are protected under national laws and 780 are recognised as Natura 2000 sites, covering 430 species and 66 habitats from the nature directives. There are a total of 9 national parks in the country. The protected areas of the country cover more than 18 000 km$^2$ or about 37 % of the total area, which is above the EU average of 26.4 %, but it has a relatively high number of small protected areas. 71 % are smaller than 1 km$^2$ (EEA, 2024a).

Amongst the key threats to biodiversity are habitat fragmentation from increased transport infrastructure, reduced use of arable land, especially grasslands, due to declining livestock farming and agricultural unprofitability, endangering rare species, and invasive species proliferating due to agricultural, forestry, and construction activities (SCBD, n.d.).

72.9 % of the protected areas are forests – which are the predominant ecosystem type of Slovakia. Of particular importance are primaeval forests as they almost remained not disturbed by human activities. Examples for such forest areas are the Badínsky primeval forest reserve as well as the Poloniny and Vihorlat areas, the latter both being protected as UNESCO heritage sites (Ministry of Foreign and European Affairs of the Slovak Republic, 2023). The importance of preserving and maintaining the management of agricultural landscapes for biodiversity is recognised by the designation of a high area of protected agroecosystems (23.1 % of the protected areas; EEA, 2024a).

The most important protected areas in terms of the absolute number of protected species are the sites Devínske jazero (113 species), Gajarské alúvium Moravy (100 species), Jakubovské rybníky (88 species), Nízke Tatry (54 species) and Muránska planina- Stolica (48 species; EEA (2024a)). The spatial distribution of both protected areas under national laws and under the Nature 2000 directive are shown in Figure 9.



Protected areas designated under national laws

Designated sites in the Natura 2000 network

*Figure 9: Spatial distribution of protected areas of Slovakia (EEA, 2024a).*

The Strategy of the Environmental Policy of the Slovak Republic aims to tackle biodiversity loss by 2030. The goal is to restore at least 15 % of degraded ecosystems, such as the upper forest boundary, salt marshes, wetlands, peat bogs, and lowland forests, which have been significantly affected by human activity (Ministry of Environment of the Slovak Republic, 2020).

# Demography

Slovakia's demographics are undergoing a shift. The population hovers around 5,6 million (CIA.gov, 2024), but an aging citizenry and potential labour shortages pose significant challenges.

In Slovakia Roman Catholicism is the majority religion with 55.8 % of the population, 5.3 % are members of the Evangelical Church of the Augsburg Confession, 4 % are Greek Catholic and 1.6 % Reformed Christians. About one quarter of the population (23.8 %) has religious affiliation (status 2021; CIA.gov, 2024).

## Age structure

In 2021, 15.3 % of the population are in the 0-14 years age-range, 66.5 % are 15–64-year-old and 18.1 % ≥65-year-old (2024 est.). The population pyramid shown in Figure 10 illustrates the distribution of the population by age group and gender with the narrowing of the pyramid at lower age groups illustrating the trend of declining birth rates.

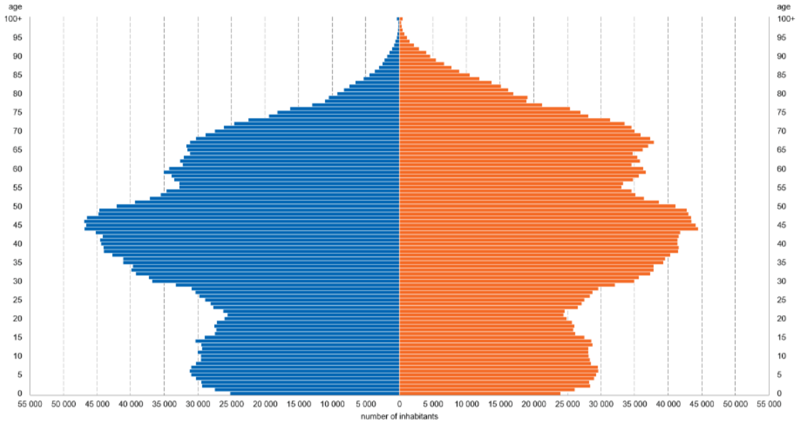
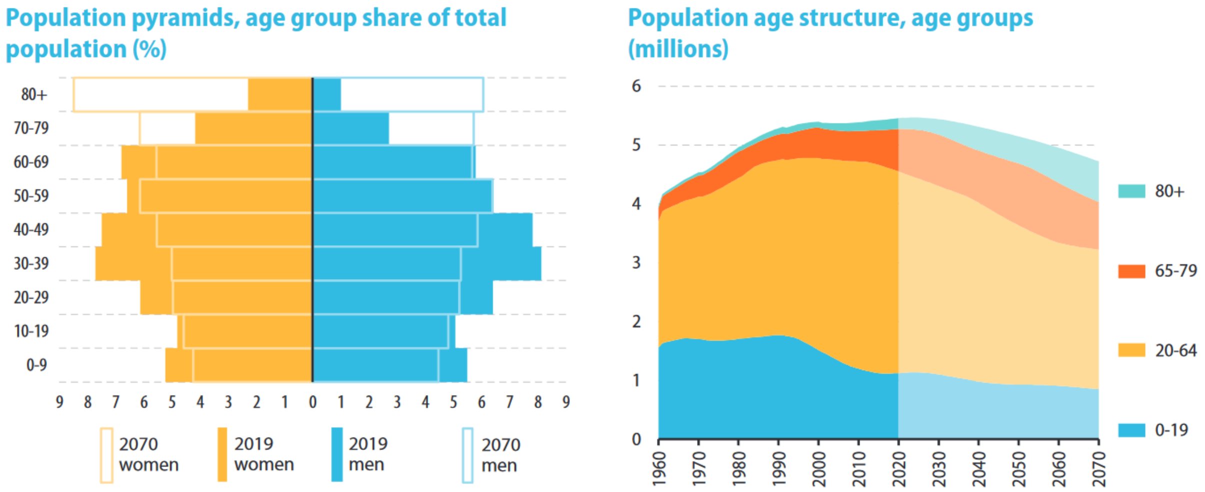


*Figure 10: Population pyramid for Slovakia (2023; Statistical Office of the Slovak Republic, 2024).*

Projections for future population and age groups of Slovakia show an aging population (see Figure 11). Especially the groups of 70+-year-olds will be growing, while all others will decline. Projections of the population development indicate a decline in the total population by (Figure 11), which would put significant pressure on the country's social and health system in the future.


Population pyramids, age group share of total population (%)

Population age structure, age groups (millions)

*Figure 11: Age structure and projections for 2070 in Slovakia (eurostat 2020).*

## Employment

The labour force participation rate of Slovakia amounted to 94 % of the population in 2023 and remained unchanged in the first quarter of 2024. The employment rate was at 72 % in the first quarter of 2024. Looking at the period from 1998 until 2024, the average employment rate was 62.1 % with a maximum of 72.7 % in the fourth quarter of 2023. (Figure 12; Trading Economics, 2024a). While the unemployment rate was at 4.9 % in May 2024, the youth unemployment rate was 20.6 %. In comparison to that, the European Union showed an unemployment rate of 6 % and a youth unemployment rate of 14.4 % in May 2024 (Trading Economics, 2024b).

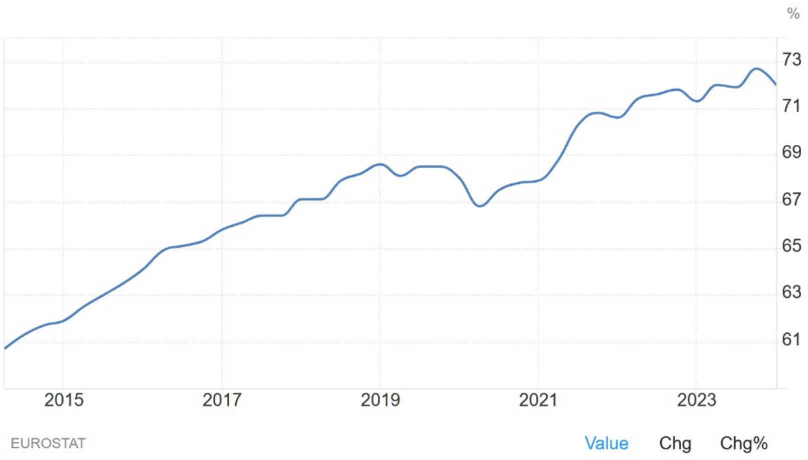


*Figure 12: Employment rate of Slovakia from 2014 to the first quarter of 2024 (Trading Economics, 2024a).*

Regarding the employment and education of Slovakian young adults (18- to 24-year-olds), it can be stated that the majority of young people are either in education, employment or both. The proportion of women who are neither employed nor in education is slightly higher (15 %) than that of men (11 %). The unemployment rate by education level of the working population aged 15 to 74 shown in Figure 13 reveals high unemployment (30.9 %) among the population with a low education level. Unemployment among the population with a medium and high education level is comparatively negligible at 4.8 % and 2.5 % respectively (Eurostat, 2020).

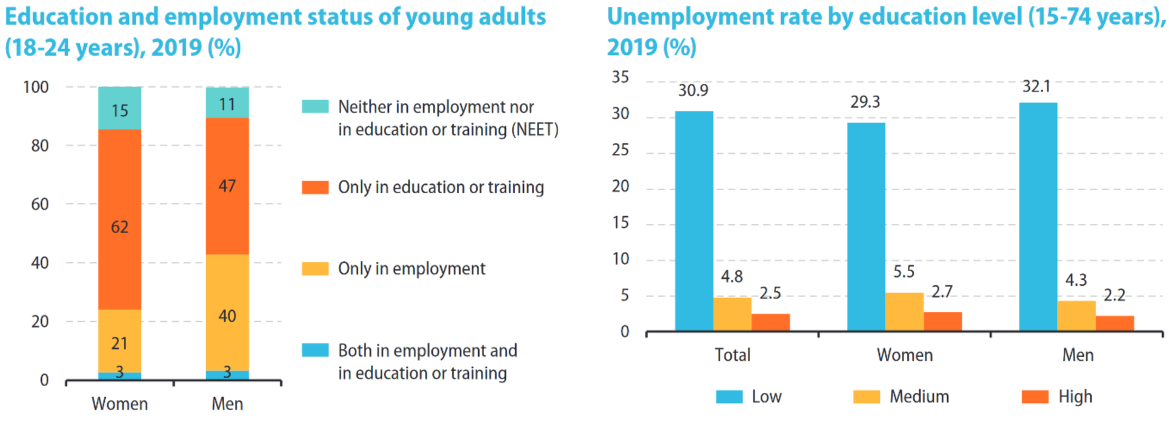
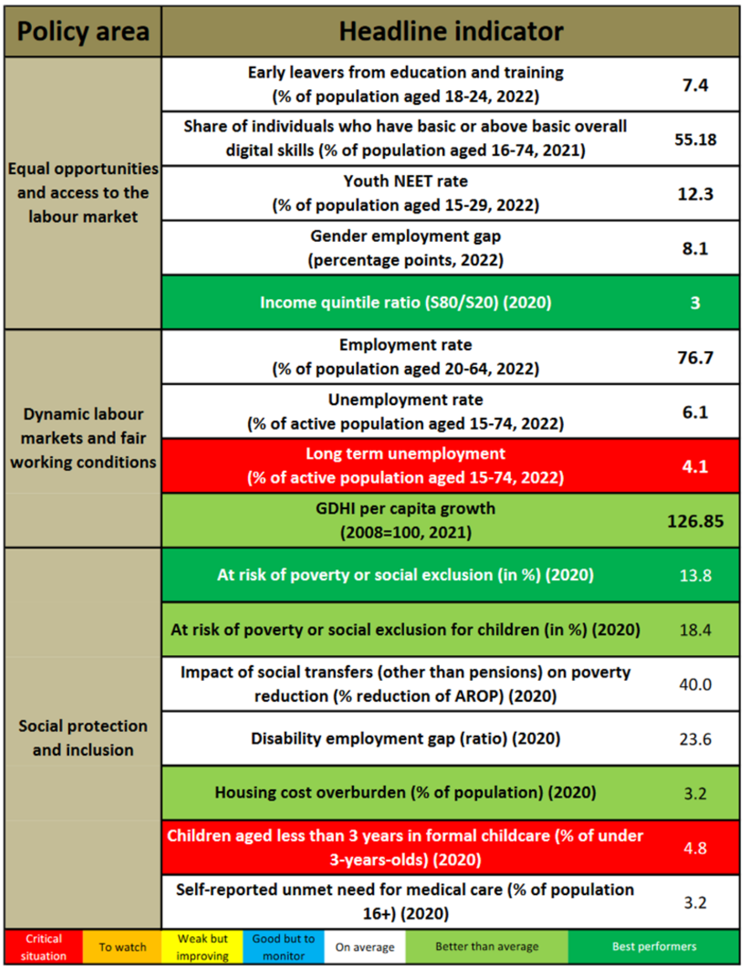


*Figure 13: Education and employment status of young adults and employment rate by education level (status 2019; eurostat 2020).*

The Social Scoreboard depicted in Figure 14 provides an overview on levels and changes of selected indicators in comparison with the respective EU averages (European Commission, 2023a). Although the Slovak labour market recovered after the COVID-19 crisis, long-term unemployment is still a challenge. 66.7 % of jobseekers in Slovakia are long-term unemployed whereas the EU average is 37.7 %. Another major challenge is the insufficient childcare provision for children under 3-years old, reflected by a relatively low labour market participation of women with young children, contributing to the persisting gender pay gap. The gender pay gap of 15.8 % is above the EU average of 13 %.



| Policy area | Headline indicator | |
|---|---|---|
| Equal opportunities and access to the labour market | Early leavers from education and training (% of population aged 18-24, 2022) | 7.4 |
| | Share of individuals who have basic or above basic overall digital skills (% of population aged 16-74, 2021) | 55.18 |
| | Youth NEET rate (% of population aged 15-29, 2022) | 12.3 |
| | Gender employment gap (percentage points, 2022) | 8.1 |
| | Income quintile ratio (S80/S20) (2020) | 3 |
| Dynamic labour markets and fair working conditions | Employment rate (% of population aged 20-64, 2022) | 76.7 |
| | Unemployment rate (% of active population aged 15-74, 2022) | 6.1 |
| | Long term unemployment (% of active population aged 15-74, 2022) | 4.1 |
| | GDHI per capita growth (2008=100, 2021) | 126.85 |
| Social protection and inclusion | At risk of poverty or social exclusion (in %) (2020) | 13.8 |
| | At risk of poverty or social exclusion for children (in %) (2020) | 18.4 |
| | Impact of social transfers (other than pensions) on poverty reduction (% reduction of AROP) (2020) | 40.0 |
| | Disability employment gap (ratio) (2020) | 23.6 |
| | Housing cost overburden (% of population) (2020) | 3.2 |
| | Children aged less than 3 years in formal childcare (% of under 3-years-olds) (2020) | 4.8 |
| | Self-reported unmet need for medical care (% of population 16+) (2020) | 3.2 |

| Critical situation | To watch | Weak but improving | Good but to monitor | On average | Better than average | Best performers |
|---|---|---|---|---|---|---|

*Figure 14: Social Scoreboard for Slovakia, 2023. Classification according to a statistical methodology agreed with the EMCO and SPC Committees, Source: European Commission (2023a).*

# Economic & Infrastructural Situation

## Economy

Slovakia became an EU member in 2004 and implemented the Euro as its official currency five years later. Its economy is highly dependent on exports and manufacturing (with a significant car manufacturing sector). The industry sector accounted for 28.6 % of the gross domestic product (GDP) in 2022 (European Commission, 2023a). GDP per capita amounted to € 22 090 in the year 2023.

The European Commission’s country report on Slovakia from 2023 (European Commission, 2023a) states that Slovakia's economy faces moderate growth prospects for the near future due to global slowdowns, high commodity prices, and rising labour costs. Inflation is projected to peak at 10.9 % in 2023, driven by energy costs, food prices and tight labour supply. Structural challenges include low labour productivity, significant regional disparities, high youth unemployment and inadequate investment in green and digital transitions. To enhance long-term productivity and competitiveness, Slovakia needs to advance its industrial transition towards sustainability, increase R&I spending, and address labour market mismatches, particularly through reskilling and upskilling initiatives (European Commission, 2023a).

## Energy

Total primary energy consumption in Slovakia in 2023 was 186.6 TWh, whereby the share from fossil fuels lies at 63.7 %, 24.5 % from nuclear and 11.8 % from renewable sources (mainly hydropower) in 2023 (Figure 15; Our world in data, 2024).

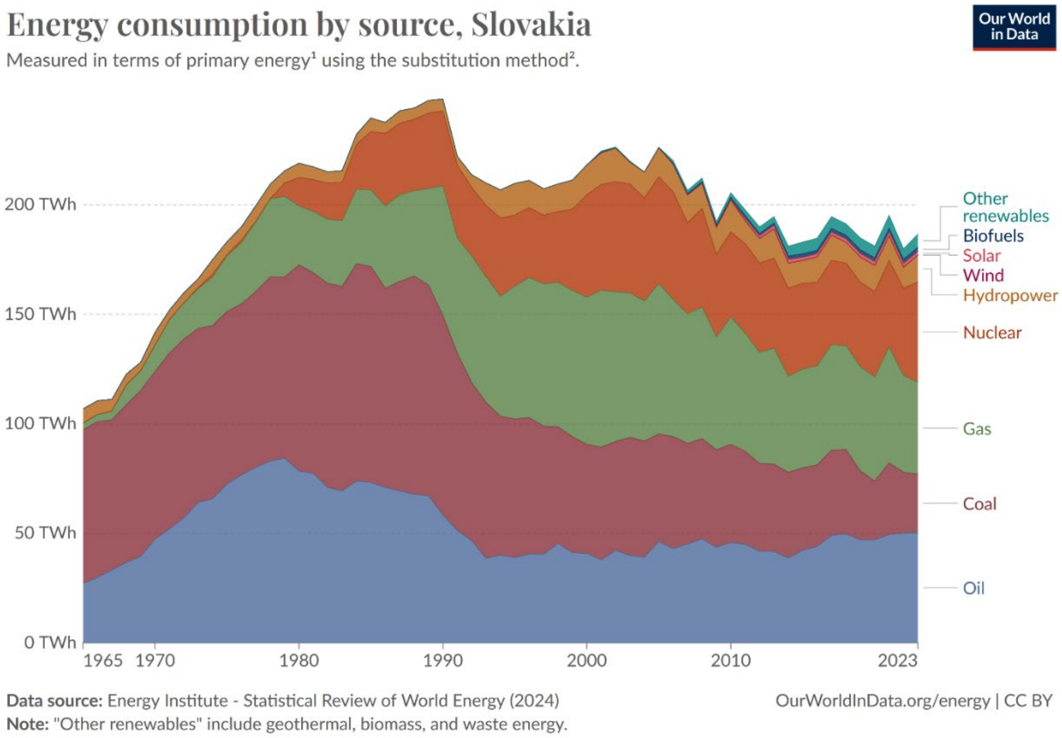
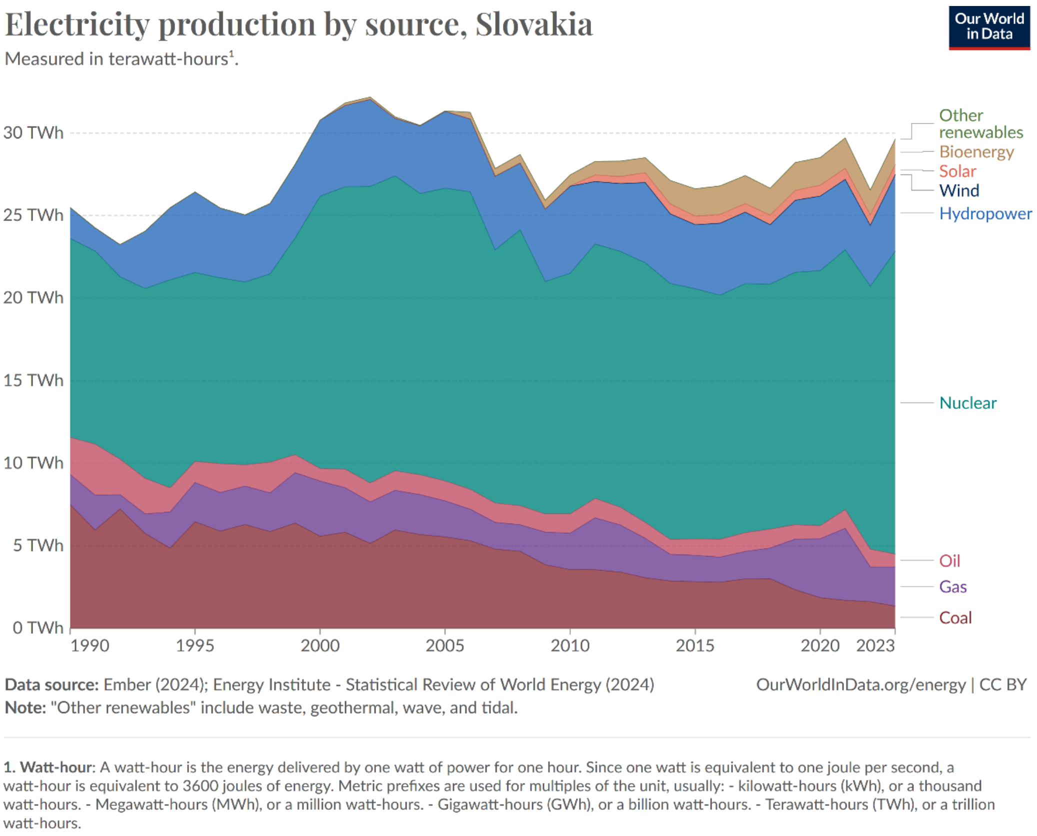


*Figure 15: Energy consumption by source in Slovakia from 1965 to 2023 (Our world in data, 2024).*

Looking at the electricity production (Figure 16), the country produced a total of 29.63 TWh in 2023. There has been a decline in oil, gas, and coal-based energy in recent decades, however the biggest share of electricity production (61.9 %) stems from nuclear energy. Just over 22 % are based on renewables (hydro, bioenergy and solar). Please note that, in line with Slovakia's coal phase-out strategy, lignite mining ceased in December 2023.



**Electricity production by source, Slovakia**

Measured in terawatt-hours[1].

**Data source:** Ember (2024); Energy Institute - Statistical Review of World Energy (2024) OurWorldInData.org/energy | CC BY

**Note:** "Other renewables" include waste, geothermal, wave, and tidal.

1. **Watt-hour:** A watt-hour is the energy delivered by one watt of power for one hour. Since one watt is equivalent to one joule per second, a watt-hour is equivalent to 3600 joules of energy. Metric prefixes are used for multiples of the unit, usually: - kilowatt-hours (kWh), or a thousand watt-hours. - Megawatt-hours (MWh), or a million watt-hours. - Gigawatt-hours (GWh), or a billion watt-hours. - Terawatt-hours (TWh), or a trillion watt-hours.

*Figure 16: Electricity production by source in Slovakia from 1990 to 2023 (Our world in data 2024).*

From 1990 to 2021, Slovakia has achieved a 38% reduction in greenhouse gas emissions, although the reduction has largely stalled in recent years. In 2021, emissions per capita ranged from 6.1 $tCO_2$ equivalent in Central Slovakia to 10.7 $tCO_2$ equivalent in the Bratislava capital region. Comparatively, the average carbon footprint per capita in the EU stood at 8 $tCO_2$ equivalent (European Commission, 2023a)

## Infrastructure

The Slovak transportation network is well-established. This includes an extensive network of roads and railways crucial for Slovakia's position as a manufacturing and transit hub (World Data, 2024b). Nevertheless, the country now faces challenges in maintaining and modernising its aging infrastructure (European Commission, n. d.). Limitations exist in infrastructure capacity, hindering efficient handling of increased freight traffic and modern logistics needs. Additionally, gaps are evident in specific areas like high-speed rail and digital connectivity in rural regions.

Looking forward, opportunities exist to leverage EU Cohesion Funds for vital infrastructure projects, particularly in the transportation and energy sectors (European Commission, 2023c). Modernising infrastructure with a focus on sustainability, such as electric vehicle charging networks or energy-efficient buildings, presents another essential need.

# Additional Climate Data

## Temperature-related climate data

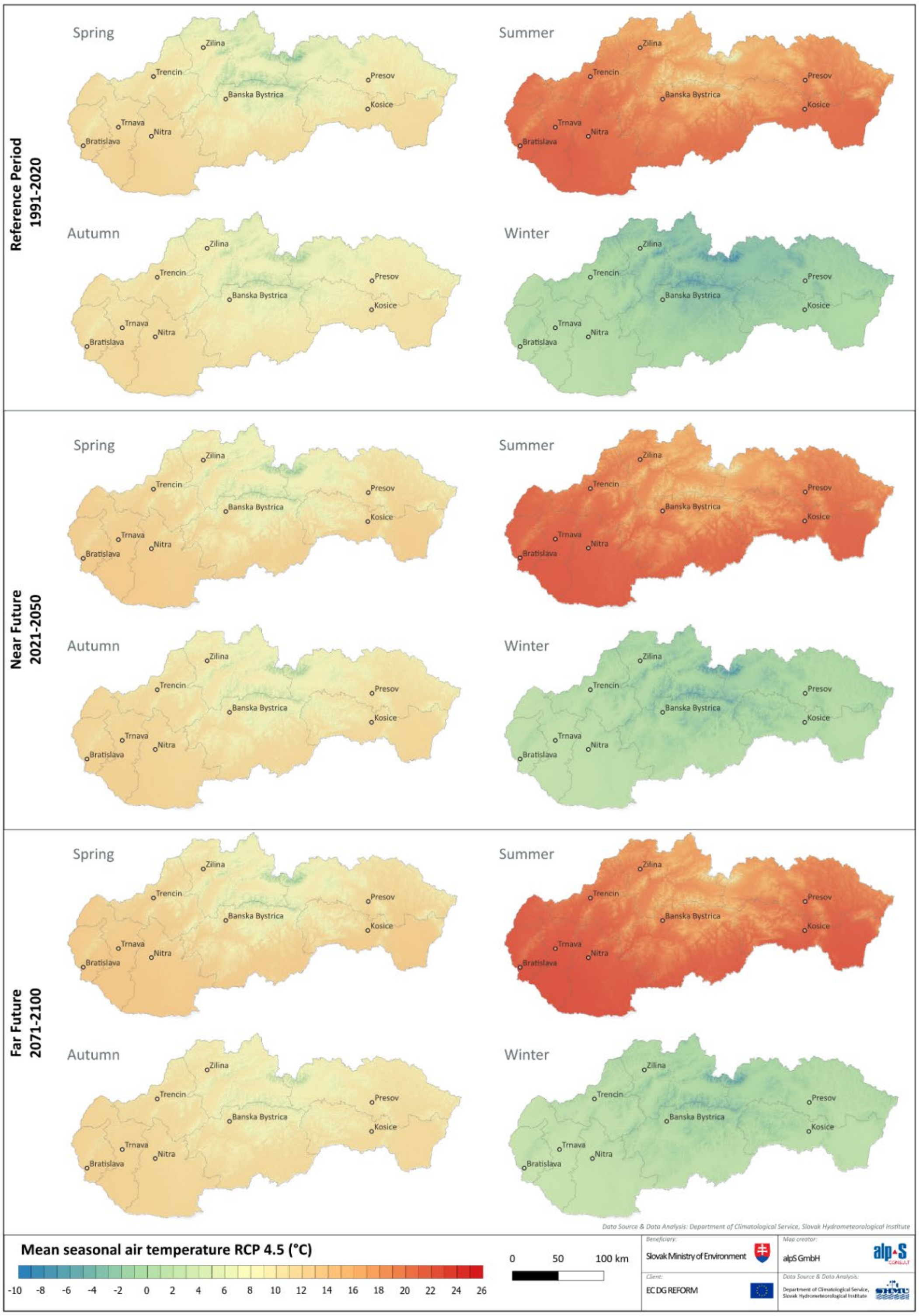
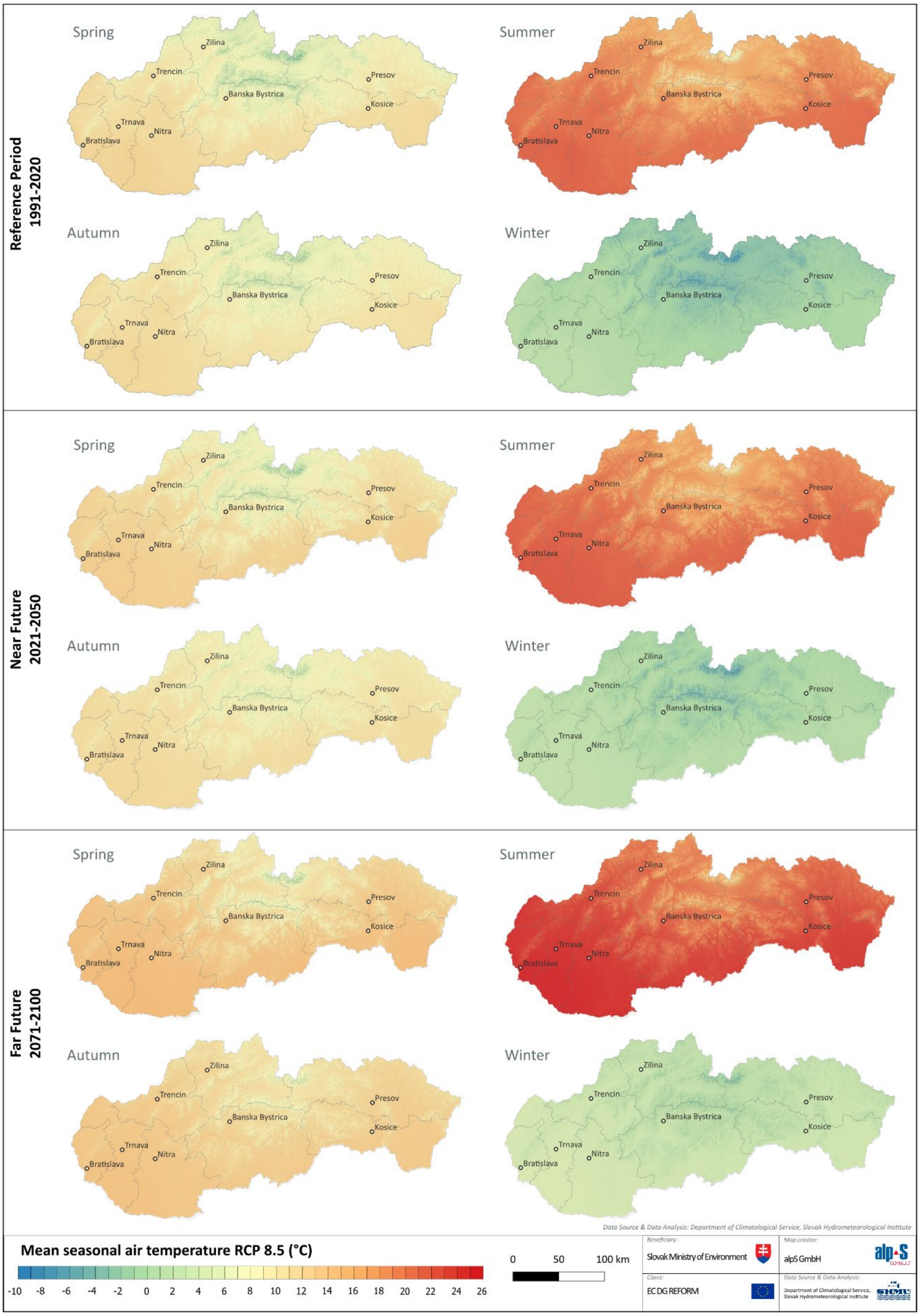


*Figure 17: Mean seasonal air temperature in °C, scenarios for the near and far future under RCP4.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*



Data Source & Data Analysis: Department of Climatological Service, Slovak Hydrometeorological Institute

*Figure 18: Mean seasonal air temperature in °C, scenarios for the near and far future under RCP8.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

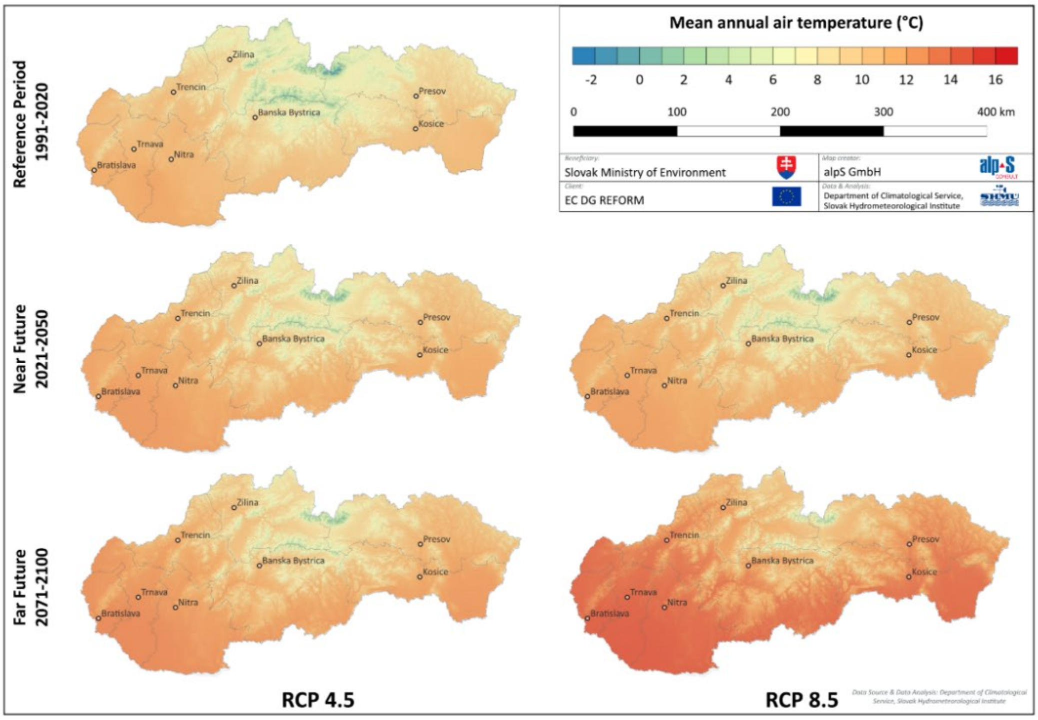


*Figure 19: Mean annual air temperature in °C, scenarios for the near and far future under RCP4.5 and RCP8.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

