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How to develop a risk and vulnerability assessment

Covenant of Mayors Guidebook | Complementary document 2

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How to develop a risk and vulnerability assessment (RVA)

Covenant of Mayors Guidebook | Complementary document 2

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CONTENTS

Abstract

The Covenant of Mayors for Climate and Energy Europe (CoM EU) is the largest European initiative for local climate and energy action. Through the CoM, municipalities voluntarily commit to tackling climate change, pursuing and advancing the commitments of national governments at a local scale.

To ensure sound and effective climate action planning, implementation and monitoring, the CoM Guidebook provides municipalities with relevant context, objectives, methodological principles, procedures, data sources and examples to develop a sustainable energy and climate action plan (SECAP). One of the key elements of the SECAP, the risk and vulnerability assessment (RVA) is a process that combines scientific data with local knowledge to assess the current local situation in terms of climate risks.

The present document provides a step-by-step guidance on how to develop a risk and vulnerability assessment, which is the ground to plan successful climate adaptation actions. The approach adopted in the CoM guidebook is grounded on scientific literature and is aligned with the IPCC framework from the Fifth Assessment Report onwards. The process to build the RVA consists of identifying past and future climate hazards, population and assets exposed as well as physical and social vulnerabilities, determining adaptive capacity to evaluate how well a community can adjust to climate impacts, analysing and prioritising risks and potential impacts. This is embedded in a framework where there is a dedicated team to develop the RVA, stakeholders are identified and engaged, and appropriate tools and techniques are explored and selected.

This document also provides insights into climate adaptation goals, which should address the most important identified risks and vulnerabilities in alignment with the community's capacity and needs.

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This document builds on the previous Guidebook 'How to develop a Sustainable Energy and Climate Action Plan (SECAP)' published in 2018, in particular on the work done on Part 2b "RISK AND VULNERABILITY ASSESSMENT (RVA)" by Yeray Hernandez, Marco Follador, and Silvia Rivas.

1 Introduction

Adapting to climate change has been growing in urgency and has become a key priority, due to the increased frequency of climate adverse events and the severity of their impacts[1] . This is reflected in the evolution of some key policy frameworks. Building on the 2013 European adaptation strategy (COM/2013/0216), the new EU strategy on adaptation to climate change (COM/2021/82) sets out how the European Union can adapt to the unavoidable impacts of climate change and become climate resilient by 2050. The strategy highlights the necessity to involve all parts of society and all levels of governance, and to improve knowledge and evidence-based action making use of robust data and risk assessment tools. In addition, in July 2021, the European Climate Law (COM/2020/8) entered into force. It requires Member States to ensure continuous progress in enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change in accordance with Article 7 of the Paris Agreement[2]. The binding law also contains provisions for Member States' adaptation strategies and plans[3].

Cities are increasingly experiencing climate related consequences and therefore, need to build a sound assessment of the risks their citizens and assets may be subject to, in order to develop suitable actions. Municipalities play a crucial role in adapting to climate change, as the impacts of climate change are often highly localised and vary significantly from one location to another.

The Covenant of Mayors has, since 2015, integrated its mitigation commitments with adaptation efforts, acknowledging the importance of addressing both aspects of the climate challenge at the local level. To support this transition, the European Commission (EC) launched a two-year pilot programme (2022-2023) to assist local and regional authorities in climate adaptation: the Policy Support Facility[4]. In parallel, the mitigation and adaptation pillars were complemented in 2022 with the launch of the energy poverty pillar, where, by focusing on vulnerable population groups, relevant synergies to both adaptation and mitigation can be sought.

The adaptation pillar of the CoM fosters synergies with the EU Mission on Adaptation to Climate Change[5], which aims to accompany at least 150 European regions and communities towards climate resilience by 2030. The Mission contributes to the delivery of the EU Adaptation Strategy by helping the regional and local authorities to better understand the climate risks that they are and will be confronted with in the future, develop their pathways to be better prepared and cope with the changing climate, and test and deploy on the ground innovative solutions needed to build resilience to climate change[6]. Knowledge, data and tools relevant to local climate adaptation gathered or created through the Mission on Adaptation and the CoM are complementary to accelerate the transition to a climate resilient future.