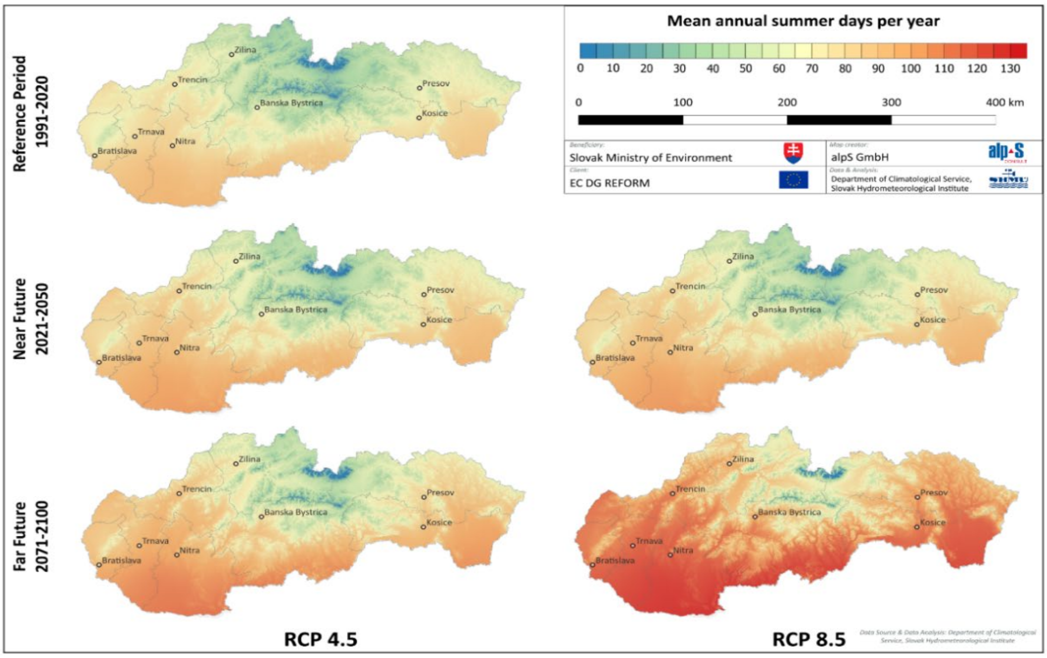


*Figure 20: Mean annual summer days (maximum temperatures reaching at least 25°C) per year in days, scenarios for the near and far future under RCP4.5 and RCP8.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

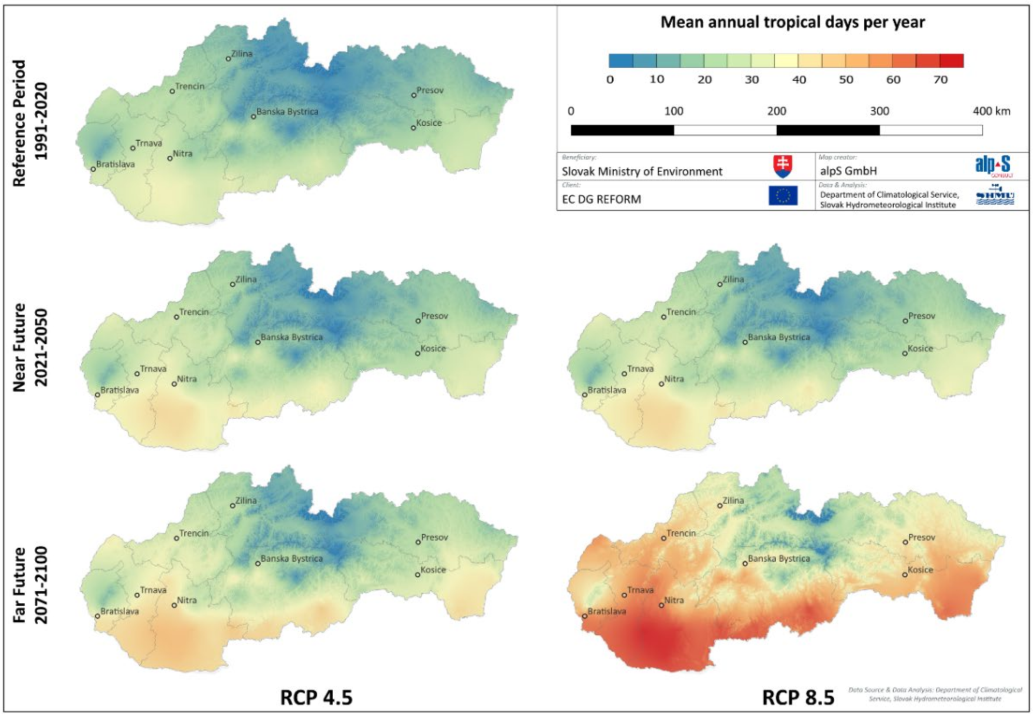


*Figure 21: Mean annual tropical days (maximum temperatures reaching at least 30°C) per year in days, scenarios for the near and far future under RCP4.5 and RCP8.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

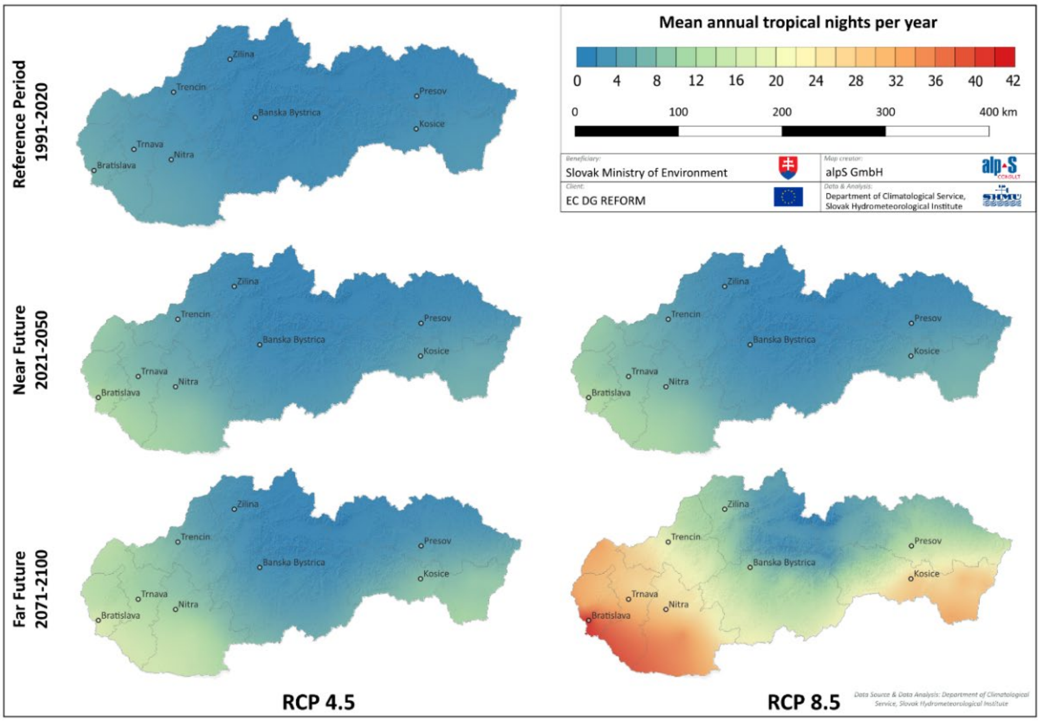


*Figure 22: Mean annual days with tropical nights (minimum temperature does not drop below 20°C) per year in days, scenarios for the near and far future under RCP4.5 and RCP8.5 are shown for Slovakia, including regional boundaries and regional capitals. Department of Climatological Service, Slovak Hydrometeorological Institute*

## Precipitation-related climate data

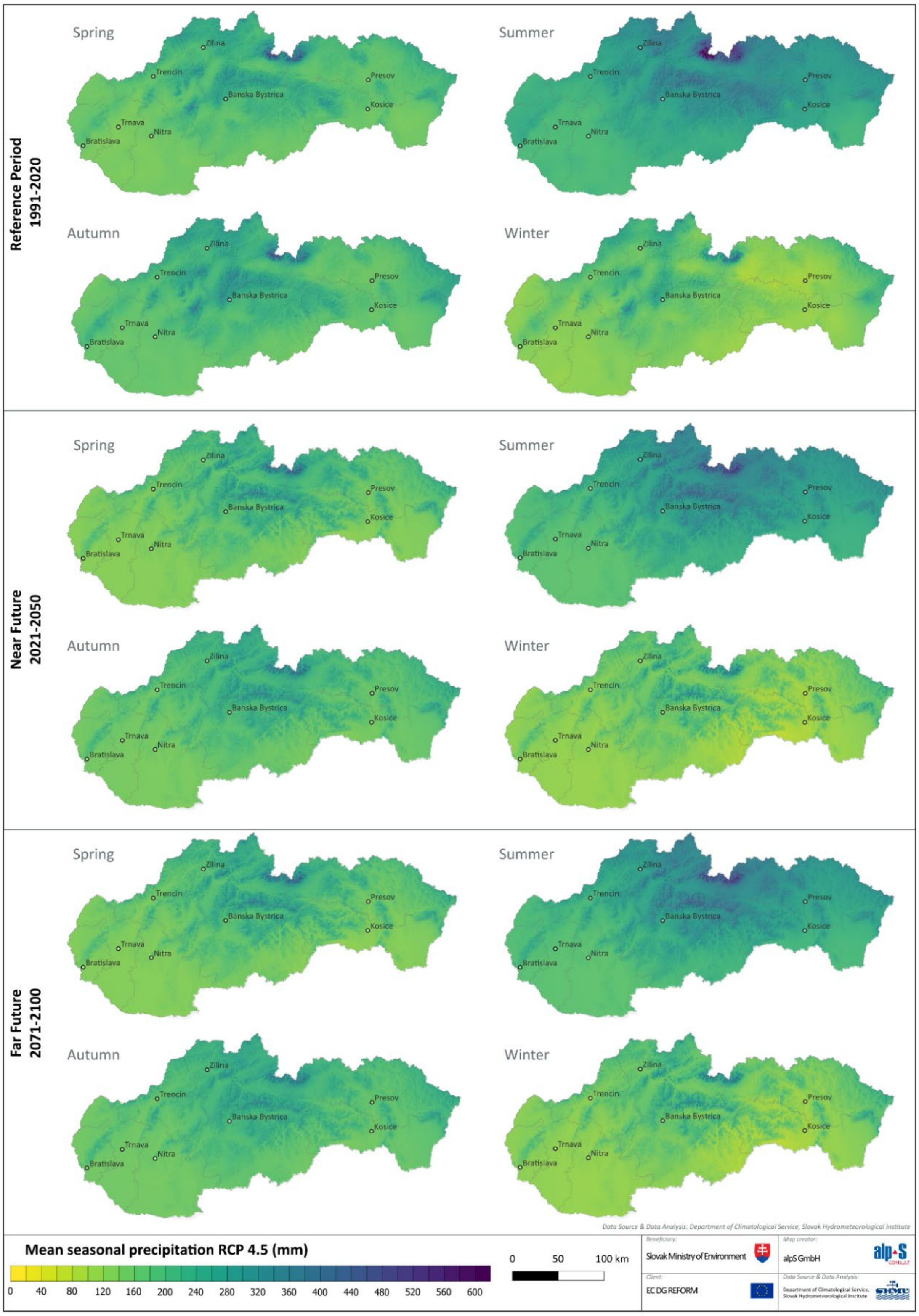


*Figure 23: Mean seasonal precipitation in mm, scenarios for the near and far future under RCP 4.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

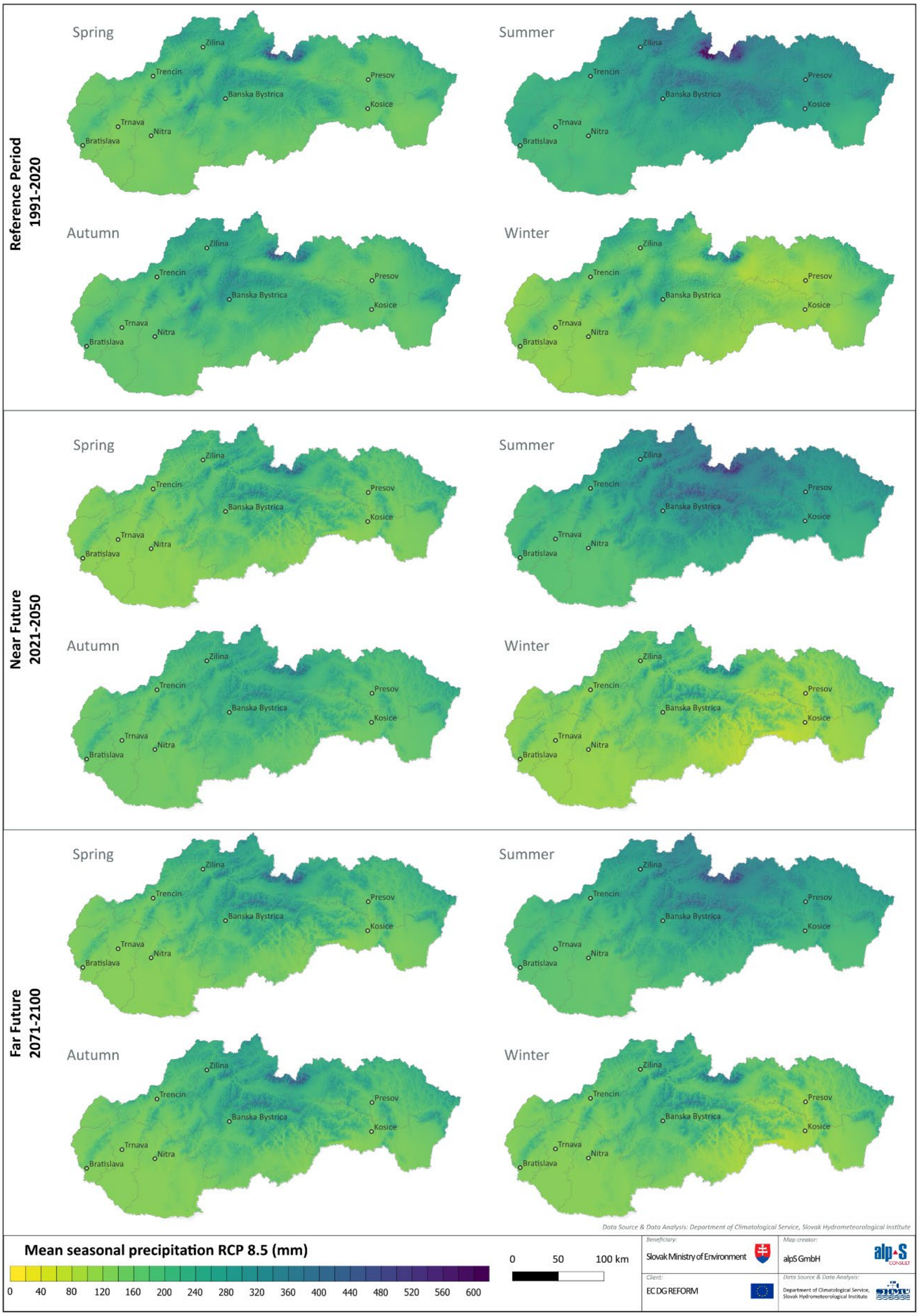


*Figure 24: Mean seasonal precipitation in mm, scenarios for the near and far future under RCP8.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

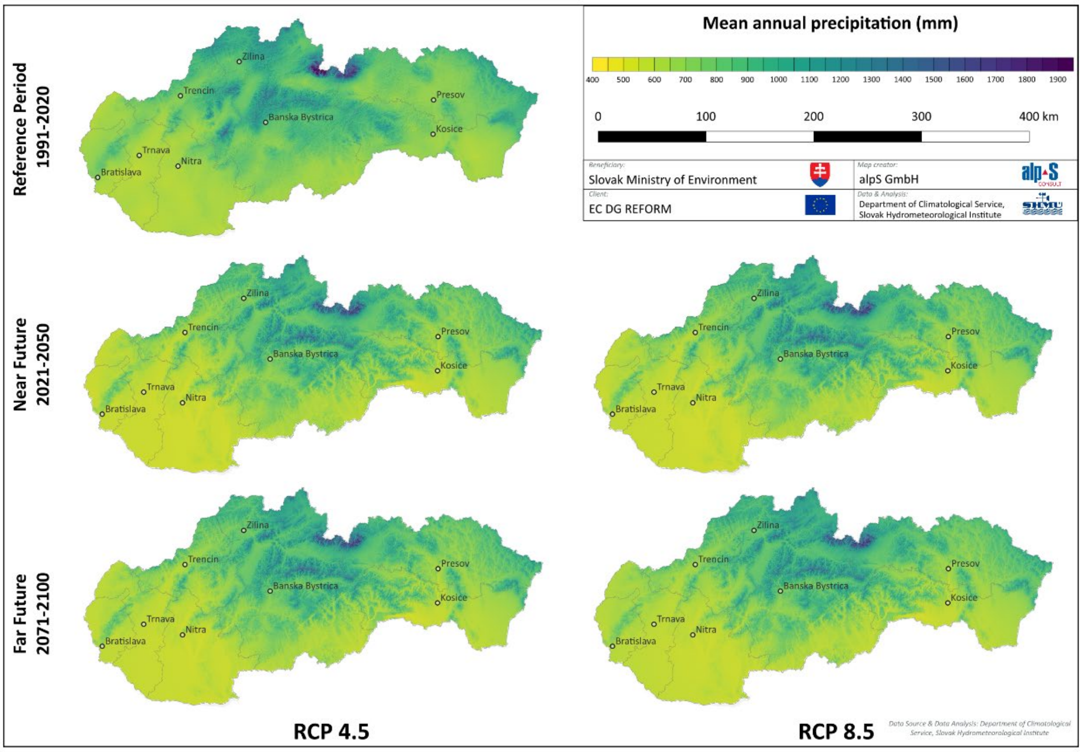


*Figure 25: Mean annual precipitation in mm, scenarios for the near and far future under RCP4.5 and RCP8.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

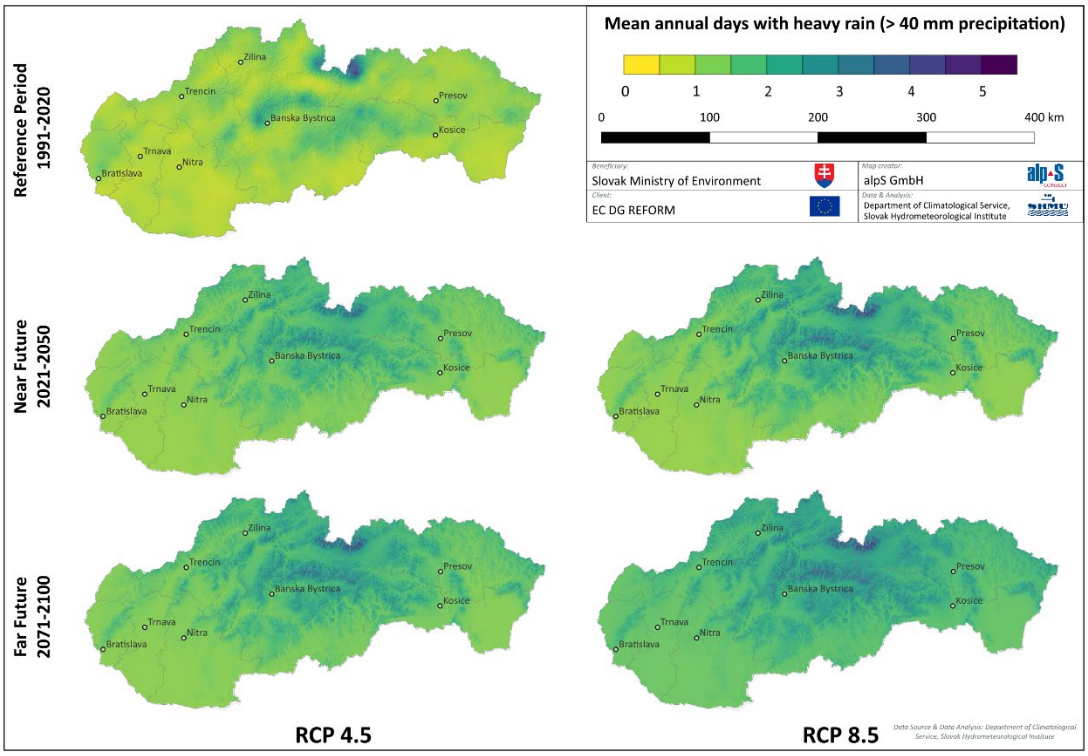


*Figure 26: Mean annual days with heavy rain in days, scenarios for the near and far future under RCP4.5 and RCP8.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

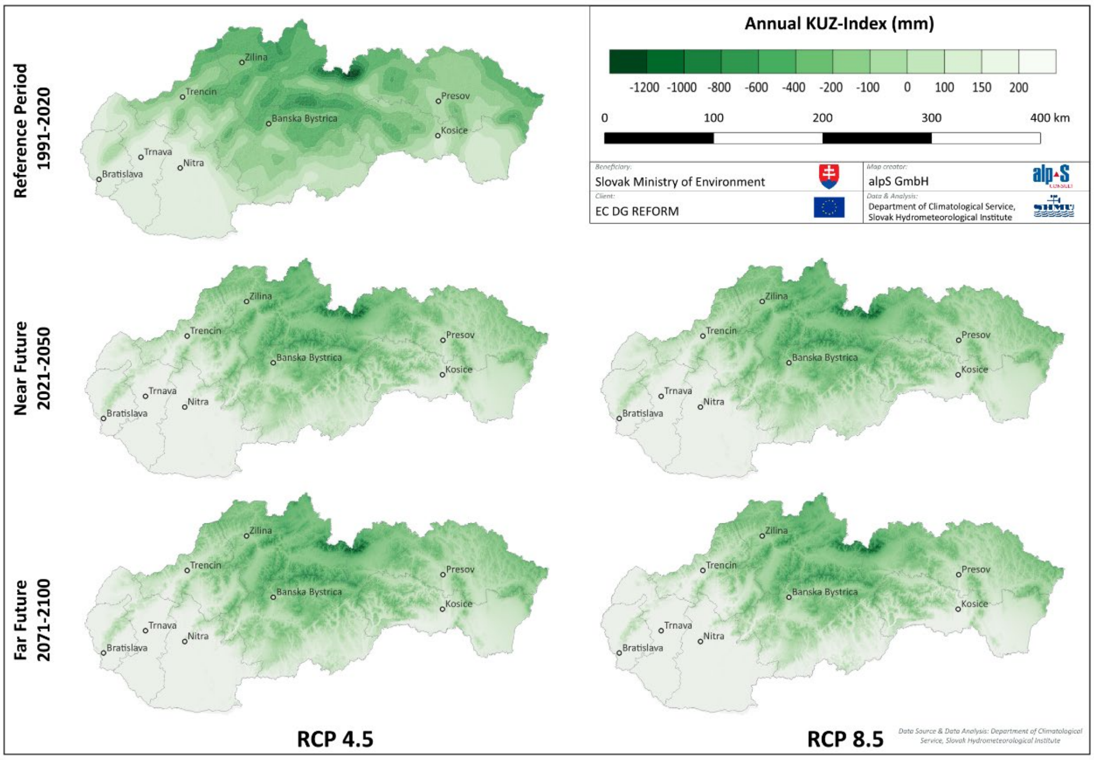


*Figure 27: Mean annual climate water index (KUZ-Index) in mm, scenarios for the near and far future under RCP4.5 and RCP8.5 are shown for Slovakia, including regional boundaries and regional capitals. Source of climate data: Department of Climatological Service, Slovak Hydrometeorological Institute.*

# Explanation of relevant climate indices

**Annual temperature:** Represents the average air temperature over the course of a calendar year. It accounts for daily temperature fluctuations throughout all seasons, giving a broad overview of the overall climate for that year, expressed in degrees Celsius (°C).

**Seasonal temperature:** Refers to the average air temperature recorded during a specific season, such as winter, spring, summer, or fall. It provides insight into the typical temperature patterns over that season, expressed in degrees Celsius (°C). This measurement helps assess seasonal climate variability and changes.

**Summer days:** Measures the number of days in a year where the maximum daily temperature exceeds 25°C. These days are typically considered warm or hot, depending on the region, and help in understanding heat trends and the frequency of warm days in a given year.

**Tropical days:** Tracks the number of days in a year where the maximum daily temperature exceeds 30°C. These are extremely hot days, often associated with tropical or subtropical climates, and help indicate the occurrence of extreme heat.

**Tropical nights:** Counts the number of nights in a year where the minimum daily temperature remains at or above 20°C. These are warm nights, often uncomfortable for those without cooling mechanisms, and are indicative of heat retention in the environment during night time.

**Frost days:** Refers to the number of days in a year when the minimum daily temperature drops below 0°C. These are days when frost formation is possible, typically associated with cold conditions or winter months. Frost days are important for agriculture, infrastructure, and energy use planning.

**Ice days:** Measures the number of days in a year when the maximum daily temperature stays below 0°C. These days remain cold throughout, with no thawing, and are typically observed in winter or colder climates. Ice days are crucial for understanding freezing conditions and their impacts on ecosystems and human activities.

**Cold spell:** A period of at least five consecutive days where the daily maximum temperature does not rise above 0°C. Cold spells are prolonged periods of freezing temperatures and can have significant impacts on heating demand, agriculture, and transportation.

**Seasonal precipitation:** Refers to the total amount of precipitation, including rain, snow, sleet, or hail, that falls during a specific season. This sum, measured in millimetres (mm), helps in understanding the seasonal distribution of moisture, which is vital for water resource management, agriculture, and ecosystem health.

**Annual precipitation:** Represents the total amount of precipitation received over the course of a calendar year, measured in millimetres (mm). It is a key indicator of overall climate conditions, water availability, and drought or flood risks.

**Heavy rain:** Indicates the number of days in a year where daily precipitation equals or exceeds 40 millimetres. Such days are considered heavy rainfall events, which can lead to flooding, soil erosion, and strain on drainage systems. Tracking heavy rain days is important for disaster preparedness and infrastructure planning.

**Annual KUZ (Climate Water Index):** A measure of the balance between the potential for water to evaporate and be transpired by plants (evapotranspiration) and the amount of precipitation received. Measured annually in millimetres (mm), a positive KUZ indicates a water deficit (more evapotranspiration than precipitation), while a negative value suggests a water surplus. This index is crucial for understanding water stress in ecosystems and agricultural areas.

# Annex C: Climate Impacts & Assessments

The following chapters present the results from the climate impact assessment workshops. Two types of impact categories were assessed, namely biophysical or direct impacts and socio-economic or indirect impacts. The latter are marked by a yellow frame.

Furthermore, definitions for the assessed impacts are provided, which are based on expert knowledge and practical experience in the field, ensuring accuracy and relevance.

## Agriculture

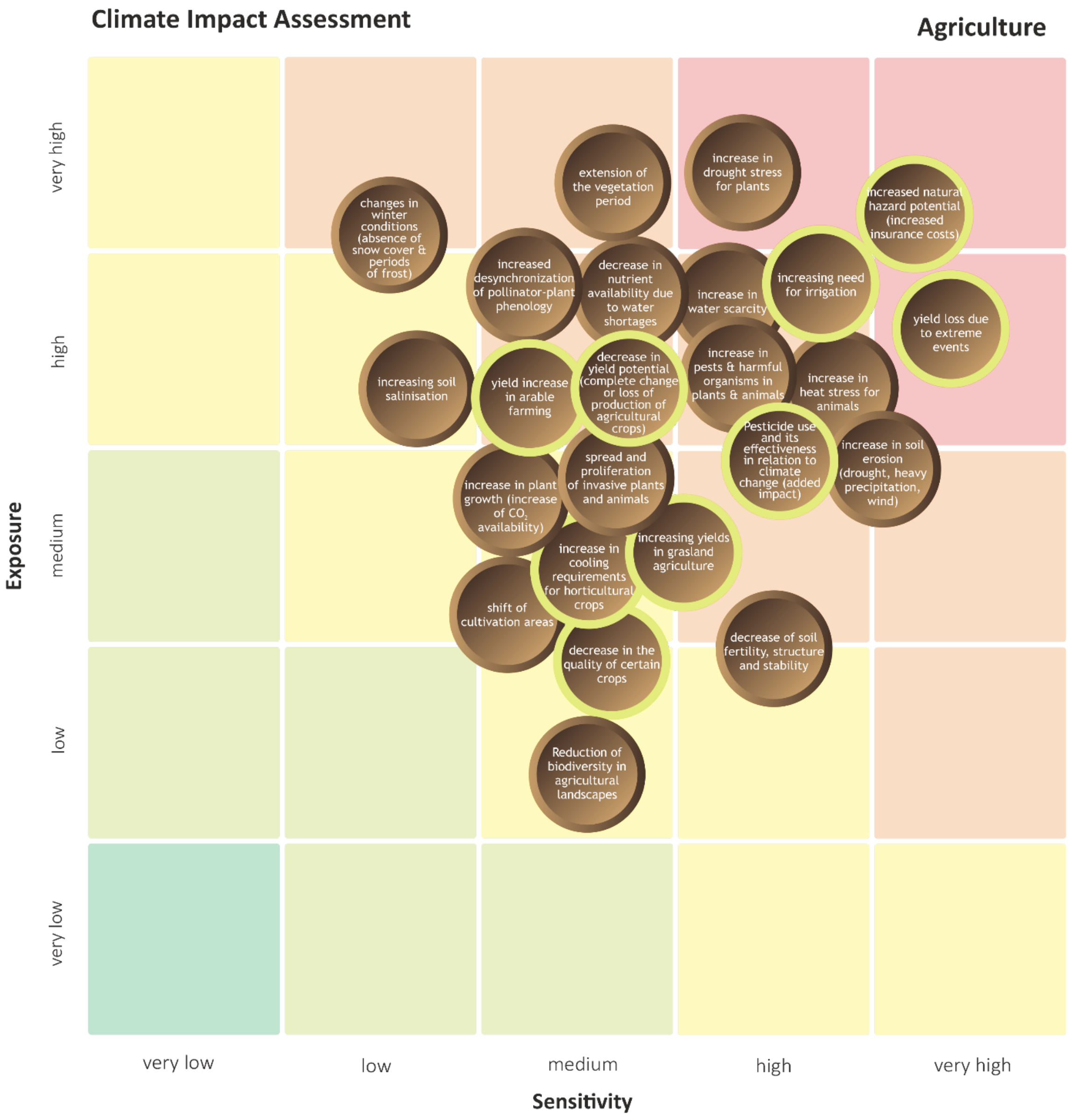


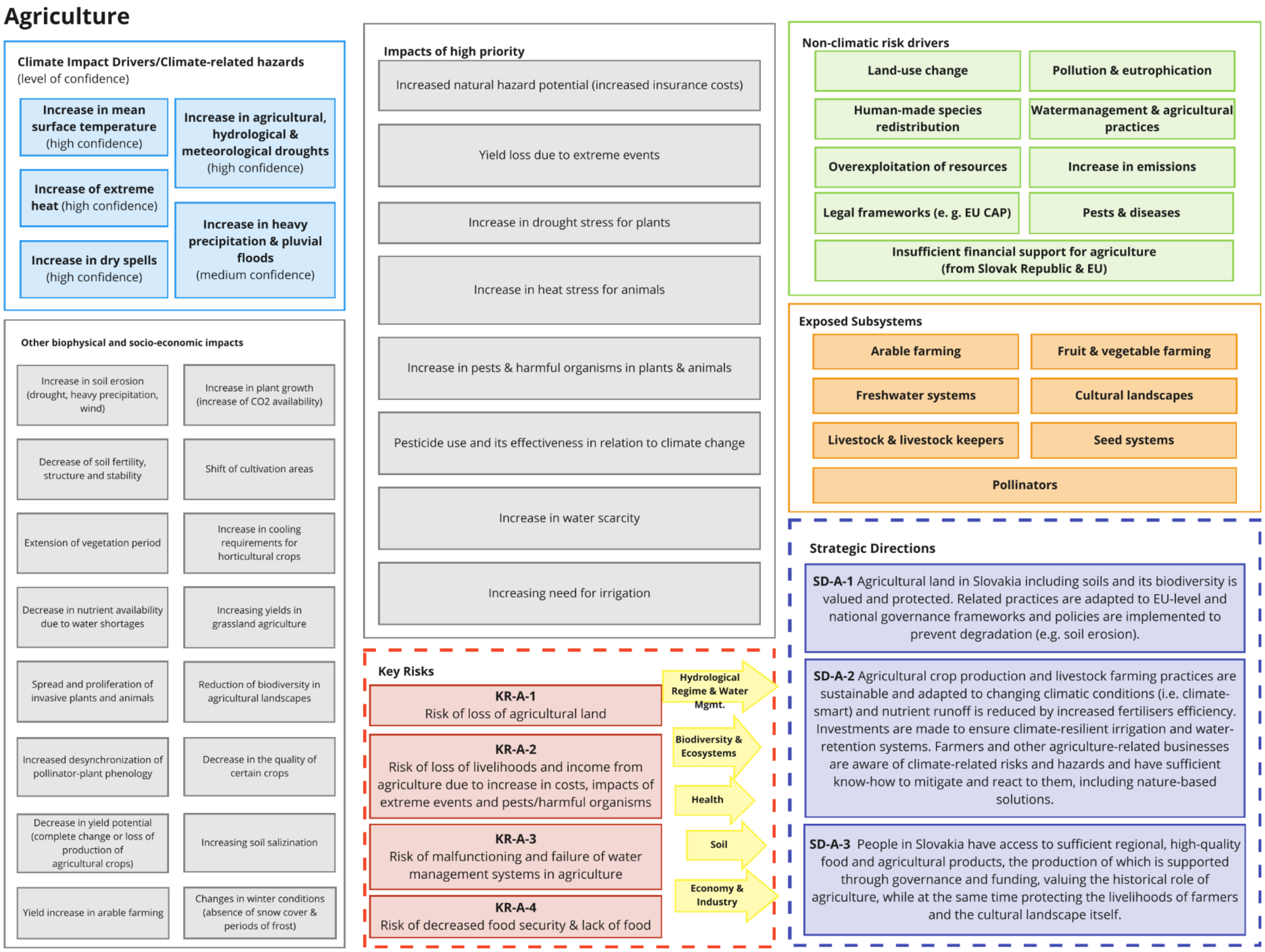
*Figure 28: Climate impacts for the sector **Agriculture** arranged in a matrix with respect to their sensitivity and exposure.*

*Table 47: Definitions of identified climate impacts for the sector **Agriculture**.*

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase in drought stress for plants | increased physiological strain and reduced productivity due to prolonged periods of water scarcity caused by abnormally dry weather over a longer period |
| increase in heat stress for animals | increased physiological strain and health risks for animals due to rising temperatures leading to reduced productivity, increased susceptibility to diseases, reproductive issues, and mortality in livestock |
| increase in pests & harmful organisms in plants & animals | increased prevalence and activity of organisms with a negative effect on agricultural systems (e.g. successive generations of detrimental organisms emerging within a single growing season) |
| increase in water scarcity | exacerbation of water shortages due to altered precipitation patterns, increased evaporation rates, and changes in the frequency and intensity of drought e.g. leading to reduced water availability for agricultural irrigation purposes |
| increase in soil erosion (drought, heavy precipitation, wind) | increased loss and deterioration of soil due to increased intensity and frequency of rainfall events and temperature fluctuations, among others |
| decrease of soil fertility, structure and stability | reduction of soil quality, including reduced nutrient availability, degradation of soil structure, and increased susceptibility to erosion, compaction, and desertification, leading to diminished agricultural productivity, ecosystem resilience, and water quality |
| extension of vegetation period | lengthening of plants` growing season due to rise in temperature leading to shifts in plant phenology and ecosystem dynamics |
| decrease in nutrient availability due to water shortages | reduction in the accessibility and uptake of essential nutrients by plants caused by insufficient water supply, leading to impaired nutrient cycling, diminished soil fertility, and compromised plant growth |
| spread and proliferation of invasive plants and animals | accelerated expansion of geographic range and abundance of non-native pest species into new habitats or regions |
| increased desynchronization of pollinator-plant phenology | disturbance in the temporal alignment of critical life stages between pollinating organisms and flowering plants |
| increase in plant growth (increase of $CO_2$ availability) | stimulation of photosynthesis and biomass production resulting from increased levels of atmospheric carbon dioxide which can enhance plant growth rates |

| Climate Impact | Definition |
|---|---|
| shift of cultivation areas | changes in the geographic distribution of agricultural production zones and cropping patterns |
| increasing soil salinization | accumulation of soluble salts in the soil matrix due to due an imbalance between precipitation and evaporation (evaporation exceeds precipitation) affecting soil structure, fertility, and water-holding capacity, reducing plant growth and agricultural productivity, and exacerbating land degradation. |
| changes in winter conditions (absence of snow cover & periods of frost) | alterations in the timing and duration of winter weather patterns, including reduced snow cover and fewer frost events, which can affect agricultural practices by influencing soil moisture levels, pest populations, and crop growth cycles |
| reduction of biodiversity in agricultural landscapes | Biodiversity in agriculture is affected both by climate change and by the way of management, its reduction is felt in the failure to fulfil the task, e.g. pollinators. |
| socio-economic | |
| increased natural hazard potential (increased insurance costs) | increased susceptibility of agricultural activities to natural hazards, leading to an escalation in insurance costs as a result of increased risks associated with crop losses and damage from extreme weather events |
| pesticide use and its effectiveness in relation to climate change | in extreme drought or rainy periods, restrictions on the effect/possibility of using pesticides (even if they have guidelines for use) are expected. Associated with the impact: increase in pests & harmful organisms in plants & animals |
| yield loss due to extreme events | reduction in agricultural productivity and crop failures resulting from severe weather phenomena like hail and storms |
| Increasing need for irrigation | increased demand for effective water management practices to sustain agricultural productivity in the face of escalating water scarcity challenges |
| increasing yields in grassland agriculture | higher productivity and biomass accumulation (e.g. due to improved grassland management or more favourable climate conditions and extended growing seasons) |
| decrease in the quality of certain crops | degradation of yield, protein content and nutritional value of specific crops resulting in increasing yield volatility |
| increase in cooling requirements for horticultural crops | growing necessity for artificial cooling measures to mitigate heat stress and maintain optimal growing conditions for horticultural crops |

| Climate Impact | Definition |
|---|---|
| yield increase in arable farming | augmentation of the quantity and quality of crops produced from cultivated land over a specified period (e.g. due to warmer winters and extended growing season) |
| decrease in yield potential (complete change or loss of production of agricultural crops) | decline in the capacity of specific crops to produce expected yields caused by heat and drought stress |



## Agriculture

**Climate Impact Drivers/Climate-related hazards**
(level of confidence)

- **Increase in mean surface temperature** (high confidence)
- **Increase of extreme heat** (high confidence)
- **Increase in dry spells** (high confidence)
- **Increase in agricultural, hydrological & meteorological droughts** (high confidence)
- **Increase in heavy precipitation & pluvial floods** (medium confidence)

**Other biophysical and socio-economic impacts**

- Increase in soil erosion (drought, heavy precipitation, wind)
- Increase in plant growth (increase of CO2 availability)
- Decrease of soil fertility, structure and stability
- Shift of cultivation areas
- Extension of vegetation period
- Increase in cooling requirements for horticultural crops
- Decrease in nutrient availability due to water shortages
- Increasing yields in grassland agriculture
- Spread and proliferation of invasive plants and animals
- Reduction of biodiversity in agricultural landscapes
- Increased desynchronization of pollinator-plant phenology
- Decrease in the quality of certain crops
- Decrease in yield potential (complete change or loss of production of agricultural crops)
- Increasing soil salizination
- Yield increase in arable farming
- Changes in winter conditions (absence of snow cover & periods of frost)

**Impacts of high priority**

- Increased natural hazard potential (increased insurance costs)
- Yield loss due to extreme events
- Increase in drought stress for plants
- Increase in heat stress for animals
- Increase in pests & harmful organisms in plants & animals
- Pesticide use and its effectiveness in relation to climate change
- Increase in water scarcity
- Increasing need for irrigation

**Key Risks**

**KR-A-1**
Risk of loss of agricultural land

**KR-A-2**
Risk of loss of livelihoods and income from agriculture due to increase in costs, impacts of extreme events and pests/harmful organisms

**KR-A-3**
Risk of malfunctioning and failure of water management systems in agriculture

**KR-A-4**
Risk of decreased food security & lack of food

**Non-climatic risk drivers**

- **Land-use change**
- **Pollution & eutrophication**
- **Human-made species redistribution**
- **Watermanagement & agricultural practices**
- **Overexploitation of resources**
- **Increase in emissions**
- **Legal frameworks (e. g. EU CAP)**
- **Pests & diseases**
- **Insufficient financial support for agriculture (from Slovak Republic & EU)**

**Exposed Subsystems**

- **Arable farming**
- **Fruit & vegetable farming**
- **Freshwater systems**
- **Cultural landscapes**
- **Livestock & livestock keepers**
- **Seed systems**
- **Pollinators**

**Strategic Directions**

**SD-A-1** Agricultural land in Slovakia including soils and its biodiversity is valued and protected. Related practices are adapted to EU-level and national governance frameworks and policies are implemented to prevent degradation (e.g. soil erosion).

**SD-A-2** Agricultural crop production and livestock farming practices are sustainable and adapted to changing climatic conditions (i.e. climate-smart) and nutrient runoff is reduced by increased fertilisers efficiency. Investments are made to ensure climate-resilient irrigation and water-retention systems. Farmers and other agriculture-related businesses are aware of climate-related risks and hazards and have sufficient know-how to mitigate and react to them, including nature-based solutions.

**SD-A-3** People in Slovakia have access to sufficient regional, high-quality food and agricultural products, the production of which is supported through governance and funding, valuing the historical role of agriculture, while at the same time protecting the livelihoods of farmers and the cultural landscape itself.

*Figure 29: Climate Impact Chain for the sector* ***Agriculture****.*

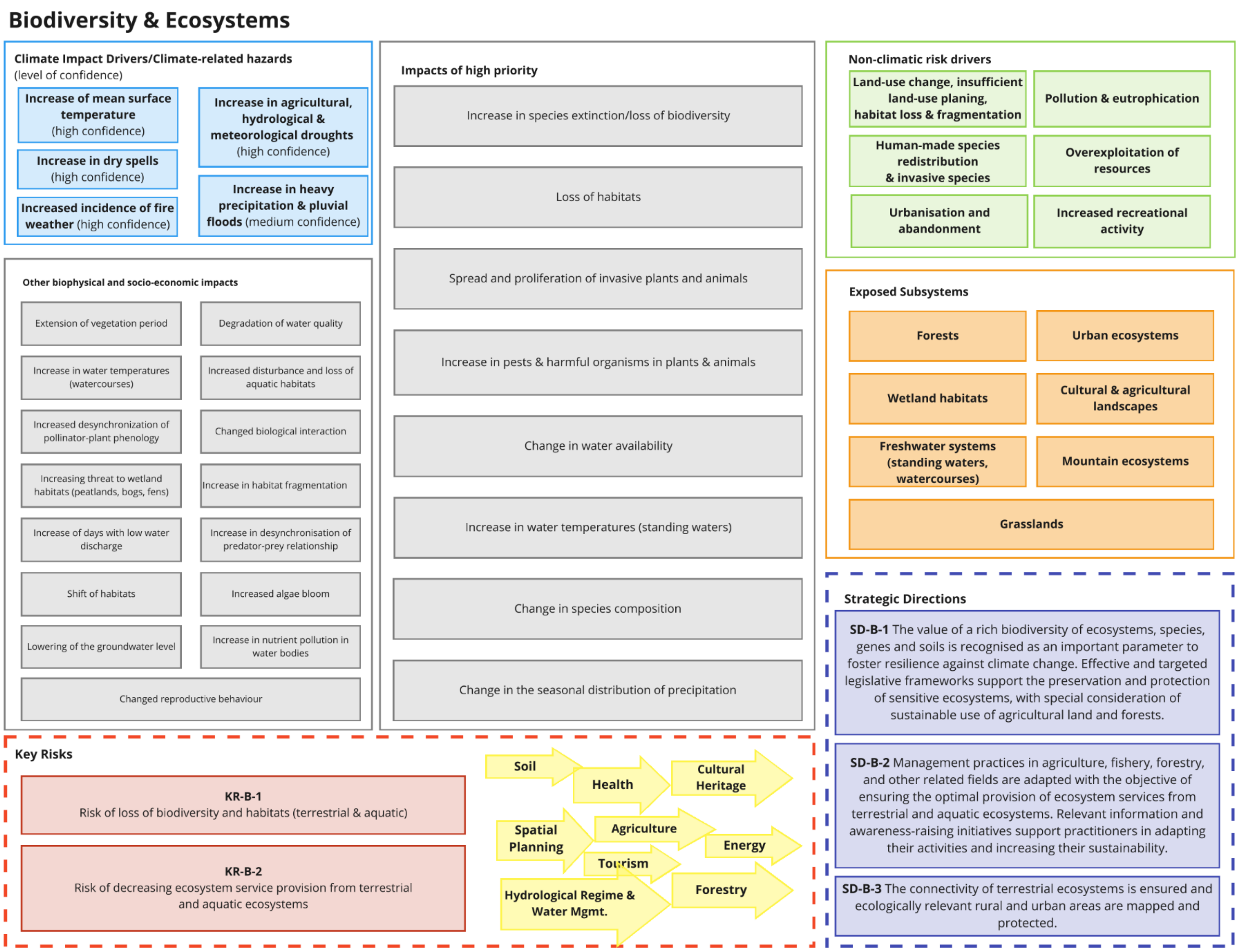
# Biodiversity & Ecosystems

*Figure 30: Climate impacts for the sector **Biodiversity & Ecosystems** arranged in a matrix with respect to their sensitivity and exposure.*

*Table 48: Definitions of identified climate impacts for the sector* ***Biodiversity & Ecosystems***.

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase in species extinction/loss of biodiversity | augmentation of rates of disappearing organisms and reduction in overall biological diversity |
| loss of habitats | degradation or disappearance of habitats crucial for various species, threatening biodiversity and ecosystem integrity |
| spread and proliferation of invasive plants and animals | (accelerated) expansion of geographic range and abundance of non-native pest species into new habitats or regions |
| increase in pests & harmful organisms in plants & animals | increased prevalence and activity of organisms with a negative effect on ecosystems and biodiversity (e.g. successive generations of detrimental organisms emerging within a single growing season) |
| change in water availability | diminishing availability of freshwater due to factors such as reduced precipitation, increased evaporation, and altered hydrological cycle |
| increase in water temperatures (standing waters) | rising temperatures in lakes, ponds and reservoirs cause increases in algae blooms and reduced oxygen levels, affecting aquatic ecosystems and water quality |
| change in the seasonal distribution of precipitation | alterations in the timing, intensity, and duration of precipitation patterns leading to shifts in vegetation composition, changes in water availability, alterations in species distributions, and potential cascading effects throughout ecosystems |
| change in species composition | changes in the distribution and abundance of organisms present within an ecosystem |
| extension of vegetation period | lengthening of plants` growing season due to rise in temperature leading to shifts in plant phenology and ecosystem dynamics |
| increase in water temperatures (watercourses) | rising temperatures in rivers, streams and other flowing water bodies cause increases in algae blooms and reduced oxygen levels, affecting aquatic ecosystems and water quality |
| increased desynchronization of pollinator-plant phenology | disturbance in the temporal alignment of critical life stages between pollinating organisms and flowering plants |
| increasing threat to wetland habitats (peatlands, bogs, fens) | escalating risks for intensified degradation processes in wetlands (e.g. the disruption of hydrological regimes, and ecological functions and biodiversity loss) |

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase of days with low water discharge | reduction in water level of running and standing waters resulting in increasing pollution and decreasing water quality and navigability |
| shift of habitats | movement or relocation of ecosystems and species to different geographical locations |
| lowering of the groundwater level | gradual reduction in the elevation of the water table within aquifers, resulting from droughts and increasing groundwater extraction |
| changed reproductive behaviour | alterations in the timing, frequency, or success of reproductive activities exhibited by various species (e.g. shifts in mating seasons, modifications in breeding locations) |
| degradation of water quality | deterioration of the chemical, physical, and biological characteristics of water bodies |
| increased disturbance and loss of aquatic habitats | degradation, reduction, or disappearance of aquatic ecosystems, leading to less favourable conditions and challenges for aquatic biota, threats to biodiversity and ecosystem services |
| changed biological interaction | disruptions in species interaction due to altering species' phenology, growth and fitness, changing species and community dynamics, altering ecological processes and ecosystem functioning |
| increase in habitat fragmentation | increased fragmentation of natural environments due to changing climatic conditions, leading to the isolation of habitats, disruption of ecological connectivity, and loss of biodiversity |
| Increase in desynchronization of predator-prey relationship | as a climate impact on biodiversity and ecosystems, leading to mismatches in the availability of prey and predators, potentially impacting population dynamics, food webs, and ecosystem stability |
| increased algae bloom | escalation of algal growth in aquatic ecosystems posing environmental threats such as oxygen depletion and toxic algal blooms |
| increase in nutrient pollution in water bodies | exacerbation of nutrient runoff and accumulation into aquatic ecosystems, leading to eutrophication, harmful algal blooms, and ecosystem degradation |



**Biodiversity & Ecosystems**

**Climate Impact Drivers/Climate-related hazards**
(level of confidence)

- **Increase of mean surface temperature** (high confidence)
- **Increase in dry spells** (high confidence)
- **Increased incidence of fire weather** (high confidence)
- **Increase in agricultural, hydrological & meteorological droughts** (high confidence)
- **Increase in heavy precipitation & pluvial floods** (medium confidence)

**Other biophysical and socio-economic impacts**

- Extension of vegetation period
- Degradation of water quality
- Increase in water temperatures (watercourses)
- Increased disturbance and loss of aquatic habitats
- Increased desynchronization of pollinator-plant phenology
- Changed biological interaction
- Increasing threat to wetland habitats (peatlands, bogs, fens)
- Increase in habitat fragmentation
- Increase of days with low water discharge
- Increase in desynchronisation of predator-prey relationship
- Shift of habitats
- Increased algae bloom
- Lowering of the groundwater level
- Increase in nutrient pollution in water bodies
- Changed reproductive behaviour

**Impacts of high priority**

- Increase in species extinction/loss of biodiversity
- Loss of habitats
- Spread and proliferation of invasive plants and animals
- Increase in pests & harmful organisms in plants & animals
- Change in water availability
- Increase in water temperatures (standing waters)
- Change in species composition
- Change in the seasonal distribution of precipitation

**Non-climatic risk drivers**

- Land-use change, insufficient land-use planing, habitat loss & fragmentation
- Pollution & eutrophication
- Human-made species redistribution & invasive species
- Overexploitation of resources
- Urbanisation and abandonment
- Increased recreational activity

**Exposed Subsystems**

- Forests
- Urban ecosystems
- Wetland habitats
- Cultural & agricultural landscapes
- Freshwater systems (standing waters, watercourses)
- Mountain ecosystems
- Grasslands

**Key Risks**

**KR-B-1**
Risk of loss of biodiversity and habitats (terrestrial & aquatic)

**KR-B-2**
Risk of decreasing ecosystem service provision from terrestrial and aquatic ecosystems

**Strategic Directions**

**SD-B-1** The value of a rich biodiversity of ecosystems, species, genes and soils is recognised as an important parameter to foster resilience against climate change. Effective and targeted legislative frameworks support the preservation and protection of sensitive ecosystems, with special consideration of sustainable use of agricultural land and forests.

**SD-B-2** Management practices in agriculture, fishery, forestry, and other related fields are adapted with the objective of ensuring the optimal provision of ecosystem services from terrestrial and aquatic ecosystems. Relevant information and awareness-raising initiatives support practitioners in adapting their activities and increasing their sustainability.

**SD-B-3** The connectivity of terrestrial ecosystems is ensured and ecologically relevant rural and urban areas are mapped and protected.

*Figure 31: Climate Impact Chain for the sector* ***Biodiversity & Ecosystems***.

# Cultural Heritage

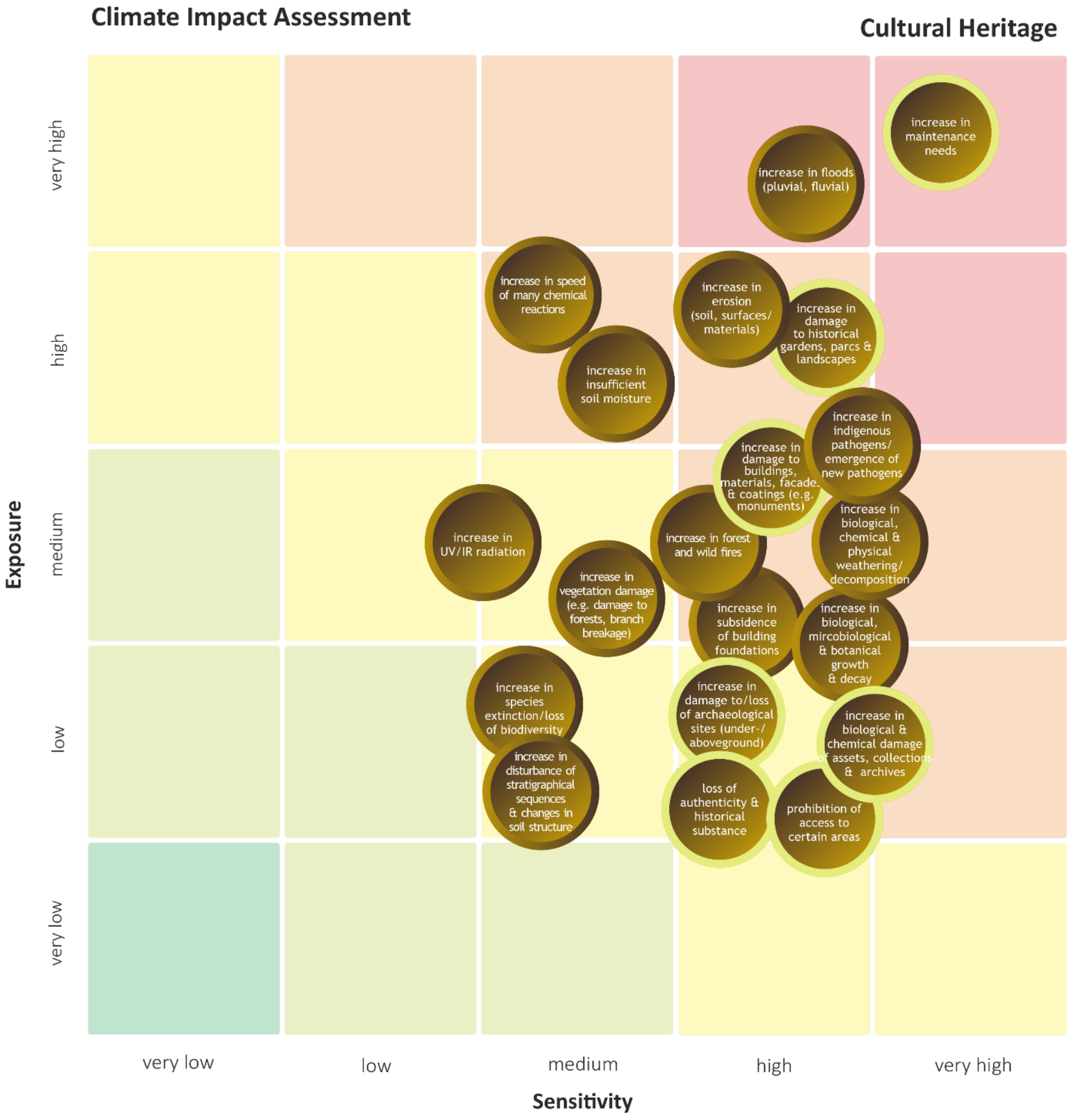


*Figure 32: Climate impacts for the sector **Cultural Heritage** arranged in a matrix with respect to their sensitivity and exposure.*

*Table 49: Definitions of identified climate impacts for the sector* ***Cultural Heritage****.*

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase in floods (pluvial, fluvial) | increase in the frequency and intensity of flood events caused by heavy precipitation (pluvial) and rivers (fluvial) |
| increase in forest & wild fires | increased occurrence, intensity, and severity of fires due to rising temperatures, prolonged droughts, and changes in precipitation patterns |
| increase in speed of many chemical reactions | acceleration of chemical processes that contribute to the deterioration or degradation of cultural artefacts and heritage materials due to warmer and more humid conditions |
| increase in erosion (soil, surfaces/materials) | rise in the rate or severity of soil loss and surface degradation affecting archaeological sites, historical buildings, monuments, artifacts, rock art and cultural landscapes |
| increase in insufficient soil moisture | growing scarcity or inadequacy of moisture content in the soil, adversely affecting the preservation and conservation of archaeological sites, artifacts (accelerated weathering of organic finds), and cultural landscapes such as historical gardens (dry out/die of plants, replanting becomes more difficult) |
| increase in indigenous pathogens/emergence of new pathogens | rise in the prevalence and activity disease-causing organisms posing risks to the preservation and condition of cultural heritage sites, artifacts, and collections |
| increase in biological, chemical & physical weathering/decomposition | reinforced processes that break down or deteriorate heritage materials, artifacts, and structures due to the actions of living organisms, chemical reactions, and physical forces |
| increase in vegetation damage (e.g. damage to forests, branch breakage) | rise in the extent or severity of harm inflicted upon plants and trees e.g. due to extreme events, decrease in soil moisture and pest infestation implicating the preservation and management of cultural heritage sites, landscapes, and structures |
| increase in biological, microbiological & botanical growth & decay | rise in the proliferation and deterioration of living organisms, including microorganisms, fungi, algae, plants, and other biological agents such as insects, which can impact the preservation and condition of cultural heritage sites, artifacts, and structures (indoor and outdoor) |
| increase in species extinction/loss of biodiversity | decline in the variety and abundance of species, impacting ecosystems, traditional knowledge, cultural practices, and the preservation of archaeological sites and landscapes |

| Climate Impact | Definition |
|---|---|
| increase in subsidence of building foundations | increase of damage of cultural heritage sites above sinking or settling of land surfaces (e.g. due to groundwater withdrawal) |
| increase in disturbance of stratigraphical sequences & changes in soil structure | increased disturbances to stratigraphic sequences/archaeological findings and alterations to the physical characteristics of soil profiles, impacting cultural heritage sites and artifacts; potentially making dating impossible and leading to loss of context and information |
| increase in UV/IR radiation | rise in the levels of electromagnetic radiation beyond the visible spectra, accelerating the deterioration, fading, corrosion and degradation of cultural artifacts, historical buildings, monuments, and archaeological sites |
| socio-economic | |
| increase in damage to buildings/building materials, facades & coatings (e.g. monuments) | rise in the extent or severity of harm inflicted upon architectural structures, construction materials, decorative surfaces, and protective layers, which can compromise the aesthetic, historical, and structural integrity of cultural heritage assets or which can lead to a total destruction of cultural heritage buildings and monuments |
| increase in damage to historical gardens, parcs & landscapes | rise in the extent or severity of harm inflicted upon designed outdoor spaces, natural environments, and cultural landscapes that hold historical, aesthetic, and ecological significance, i.e. are of cultural value |
| increase in maintenance needs | growing demand for regular upkeep, repair, and preservation efforts required to ensure the integrity, safety, and longevity of cultural heritage sites, buildings, artifacts, collections, and landscapes |
| increase in damage to/loss of archaeological sites (underground/aboveground) | growing threat to the preservation and integrity of sites containing historical artifacts, structures, and cultural deposits/findings |
| increase in biological & chemical damage of assets, collections & archives (e.g. papers, textiles, photographs, wood, metal) | growing risk of deterioration and degradation of historical artefacts inflicted by biological agents as well as chemical processes (e.g. oxidation, acidification, and pollutant exposure) |
| prohibition of access to certain areas | restrictions or limitations imposed on individuals, visitors, or the public from entering or interacting with specific sites, buildings, landscapes, or archaeological areas |
| *increase in effort, controls & time needed at construction sites [not discussed & no feedback received]* | *increased requirement of resources and precautions to ensure the preservation and protection of heritage assets during construction activities* |

| Climate Impact | Definition |
|---|---|
| loss of authenticity & historical substance | degradation, alteration, or diminishing of the original characteristics, significance, and integrity of cultural heritage sites, buildings, artifacts, collections, and landscapes |

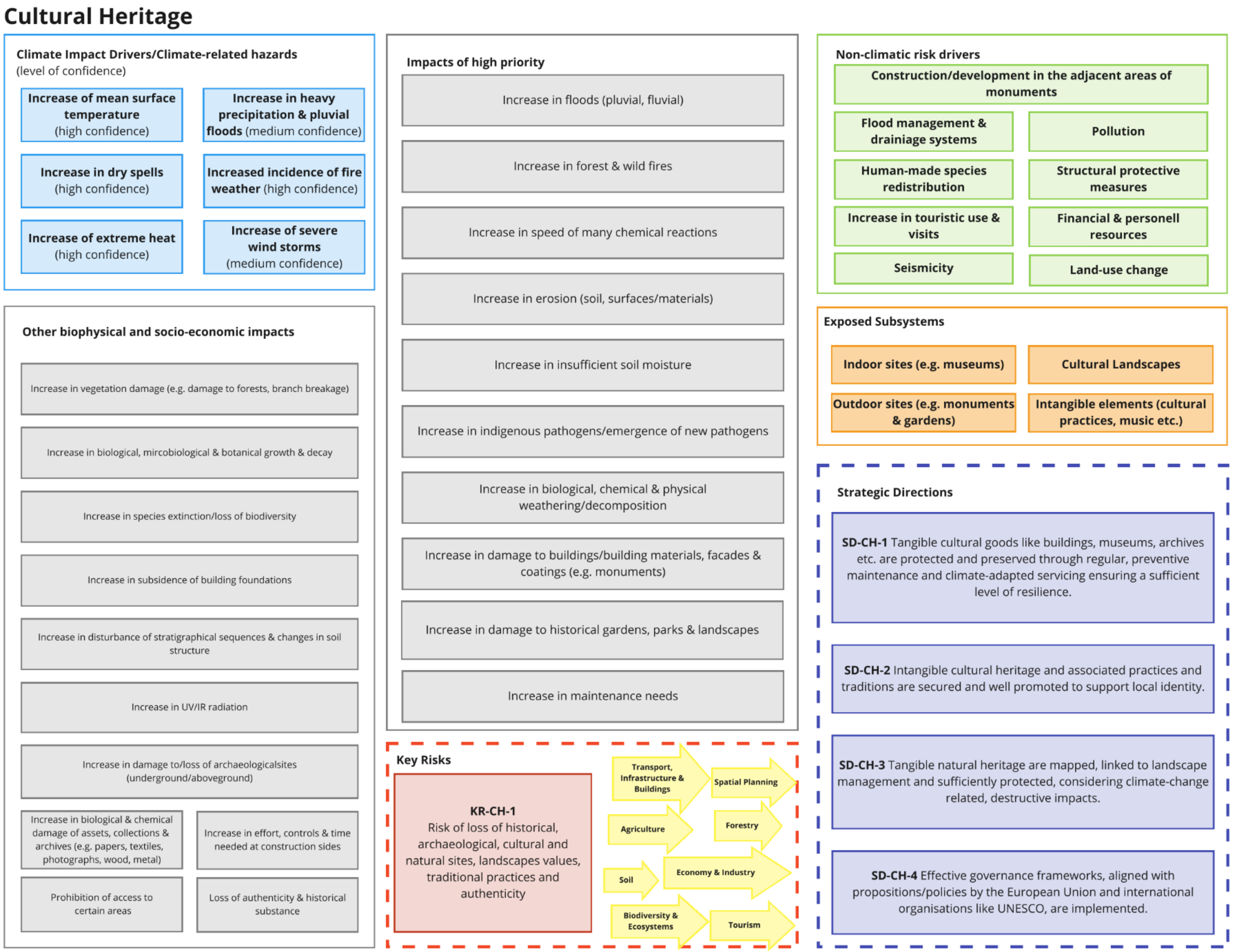


*Figure 33: Climate Impact Chain for the sector **Cultural Heritage**.*

# Disaster Risk Management, Civil Protection & Critical Infrastructure

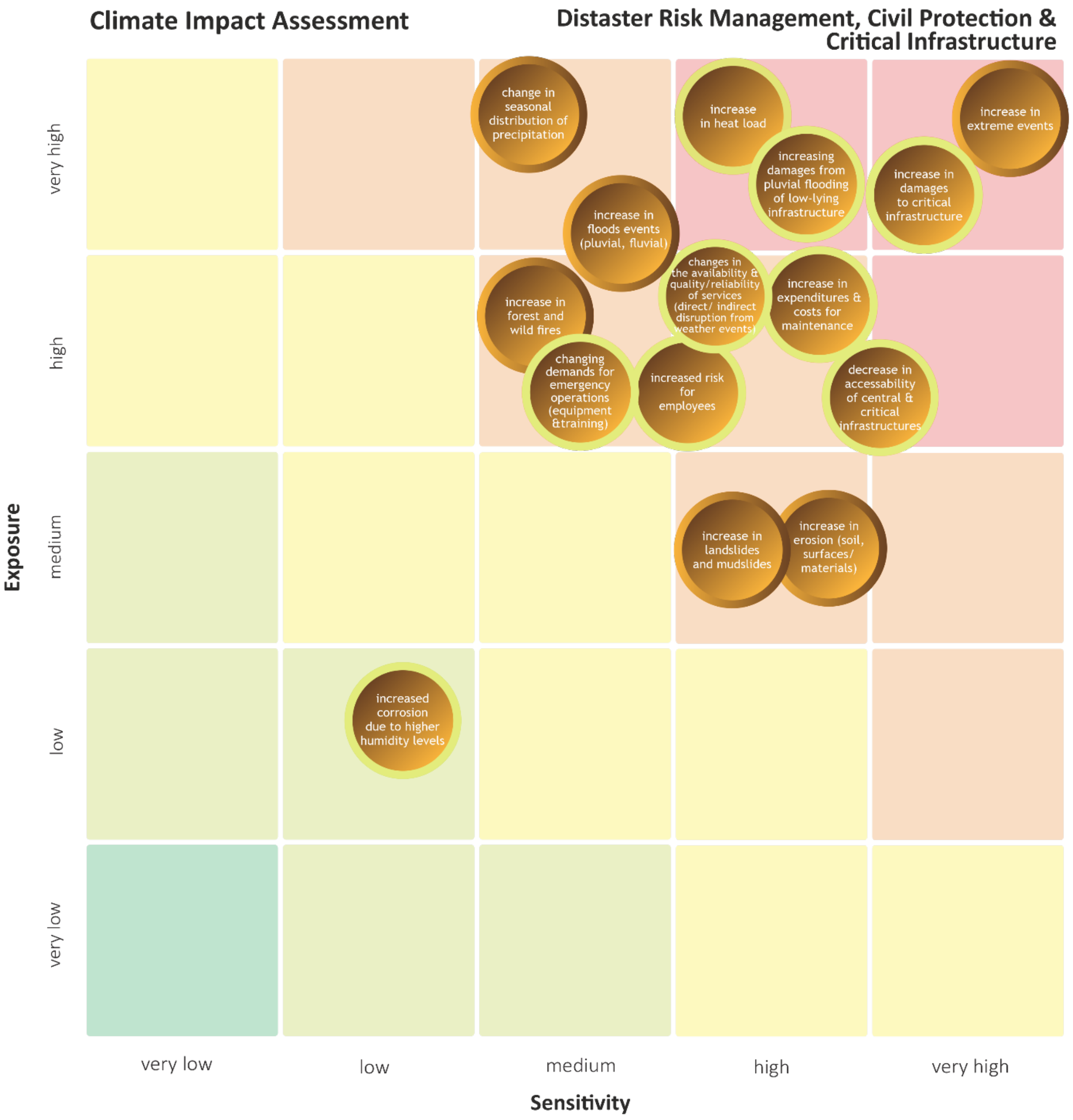
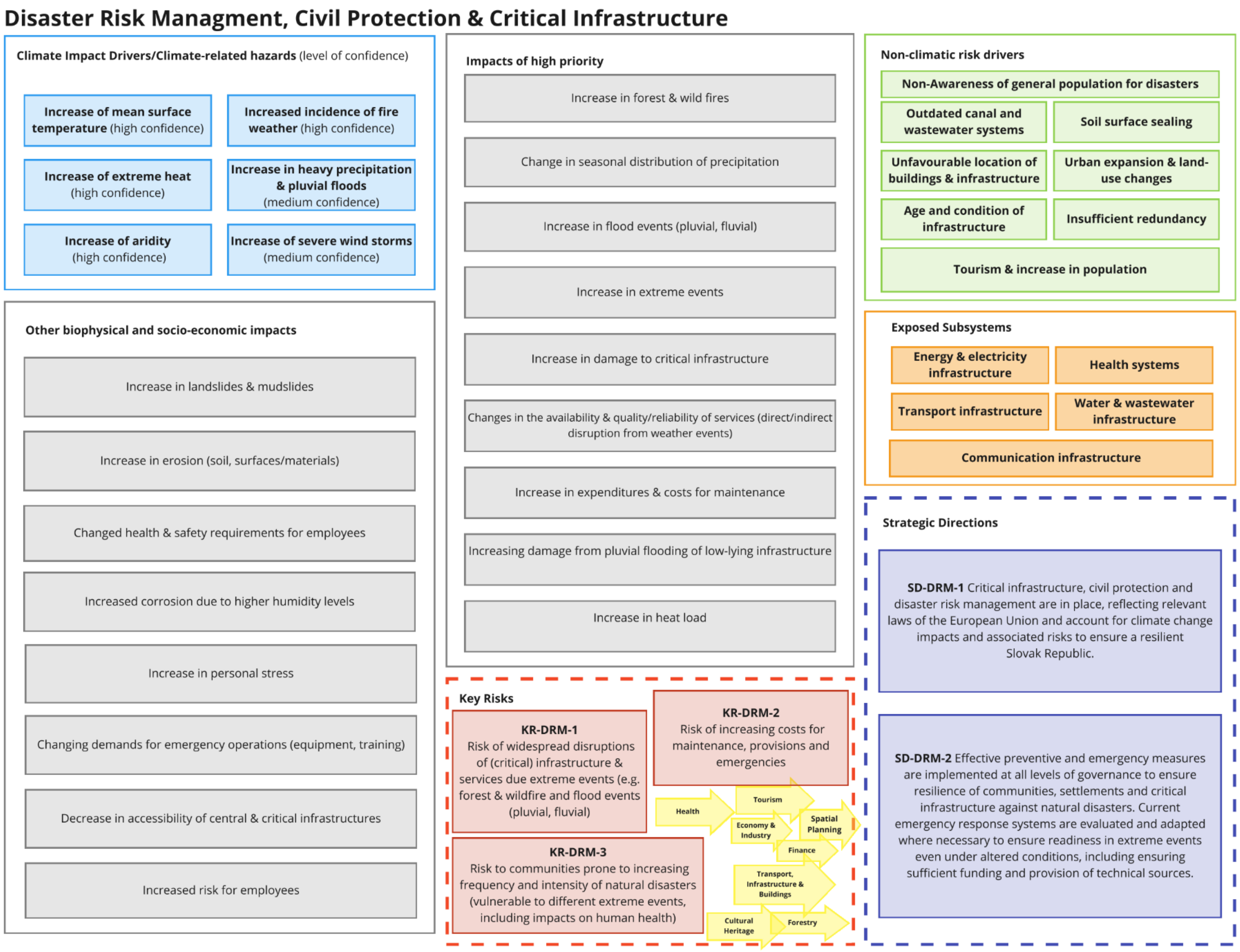


*Figure 34:Climate impacts for the sector **Disaster Risk Management, Civil Protection & Critical Infrastructure** arranged in a matrix with respect to their sensitivity and exposure.*

*Table 50: Definitions of identified climate impacts for the sector* ***Disaster Risk Management, Civil Protection & Critical Infrastructure****.*

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase in forest & wild fires | increased occurrence, intensity, and severity of fires due to rising temperatures, prolonged droughts, and changes in precipitation patterns |
| change in seasonal distribution of precipitation | alterations in the timing, intensity, and frequency of rainfall patterns throughout the year, influenced by climate change-induced shifts in atmospheric circulation patterns and moisture availability |
| increase in flood events (pluvial, fluvial) | increase in the frequency and intensity of flood events caused by heavy precipitation (pluvial) and rivers (fluvial) |
| increase in extreme events | more frequent and more severe occurrence of weather phenomena such as heat waves, droughts and storms disrupting infrastructure |
| increase in landslides & mudslides | increased occurrence of movements of mass of rocks, debris or earth down a slope or channel containing suspended particles due to increase of heavy or long-lasting precipitation events or rapid snow melt |
| increase in erosion (soil, surfaces/materials) | accelerated wearing away of soil, sediment, and land surfaces, often exacerbated by intensified rainfall and flooding; wear-away of protective coatings, degradation of surface materials, and compromising structural integrity, leading to corrosion, deterioration, and failure of infrastructure components such as roads, bridges, and buildings |
| socio-economic | |
| increase in damage to critical infrastructure | overheating of infrastructure components such as electrical systems, data centres, and telecommunications equipment; damage due to increase in erosion and extreme events (water-/solid mass-/fire-/wind-related climate hazards) |
| changes in the availability & quality/reliability of services (direct/indirect disruption from weather events) | alterations in the reliability, accessibility, and performance of digital systems and emergency response capabilities due to climate-related disruptions such as extreme weather events, power outages, and infrastructure damage; reduced reliability of wireless services with higher rainfall rates; reduced range of wireless signals due to rising extreme temperatures |
| increase in expenditures & costs for maintenance | escalation in financial resources required for the maintenance and operation of civil protection infrastructure and services, including emergency response systems and disaster preparedness measures |

| | |
|---|---|
| increasing damage from pluvial flooding of low-lying infrastructure | low-lying infrastructure, underground facilities and access-holes are at risk of flooding |
| increase in heat load | increased temperatures and prolonged heat waves, leading to overheating of infrastructure components such as electrical systems, data centres, and telecommunications equipment; increasing the risk of equipment failures, service disruptions, and data loss, posing challenges for maintaining operational reliability, ensuring cybersecurity, and safeguarding critical services |
| increased corrosion due to higher humidity levels | accelerated degradation of surfaces, materials, and infrastructure components caused by moisture-related processes such as corrosion, rusting, and wear, compromising the structural integrity, functionality and longevity of CI and ICT |
| changing demands for emergency operations (equipment, training) | evolving requirements for specialised equipment, training programs, and response protocols to address emerging climate-related hazards and risks such as extreme weather events, natural disasters, and infrastructure failures |
| decrease in accessibility of central & critical infrastructures | reduced ability to reach, utilise, or maintain essential facilities and services due to climate-related disruptions such as flooding, storm damage, or transportation network failures |

 
**Disaster Risk Managment, Civil Protection & Critical Infrastructure**

**Climate Impact Drivers/Climate-related hazards** (level of confidence)

- **Increase of mean surface temperature** (high confidence)
- **Increased incidence of fire weather** (high confidence)
- **Increase of extreme heat** (high confidence)
- **Increase in heavy precipitation & pluvial floods** (medium confidence)
- **Increase of aridity** (high confidence)
- **Increase of severe wind storms** (medium confidence)

**Other biophysical and socio-economic impacts**

- Increase in landslides & mudslides
- Increase in erosion (soil, surfaces/materials)
- Changed health & safety requirements for employees
- Increased corrosion due to higher humidity levels
- Increase in personal stress
- Changing demands for emergency operations (equipment, training)
- Decrease in accessibility of central & critical infrastructures
- Increased risk for employees

**Impacts of high priority**

- Increase in forest & wild fires
- Change in seasonal distribution of precipitation
- Increase in flood events (pluvial, fluvial)
- Increase in extreme events
- Increase in damage to critical infrastructure
- Changes in the availability & quality/reliability of services (direct/indirect disruption from weather events)
- Increase in expenditures & costs for maintenance
- Increasing damage from pluvial flooding of low-lying infrastructure
- Increase in heat load

**Key Risks**

**KR-DRM-1**
Risk of widespread disruptions of (critical) infrastructure & services due extreme events (e.g. forest & wildfire and flood events (pluvial, fluvial)

**KR-DRM-2**
Risk of increasing costs for maintenance, provisions and emergencies

**KR-DRM-3**
Risk to communities prone to increasing frequency and intensity of natural disasters (vulnerable to different extreme events, including impacts on human health)

**Non-climatic risk drivers**

- **Non-Awareness of general population for disasters**
- **Outdated canal and wastewater systems**
- **Soil surface sealing**
- **Unfavourable location of buildings & infrastructure**
- **Urban expansion & land-use changes**
- **Age and condition of infrastructure**
- **Insufficient redundancy**
- **Tourism & increase in population**

**Exposed Subsystems**

- **Energy & electricity infrastructure**
- **Health systems**
- **Transport infrastructure**
- **Water & wastewater infrastructure**
- **Communication infrastructure**

**Strategic Directions**

**SD-DRM-1** Critical infrastructure, civil protection and disaster risk management are in place, reflecting relevant laws of the European Union and account for climate change impacts and associated risks to ensure a resilient Slovak Republic.

**SD-DRM-2** Effective preventive and emergency measures are implemented at all levels of governance to ensure resilience of communities, settlements and critical infrastructure against natural disasters. Current emergency response systems are evaluated and adapted where necessary to ensure readiness in extreme events even under altered conditions, including ensuring sufficient funding and provision of technical sources.

*Figure 35: Climate Impact Chain for the sector **Disaster Risk Management, Civil Protection & Critical Infrastructure**.*

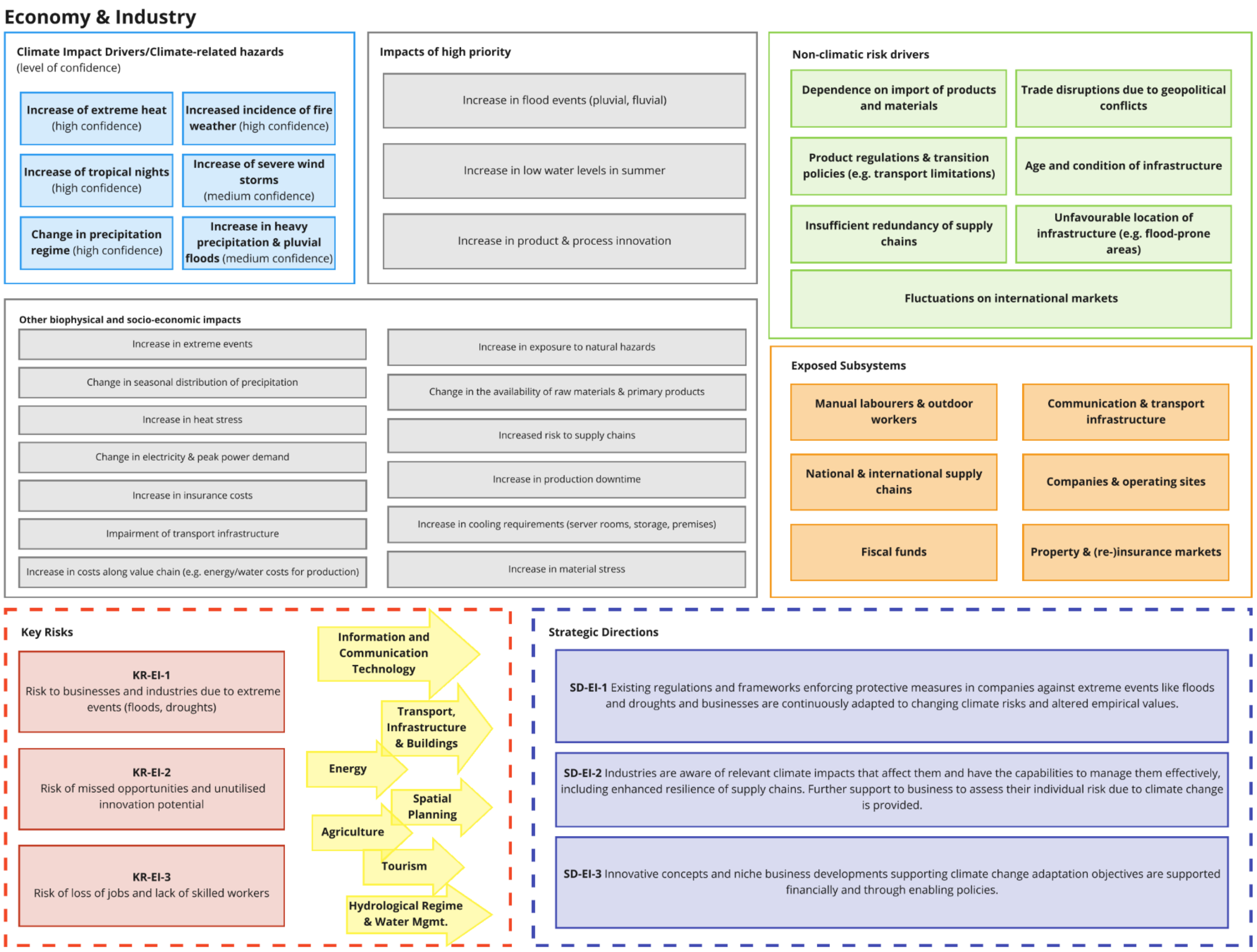
# Economy & Industry

*Figure 36: Climate impacts for the sector* ***Economy & Industry*** *arranged in a matrix with respect to their sensitivity and exposure.*

*Table 51: Definitions of identified climate impacts for the sector* ***Economy & Industry****.*

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase in flood events (pluvial, fluvial) | increase in the frequency and intensity of flood events caused by heavy precipitation (pluvial) and rivers (fluvial) |
| increase in low water levels in summer | reduction in water level of running and standing waters resulting in increasing pollution and decreasing water quality and navigability |
| increase in extreme events | more frequent and more severe occurrence of weather phenomena such as heat waves, droughts, storms and wildfires causing increased costs for rehabilitation and further along the value chain, e.g. through the impact on humans |
| increase in heat stress | increased risks of heat-related illnesses, discomfort and reduction of performance among workers, particularly in urban areas as well as thermal stress on infrastructure, causing structural damage, degradation of materials, and increased energy consumption for cooling |
| socio-economic | |
| increase in product & process innovation | rise in the development and implementation of new or improved products and methods of production within an industry or organization |
| change in electricity & peak power demand | alterations in consumption patterns of electrical energy due to temperature variations |
| increase in insurance costs | escalation in premiums or payments required to secure insurance coverage for various assets, liabilities, or risks due to factors such as increased frequency or severity of extreme events like floods, storms and heat waves |
| impairment of transport infrastructure | deterioration, damage, or dysfunctionality of transportation systems such as roads, bridges, railways, airports, or ports e.g. due to extreme events such as floods or storms |
| increase in exposure to natural hazards | increased vulnerability to natural hazards (e.g. floods, landslides, wildfires) due to alterations in human activities, land use patterns, and socio-economic factors |
| change in the availability of raw materials & primary products | alterations in the accessibility, quantity, or quality of natural resources and fundamental materials used in the production of goods and services |

| Climate Impact | Definition |
|---|---|
| increased risk to supply chains | increased probability of disruptions or susceptibilities within the networks of interconnected entities involved in the production, distribution, and delivery of goods and services (e.g. delay in the delivery of materials and products, production losses shortage of skilled workers) e.g. due to extreme events like storms or floods |
| increase in production downtime | rise in the amount of time during which production processes or operations are temporarily halted or suspended within a manufacturing facility or production environment |
| increase in cooling requirements (server rooms, storage, premises) | rising demand for air conditioning and cooling systems due to increased temperatures and heat waves |
| increase in material stress | deterioration and weakening of materials used in various applications, such as structural components, machinery parts, or manufacturing materials due to prolonged exposure to increased heat, changed humidity and other atmospheric variables |
| increase in costs along value chain (e.g. energy/water costs for production) | rise of expenses incurred across various stages of production, distribution, and consumption processes, including increased expenditures on essential resources |



**KR-EI-1**
Risk to businesses and industries due to extreme events (floods, droughts)

**KR-EI-2**
Risk of missed opportunities and unutilised innovation potential

**KR-EI-3**
Risk of loss of jobs and lack of skilled workers

**SD-EI-1** Existing regulations and frameworks enforcing protective measures in companies against extreme events like floods and droughts and businesses are continuously adapted to changing climate risks and altered empirical values.

**SD-EI-2** Industries are aware of relevant climate impacts that affect them and have the capabilities to manage them effectively, including enhanced resilience of supply chains. Further support to business to assess their individual risk due to climate change is provided.

**SD-EI-3** Innovative concepts and niche business developments supporting climate change adaptation objectives are supported financially and through enabling policies.

*Figure 37: Climate Impact Chain for the sector **Economy & Industry**.*

# Energy

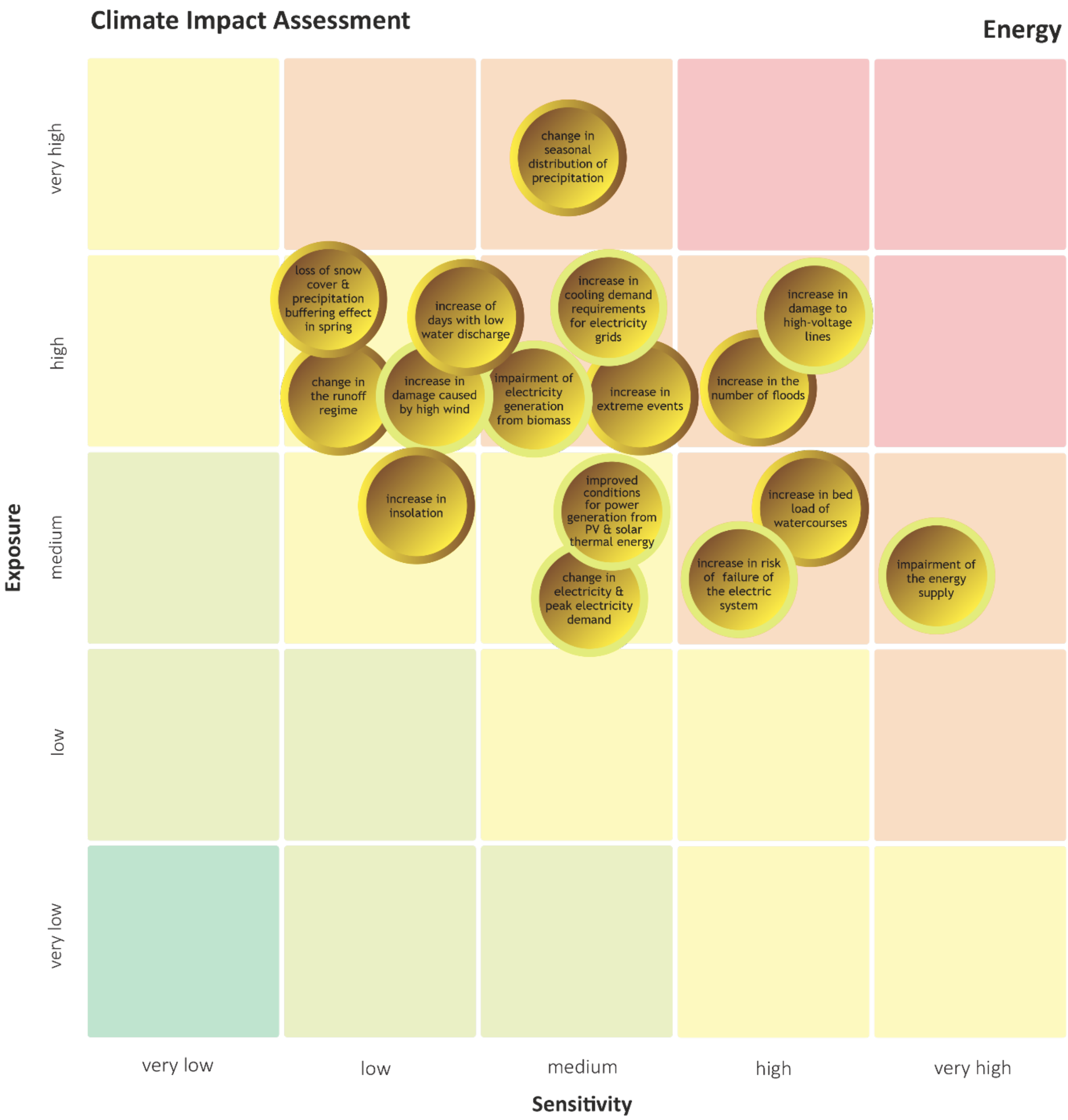
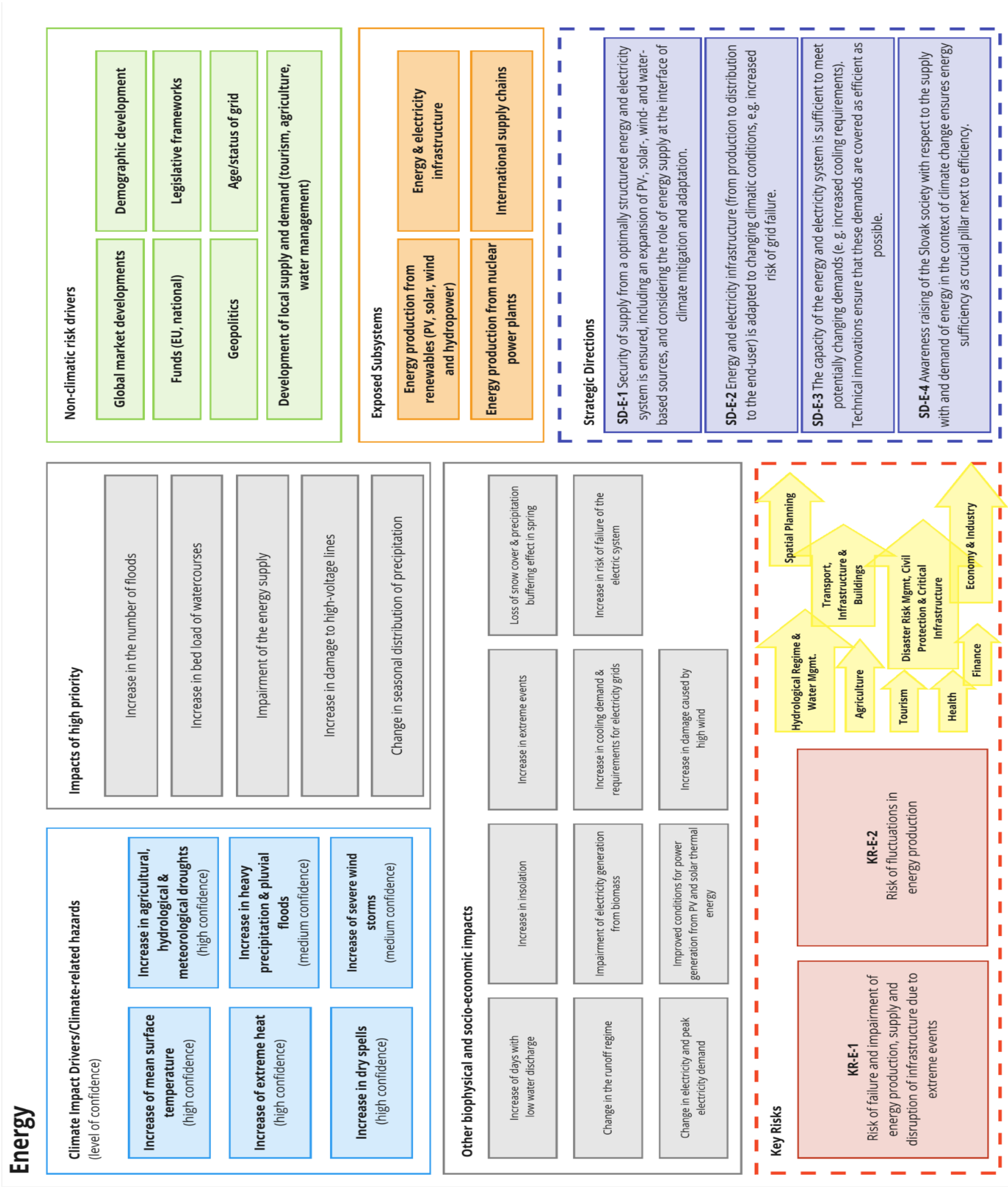


*Figure 38: Climate impacts for the sector **Energy** arranged in a matrix with respect to their sensitivity and exposure.*

| Climate Impact | Definin |
|---|---|
| biophysical | |
| increase in the number of floods | rise in the frequency or severity of flood events that directly impact energy infrastructure, operations, and resources |
| increase in bed load of watercourses | rise in the amount of sediment, debris, and other materials carried along the bottom of rivers, streams, and other waterways |
| increase in extreme events | more frequent and more severe occurrence of weather phenomena such as heat waves, droughts, storms and wildfires cause increased costs for rehabilitation and further along the value chain, e.g. through the impact on humans |
| loss of snow cover & precipitation buffering effect in spring | reduced water retention in the form of snow in winter leading to altered runoff regimes and reducing water supply in spring & summer (decreasing buffering effect through loss of snow cover) |
| change in seasonal distribution of precipitation | shifts in the timing and intensity of rainfall patterns throughout the year; alterations can affect water availability, storage, distribution, energy production and demand |
| increase of days with low water discharge | reduction in water level of running and standing waters resulting in increasing pollution and decreasing water quality and navigability |
| increase in insolation | increase in number of days with low cloud cover resulting in greater solar energy availability and energy yield |
| change in the runoff regime | alterations in the timing and magnitude of running waters influencing hydroelectric power generation |
| socio-economic | |
| impairment of the energy supply | disruptions, limitations, or inadequacies in the availability, reliability, or accessibility of energy resources and infrastructure needed to meet demand |
| increase in damage to high-voltage lines | rise in the frequency or severity of physical harm or impairment inflicted upon electrical transmission infrastructure due to extreme weather events |
| increase in damage caused by high wind | adverse impacts on electrical power production from wind turbines due to extreme weather events (storms) |
| impairment of electricity generation from biomass | adverse impacts on electrical power production from biomass due to impairment of biomass feedstock by climatic factors such as droughts or flooding |

| | |
|---|---|
| change in electricity and peak electricity demand | alterations in consumption patterns of electrical energy e.g. due to temperature variations |
| improved conditions for power generation from PV and solar thermal energy | increasing solar radiation leads to more favourable conditions for power generation from PV and solar thermal energy |
| increase in cooling demand & requirements for electricity grids | rising demand for air conditioning and cooling systems due to increased temperatures and heat waves to ensure stable functioning of electricity grid |
| increase in risk of failure of the electric system | increased likelihood of disruptions, breakdowns, or malfunctions occurring within the electrical infrastructure |

*Table 52: Definitions of identified climate impacts for the sector* ***Energy.***



**KR-E-1** Risk of failure and impairment of energy production, supply and disruption of infrastructure due to extreme events

**KR-E-2** Risk of fluctuations in energy production

**SD-E-1** Security of supply from a optimally structured energy and electricity system is ensured, including an expansion of PV-, solar-, wind- and water-based sources, and considering the role of energy supply at the interface of climate mitigation and adaptation.

**SD-E-2** Energy and electricity infrastructure (from production to distribution to the end-user) is adapted to changing climatic conditions, e.g. increased risk of grid failure.

**SD-E-3** The capacity of the energy and electricity system is sufficient to meet potentially changing demands (e. g. increased cooling requirements). Technical innovations ensure that these demands are covered as efficient as possible.

**SD-E-4** Awareness raising of the Slovak society with respect to the supply with and demand of energy in the context of climate change ensures energy sufficiency as crucial pillar next to efficiency.

*Figure 39: Climate Impact Chain for the sector* ***Energy****.*

# Finance

*Figure 40: Climate impacts for the sector **Finance** arranged in a matrix with respect to their sensitivity and exposure.*

*Table 53: Definitions of identified climate impacts for the sector **Finance**.*

| Climate Impact | Definition |
|---|---|
| **biophysical** | |
| increase in extreme events | more frequent and more severe occurrence of weather phenomena such as storms, heat waves, floods, droughts, storms and wildfires causing increased costs for rehabilitation and further along the value chain, e.g. through the impact on humans |
| **socio-economic** | |
| increase in insurance costs | rising premiums and coverage limitations for property and infrastructure due to increased risks associated with climate-related hazards such as floods, storms, and wildfires |
| change in requirements for prudential frameworks (need to incorporating climate-related risks) | necessity for financial institutions to adjust their risk management and regulatory frameworks to account for the impacts of climate change |
| increase in financial needs for adaptation and mitigation measures | growing demand for funding to implement strategies and measures aimed at adapting to and mitigating climate change impacts, including transitioning towards low-carbon and climate-resilient pathways |
| decrease in public finances (e.g. tax revenues, increased government expenditures, lower credit rating) | reduction in government revenues, increased expenditures, and potential credit rating downgrades due to the economic repercussions of climate-related events |
| increase in insurance premia & widening of existing protection gap | rise in costs for insurance coverage and the expansion of the disparity between insured losses and uninsured risks |
| increase in probability of default and loss of asset value affecting financial institutions | increased risks of borrowers failing to meet their financial obligations and decreases in the worth of financial assets, respectively |
| increase in tighter financial conditions | more difficult access to credit, rising interest rates and stricter lending criteria |
| increase in liquidity risk | increased possibility of financial institutions to encounter difficulties in meeting its short-term financial obligations or funding needs |
| increase in operational risk (damage to offices and/or data centres) | increased probability of disruptions, losses, or failures in business operations due to physical damage or impairment to infrastructure, facilities, or technological systems |

| | |
|---|---|
| increase in demand for insurances | rise in the number of individuals, businesses, or entities seeking insurance coverage to protect against climate change induced risks |

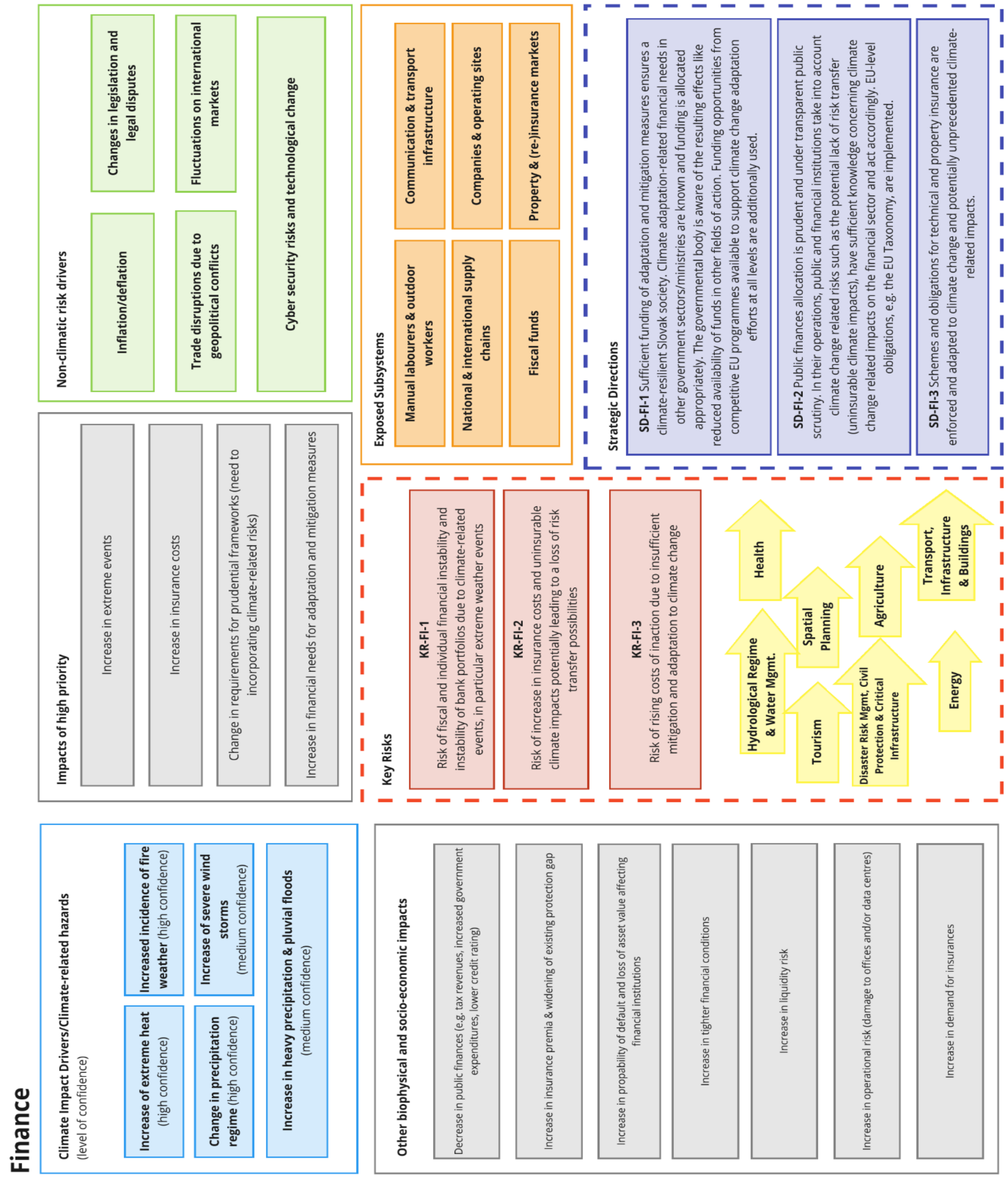


*Figure 41: Climate Impact Chain for the sector* ***Finance***.

# Forestry

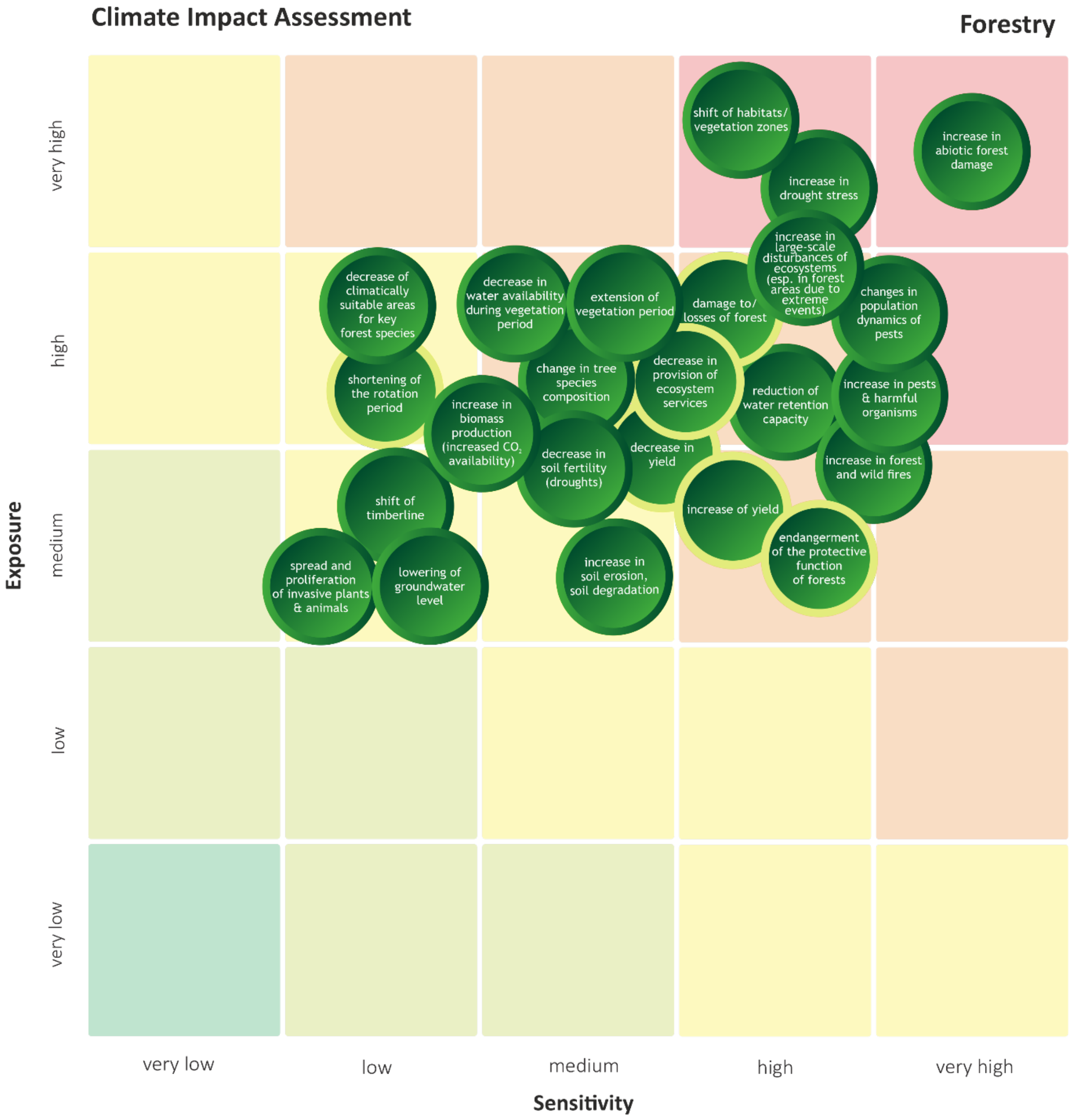


*Figure 42: Climate impacts for the sector **Forestry** arranged in a matrix with respect to their sensitivity and exposure.*

*Table 54: Definitions of identified climate impacts for the sector* ***Forestry***.

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase in abiotic forest damage | escalating detrimental effects on forests caused by non-living factors such as extreme weather events, temperature fluctuations, and soil degradation |
| shift of habitats/vegetation zones | movement or relocation of ecosystems and vegetation communities to different geographical locations |
| increase in drought stress | increased physiological strain and reduced productivity due to prolonged periods of water scarcity caused by abnormally dry weather over a longer period |
| increase in pests & harmful organisms | increased prevalence and activity of organisms with a negative effect on forest ecosystems and biodiversity (e.g. successive generations of detrimental organisms emerging within a single growing season) |
| changes in population dynamics of pests | alterations in the abundance, distribution, and behavior of insect pests and pathogens within forest ecosystems leading to increased damage to trees, reduced timber quality, and ecosystem disturbances |
| reduction of water retention capacity | reduced ability to hold onto water, resulting in increased drought stress for plants, increased soil erosion and decreased resilience to climate extremes |
| increase in large-scale disturbances of ecosystems (especially in forest areas due to extreme events) | rising frequency, intensity, and extent of disruptive events such as wildfires, storms, insect outbreaks, and disease epidemics |
| increase in forest and wild fires | increased occurrence, intensity, and severity of fires due to rising temperatures, prolonged droughts, and changes in precipitation patterns |
| extension of vegetation period | lengthening of plants` growing season due to rise in temperature leading to shifts in plant phenology and ecosystem dynamics |
| decrease in water availability during vegetation period | reduction in the amount of water accessible for plant growth and development throughout the active growing season due to factors such as reduced precipitation, increased evaporation, and altered hydrological cycles |
| decrease in soil fertility (droughts) | reduction in the capacity of soil to sustain ecosystem productivity, resulting from prolonged dry periods that diminish soil moisture, disrupt nutrient cycling, and lead to soil degradation |
| change in tree species composition | alteration in the relative abundance and distribution of different tree species within a forest ecosystem |

| Climate Impact | Definition |
|---|---|
| increase in soil erosion, soil degradation | increased loss and deterioration of soil due to increased intensity and frequency of rainfall events and temperature fluctuations, among other things |
| increase in biomass production (increased CO2 availability) | augmentation of plant growth and productivity due to increased atmospheric carbon dioxide levels, which enhance photosynthesis and stimulate biomass accumulation in ecosystems |
| decrease of climatically suitable areas for key forest species | decline in the geographic range where environmental conditions are conducive to the growth and survival of important tree species |
| spread and proliferation of invasive plants and animals | (accelerated) expansion of geographic range and abundance of non-native pest species into new habitats or regions |
| lowering of groundwater level | decrease in the depth of underground water reservoirs, e.g. due to reduced recharge rates caused by alterations in precipitation patterns and increased evapotranspiration |
| shift of timberline | movement of the boundary where forests transition to alpine or tundra ecosystems, typically upslope |
| socio-economic | |
| damage to/losses of forest | adverse effects and reductions of the extent of forest ecosystems leading to the degradation of biodiversity, loss of habitat for wildlife, and the loss of other ecosystem services |
| decrease in provision of ecosystem services | decline in the capacity of forest ecosystems to provide essential benefits such as carbon sequestration, oxygen production, water regulation, soil stabilization, biodiversity conservation |
| increase of yield | augmentation of forestry productivity |
| endangerment of the protective function of forests | escalating risk to the capacity of forests to mitigate natural hazards such as landslides or avalanches |
| decrease in yield | reduction of forestry productivity |
| shortening of the rotation period | reduction in the time interval between successive harvests of timber or other forest products, typically by accelerated growth of trees |

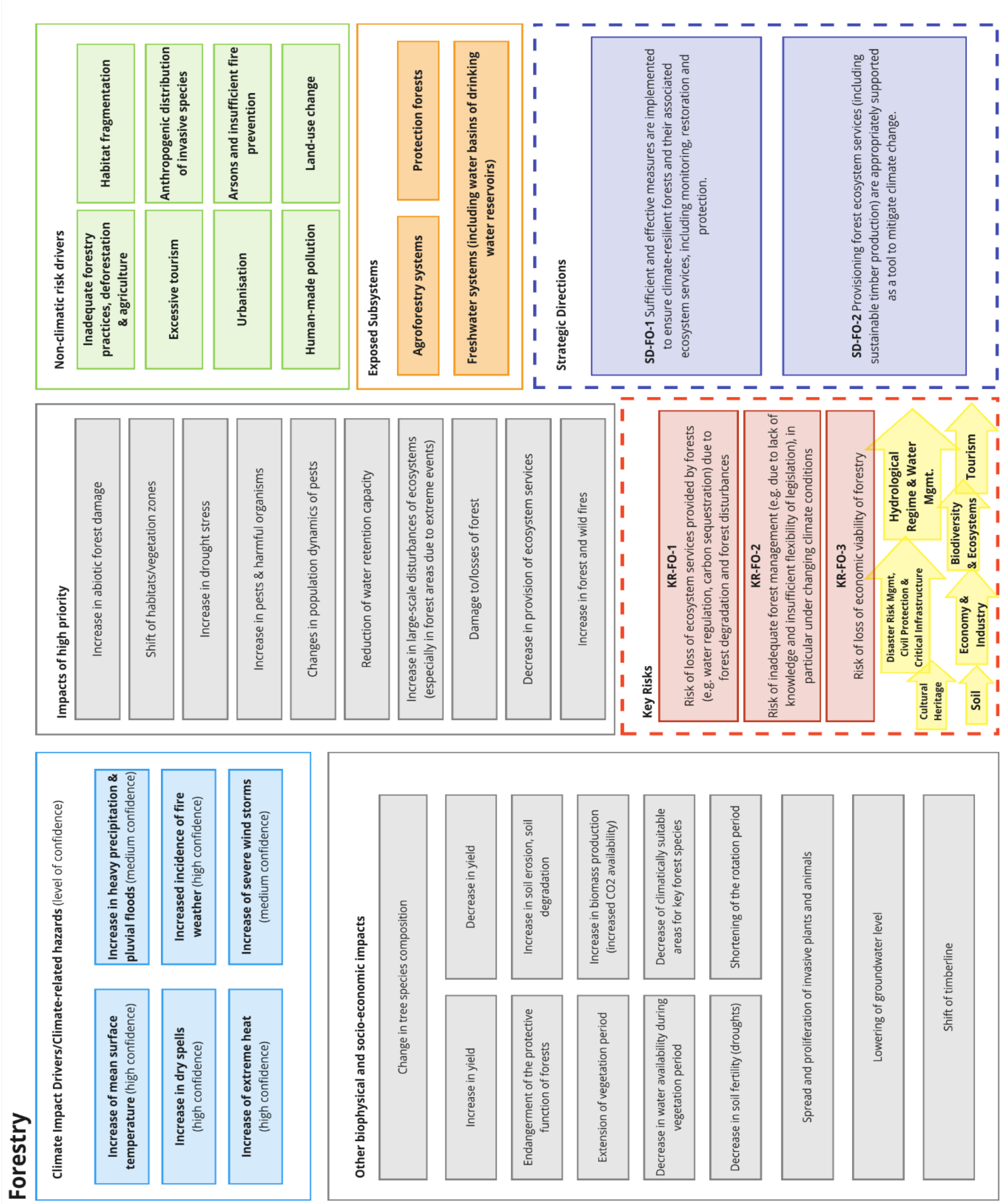


*Figure 43: Climate Impact Chain for the sector **Forestry**.*

# Geological Environment & Soil

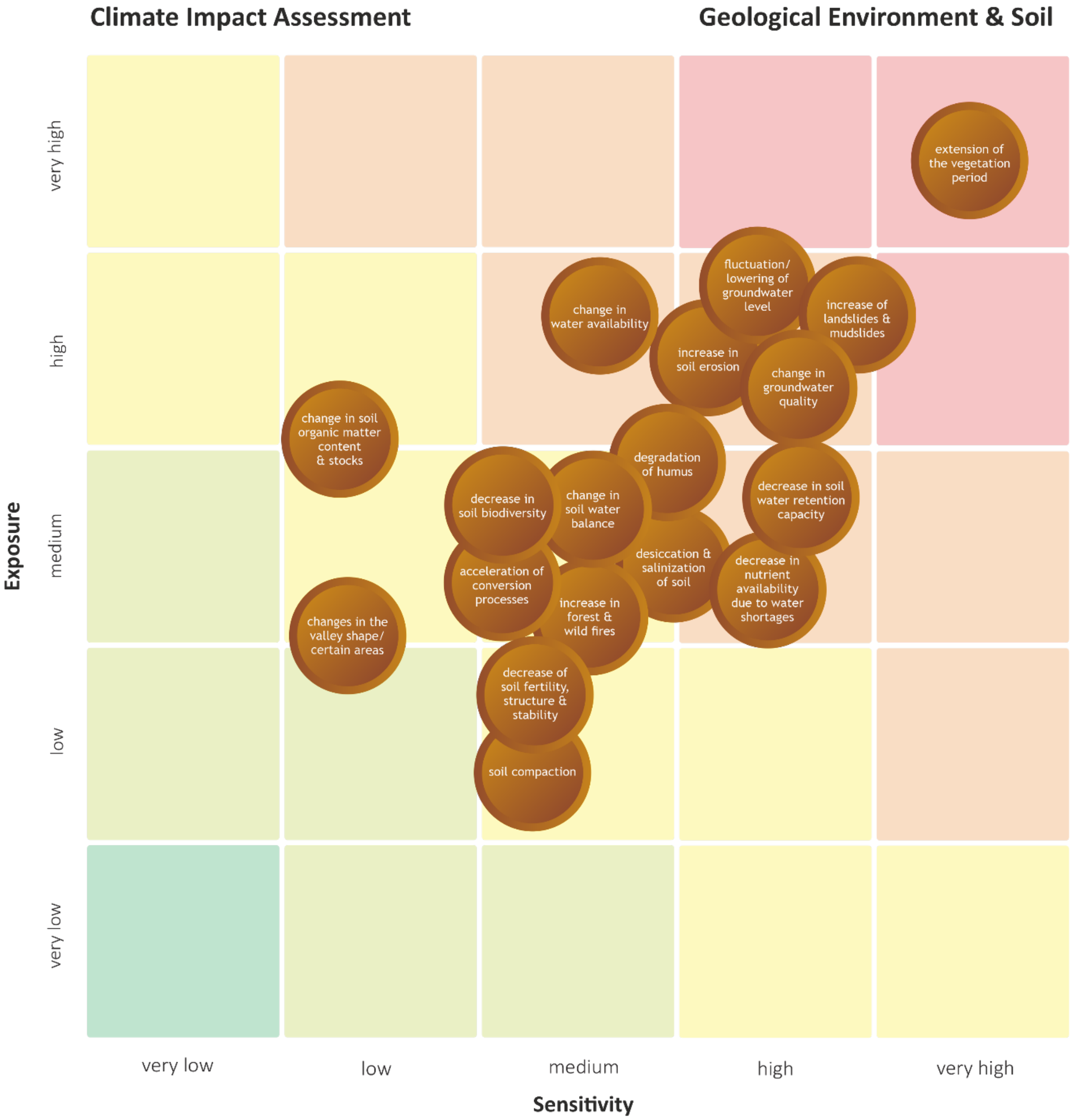


*Figure 44: Climate impacts for the sector* ***Geological Environment & Soil*** *arranged in a matrix with respect to their sensitivity and exposure.*

*Table 55: Definitions of identified climate impacts for the sector **Geological Environment & Soil**.*

| Climate Impact | Definition |
|---|---|
| biophysical | |
| extension of the vegetation period | lengthening of plants` growing season due to rise in temperature leading to shifts in plant phenology and ecosystem dynamics |
| increase of landslides and mudslides | increased occurrence of movements of mass of rocks, debris or earth down a slope or channel containing suspended particles due to increase of heavy or long-lasting precipitation events or rapid snow melt |
| fluctuation/lowering of the groundwater level | although many factors influence slope deformations, climate change is identified as a very significant factor. In Slovakia, slope deformations account for 5.25% of the total territory – data for 2006. Associated with: fluctuations in the groundwater level. |
| lowering of groundwater level | decrease in the depth of underground water reservoirs, e.g. due to reduced recharge rates caused by alterations in precipitation patterns, increased evapotranspiration |
| change in groundwater quality | in Slovakia, the quality of underground water (UW) is not investigated and monitored (partial interest of VUHV), in the current state it is not possible to evaluate the consequences/impacts of pollution as a result of human activity, not even as an impact of climate change. The extreme manifestations of climate change are certainly related to the quality of groundwater, e.g. in the short term, during floods, the sources cannot be used for the supply of drinking water. Associated with: lowering of the groundwater level |
| increase in soil erosion | increased loss and deterioration of soil due to increased intensity and frequency of rainfall events and temperature fluctuations, among other things |
| change in water availability | alterations in soil moisture levels due to factors such as altered precipitation patterns, increased frequency of droughts or floods, and changes in snowmelt timing, affecting nutrient cycling, plant growth, microbial activity, soil erosion, and soil health |
| decrease in soil water retention capacity | reduced ability to hold onto water, resulting in increased drought stress for plants, increased irrigation needs for agriculture, increased soil erosion and decreased resilience to climate extremes |
| decrease in nutrient availability due to water shortages | diminishing of the availability of essential nutrients in the soil due to reduced soil moisture levels due to alteration in precipitation patterns |
| desiccation of soil | significant decline of soil moisture levels |
| degradation of humus | deterioration of organic matter in soil, leading to a reduction in soil fertility, structure, and ability to retain water and nutrients; affects the agricultural |

| Climate Impact | Definition |
|---|---|
|  | sector by diminishing crop productivity, increasing soil erosion and desertification risks, and necessitating soil conservation measures and sustainable land management practices |
| decrease in soil biodiversity | decline in the variety and abundance of microorganisms, fungi, and other organisms inhabiting soil ecosystems, resulting from factors such as changes in temperature, moisture, and land use patterns; impairing soil fertility, nutrient cycling, and pest regulation services |
| acceleration of conversion processes | accelerated rate at which natural soil characteristics, such as composition, structure, and fertility, undergo changes |
| change in soil water balance | alterations in the distribution and availability of water within the soil profile, affecting soil moisture levels, groundwater recharge, plant water uptake, and overall soil health |
| increase in forest and wild fires | increased occurrence, intensity, and severity of fires due to rising temperatures, prolonged droughts, and changes in precipitation patterns |
| change in soil organic matter content and stocks | alterations in the quantity and quality of organic materials present within soils |
| decrease of soil fertility, structure and stability | deterioration of soil quality due to factors such as erosion, nutrient depletion, and compaction, exacerbated by climate change-induced shifts in precipitation patterns and temperatures; diminishing water retention capacity, and increasing vulnerability to erosion and desertification |
| soil compaction | increased soil density and decreased pore space, impeding the movement of water, air, and nutrients within the soil profile adversely affecting soil structure, microbial activity, root growth, and overall soil health |
| changes in the valley shape/certain areas | modifications in the morphology, dimensions, and topographic features of valleys, such as shifts in the width, depth, slope, or alignment of valleys caused by e.g. increased erosion or fluvial dynamics |

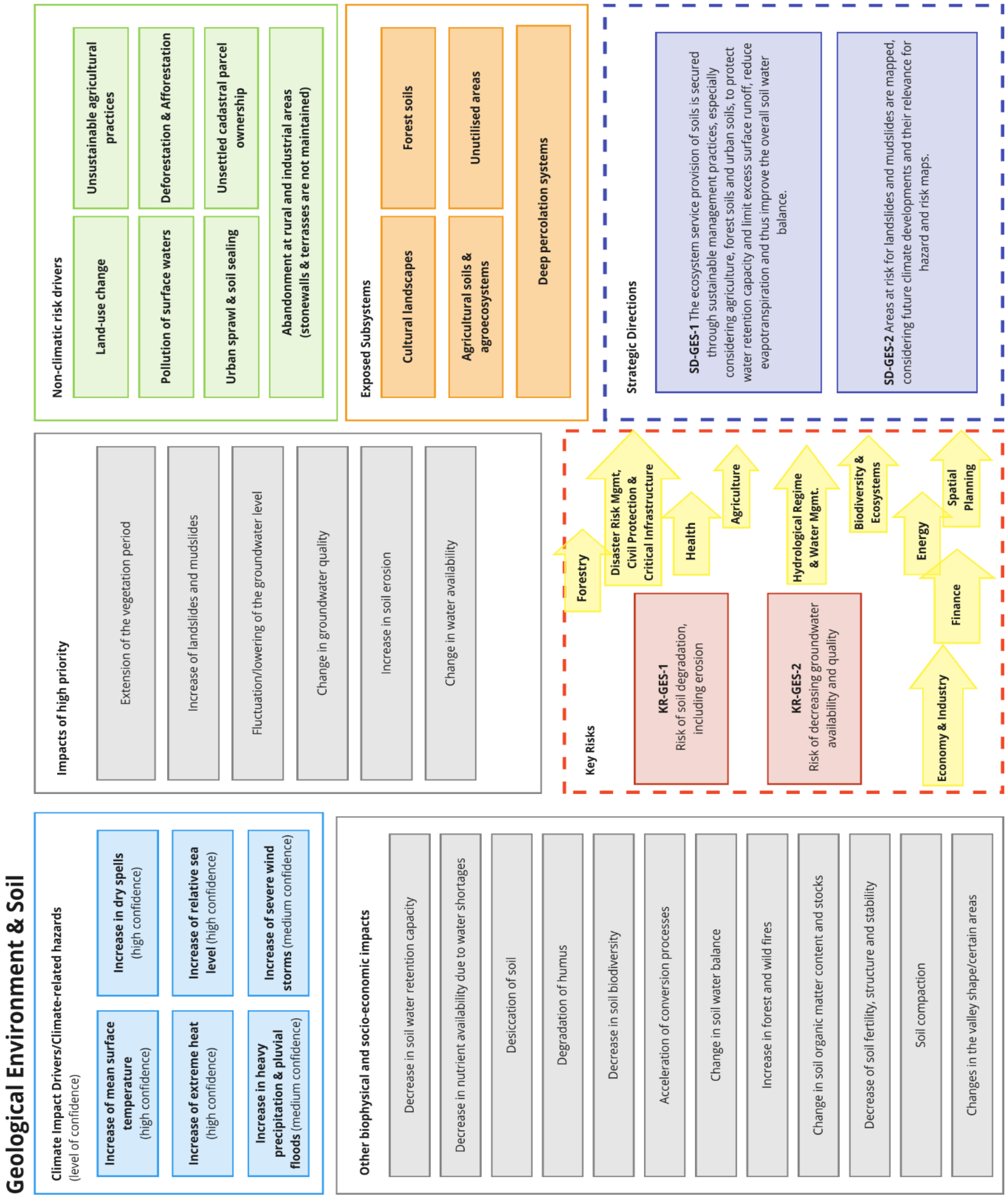


*Figure 45: Climate Impact Chain for the sector **Geological Environment & Soil**.*

# Health

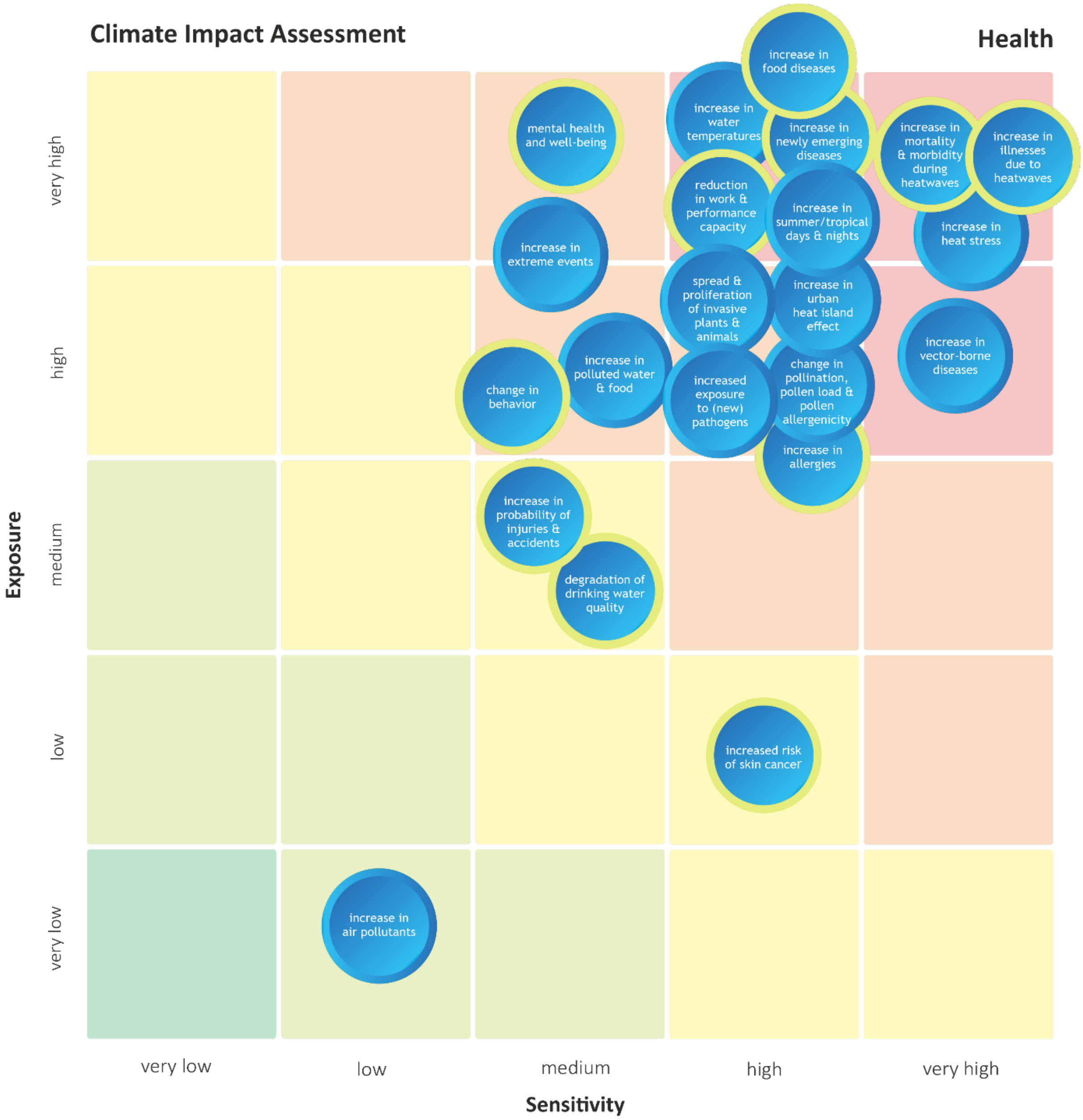
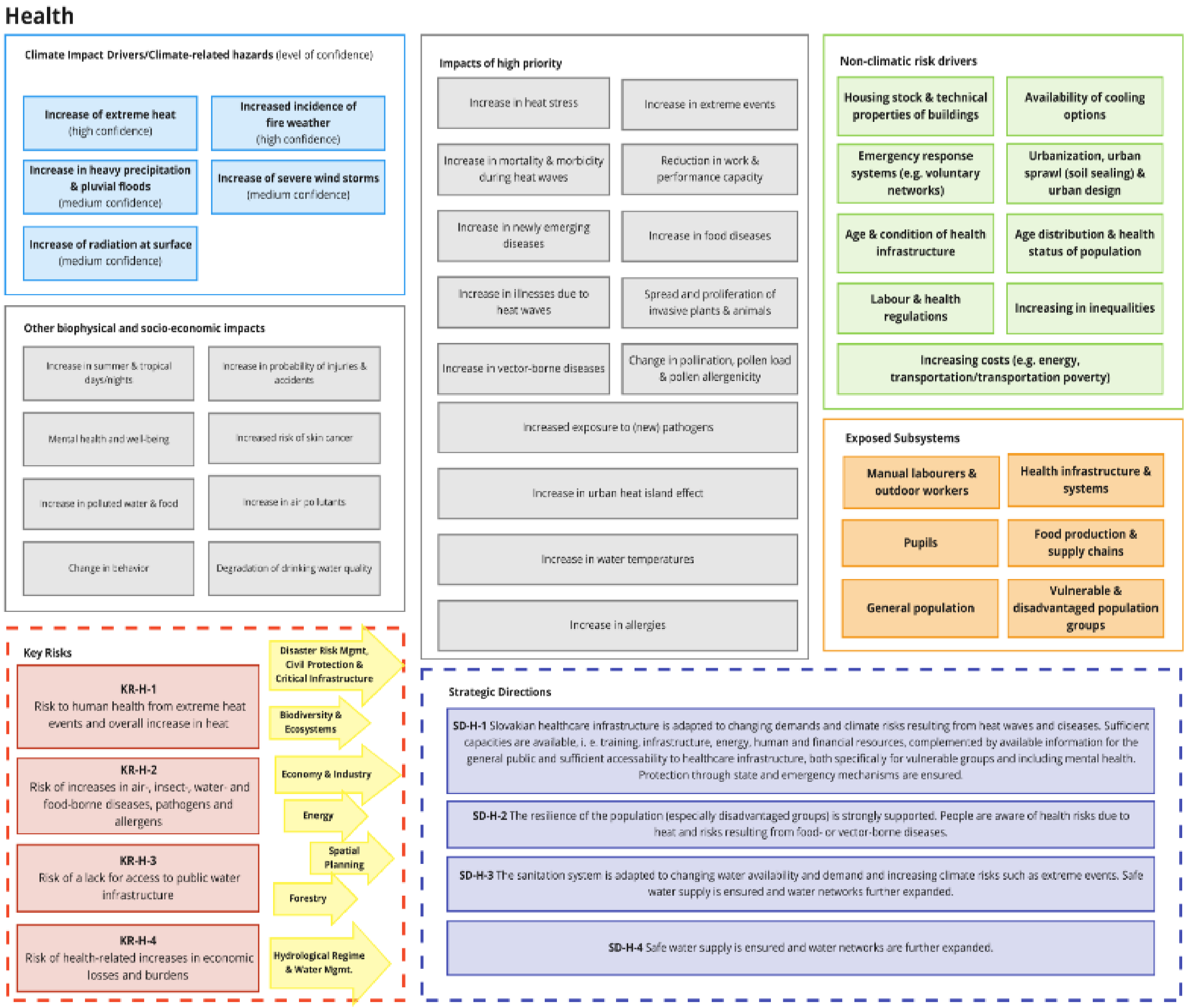


*Figure 46: Climate impacts for the sector **Health** arranged in a matrix with respect to their sensitivity and exposure.*

*Table 56: Definitions of identified climate impacts for the sector **Health**.*

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase in heat stress | increased physiological strain caused by exposure to high temperatures and humidity levels, which impedes the regulation of internal body temperature, resulting in heat rash and cramps to heat exhaustion and heatstroke |
| increase in vector-borne diseases | rise in the incidence and prevalence of illnesses by organisms that transmit pathogens to humans (vectors) such as mosquitoes, ticks, fleas, and flies |
| increase in extreme events | more frequent and more severe occurrence of weather phenomena such as storms, heat waves, floods, droughts, storms and wildfires causing increased costs for rehabilitation and further along the value chain, e.g. through the impact on humans |
| increase in food diseases | increased prevalence and incidence of illnesses caused by pathogens and pests transmitted through contaminated food sources |
| spread and proliferation of invasive plants & animals | (accelerated) expansion of geographic range and abundance of non-native pest species into new habitats or regions |
| change in pollination, pollen load & pollen allergenicity | variations in the timing and quantity of pollen release, increase in the amount of pollen dispersed, and the potency of pollen inducing allergic reactions in susceptible individuals |
| increased exposure to (new) pathogens | increased abundance of disease-causing bacteria, viruses, and parasites, due to expanded geographic range and accelerated proliferation |
| increase in urban heat island effect | Urban heat islands are areas of higher temperature in cities as these areas are heavily sealed and green spaces are limited. Urban heat islands can lead to an alteration of air pollutant transport, wind patterns and photochemical production, among others. An increase in mean air temperature and temperature extremes are characteristics of urban heat islands |
| increase in water temperatures | rise in the average temperature of water bodies, which poses health risks such as increase of waterborne-diseases |
| increase in summer & tropical days/nights | rise in the frequency and duration of hot weather events (summer day: max. air temperature >25°C; tropical day: max. air temperature > 30°C; tropical night: min. air temperature >20 °C), affecting exceedance of comfort temperature levels and leading to increased cooling demand |
| increase in air pollutants | rise in the concentration of harmful substances in the air, such as particulate matter (PM), nitrogen dioxide (NO2), sulfur dioxide |

| Climate Impact | Definition |
|---|---|
| | (SO2), ozone (O3), carbon monoxide (CO), and volatile organic compounds (VOCs) |
| socio-economic | |
| increase in mortality & morbidity during heat waves | increased rates of death and illness during periods of prolonged and extreme heat |
| increase in newly emerging diseases | rise in the number of diseases that are newly recognised or have recently emerged in human populations |
| increase in illnesses due to heat waves | increased incidence of heat-related conditions such as heat exhaustion, heatstroke, dehydration, and exacerbation of pre-existing health conditions, particularly impacting vulnerable groups |
| reduction in work & performance capacity | diminished ability of individuals to carry out tasks and perform at their usual levels of productivity, and reduction of cognitive performance as a result of exposure to high temperatures |
| increase in allergies | rise in the prevalence and incidence of allergic reactions and allergic diseases |
| mental health and well-being | The impact is manifested not only in reduced work productivity, but especially in the younger generation, the frequency of anxiety and depression is increasing due to the state of the climate change problem and un/implemented solutions. |
| change in behaviour | the behaviour of residents is changing in making decisions about spending free time, choosing housing, place and time of vacations, etc. |
| degradation of drinking water quality | decline in the purity and safety of water intended for human consumption |
| increase in probability of injuries & accidents | increased likelihood of incidents such as falls, burns, and traffic collisions during extreme weather events, periods of heat waves, and other environmental hazards |
| increased risk of skin cancer | increased probability of developing dermatologic carcinoma due prolonged and increased exposure to ultraviolet (UV) radiation from the sun |



**KR-H-1** Risk to human health from extreme heat events and overall increase in heat

**KR-H-2** Risk of increases in air-, insect-, water- and food-borne diseases, pathogens and allergens

**KR-H-3** Risk of a lack for access to public water infrastructure

**KR-H-4** Risk of health-related increases in economic losses and burdens

**SD-H-1** Slovakian healthcare infrastructure is adapted to changing demands and climate risks resulting from heat waves and diseases. Sufficient capacities are available, i. e. training, infrastructure, energy, human and financial resources, complemented by available information for the general public and sufficient accessability to healthcare infrastructure, both specifically for vulnerable groups and including mental health. Protection through state and emergency mechanisms are ensured.

**SD-H-2** The resilience of the population (especially disadvantaged groups) is strongly supported. People are aware of health risks due to heat and risks resulting from food- or vector-borne diseases.

**SD-H-3** The sanitation system is adapted to changing water availability and demand and increasing climate risks such as extreme events. Safe water supply is ensured and water networks further expanded.

**SD-H-4** Safe water supply is ensured and water networks are further expanded.

Figure 47: Climate Impact Chain for the sector *Health*.

# Hydrological Regime & Water Resource Management

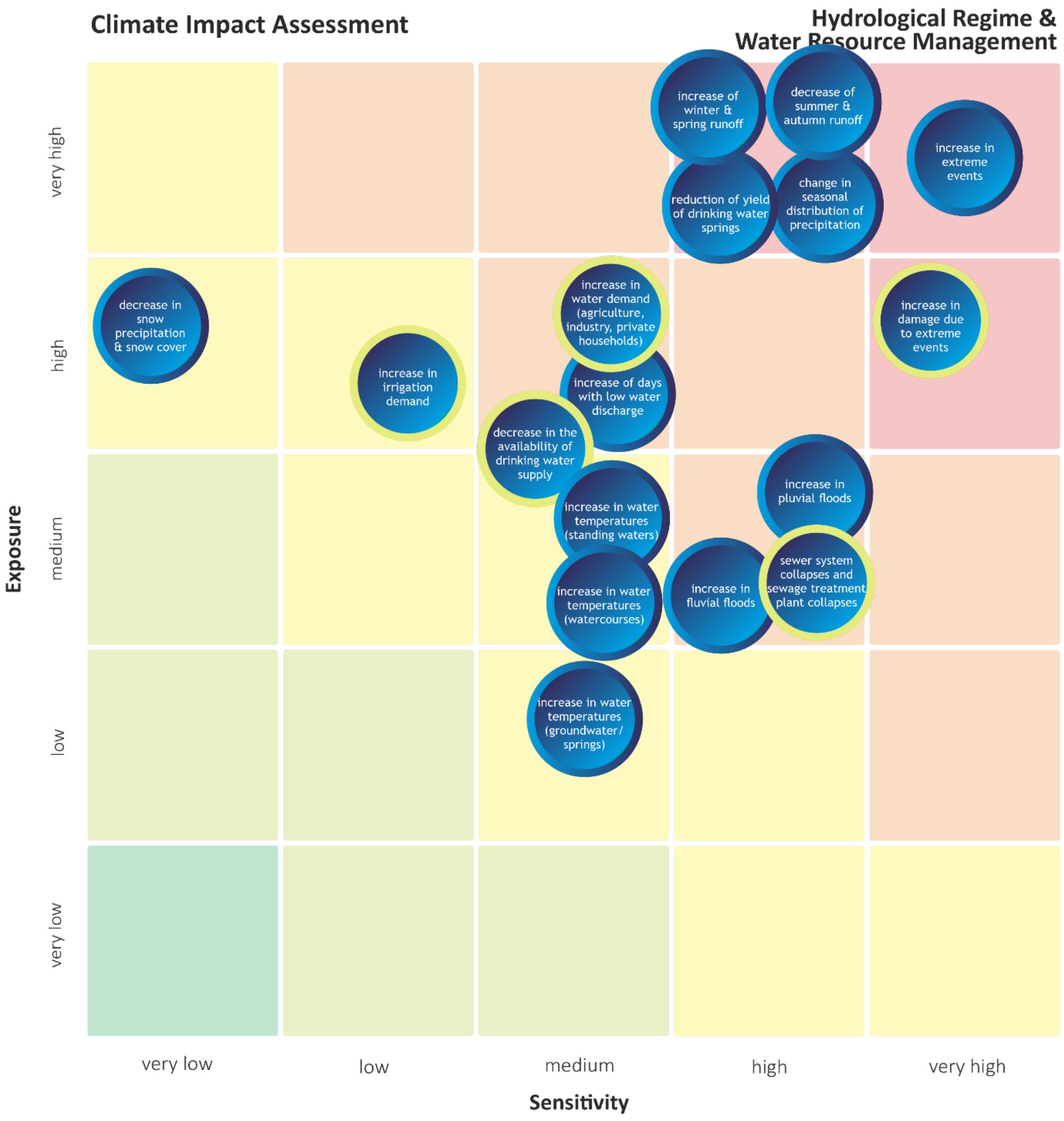
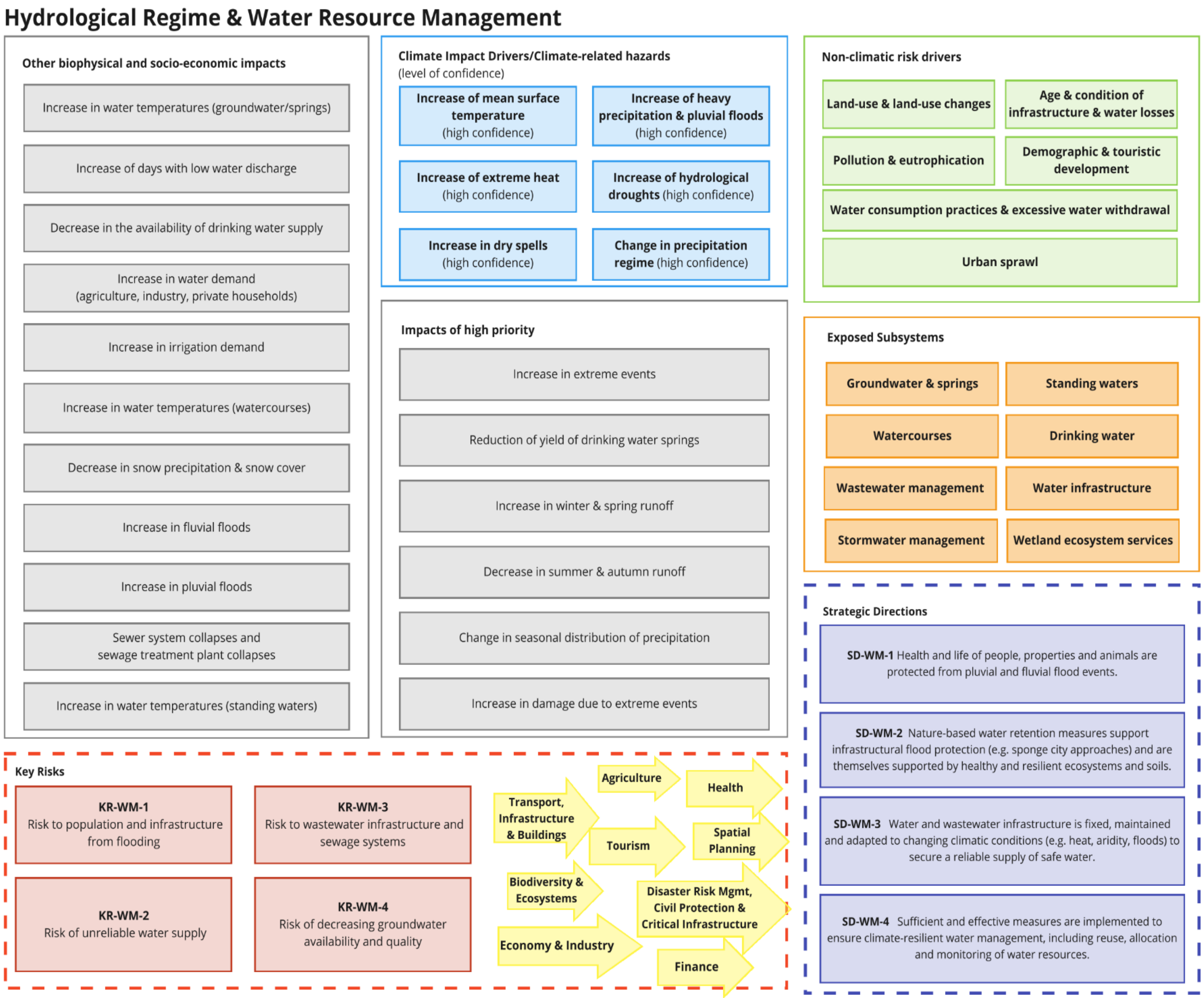


*Figure 48: Climate impacts for the sector* ***Hydrological Regime & Water Resource Management*** *arranged in a matrix with respect to their sensitivity and exposure.*

*Table 57: Definitions of identified climate impacts for the sector* ***Hydrological Regime & Water Resource Management****.*

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase in extreme events | more frequent and more severe occurrence of weather phenomena such as storms, heat waves, floods, droughts, storms and wildfire disrupting infrastructure, affecting water quality and quantity, enhancing erosion and sedimentation |
| reduction of yield of drinking water springs | decrease in the flow rates of springs providing drinking water due to alterations in precipitation patterns |
| increase in winter & spring runoff | rise in the volume of water flowing over the land surface and into rivers, streams, and other water bodies during the winter and spring seasons |
| decrease in summer & autumn runoff | decline in the volume of water flowing over the land surface and into rivers, streams, and other water bodies during the summer and autumn seasons |
| change in seasonal distribution of precipitation | shifts in the timing and intensity of rainfall patterns throughout the year; alterations can affect water availability, storage, and distribution |
| increase of days with low water discharge | reduction in the flow of watercourses resulting in reduced pollutant dilution and water quality |
| decrease in snow precipitation & snow cover | reduced water retention in the form of snow in winter leading to altered runoff regimes and reducing water supply in the summer |
| increase in fluvial floods | rise in the frequency and intensity of flood events in rivers, accompanied by alterations in the anticipated magnitudes and patterns of these occurrences |
| increase in pluvial floods | rise in the frequency and intensity of flood events from heavy precipitation, accompanied by alterations in the anticipated magnitudes and patterns of these occurrences |
| increase in water temperatures (watercourses) | rising temperatures in rivers, streams and other flowing water bodies cause increases in algae blooms and reduced oxygen levels, affecting aquatic ecosystems and water quality |
| increase in water temperatures (standing waters) | rising temperatures in lakes, ponds and reservoirs cause increases in algae blooms and reduced oxygen levels, affecting aquatic ecosystems and water quality |

| | |
|---|---|
| increase in water temperatures (groundwater/springs) | rising temperatures in subsurface aquifers and natural spring sources altering groundwater availability, affecting ecosystem dynamics, and exacerbating water scarcity challenges |
| socio-economic | |
| increase in damage due to extreme events | increased occurrence of intense storms, floods, droughts, and heat waves; disrupting and damaging infrastructure |
| decrease in the availability of drinking water supply | reduction in the quantity and quality of potable water accessible to communities, often resulting from factors such as drought, contamination, or overexploitation |
| increase in water demand (agriculture, industry, private households) | increased levels of water demand for irrigation, cooling etc. and reduction in the frequency and quantity of precipitation necessitating the proactive planning of water distribution to prevent water scarcity and conflicts over water use |
| increase in irrigation demand | reduction in the frequency and quantity of precipitation necessitating the use of alternative watering systems for agriculture and green spaces |
| sewer system collapses and sewage treatment plant collapses | necessity to adapt infrastructure to cope with changing precipitation patterns and increased stormwater runoff |



## Hydrological Regime & Water Resource Management

**Other biophysical and socio-economic impacts**

- Increase in water temperatures (groundwater/springs)
- Increase of days with low water discharge
- Decrease in the availability of drinking water supply
- Increase in water demand (agriculture, industry, private households)
- Increase in irrigation demand
- Increase in water temperatures (watercourses)
- Decrease in snow precipitation & snow cover
- Increase in fluvial floods
- Increase in pluvial floods
- Sewer system collapses and sewage treatment plant collapses
- Increase in water temperatures (standing waters)

**Climate Impact Drivers/Climate-related hazards**
(level of confidence)

- **Increase of mean surface temperature** (high confidence)
- **Increase of heavy precipitation & pluvial floods** (high confidence)
- **Increase of extreme heat** (high confidence)
- **Increase of hydrological droughts** (high confidence)
- **Increase in dry spells** (high confidence)
- **Change in precipitation regime** (high confidence)

**Impacts of high priority**

- Increase in extreme events
- Reduction of yield of drinking water springs
- Increase in winter & spring runoff
- Decrease in summer & autumn runoff
- Change in seasonal distribution of precipitation
- Increase in damage due to extreme events

**Non-climatic risk drivers**

- **Land-use & land-use changes**
- **Age & condition of infrastructure & water losses**
- **Pollution & eutrophication**
- **Demographic & touristic development**
- **Water consumption practices & excessive water withdrawal**
- **Urban sprawl**

**Exposed Subsystems**

- **Groundwater & springs**
- **Standing waters**
- **Watercourses**
- **Drinking water**
- **Wastewater management**
- **Water infrastructure**
- **Stormwater management**
- **Wetland ecosystem services**

**Strategic Directions**

- **SD-WM-1** Health and life of people, properties and animals are protected from pluvial and fluvial flood events.
- **SD-WM-2** Nature-based water retention measures support infrastructural flood protection (e.g. sponge city approaches) and are themselves supported by healthy and resilient ecosystems and soils.
- **SD-WM-3** Water and wastewater infrastructure is fixed, maintained and adapted to changing climatic conditions (e.g. heat, aridity, floods) to secure a reliable supply of safe water.
- **SD-WM-4** Sufficient and effective measures are implemented to ensure climate-resilient water management, including reuse, allocation and monitoring of water resources.

**Key Risks**

- **KR-WM-1** Risk to population and infrastructure from flooding
- **KR-WM-3** Risk to wastewater infrastructure and sewage systems
- **KR-WM-2** Risk of unreliable water supply
- **KR-WM-4** Risk of decreasing groundwater availability and quality

*Figure 49: Climate Impact Chain for the sector **Hydrological Regime & Water Resource Management**.*

# Information & Communication Technology

*Figure 50: Climate impacts for the sector **Information & Communication Technology** arranged in a matrix with respect to their sensitivity and exposure.*

*Table 58: Definitions of identified climate impacts for the sector Information & Communication Technology.*

| Climate Impact | Definition |
|---|---|
| **biophysical** | |
| increase in forest and wild fires | increased occurrence, intensity, and severity of fires due to rising temperatures, prolonged droughts, and changes in precipitation patterns |
| increase in heat load | increased temperatures and prolonged heat waves, leading to overheating of infrastructure components such as electrical systems, data centers, and telecommunications equipment; increasing the risk of equipment failures, service disruptions, and data loss, posing challenges for maintaining operational reliability, ensuring cybersecurity, and safeguarding critical services |
| increase in erosion (soil, surfaces/materials) | accelerated wearing away of soil, sediment, and land surfaces, often exacerbated by intensified rainfall and flooding; wear-away of protective coatings, degradation of surface materials, and compromising structural integrity, leading to corrosion, deterioration, and failure of infrastructure components such as roads, bridges, and buildings |
| increase in extreme events | more frequent and more severe occurrence of weather phenomena such as storms, heat waves, floods, droughts and storms posing increased risks to Information and Communication Technology (ICT) infrastructure, operations, and services |
| **socio-economic** | |
| increase in damage to critical infrastructure | rise in adverse effects inflicted upon essential Information and Communication Technology (ICT) systems, e.g. due to extreme events, such as storms, floods, and wildfires, resulting in disruptions to communication networks, data centers, and other vital ICT services |
| changes in the availability and quality/reliability of services (direct/indirect disruption from weather events) | alterations in the provision and dependability of essential services, both directly and indirectly influenced by weather events and climate variability, leading to disruptions in sectors such as transportation, energy, water supply, healthcare, and communication |
| increasing demand for ICT services responding to climate risks | rising need for Information and Communication Technology (ICT) solutions aimed at addressing and mitigating climate-related hazards, such as extreme weather events and environmental changes, through enhanced monitoring, early warning systems, data analysis, and communication infrastructure |
| increasing damage from pluvial flooding of low-lying infrastructure | escalating harm inflicted upon infrastructure situated in low-lying areas due inundation caused by intense rainfall events |

| Climate Impact | Definition |
|---|---|
| increased impacts on infrastructure from extreme events | heightened adverse effect on Information and Communication Technology (ICT) infrastructure, operations, and services due to rising occurrence and severity of weather and climate-related phenomena such as heat waves, storms, floods, droughts, and wildfires |
| increasing material stress and asset degradation from chronic changes in climate variables | progressive deterioration and strain experienced by infrastructure, buildings, and other physical assets |
| increase in frequency of failure and shortening of life spans | increased occurrence of structural and functional breakdowns, as well as reduced longevity, experienced by various systems, infrastructure, and assets due to more frequent and severe climate-related events and stressors |
| increased water usage for on-site cooling (e. g. data centres) | rising demand for air conditioning and cooling systems for essential Information and Communication Technology (ICT) systems due to increased temperatures and heat waves |
| increase in expenditures and costs for maintenance | rise in financial resources required to sustain and repair ICT infrastructure, systems, and services due to the impacts of changing climatic conditions, such as extreme weather events, which may damage or disrupt communication networks, data centres, and other ICT facilities |
| changed health and safety requirements for employees | adaptations in workplace regulations and guidelines tailored to protect the health and safety of ICT workers |
| increased corrosion due to higher humidity levels | increased rates of deterioration and rusting of metallic surfaces and structures as a result of prolonged exposure to increased moisture content in the air, leading to degradation, weakening, and potential failure of materials and infrastructure component |
| increase in personnel stress | rising levels of psychological strain experienced by individuals working in the ICT sector due to increased challenges and disruptions posed by climate-related events, such as extreme weather events and infrastructure damage, which can exacerbate work demands, increase job uncertainty, and intensify pressure to ensure the resilience and continuity of ICT services |

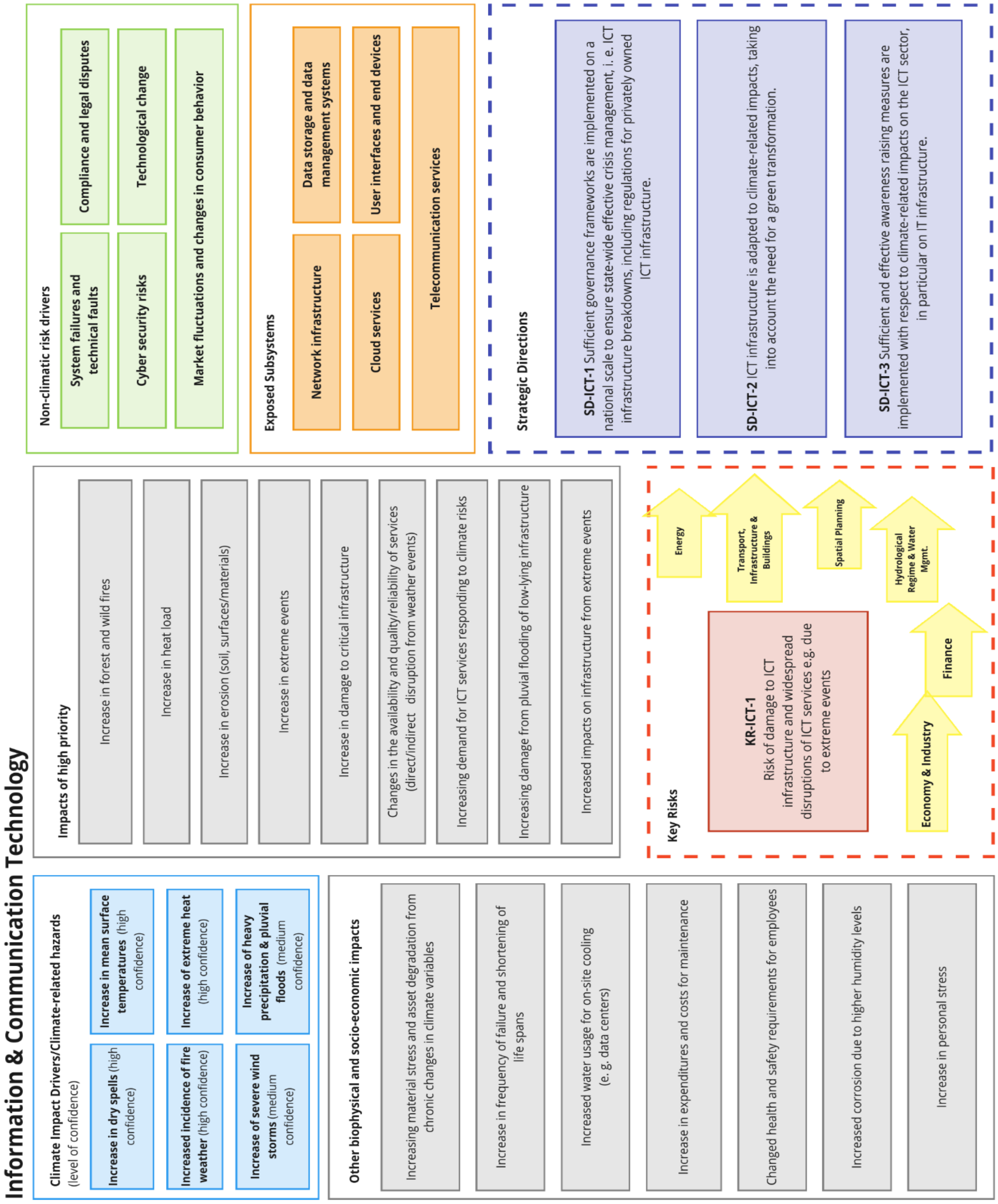


*Figure 51: Climate Impact Chain for the sector **Information & Communication Technology**.*

## Spatial Planning

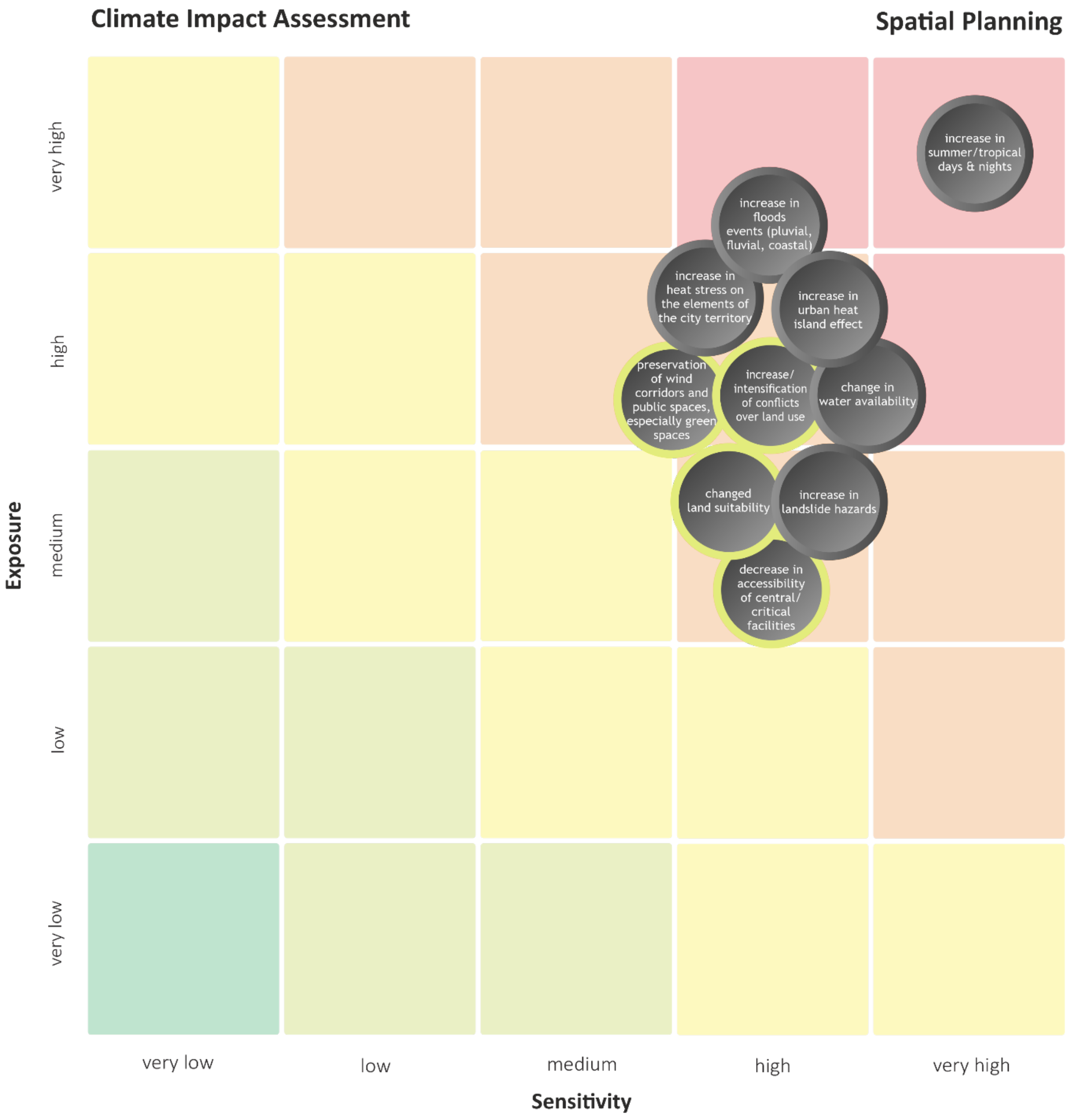


*Figure 52: Climate impacts for the sector **Spatial Planning** arranged in a matrix with respect to their sensitivity and exposure.*

*Table 59: Definitions of identified climate impacts for the sector* ***Spatial Planning****.*

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase in summer & tropical days/nights | rising temperatures and prolonged heat waves, leading to increased risks of heat-related illnesses and discomfort among populations, particularly in urban areas as well as thermal stress on buildings, causing structural damage, degradation of building materials, and increased energy consumption for cooling |
| increase in flood events (pluvial, fluvial) | increase in the frequency and intensity of flood events caused by heavy precipitation (pluvial), rivers (fluvial) |
| increase in urban heat island effect | Urban heat islands are areas of higher temperature in cities as these areas are heavily sealed and green spaces are limited. Urban heat islands can lead to an alteration of air pollutant transport, wind patterns and photochemical production, among others. An increase in mean air temperature and temperature extremes are characteristics of urban heat islands |
| increase in heat stress on the elements of the city territory (primarily on the living elements of the city) | rising temperatures and prolonged heat waves, leading to increased risks of heat-related illnesses and discomfort among populations, particularly in urban areas as well as thermal stress on green and blue infrastructure as well as buildings, causing structural damage, degradation of building materials, and increased energy consumption for cooling. |
| change in water availability | diminishing availability of freshwater due to factors such as reduced precipitation, increased evaporation, and altered hydrological cycles; necessitating stricter conservation measures, efficient allocation strategies, and investment in alternative water sources to ensure sustainable supply for irrigation of (urban) green spaces |
| increase in landslide hazards | increased occurrence of mass movements triggered by intense rainfall events and soil saturation, freeze-thaw-cycles and increased erosion from wind |
| socio-economic | |
| increase / intensification of conflicts over land use | increased competition and disputes among stakeholders over the allocation and management of land resources, exacerbated by climate-induced changes in environmental conditions and socio-economic pressures |
| preservation of wind corridors and public spaces, especially green spaces | increased demands for preserving green areas and ensuring clear pathways for air circulation, driven by concerns over urban heat island effects and air pollution |
| changed land suitability | alterations in the suitability of land for various uses, such as agriculture, forestry, and urban development, due to climate-induced |

| | |
|---|---|
| | shifts in environmental conditions, occurrence and spatial extension of extreme events, and resource availability |
| decrease in accessibility of central/critical facilities | reduced availability and reliability of essential services and infrastructure (e.g. urban network infrastructure/transportation) due to climate-induced disruptions such as extreme weather events, deteriorating transportation networks, and infrastructure susceptibility (aging of infrastructure); accessibility of infrastructure by repair workers to reinstate functionality |

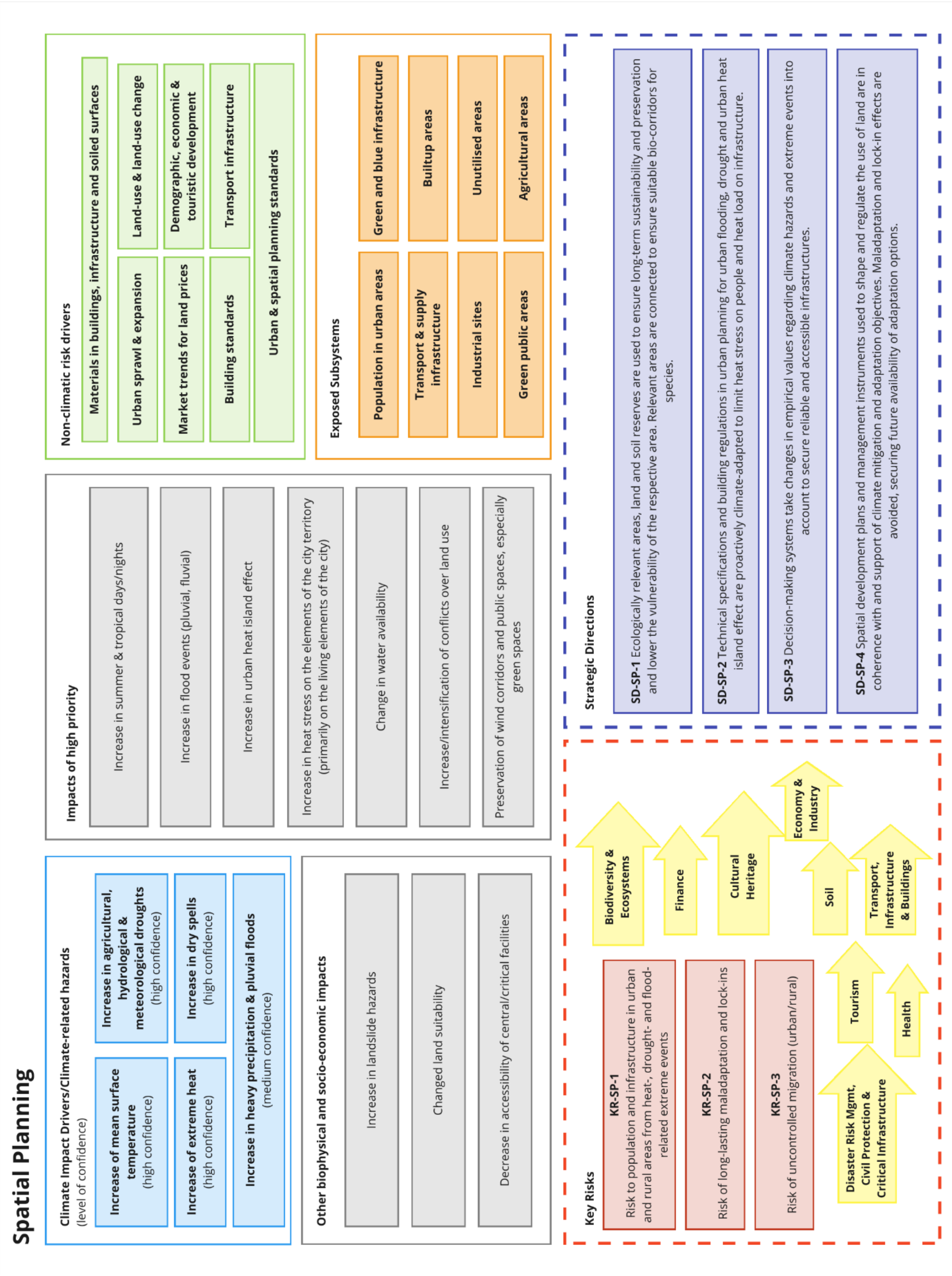


*Figure 53: Climate Impact Chain for the sector **Spatial Planning**.*

# Tourism

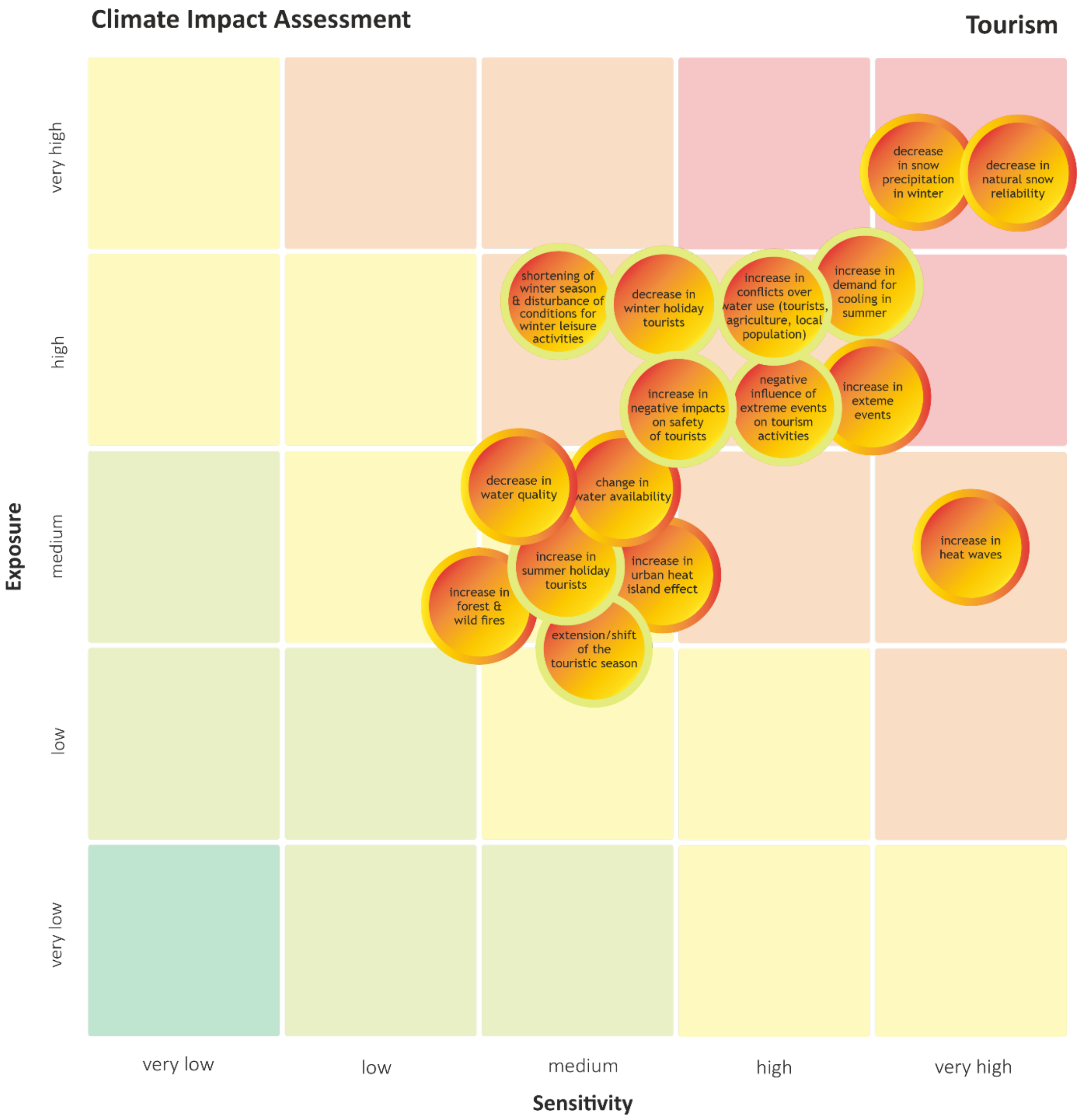
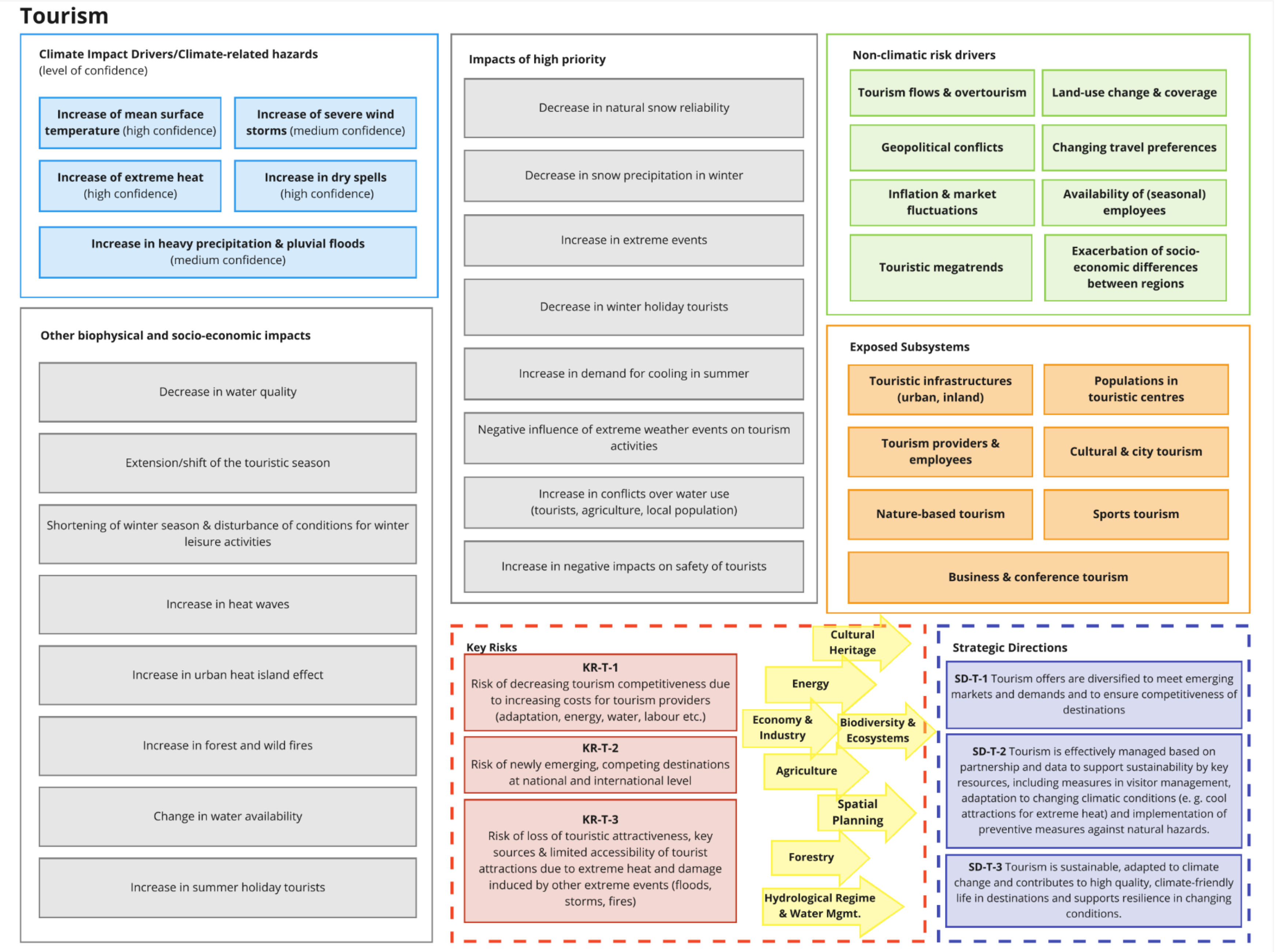


*Figure 54: Climate impacts for the sector* ***Tourism*** *arranged in a matrix with respect to their sensitivity and exposure.*

*Table 60: Definitions of identified climate impacts for the sector **Tourism**.*

| Climate Impact | Definition |
|---|---|
| biophysical | |
| decrease in natural snow reliability | trend of reduced predictability and decline of snow cover duration in winter tourism destinations |
| decrease in snow precipitation in winter | reduction in the amount of snowfall occurring within a region over time, affecting winter tourism and snow-dependent recreational activities |
| increase in extreme events | more frequent and more severe occurrence of weather phenomena such as floods, droughts and storms |
| increase in heat waves | rise of periods of abnormally hot weather lasting for several days or longer, with temperatures significantly higher than the historical average temperatures for the area |
| increase in urban heat island effect | Urban heat islands are areas of higher temperature in cities as these areas are heavily sealed and green spaces are limited. Urban heat islands can lead to an alteration of air pollutant transport, wind patterns and photochemical production, among others. An increase in mean air temperature and temperature extremes are characteristics of urban heat islands |
| increase in forest and wild fires | increased occurrence, intensity, and severity of fires due to rising temperatures, prolonged droughts, and changes in precipitation patterns |
| change in water availability | diminishing availability of freshwater due to factors such as reduced precipitation, increased evaporation, and altered hydrological cycles |
| decrease in water quality | deterioration of the chemical, physical, and biological characteristics of water bodies |
| socio-economic | |
| decrease in winter holiday tourists | decline in visitor numbers during the winter season at tourist destinations, primarily caused by adverse effects of climate change such as altered snow conditions |
| increase in demand for cooling in summer | rising demand for air conditioning and cooling systems due to increased temperatures and heat waves |
| negative influence of extreme weather events on tourism activities | adverse effects caused by severe and unpredictable extreme events such as storms, floods, wildfires, and heat waves, diminishing the overall appeal and viability of tourism destinations |

| | |
|---|---|
| increase in conflicts over water use (tourists, agriculture, local population) | rise in disputes or tensions arising from competing demands for limited water resources, exacerbated by climate change-induced alterations in precipitation patterns, water availability, and increasing water stress |
| increase in negative impacts on safety of tourists | rise in incidents, hazards, or risks that compromise the well-being, safety, and peace of mind of travellers visiting a destination |
| shortening of winter season & disturbance of conditions for winter leisure activities | reduction in the duration and quality of winter weather conditions, such as snowfall and cold temperatures, which are essential for traditional winter recreational pursuits such as skiing, snowboarding, ice skating, and snowmobiling |
| increase in summer holiday tourists | rise in the number of tourists traveling during the summer season |
| extension/shift of the touristic season | changes in timing and duration of peak tourist activity periods, leading to prolonged or shifted periods of high tourism demand |


**Tourism**

**Climate Impact Drivers/Climate-related hazards**
(level of confidence)

- **Increase of mean surface temperature** (high confidence)
- **Increase of severe wind storms** (medium confidence)
- **Increase of extreme heat** (high confidence)
- **Increase in dry spells** (high confidence)
- **Increase in heavy precipitation & pluvial floods** (medium confidence)

**Other biophysical and socio-economic impacts**

- Decrease in water quality
- Extension/shift of the touristic season
- Shortening of winter season & disturbance of conditions for winter leisure activities
- Increase in heat waves
- Increase in urban heat island effect
- Increase in forest and wild fires
- Change in water availability
- Increase in summer holiday tourists

**Impacts of high priority**

- Decrease in natural snow reliability
- Decrease in snow precipitation in winter
- Increase in extreme events
- Decrease in winter holiday tourists
- Increase in demand for cooling in summer
- Negative influence of extreme weather events on tourism activities
- Increase in conflicts over water use (tourists, agriculture, local population)
- Increase in negative impacts on safety of tourists

**Non-climatic risk drivers**

- **Tourism flows & overtourism**
- **Land-use change & coverage**
- **Geopolitical conflicts**
- **Changing travel preferences**
- **Inflation & market fluctuations**
- **Availability of (seasonal) employees**
- **Touristic megatrends**
- **Exacerbation of socio-economic differences between regions**

**Exposed Subsystems**

- **Touristic infrastructures (urban, inland)**
- **Populations in touristic centres**
- **Tourism providers & employees**
- **Cultural & city tourism**
- **Nature-based tourism**
- **Sports tourism**
- **Business & conference tourism**

**Key Risks**

**KR-T-1**
Risk of decreasing tourism competitiveness due to increasing costs for tourism providers (adaptation, energy, water, labour etc.)

**KR-T-2**
Risk of newly emerging, competing destinations at national and international level

**KR-T-3**
Risk of loss of touristic attractiveness, key sources & limited accessibility of tourist attractions due to extreme heat and damage induced by other extreme events (floods, storms, fires)

**Strategic Directions**

**SD-T-1** Tourism offers are diversified to meet emerging markets and demands and to ensure competitiveness of destinations

**SD-T-2** Tourism is effectively managed based on partnership and data to support sustainability by key resources, including measures in visitor management, adaptation to changing climatic conditions (e. g. cool attractions for extreme heat) and implementation of preventive measures against natural hazards.

**SD-T-3** Tourism is sustainable, adapted to climate change and contributes to high quality, climate-friendly life in destinations and supports resilience in changing conditions.

*Figure 55: Climate Impact Chain for the sector Tourism.*

# Transport, Infrastructure & Buildings

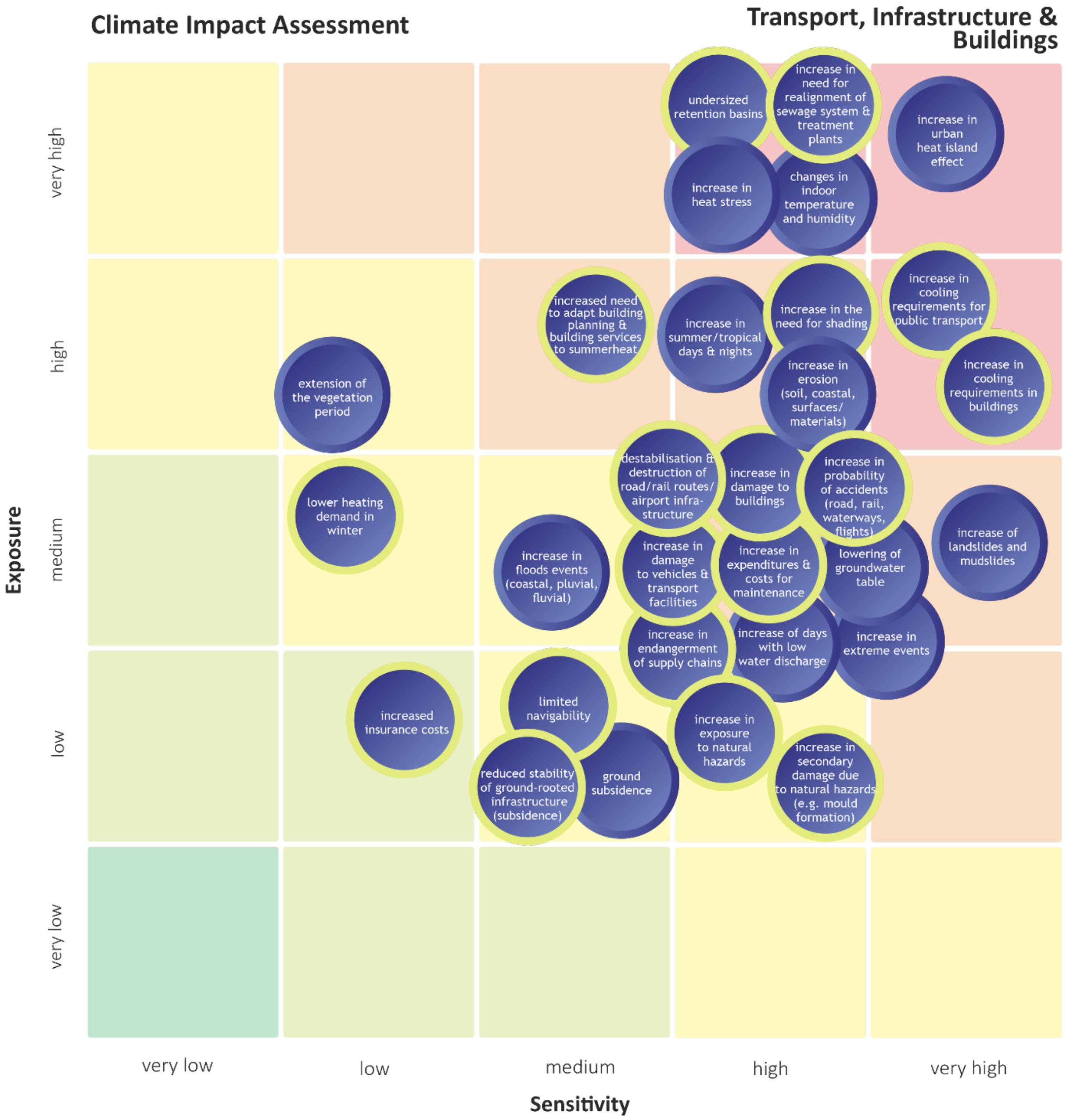


*Figure 56: Climate impacts for the sector* ***Transport, Infrastructure & Buildings*** *arranged in a matrix with respect to their sensitivity and exposure.*

*Table 61: Definitions of identified climate impacts for the sector* ***Transport, Infrastructure & Buildings.***

| Climate Impact | Definition |
|---|---|
| biophysical | |
| increase of landslides and mudslides | increased occurrence of movements of mass of rocks, debris or earth down a slope or channel containing suspended particles due to increase of heavy or long-lasting precipitation events or rapid snow melt |
| changes in indoor temperature and humidity | variations in the thermal and moisture conditions within enclosed spaces with impacts on indoor air quality and growth of mould |
| increase in urban heat island effect | Urban heat islands are areas of higher temperature in cities as these areas are heavily sealed and green spaces are limited. Urban heat islands can lead to an alteration of air pollutant transport, wind patterns and photochemical production, among others. An increase in mean air temperature and temperature extremes are characteristics of urban heat islands |
| increase in summer/tropical days & nights | rise in the frequency of hot weather events (tropical days/hot days: max. temperature > 30°C; tropical nights: minimum temperature remains above 20 °C), affecting exceedance of comfort temperature levels and leading to increased cooling demand |
| increase in heat stress | increased physiological strain caused by exposure to high temperatures and humidity levels affecting workers; hotter temperature has to be considered for the composition of asphalt and concrete; increased water & energy demand for cooling |
| increase in erosion (soil, surfaces/materials) | accelerated wearing away of soil, sediment, and land surfaces, often exacerbated by intensified rainfall and flooding; wear-away of protective coatings, degradation of surface materials, and compromising structural integrity, leading to corrosion, deterioration, and failure of infrastructure components such as roads, bridges, and buildings |
| lowering of groundwater table | decline in the level of underground water reserves due to changed participation patterns and/ or human consumption exceeding the natural recharge rate of the aquifer |
| increase in extreme events | more frequent and more severe occurrence of weather phenomena such as heat waves, droughts, storms and wildfires |
| increase in flood events (pluvial, fluvial) | increase in the frequency and intensity of flood events caused by heavy precipitation (pluvial) and rivers (fluvial) |
| extension of the vegetation period | lengthening of plants` growing season due to rise in temperature impacting infrastructure maintenance |

| Climate Impact | Definition |
|---|---|
| increase of days with low water discharge | reduction in the flow of watercourses resulting in reduced pollutant dilution and water quality |
| ground subsidence | gradual sinking or settling of a land surface (e.g. due to groundwater withdrawal) with negative effects on the statics of buildings and infrastructure; can result in lowering of the ground level, structural damage to buildings, roads, and other infrastructure above the affected area |
| socio-economic | |
| increase of cooling requirements in buildings | rising demand for air conditioning and cooling systems due to increased temperatures and heat waves |
| increase in need for realignment of sewage system & sewage treatment plants | growing demand to modify or reconfigure existing sewage infrastructure to address changing climate conditions |
| increased need to adapt building planning & building services to summer heat | increasing requirement of implementing measures such as improved insulation, ventilation, shading, and energy-efficient cooling technologies to maintain comfortable indoor environments amidst rising temperatures |
| undersized retention basins | inadequately sized water management structures to capture and temporarily hold excess rainwater or runoff during heavy precipitation events |
| increase in the need for shading | growing demand for structures or natural elements that provide shade, particularly in outdoor spaces, to mitigate the adverse effects of excessive sunlight and heat exposure |
| increase for cooling requirements in public transport | rising demand for air conditioning and cooling systems within vehicles such as buses, trains, and tram due to increased temperatures and heat waves |
| increase in exposure to natural hazards | increased vulnerability to natural disasters (e.g. floods, landslides, wildfires) due to alterations in human activities, land use patterns, and socio-economic factors |
| lower heating demand in winter | reduction of energy consumption for heating in colder seasons due to milder temperatures |
| increase in damage to buildings | increased vulnerability of structures to extreme weather events and temperature fluctuations |
| increase in secondary damage due to natural hazards (e.g. mould formation) | indirect negative effects of storms, floods etc. increase due to socio-economic developments such as urbanisation leading to an increased damage potential |

| Climate Impact | Definition |
|---|---|
| reduced stability of ground-rooted infrastructure (subsidence) | increase of damage to infrastructure due to sinking or settling of land surfaces |
| increase in expenditures and costs for maintenance | rise in financial resources required to repair, upgrade, and sustainably manage assets and other infrastructure in response to climate-related impacts such as extreme weather events, sea-level rise, and temperature fluctuations |
| increased insurance costs | upward trend in premiums and coverage costs for insurance policies caused by the increased risks and uncertainties associated with climate-related events. These include higher pay-outs for losses caused by extreme weather events such as storms, floods, forest fires |
| increase in endangerment of supply chains | increased probability of disruptions or susceptibilities within the networks of interconnected entities involved in the production, distribution, and delivery of goods and services (e.g. delay in the delivery of materials and products, production losses shortage of skilled workers) e.g. due to extreme events like storms or floods |
| limited navigability | reduce navigation capacity in rivers due to droughts, impacting inland waterway transport |
| destabilisation & destruction of road/rail routes/airport infrastructure | increased susceptibility of transportation infrastructure to damage and degradation due to extreme weather events such as heavy rainfall, flooding or storm |
| increase in damage to vehicles and transport facilities | growing risk of harm and deterioration faced by transportation infrastructure and vehicles due to extreme weather events such as heavy rainfall, flooding or storm |
| increase in probability of accidents (road, rail, waterways, flights) | increased likelihood of accidents occurring across various transportation modes as a result of changing climatic conditions, including extreme weather events, such as storms, floods, and heat waves, which can impair visibility, disrupt infrastructure, and pose hazards to transportation safety |

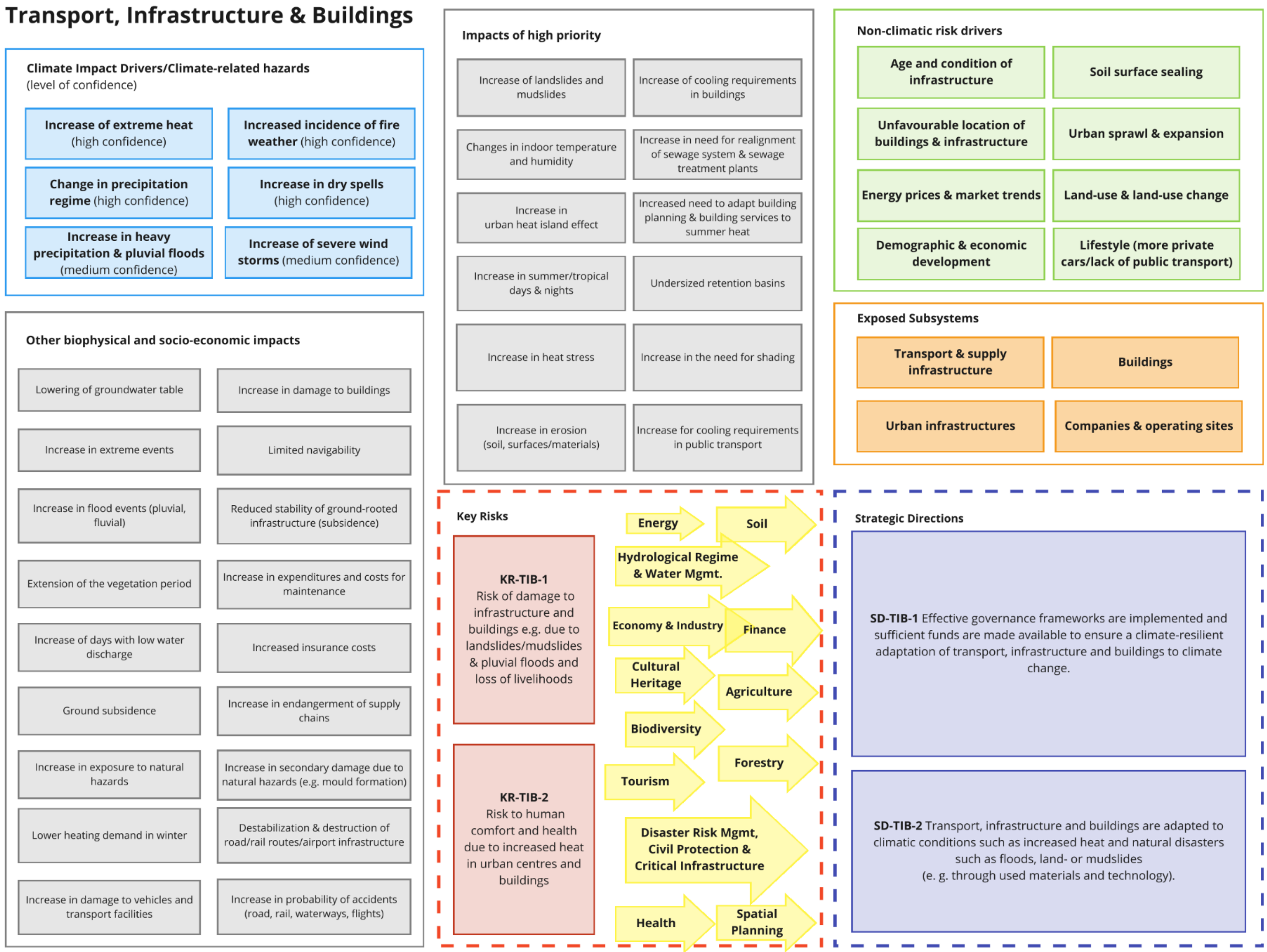


Figure 57: Climate Impact Chain for the sector *Transport, Infrastructure & Buildings*.

# 8 References

Amanatidou, E., Giesecke, S., Jarmai, K., Loikkanen, T., Warnke, P., 2012. VERA Deliverable 1.2 Typology of RTDI directed towards Grand Societal Challenges.

Anisimov, A., Magnan, A.K. (Eds.) (2023). *The global transboundary climate risk report*.

ARCH Research Project (n. d.). Saving cultural heritage. https://savingculturalheritage.eu/.

Authority for Spatial Planning and Construction (s. a.). Spatial planning. https://stavebny-urad.gov.sk/en/spatial-planning. Accessed 12 August 2024.

Bandt, O. de, Kuntz, L.-C., Pankratz, N., Pegoraro, F., Solheim, H., Sutton, G., Takeyama, A., Xia, D., 2023. The effects of climate change-related risks on banks: a literature review. Basel Committeee of Banking Supervision. https://www.bis.org/bcbs/publ/wp40.htm. Accessed 6 June 2024.

Bárek, V., Halaj, P., Igaz, D. (2009). The Influence of Climate Change on Water Demands for Irrigation of Special Plants and Vegetables in Slovakia. In: Střelcová, K., Mátyás, C., Kleidon, A., Lapin, M., Matejka, F., Blaženec, M., Škvarenina, J., Holécy, J. (Eds.) *Bioclimatology and Natural Hazards*. Springer Netherlands, Dordrecht, pp. 271–282.

Becokova, A., Stuchlik, E., Krecek, J. (2009). Impacts of global climate change on the hydrological cycle in a small alpine catchment: The High Tatras, Slovakia. *Environmentalica* (23), 33–43.

Belčáková, I., Slámová, M., Demovičová, Z. (2022). Importance of Urban Green Areas in the Context of Current and Future Global Changes: Lessons Learned from a Case Study in Bratislava (Slovakia). *Sustainability* 14 (22), 14740.

Belčáková, I., Świąder, M., Bartyna-Zielińska, M. (2019). The Green Infrastructure in Cities as A Tool for Climate Change Adaptation and Mitigation: Slovakian and Polish Experiences. *Atmosphere* 10 (9), 552.

Berninger, K., Lager, F., Botnen Holm, T., Tynkkynen, O., Klein, R.J., Aall, C., Dristig, A., Määttä, H., Perrels, A., Davis, M. (2022). *Nordic Perspectives on Transboundary Climate Risk: Current knowledge and pathways for action.* Nordic Council of Ministers.

Boďo, Š., Lüttmerding, G., Gálik, R., Kunc, P., Knížková, I., Gürdil, G.A.K. (2022). Analysis of Selected Data from Robotic Milking Regarding to Heat Stress of Dairy Cows. *Acta Technologica Agriculturae* 25 (2), 92–96.

Boyle, M.J. (2024). Infrastructure: Definition, Meaning, and Examples. https://www.investopedia.com/terms/i/infrastructure.asp. Accessed 10 June 2024.

Breil, M., Downing, C., Kazmierczak, A., Mäkinen, K., Romanovska, L., 2018. Social vulnerability to climate change in European cities – state of play in policy and practice. Technial Paper ETC/CCA 2018/1. https://ora.ox.ac.uk/objects/uuid:73ed1b8d-3a0f-44d6-a841-e98879ba7d8a/files/s7m01bm91h. Accessed 26 September 2024.

Carter, F.W., Turnock, D. (2002). *Environmental problems of East Central Europe,* 2nd ed. ed. Routledge, London, New York.

Carter, T.R., Benzie, M., Campiglio, E., Carlsen, H., Fronzek, S., Hildén, M., Reyer, C.P., West, C. (2021). A conceptual framework for cross-border impacts of climate change. *Global Environmental Change* 69, 102307.

Černecký, J., Gajdoš, P., Ďuricová, V., Spulerova, J., Cernecka, L., Švajda, J., Ulrych, L., Andráš, P., Rybanič, R., Považan, R. (2023). *Value of ecosystems and ecosystem services in Slovakia*.

Černecký, J., Gajdoš, P., Špulerová, J., Halada, Ľ., Mederly, P., Ulrych, L., Ďuricová, V., Švajda, J., Černecká, Ľ., Andráš, P., Rybanič, R. (2020). Ecosystems in Slovakia. *Journal of Maps* 16 (2), 28–35.

Cheng, M., McCarl, B., Fei, C. (2022). Climate Change and Livestock Production: A Literature Review. *Atmosphere* 13 (1), 140.

CIA.gov (2024). Explore all countries: Slovakia. https://www.cia.gov/the-world-factbook/countries/slovakia/.

Čimo, J., Aydın, E., Šinka, K., Tárník, A., Kišš, V., Halaj, P., Toková, L., Kotuš, T. (2020a). Change in the Length of the Vegetation Period of Tomato (Solanum lycopersicum L.), White Cabbage (Brassica oleracea L. var. capitata) and Carrot (Daucus carota L.) Due to Climate Change in Slovakia. *Agronomy* 10 (8).

Čimo, J., Šinka, K., Tárník, A., Aydin, E., Kišš, V., Toková, L. (2020b). Impact of climate change on vegetation period of basic species of vegetables in Slovakia. *Journal of Water and Land Development* (No 47), 38–46.

Copernicus (2025). Copernicus Global Climate Report 2024 confirms last year as the warmest on record, first ever above 1.5°C annual average temperature. https://www.copernicus.eu/en/news/news/copernicus-global-climate-report-2024-confirms-last-year-warmest-record-first-ever-above. Accessed 12 February 2025.

Copernicus, L.M.S. (n. d.). Understanding and managing urban green spaces. https://land.copernicus.eu/en/use-cases/understanding-and-managing-urban-green-spaces/understanding-and-managing-urban-green-spaces. Accessed 25 November 2024.

Copernicus, L.M.S. (2019). Land Cover Viewer: Web Application. Global land cover change maps. https://lcviewer.vito.be/2019.

Council Directive (2008). *2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection. 2008/114/EC.*

Cowls, J., Tsamados, A., Taddeo, M., Floridi, L. (2023). The AI gambit: leveraging artificial intelligence to combat climate change-opportunities, challenges, and recommendations. *AI & society* 38 (1), 283–307.

CPD (n. d.). Cities at risk: dealing with the pressures of climate change. https://www.cdp.net/en/research/global-reports/cities-at-risk. Accessed 18 September 2024.

Crocetti, L., Forkel, M., Fischer, M., Jurečka, F., Grlj, A., Salentinig, A., Trnka, M., Anderson, M., Ng, W.-T., Kokalj, Ž., Bucur, A., Dorigo, W. (2020). Earth Observation for agricultural drought monitoring in the Pannonian Basin (southeastern Europe): current state and future directions. *Regional Environmental Change* 20 (4), 123.

Čuka, P., Šenková, A. (2017). Geography of Tourism of Slovakia. In: *The Geography of Tourism of Central and Eastern European Countries: Second Edition*, pp. 437–465.

Danáčová, M., Földes, G., Labat, M.M., Kohnová, S., Hlavčová, K. (2020). Estimating the Effect of Deforestation on Runoff in Small Mountainous Basins in Slovakia. *Water* 12 (11), 3113.

Danielzyk, R., Münter, A., 2018. Spatial planning. https://www.arl-international.com/sites/default/files/dictionary/2021-09/spatial_planning_raumplanung.pdf.

Deutsches Institut für Normung e. V. (2021). Anpassung an den Klimawandel – Vulnerabilität, Auswirkungen und Risikobewertung.

Devot, A., Royer, L., Arvis, B., Deryng, D., Caron Giauffret, E., Giraud, L., Ayral, V., Rouillard, J., 2023. The impact of extreme climate events on agricultural production in the EU: Research for AGRI Committee PE 733.115. Directorate-General for Internal Policies (EU Commission). https://www.europarl.europa.eu/RegData/etudes/STUD/2023/733115/IPOL_STU(2023)733115_EN.pdf. Accessed 24 June 2024.

Dixson-Declève, S., Gaffney, O., Ghosh, J., Randers, J., Rockström, J., Stoknes, P.E. (2022). *Earth for all. Ein Survivalguide für unseren Planeten: der neue Bericht an den Club of Rome, 50 Jahre nach "Die Grenzen des Wachstums",* 4. Auflage ed. oekom, München.

DW (2024). Slovakia's capital hit by biggest floods in 30 years: Catastrophe | Slovakia. https://www.dw.com/en/slovakias-capital-hit-by-biggest-floods-in-30-years/a-70251068. Accessed 18 February 2025.

ECOLEX (n. d.). Act no. 543/2002 on the protection of nature and landscapes. https://www.ecolex.org/details/legislation/act-no-5432002-on-the-protection-of-nature-and-landscapes-lex-faoc079610/. Accessed 15 January 2025.

EEA, 2020a. Healthy environment, healthy lives: how the environment influences health and well-being in Europe. EEA report 21/2019, Copenhagen. https://www.eea.europa.eu/publications/healthy-environment-healthy-lives. Accessed 25 November 2024.

EEA (2020b). *State of nature in the EU. Results from reporting under the nature directives 2013-2018.* Publications Office of the European Union, Luxembourg.

EEA (2022). Who benefits from nature: Briefing. https://www.eea.europa.eu/publications/who-benefits-from-nature-in/who-benefits-from-nature-in. Accessed 25 November 2024.

EEA (2024a). Biodiversity Information System for Europe - Slovakia. https://biodiversity.europa.eu/countries/slovakia.

EEA, 2024b. European Climate Risk Assessment. EEA report 01/2024, Kopenhagen. https://www.eea.europa.eu/publications/european-climate-risk-assessment. Accessed 11 March 2024.

EEA (2024c). Executive Summary. In: European Environment Agency (EEA) (Ed.) *European Climate Risk Assessment*, Kopenhagen.

EEA (2024d). Soil. https://www.eea.europa.eu/en/topics/in-depth/soil. Accessed 12 June 2024.

EEA (2024e). *Urban adaptation in Europe: what works? Implementing climate action in European cities.* Publications Office of the European Union, Luxembourg.

Enerdata, 2023. Slovakia energy report. https://www.enerdata.net/estore/country-profiles/slovakia.html. Accessed 30 July 2024.

Esser, S., Schulz, S., Schwartzkopff, J. (2018). Climate & Energy Snapshot: Slovakia. E3G. https://www.e3g.org/publications/climate-energy-snapshot-slovakia/.

EU Commission (2024). *REGULATION (EU) 2024/1991 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869. 2024/1991.*

EU Competence Centre on Foresight (2024). The Megatrends Hub. https://knowledge4policy.ec.europa.eu/foresight/tool/megatrends-hub_en. Accessed 16 December 2024.

European Central Bank (n.d.). Managing climate-related risks. https://www.ecb.europa.eu/ecb/climate/managing_mitigating_climatel_risk/html/index.en.html. Accessed 6 June 2024.

European Commission (n. d.). "Basic infrastructure" Operational Programme. https://ec.europa.eu/regional_policy/in-your-country/programmes/2000-2006/sk/basic-infrastructure-operational-programme_en.

European Commission (2019). European Civil Protection and Humanitarian Aid Operations: Slovakia. https://civil-protection-humanitarian-aid.ec.europa.eu/what/civil-protection/national-disaster-management-system/slovakia_en. Accessed 30 July 2024.

European Commission, 2020. EU Biodiversity Strategy for 2030: Bringing nature back into our lives, Brussels. https://eur-lex.europa.eu/resource.html?uri=cellar:a3c806a6-9ab3-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF.

European Commission (2021a). *COMMISSION STAFF WORKING DOCUMENT. IMPACT ASSESSMENT REPORT Accompanying the document. supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives.*

European Commission, 2021b. Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change, Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0082.

European Commission (2021c). *New EU Forest Strategy for 2030.*

European Commission, 2022a. Digital Economy and Society Index (DESI): Slovakia. https://digital-strategy.ec.europa.eu/en/policies/desi-slovakia. Accessed 12 July 2024.

European Commission (2022b). *Directive (EU) 2022/2557 of the European Parliament and of the Council of 14 December 2022 on the resilience of critical entities and repealing Council Directive 2008/114/EC (Text with EEA relevance). 2022/2557.*

European Commission (2023a). 2023 Country Report - Slovakia. https://economy-finance.ec.europa.eu/system/files/2023-05/SK_SWD_2023_625_en.pdf. Accessed 11 July 2024.

European Commission (2023b). COMMISSION STAFF WORKING DOCUMENT: Assessment of progress on climate adaptation in the individual Member States according to the European Climate Law. https://climate.ec.europa.eu/system/files/2023-12/SWD_2023_932_1_EN.pdf.

European Commission (2023c). EU Cohesion Policy: More than €190 million for a better railway infrastructure in Slovakia. https://ec.europa.eu/regional_policy/whats-new/newsroom/24-04-2023-eu-cohesion-policy-more-than-eur190-million-for-a-better-railway-infrastructure-in-slovakia_en.

European Commission (2023d). Slovakia - Draft Updated NECP 2021-2030. https://commission.europa.eu/publications/slovakia-draft-updated-necp-2021-2030_en.

European Commission (2024a). 2024 European Semester: Country Reports. https://economy-finance.ec.europa.eu/publications/2024-european-semester-country-reports_en.

European Commission (2024b). EU Policy for cultural heritage. https://culture.ec.europa.eu/cultural-heritage/eu-policy-for-cultural-heritagehttps://culture.ec.europa.eu/cultural-heritage/eu-policy-for-cultural-heritage. Accessed 15 April 2024.

European Environment Agency (EEA) (s. a.). ClimateADAPT. https://climate-adapt.eea.europa.eu/.

European Union, 2020. The social and employment situation of Roma communities in Slovakia, Luxembourg. https://www.europarl.europa.eu/RegData/etudes/STUD/2020/648778/IPOL_STU(2020)648778_EN.pdf. Accessed 25 November 2024.

Eurostat (2020). Demographic change in Europe: Country factsheets: Slovakia. https://ec.europa.eu/eurostat/documents/12743486/14207633/SK-EN.pdf.

Eurostat (2024). Share of fossil fuels in gross available energy. https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ffgae/default/table?lang=en.

FAO (2021). *The State of Food and Agriculture 2021. Making agrifood systems more resilient to shocks and stresses.* FAO, Rome.

Fendeková, M. (2018a). Groundwater Drought Occurrence in Slovakia. *Water Resources in Slovakia: Part II* 70, 91–104.

Fendeková, M. (2018b). Major Droughts in Slovakia in the Twenty-First Century. *Water Resources in Slovakia: Part II* 70, 125–144.

Fendeková, M., Gauster, T., Labudová, L., Vrablíková, D., Danáčová, Z., Fendek, M., Pekárová, P. (2018). Analysing 21st century meteorological and hydrological drought events in Slovakia. *Journal of Hydrology and Hydromechanics* 66 (4), 393–403.

Fritzsche, K., Schneiderbauer, S., Bubeck, P., Kienberger, S., Buth, M., Zebisch, M., Kahlenborn, W., 2014. The Vulnerability Sourcebook: Concept and guidelines for standardised vulnerability assessments, Bonn. https://www.adaptationcommunity.net/download/va/vulnerability-guides-manuals-reports/vuln_source_2017_EN.pdf. Accessed 14 May 2024.

Froese, R., Schilling, J. (2019). The Nexus of Climate Change, Land Use, and Conflicts. *Current Climate Change Reports* 5 (1), 24–35.

Fu, G., Horrocks, L., Winne, S. (2016). Exploring impacts of climate change on UK's ICT infrastructure. *Infrastructure Asset Management* 3 (1), 42–52.

Galaz, V. (Ed.) (2019). *Global Challenges, Governance, and Complexity. Applications and Frontiers.* Edward Elgar Publishing, Cheltenham, UK, Northampton, MA, USA.

Gera, M., Damborská, I., Lapin, M., Melo, M. (2017). Climate Changes in Slovakia: Analysis of Past and Present Observations and Scenarios of Future Developments. *Water Resources in Slovakia: Part II* 70, 21–47.

German Environment Agency (GEA), 2022. How to perform a robust climate risk and vulnerability assessment for EU taxonomy reporting?: Recommendations for companies - Final draft.

GIZ, 2023. Climate Risk Sourcebook, Bonn. https://www.adaptationcommunity.net/wp-content/uploads/2023/10/giz_2023_Climate_Risk_Sourcebook.pdf. Accessed 19 March 2024.

Glaser-Opitz, Z., Kulla, M., Spišiak, P. (2012). Water Mills in Slovakia as a Cultural Heritage Phenomenon. *Geografické informácie* 16, 67–76.

Global forest watch (2024). Slovakia. https://www.globalforestwatch.org/dashboards/country/SVK/?category=fires. Accessed 13 June 2024.

Government of the Slovak Republic, 2019. New action plan for the environment and health of the inhabitants of the Slovak Republic, NEHAP V. https://www.uvzsr.sk/web/uvz/akcny-plan-pre-zivotne-prostredie-a-zdravie-obyvatelov.

Gubka, A., Nikolov, C., Galko, J., Vakula, J., Kunca, A., Leontovy, R. (2013). History, Present and Expected Future of Forests in Slovakia. *American Journal of Plant Sciences* Vol.04No.03, 6.

Harris, K., Lager, F., Jansen, M.K., Benzie, M. (2022). Rising to a New Challenge: A Protocol for Case-Study Research on Transboundary Climate Risk. *Weather, Climate, and Society* 14 (3), 755–768.

Hayes, A. (2021). Transportation Sector and Transportation Industry Investments. https://www.investopedia.com/terms/i/infrastructure.asp. Accessed 10 June 2024.

Hlavčová, K., Lapin, M., Valent, P., Szolgay, J., Kohnová, S., Rončák, P. (2015). Estimation of the impact of climate change-induced extreme precipitation events on floods. *Contributions to Geophysics and Geodesy* 45 (3), 173–192.

Hobbie, S.E., Grimm, N.B. (2020). Nature-based approaches to managing climate change impacts in cities. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 375 (1794), 20190124.

Hwang, H., Roehn, O., 2022. Tackling the challenges of population ageing in the Slovak Republic. OECD Economics Department Working Papers No. 1701, Paris. https://doi.org/10.1787/03edcf77-en. Accessed 16 December 2024.

IEA (2018). Energy Policies of IEA Countries: Slovak Republic 2018 Review. https://www.iea.org/reports/energy-policies-of-iea-countries-slovak-republic-2018-review.

IEA (2022). Climate Resilience Policy Indicator. https://www.iea.org/reports/climate-resilience-policy-indicator.

IEA (2023a). Industry - Energy System. https://www.iea.org/energy-system/industry.

IEA (2023b). Light industry. https://www.iea.org/energy-system/industry/light-industry.

IMF, 2022. SUPPLY BOTTLENECKS IN 2021: THE CASE OF SLOVAKIA. https://www.imf.org/en/Publications/CR/Issues/2022/07/08/Slovak-Republic-Selected-Issues-520548.

Institute for Environmental Policy, 2023. Institute for Environmental Policy Identifying climate risk levels of Slovak municipalities, Bratislava. https://www.minzp.sk/files/iep/analyzy/iep-identifying-climate-risk-levels-2023.pdf. Accessed 25 November 2024.

International Energy Agency (IEA) (n. d.). Buildings. https://www.iea.org/energy-system/buildings. Accessed 10 June 2024.

International Energy Agency (IEA) (2022). Slovak Republic Climate Resilience Policy Indicator. https://www.iea.org/articles/slovak-republic-climate-resilience-policy-indicator. Accessed 2 July 2024.

International Organization for Migration, 2008. Migration and Climate Change. IOM Migration Research Series 31, Geneva. https://www.ipcc.ch/apps/njlite/srex/njlite_download.php?id=5866. Accessed 15 January 2025.

International Risk Governance Council (IRGC), 2010. The Emergence of Risks: Contributing Factors. https://infoscience.epfl.ch/record/228055/files/The%20Emergence%20of%20Risks%20Contributing%20Factors.pdf. Accessed 2 July 2024.

Interreg Central Europe (2024). Current drought event in Slovakia. https://www.interreg-central.eu/news/current-drought-event-in-slovakia/. Accessed 20 September 2024.

IPCC (2014). Emergent Risks and Key Vulnerabilities. In: IPCC (Ed.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, pp. 1039–1099.

IPCC (2021a). Annex VII: Glossary. In: IPCC (Ed.) *Climate Change 2021 – The Physical Science Basis*. Cambridge University Press, pp. 2215–2256.

IPCC (Ed.) (2021b). *Climate Change 2021 – The Physical Science Basis.* Cambridge University Press.

IPCC (2021c). Interactive Atlas. In: IPCC (Ed.) *Climate Change 2021 – The Physical Science Basis*. Cambridge University Press.

IPCC (2022a). Annex II: Glossary. In: IPCC (Ed.) *Climate Change 2022 – Impacts, Adaptation and Vulnerability*. Cambridge University Press, pp. 2897–2930.

IPCC (2022b). Chapter 6: Cities, Settlements and Key Infrastructure. In: IPCC (Ed.) *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of working group 2 to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, New York.

IPCC (Ed.) (2022c). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of working group 2 to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, New York.

IPCC (2022d). Europe. In: IPCC (Ed.) *Climate Change 2022 – Impacts, Adaptation and Vulnerability*. Cambridge University Press, pp. 1817–1928.

IPCC (2022e). Point of Departure and Key Concepts. In: IPCC (Ed.) *Climate Change 2022 – Impacts, Adaptation and Vulnerability*. Cambridge University Press, pp. 121–196.

IPCC (2022f). Summary for Policymakers: Climate Change 2022 - Impacts, Adaptation and Vulnerability. In: IPCC (Ed.) *Climate Change 2022 – Impacts, Adaptation and Vulnerability*. Cambridge University Press.

IPCC (2022g). Technical Summary. In: IPCC (Ed.) *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of working group 2 to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, New York, pp. 37–118.

IPCC (2022h). Water. In: IPCC (Ed.) *Climate Change 2022 – Impacts, Adaptation and Vulnerability*. Cambridge University Press, pp. 551–712.

IPCC, 2023a. Overarching Frequently Asked Questions and Answers. Sixth Assessment Report. Working Group II - Impacts, Adaptation and Vulnerability. https://www.ipcc.ch/report/ar6/wg2/about/frequently-asked-questions/keyfaq4/. Accessed 11 February 2025.

IPCC (2023b). Summary for Policymakers. In: Intergovernmental Panel on Climate Change (Ed.) *Synthesis Report of the IPCC Sixth Assessment Report (AR6).*

IPCC (2023c). Transport. In: Change, I.P.o.C. (Ed.) *Climate Change 2022 - Mitigation of Climate Change*. Cambridge University Press, pp. 1049–1160.

Islam, N.S., Winkel, J., 2017. Climate Change and Social Inequality. DESA Working Paper 152. https://desapublications.un.org/file/183/download. Accessed 27 September 2024.

ISO (2018). Risk management: Guidelines, Geneva.

ISO (2021). Adaptation to climate change: Guidelines on vulnerability, impacts and risk assessment, Geneva.

Izakovičová, Z., Špulerová, J., Raniak, A. (2022). The Development of the Slovak Agricultural Landscape in a Changing World. *Frontiers in Sustainable Food Systems* 6.

Izakovičová, Z., Mańkovská, B., Oszlányı, J. (2017). Assessing forest degradation in Slovakia. *Biological Diversity and Conservation* (10 (2)), 63–67.

Jaďuďová, L. (2019). Ľudová umelecká výroba ako súčasť kultúrneho dedičstva: Folk art production as a part of cultural heritage. *Muzeológia a kultúrne dedičstvo*, 177–191.

Kapsdorferova, Z., Ceres, M., Zabojnikova, V., Svikruhova, P., Katanikova, R. (2023). Challenges and innovative approaches in the agricultural and food industry and changing consumer behaviour in the milk and milk products market: Case of Slovakia. *Agricultural Economics* 69 (6), 246–254.

Kenton, W. (2021). Financial Sector: Definition, Examples, Importance to Economy. https://www.investopedia.com/terms/f/financial_sector.asp. Accessed 6 June 2024.

Kišš, V., Minárik, M., Čimo, J., Tárník, A., Mikulová, K. (2023). Changes in the Agroclimatic Areas of Slovakia in 1961–2020. *Journal of Ecological Engineering* 24 (7), 293–300.

Kišš, V., Pagáč, J., Tárník, A., Čimo, J. (2022a). Changes in Vegetation Period Length in Slovakia under the Conditions of Climate Change for 1931–2110. *Sustainability* 14 (19).

Kišš, V., Tárník, A., Pagáč, J., Minárik, M. (2022b). *PRECIPITATION CONDITIONS EVALUATION IN SLOVAKIA FOR 1991-2020*.

Kochanek, E. (2021). The Energy Transition in the Visegrad Group Countries. *Energies* 14 (8).

Kopáčiková, E., Hlaváčiková, H., Lešková, D. (2020). Climate change impact study on 100-year floods of selected Slovak catchments. *Acta Hydrologica Slovaca* 21 (2), 160–171.

Korená Hillayová, M., Báliková, K., Giertliova, B., Drábek, J., Holecy, J. (2021). Possibilities of forest property insurance against the risk of fire in Slovakia. *Journal of Forest Science* 67, 204–211.

Kubiak-Wójcicka, K., Zeleňáková, M., Blištan, P., Simonová, D., Pilarska, A. (2021). Influence of climate change on low flow conditions. Case study: Laborec River, eastern Slovakia. *Ecohydrology & Hydrobiology* 21 (4), 570–583.

Labudová, L., Faško, P., Ivaňáková, G. (2015). Changes in climate and changing climate regions in Slovakia. *Moravian Geographical Reports* 23 (3), 71–82.

Labudová, L., Ivaňáková, G., Faško, P., Kajaba, P., Labuda, M. (2024). Changes in drought occurrence and intensity in the context of climate change in Slovakia. *Theoretical and Applied Climatology* 155 (5), 4009–4022.

Labudová, L., Labuda, M., Takáč, J. (2017). Comparison of SPI and SPEI applicability for drought impact assessment on crop production in the Danubian Lowland and the East Slovakian Lowland. *Theoretical and Applied Climatology* 128 (1-2), 491–506.

Lapin, M. (2021). Climate Change, Its Impacts and Possible Measures in Slovakia. *Acta Horticulturae et Regiotecturae* 24 (s1), 90–96.

Lehotský, M., Boltižiar, M. (Eds.) (2022). *Landscapes and Landforms of Slovakia.* Springer International Publishing, Cham.

Lenton, T.M., Armstrong McKay,, D.I., Loriani, S., Abrams, J.F., Lade, S.J., Donges, J.F., Milkoreit, M., Powell, T., Smith, S.R., Zimm, C., Buxton, J.E., Bailey, E., Laybourn, L., Ghadiali, A., Dyke, J.G. (Eds.) (2023). *The Global Tipping Points Report 2023.* University of Exeter, Exeter.

Libor, U., Guttová, A., Urban, P., Hindánková, A., Kučera, J., Kučera, V., Šibík, J., Mútňanová, M. (2018). Biodiversity in Slovakia. In: Pullaiah, T. (Ed.) *Global Biodiversity*. Apple Academic Press.

Lückenrath, D., Milde, K., Ullrich, O., 2021. The ARCH Project: Investigating the Impact of Climate Change on Historic Areas. Fraunhofer Institute for Inteligent Analysis and Information Systems IAIS. https://www.sne-journal.org/fileadmin/user_upload_sne/SNE_Issues_OA/SNE_31_2/articles/sne.31.2.10561.sn.OA.pdf.

Macko, J. (2021). Včela medonosná a včelárstvo ako súčasť kultúrneho dedičstva: The Honey bee and Beekeeping as Part of the Cultural Heritage. *Studia Scientifica Facultatis Paedagogicae Universitas Catholica Ružomberok*.

Markard, J. (2011). Infrastructure sector characteristics and implications for innovation and sectoral change. *Journal of Infrastructure Systems* (17(3)), 107–117.

McDermott, T.K.J. (2022). Global exposure to flood risk and poverty. *Nature communications* 13 (1), 3529.

Mederly, P., Černecký, J. (2020). *A Catalogue of Ecosystem Services in Slovakia Benefits to Society,* 1st ed. 2020 ed. Springer International Publishing, Cham.

Miľanová, Ľ. (2018). VÝZNAMNÉ LESNÍCKE MIESTA – VKLAD LESNÍKOV DO KULTÚRNEHO DEDIČSTVA SPOLOČNOSTI: Special forestry sites – the contribution of foresters to the cultural heritage of the community. *Muzeológia a kultúrne dedičstvo*.

Mindas, J., Škvareninová, J. (2016). Biodiversity and climate change: Consequences for upper tree line in Slovakia. *Forestry Journal* 62.

Minďáš, J. (2005). IMPACT OF GLOBAL CLIMATE CHANGE ON FOREST ECOSYSTEMS IN SLOVAKIA – GENERAL OVERVIEW.

Ministry of Agriculture and Rural Development of the Slovak Republic (2020a). Agriculture and Food Sector. https://www.mpsr.sk/en/index.php?navID=16&id=78.

Ministry of Agriculture and Rural Development of the Slovak Republic (2020b). Development Trends and Prospects. https://www.mpsr.sk/en/index.php?navID=24.

Ministry of Agriculture and Rural Development of the Slovak Republic (2020c). Plant Production. https://www.mpsr.sk/en/index.php?navID=25. Accessed 24 June 2024.

Ministry of Agriculture and Rural Development of the Slovak Republic, 2020d. Report on Agriculture and Food Sector in the Slovak Republic for 2020: Green Report. https://www.mpsr.sk/en/index.php?navID=16&id=78. Accessed 24 June 2024.

Ministry of Agriculture and Rural Development of the Slovak Republic, 2023. Report on the agriculture and food sector in the Slovak Republic in 2022: Green Report, Bratislava. https://www.mpsr.sk/en/download.php?fID=266. Accessed 20 September 2024.

Ministry of Agriculture and Rural Development of the Slovak Republic (2024a). Animal Production. https://www.mpsr.sk/en/index.php?navID=26. Accessed 24 June 2024.

Ministry of Agriculture and Rural Development of the Slovak Republic (2024b). Organic Agriculture. https://www.mpsr.sk/en/index.php?navID=27.

Ministry of Economy of the Slovak Republic (2023). Draft update of the Integrated National energy and climate Draft update of the Integrated National energy and climate plan for 2021-2030. https://commission.europa.eu/document/download/4f373d12-ce73-403a-a2d5-0107bf3e0c24_en?filename=SLOVAKIA%20-%20DRAFT%20UPDATED%20NECP%202021-2030_EN.pdf.

Ministry of Environment of the Slovak Republic (s. a.). Územia európskeho významu (ÚEV). https://www.minzp.sk/natura2000/uzemia-europskeho-vyznamu/.

Ministry of Environment of the Slovak Republic (2014). Adaptation Strategy of the Slovak Republic on Adverse Impacts of Climate Change: Overview: Executive Summary. https://climate-adapt.eea.europa.eu/en/countries-regions/countries/nas_summary_slovakia.pdf/@@download/file.

Ministry of Environment of the Slovak Republic, 2018a. Adaptation Strategy of the Slovak Republic on Adverse Impacts of Climate Change.

Ministry of Environment of the Slovak Republic, 2018b. H2O DNOTA JE VODA: Akčný plán na riešenie dôsledkov sucha a nedostatku vody. https://www.minzp.sk/voda/koncepcne-dokumenty/h2odnota-je-voda-akcny-plan-riesenie-dosledkov-sucha-nedostatku-vody.html. Accessed 20 September 2024.

Ministry of Environment of the Slovak Republic, 2020. Greener Slovakia: Strategy of the Environmental Policy of the Slovak Republic until 2030. https://www.minzp.sk/files/iep/greener_slovakia-strategy_of_the_environmental_policy_of_the_slovak_republic_until_2030.pdf.

Ministry of Environment of the Slovak Republic, 2021a. Akčný plán pre implementáciu Stratégie adaptácie SR na zmenu klímy. https://www.minzp.sk/files/odbor-politiky-zmeny-klimy/akcny-plan-implementaciu-nas.pdf. Accessed 30 July 2024.

Ministry of Environment of the Slovak Republic, 2021b. National Action Plan (NAP) for the Slovak Republik.

Ministry of Environment of the Slovak Republic, 2023. National Communications (NC) NC 8. Biennial Reports (BR). BR5. https://unfccc.int/documents/626514.

Ministry of Investments, Regional Development and Informatization of the Slovak Republic, 2023. Second Voluntary National Review of the Slovak Republic on the Implementation of the 2030 Agenda for Sustainable Development, Bratislava. https://planipolis.iiep.unesco.org/sites/default/files/ressources/slovakia_vnr_2023_eng.pdf. Accessed 26 April 2024.

Ministry of the Environment of the Slovak Republic (n. d.). Protected bird areas (CHVÚ). https://www.minzp.sk/natura2000/chranene-vtacie-uzemia/. Accessed 15 January 2025.

Ministry of Transport and Construction of the Slovak Republic, 2019a. The Urban Development Policy of the Slovak Republic by 2030. Short Version, Bratislava. https://www.mindop.sk/uploads/media/177add300b0faa6f4201a4d8a240021e77552653.pdf. Accessed 11 October 2024.

Ministry of Transport and Construction of the Slovak Republic, 2019b. The Urban Development Policy of the Slovak Republic by 2030: Short version, Bratislava. https://nupdb.urbanpolicyplatform.org/storage/app/public/pdf/3e2DFw0wgSoaVSqqQ8Mf1j7gj41M5NIWBiXICaXd.pdf. Accessed 20 September 2024.

Minority Rights Group (2023). Roma in Slovakia. https://minorityrights.org/communities/roma-15/. Accessed 25 November 2024.

MRFCJ (2022). Principles of Climate Justice. https://www.mrfcj.org/principles-of-climate-justice/. Accessed 26 September 2024.

Národná Banka Slovenska, 2021. Climate Pledge of the National Bank of Slovakia: Information for Public. https://nbs.sk/en/news/climate-pledge-of-the-national-bank-of-slovakia/. Accessed 6 June 2024.

Národná Banka Slovenska, 2022. Annual Report. https://nbs.sk/en/publications/annual-report/.

Naughtin, C.K., Schleiger, E., Bratanova, A., Terhorst, A., Hajkowicz, S. (2024). Forty years in the making: A systematic review of the megatrends literature. *Futures* 157, 103329.

Negm, A.M., Zeleňáková, M. (Eds.) (2019). *Water Resources in Slovakia: Part II.* Springer International Publishing, Cham.

OECD, 2023. Adaptation measurement: Assessing municipal climate risks to inform adaptation policy in the Slovak Republic. https://www.oecd-ilibrary.org/environment/adaptation-measurement-assessing-municipal-climate-risks-to-inform-adaptation-policy-in-the-slovak-republic_dad34bb3-en.

OECD (2024). OECD Environmental Performance Reviews: Slovak Republic 2024. https://www.oecd-ilibrary.org/environment/oecd-environmental-performance-reviews-slovak-republic-2024_108238e8-en. Accessed 2 July 2024.

OECD iLibrary (2024). Slovak Republic: Tourism Trends and Policies 2022. https://www.oecd-ilibrary.org/sites/dba2fbca-en/index.html?itemId=/content/component/dba2fbca-en. Accessed 17 June 2024.

Oscar, G., Venora, G., eds (2011). *Biodiversity loss in a changing planet*.

Our world in data (2024). Energy consumption by source, Slovakia. https://ourworldindata.org/grapher/energy-consumption-by-source-and-country?stackMode=absolute&time=earliest.2023&facet=none&country=~SVK.

Parks.it (n. d.). Parks, Reserves, and Other Protected Areas in Slovakia. https://www.parks.it/world/SK/Eindex.html. Accessed 15 January 2025.

Parsons, E.S., Jowell, A., Veidis, E., Barry, M., Israni, S.T. (2024). Climate change and inequality. *Pediatric Research*.

Pauditsova, E., Reháčková, T. (2006). *Vegetácia v urbánnom prostredí.* Cicero s.r.o. Bratislava, Slovakia.

Pauditšová, E., Streberová, E., Lückenrath, D., Milde, K., Nickel, K., Gondová, A., Musilová, M., Rone, E., Ullrich, O., Konrad, I., Bogen, M., 2020. Specification of Planning Process of Adaptation to Climate Change in Urban Areas with Historic Objects. ADAPT Nothern Heritage Conference Edinburgh 2020; Northern Periphery and Arctic Programme; Europäische Union. https://savingculturalheritage.eu/fileadmin/user_upload/Publications/ANH2020_Pauditsova_et_al.pdf.

Pawson, R., Wong, G., Owen, L. (2011). Known Knowns, Known Unknowns, Unknown Unknowns. *American Journal of Evaluation* 32 (4), 518–546.

Petrikovičová, L., Rampašeková, Z., Sobocká, J. (2020). A Detailed Identification of Erosionally Endangered Agricultural Land in Slovakia (Case Study of Nitra Upland). *Sustainability* 12 (12), 4863.

Porter, L., Rickards, L., Verlie, B., Bosomworth, K., Moloney, S., Lay, B., Latham, B., Anguelovski, I., Pellow, D. (2020). Climate Justice in a Climate Changed World. *Planning Theory & Practice* 21 (2), 293–321.

Považan, R., Blaško, R. (2023). *Globálne megatrendy v životnom prostredí. Aktualizácia environmentálnych globálnych megatrendov a ich implikácie pre Slovensko*.

Pullaiah, T. (2018). *Global Biodiversity: Volume 2: Selected Countries in Europe*. Apple Academic Press.

Ratter, B.M. (2012). Complexity and Emergence: Key Concepts in Non-Linear Dynamic Systems. In: Glaser, M., Krause, G., Ratter, B.M., Welp, M. (Eds.) *Human-nature interactions in the anthropocene. Potentials of social-ecological systems analysis*. Routledge, New York, 90-104.

Reháčková, T., Pauditšová, E. (2004). Evaluation of urban green spaces in Bratislava. *Boreal Environment Research* 9, 469–477.

Roe, E. (2020). Control, manage or cope? A politics for risks, uncertainties and unknown-unknowns. In: Scoones, I., Stirling, A. (Eds.) *The politics of uncertainty. Challenges of transformation*. Routledge, earthscan from Routledge, London, New York, NY, pp. 73–84.

Rončák, P., Hlavčová, K., Kohnová, S., Szolgay, J. (2019). Impacts of Future Climate Change on Runoff in Selected Catchments of Slovakia. In: Leal Filho, W., Trbic, G., Filipovic, D. (Eds.) *Climate Change Adaptation in Eastern Europe*. Springer International Publishing, Cham, pp. 279–292.

Santusová, D., Jakubík, P., 2020. Kritická infraštruktúra v Slovenskej republike. https://veda.polac.cz/wp-content/uploads/2020/11/Kriticka-infrastruktura-v-Slovenskej-republike.pdf. Accessed 31 July 2024.

SCBD (n.d.). Biodiversity Facts Status and trends of biodiversity, including benefits from biodiversity and ecosystem services: Slovakia - Country Profile. https://www.cbd.int/countries/profile?country=sk. Accessed 10 July 2024.

Schleussner, C.-F., Donges, J.F., Donner, R.V., Schellnhuber, H.J. (2016). Armed-conflict risks enhanced by climate-related disasters in ethnically fractionalized countries. *Proceedings of the National Academy of Sciences of the United States of America* 113 (33), 9216–9221.

Šiška, B., Nejedlik, P. (2013). *Climate change impacts and the adaptation options in agriculture in Slovakia*.

Škvarenina, J., Križová, E., Tomlain, J., 2004. Impact of the climate change on the water balance of altitudinal vegetation stages in Slovakia. Supplement 2, Bratislava. https://www.researchgate.net/profile/skvarenina-jaroslav/publication/282417894_impact_of_the_climate_change_on_the_water_balance_of_altitudinal_vegetation_stages_in_slovakia/links/602d6ddfa6fdcc37a8331f67/impact-of-the-climate-change-on-the-water-balance-of-altitudinal-vegetation-stages-in-slovakia.pdf?_sg%5b0%5d=started_experiment_milestone&origin=journaldetail.

Slobodová Nováková, K. (2019). Vinohradnícke a vinárske tradície ako významná súčasť kultúrneho dedičstva a kultúrneho potenciálu Trnavska a Záhoria: Viticulture and Wine-Growing Traditions as an Important Part of the Cultural Heritage and Cultural Potential of Trnava and Záhorie.

Slovak Museum of Nature Protection and Speleology (2017). State Inventory of Specially Protected Parts of Nature and Landscape. https://www.smopaj.sk/en/statny-zoznam.

Slovak Republic, 2021. Security Strategy of the Slovak Republic. https://www.mzv.sk/documents/30297/4638226/security-strategy-of-the-slovak-republic.pdf. Accessed 31 July 2024.

Slovenská Akadémia Vied, 2021. Klimatické zmeny sú vysokým rizikom pre finančný sektor. https://www.sav.sk/?lang=sk&doc=services-news&source_no=20&news_no=9546. Accessed 6 June 2024.

Smithers, R.J., Dworak, T., 2023. Assessing climate change risks and vulnerabilities (climate risk assessment): A DIY Manual, Brussels. https://ricardo.ent.box.com/s/l2quwq5zjoo032jccsgso3cep6h7ej3n. Accessed 19 March 2024.

Sobocká, J. (2017). European Soil Partnership and Soil Policy in Slovakia: Giving soils a voice! ENSA Bratislava 2017. https://esdac.jrc.ec.europa.eu/public_path/shared_folder/ENSA/ENSA_Bratislava_2017_Jaroslava_Sobocka.pdf.

Spratt, D., Dunlop, I., 2018. What Lies Beneath: The Understatement Of Existential Climate Risk, Melbourne.

Správa, Z. (2017). METODICKÁ PRÍRUČKA POSUDZOVANIA DOPADOV ZMENY METODICKÁ PRÍRUČKA POSUDZOVANIA DOPADOV ZMENY KLÍMY NA VEĽKÉ PROJEKTY V SEKTORE DOPRAVA. https:/https://www.opii.gov.sk/download/f/zmena_klimy/metodicka_prirucka_posudzovania_dopadov_zmeny_klimy.pdf/www.opii.gov.sk/download/f/zmena_klimy/metodicka_prirucka_posudzovania_dopadov_zmeny_klimy.pdf.

State Nature Protection of the Slovak Republic (2024). Biosferické rezervácie: Program UNESCO Človek a biosféra (MaB). https://www.sopsr.sk/web/?cl=1600. Accessed 25 June 2024.

statista (2024). Travel & Tourism - Slovakia: Market Insights Mobility. https://www.statista.com/outlook/mmo/travel-tourism/slovakia.

Statistical Office of the Slovak Republic (2024). Structure of population by sex and age. https://vekovastruktura.statistics.sk/index.php?lang=en&geo=SK0. Accessed 25 September 2024.

Štátna ochrana prírody Slovenskej republiky (n. d.). Chránené územia prírody Slovenskej republiky. https://www.sopsr.sk/web/?cl=114. Accessed 15 January 2025.

Štátna ochrana prírody Slovenskej republiky (2023). Biotope catalog of Slovakia - second edition. http://www.biomonitoring.sk/CMS/Publication/Detail/40. Accessed 25 June 2024.

Štátna ochrana prírody Slovenskej republiky (2024). State Nature Conservancy of the Slovak Republic. https://www.sopsr.sk/web/.

Štefko, R., Vašaničová, P., Litavcová, E., Jenčová, S. (2018). Tourism Intensity in the NUTS III Regions of Slovakia. *Journal of Tourism and Services* 9, 45–59.

Štefunková, Z., Hlavčová, K., Lapin, M. (2013). Runoff change scenarios based on regional climate change projections in mountainous basins in Slovakia. *Contributions to Geophysics and Geodesy* 43 (4), 327–350.

Štrba, Ľ., Lacika, J., Huba, M., Liščák, P., Molokáč, M. (2022). Geoheritage, Historical and Cultural Landscape and Its Protection in Slovakia. In: Lehotský, M., Boltižiar, M. (Eds.) *Landscapes and Landforms of Slovakia*. Springer International Publishing, Cham, pp. 415–436.

Supuka, J., Pejchal, M., Kuczman, G. (2015). Stromové dedičstvo v kultúrnej krajine a dendrologických objektoch. *Životné prostredie : revue pre teóriu a starostlivosť o životné prostredie*.

Sviček, M., Buchová, K., Čičová, T. (2022). Identifying current policy ambitions and future soil aspirational goals in Slovaka. https://www.pedosphereresearch.sk/wp-content/uploads/Pedosphere_Research-02-01-2022-Short_communication-Svicek-Buchova-Cicova1.pdf.

Talebian, S., Benzie, M., Harris, K., Jarząbek, Ł., Magnuszewski, P., Carter, T.R., Obermeister, N. (2023). A conceptual framework for responding to cross-border climate change impacts: PREPRINT-Version.

Taneja, S., Mandys, F. (2024). Is Digitalisation Boosting the Decarbonisation of Industries? University of Kent, University of Cambridge. https://spe.org.uk/site/assets/files/12311/11_is_digitalisation_boosting_the_decarbonisation_of_industries.pdf.

The Slovak Spectator (2023). Gloomy outlook for Slovak ski resorts as temperatures rise. https://spectator.sme.sk/c/23113568/climate-change-threatens-ski-resorts-in-slovakia.html. Accessed 2 July 2024.

The Slovak Spectator (2024). News digest: More international travellers visit Slovakia (but it's not what it used to be). https://spectator.sme.sk/c/23281382/news-digest-more-international-travellers-visit-slovakia-but-its-not-what-it-used-to-be.html. Accessed 17 June 2024.

Tomka, J., Huba, J., Pavlík, I. (2022). State of conservation of animal genetic resources in Slovakia. *Genetic Resources* 3 (6), 49–63.

Trading Economics (2024a). Slovakia Unemployment Rate. https://tradingeconomics.com/slovakia/unemployment-rate.

Trading Economics (2024b). Unemployment Rate | Europe. https://tradingeconomics.com/country-list/unemployment-rate?continent=europe.

Uber, M., Haller, M., Brendel, C., Hillebrand, G., Hoffmann, T. (2024). Past, present and future rainfall erosivity in central Europe based on convection-permitting climate simulations. *Hydrology and Earth System Sciences* 28 (1), 87–102.

Umweltbundesamt (UBA), 2016. Klimawirkungsketten. eurac research; bosch & partner.

Umweltbundesamt (UBA), 2021. Klimawirkungs- und Risikoanalyse 2021 für Deutschland: Kurzfassung. Ressortforschungsplan des Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit. http://www.umweltbundesamt.de/publikationen.

UN (n. d.). Goal 10: Reduce inequality within and among countries. https://www.un.org/sustainabledevelopment/inequality/. Accessed 26 September 2024.

UN, 2015. Transforming Our World: The Agenda 2030 for Sustainable Development A/RES/70/1.

UNDRR (2021). Policy brief: Disaster risk reduction and climate change. https://www.undrr.org/publication/policy-brief-disaster-risk-reduction-and-climate-change.

UNDRR, UNU-EHS, 2022. Understanding and managing cascading and systemic risks: lessons from COVID-19, Bonn, Geneva. https://www.undrr.org/media/79311/download?startDownload=20240702. Accessed 2 July 2024.

UNECE, 2008. Spatial Planning: Key Instrument for Development and Effective Governance with Special Reference to Countries in Transition. https://unece.org/fileadmin/DAM/hlm/documents/Publications/spatial_planning.e.pdf.

UN-EHS (2024). 5 Insights into AI as a Double-Edged Sword in Climate Action. https://unu.edu/ehs/series/5-insights-ai-double-edged-sword-climate-action. Accessed 16 December 2024.

UNEP (2024). Climate change and security risks. https://www.unep.org/topics/disasters-and-conflicts/environment-security/climate-change-and-security-risks. Accessed 10 December 2024.

UNESCO (2024a). Tentative Lists: Slovakia. https://whc.unesco.org/en/tentativelists/?action=listtentative&state=sk&order=states. Accessed 2 May 2024.

UNESCO (2024b). World Heritage Convention: State Parties - Slovakia. https://whc.unesco.org/en/statesparties/sk. Accessed 2 May 2024.

UNESCO Institute of Statistics (2024). Cultural heritage: Definition. https://uis.unesco.org/en/glossary-term/cultural-heritage. Accessed 15 April 2024.

UNFCCC (2023). Slovakia. National Communication (NC). NC 8. Biennial Reports (BR). BR 5. https://unfccc.int/documents/626514.

United Nations Office for Disaster Risk Reduction (UNDRR), 2022. Technical Guidance on Comprehensive Risk Assessment and Planning in the Context of Climate Change. Accessed 17 April 2023.

Univerzita Komenského v Bratislave (2021). Slovenská republika - sumárne štatistiky: Mestá Slovenskej republiky. http://www.sodbtn.sk/obce/statistika_obce.php. Accessed 25 November 2024.

Varga, A. (2021). Climate Change and Its Impact on Agriculture. *Acta Horticulturae et Regiotecturae* 24, 50–57.

Vlcko, J., Greif, V., Grof, V., Jezny, M., Petro, L., Brcek, M. (2009). Rock displacement and thermal expansion study at historic heritage sites in Slovakia. *Environmental Geology* 58 (8), 1727–1740.

WHO, 2016. Urban green spaces and health WHO/EURO:2016-3352-43111-60341. https://iris.who.int/handle/10665/345751. Accessed 25 November 2024.

Wildavsky, A., Dake, K. (1990). Theories of Risk Perception: Who Fears What and Why? *Daedalus* 119 (4), 41–60.

World Bank (2018). Urban Population - Slovak Republic. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=SK&most_recent_value_desc=true&view=chart. Accessed 12 August 2024.

World Bank Group (2021). Climate Change Knowledge Portal: Country: Slovak Republic. https://climateknowledgeportal.worldbank.org/country/slovak-republic. Accessed 2 July 2024.

World Bank Group (2022). Water Resource Management. https://www.worldbank.org/en/topic/water-resourcesmanagement#2. Accessed 10 October 2024.

World Data (2024a). Tourism in Slovakia. https://www.worlddata.info/europe/slovakia/tourism.php. Accessed 17 June 2024.

World Data (2024b). Transport and infrastructure in Slovakia. https://www.worlddata.info/europe/slovakia/transport.php.

World Economic Forum (WEF), 2024. Global Risk Report 2024. Insight Report. https://www.weforum.org/publications/global-risks-report-2024/. Accessed 2 July 2024.

World Health Organization (WHO), 2022. Health and climate change: country profile 2021: Slovakia. https://www.who.int/publications/i/item/WHO-HEP-ECH-CCH-21.01.11.

Zeleňáková, M., Fendeková, M. (2019). Climate Change Impacts on Water Resources. In: Negm, A.M., Zeleňáková, M. (Eds.) *Water Resources in Slovakia: Part II*, vol. 70. Springer International Publishing, Cham, pp. 3–19.

Zeleňáková, M., Vido, J., Portela, M., Purcz, P., Blištán, P., Hlavatá, H., Hluštík, P. (2017). Precipitation Trends over Slovakia in the Period 1981–2013. *Water* 9 (12), 922.

Visit our website:

Find out more
about the Technical
Support Instrument:

Trinomics

Funded by
the European Union