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[1] European Climate Risk Assessment: https://www.eea.europa.eu/en/analysis/publications/european-climate-risk-assessment

[2] Paris Agreement (OJ L 282 19.10.2016, p. 4, CELEX: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:22016A1019(01))

[3] Building a climate-resilient future - European Commission: https://climate.ec.europa.eu/news-your-voice/news/building-climate-resilient-future-2023-07-26_en

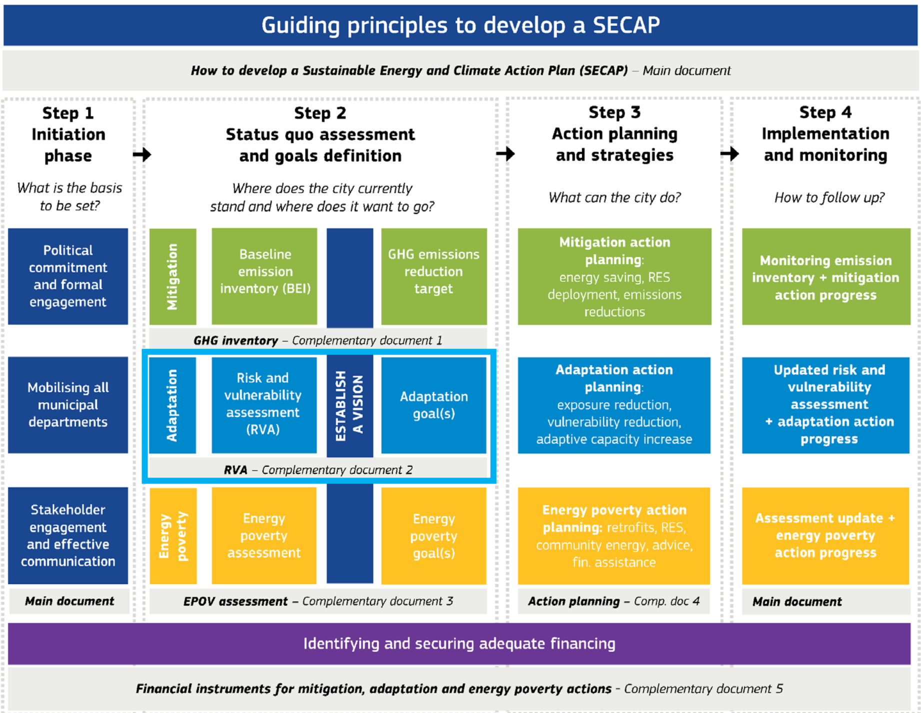
[4] The Policy Support Facility: https://eu-mayors.ec.europa.eu/en/resources/adaptation-resources

[5] EU Mission on Adaptation to Climate Change: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/adaptation-climate-change_en#contact

[6] https://climate-adapt.eea.europa.eu/en/mission

Complementing existing guidelines[7], the present document provides a step-by-step guidance on how to develop a risk and vulnerability assessment (RVA) which is the ground to plan successful climate adaptation actions. The RVA is one of the key elements of the sustainable energy and climate action plan (SECAP) aimed at soundly assessing the current local situation in terms of climate risks. This document builds upon the Guidebook 'How to develop a Sustainable Energy and Climate Action Plan (SECAP)', published in 2018 (Bertoldi, 2018), particularly on part b of document 2. It is one of the five complementary documents of the modular guidebook ("How to develop a Sustainable Energy and Climate Action Plan (SECAP)"). As it can be seen in the figure below (Figure 1), this document focuses on the 'status quo assessment and goals definition' step of the SECAP process, with a focus on the adaptation pillar.

Figure 1. How to develop a Sustainable Energy and Climate Action Plan guidebook – Complementary document 2: risk and vulnerability assessment



Sources: JRC elaboration

With a growing interest in adaptation, numerous resources have become available—including guidance documents, platforms, and tools—that address multiple aspects of climate change adaptation. A few interesting and useful examples are presented in the box below (Box 1).

This document is structured as follows. Section 2 gives an overview of the RVA concepts, with definitions and existing approaches. In section 3, the foundations for a meaningful RVA are described, while section 4, and 5 provide insights into the key concepts and factors determining risks, hazards, exposure and vulnerability. Section 6 and 7 cover the risk analysis and goal setting. Finally, sections 8 and 9 delve into reporting and monitoring.

[7] Such as those published by the EC to support Member States in preparing their adaptation strategies: Guidelines on Member States' adaptation strategies and plans, 2023

Box 1. Key resources on climate change adaptation

Climate Adaptation Platform (Climate-ADAPT)[8] - launched in 2012, it has been supporting and driving EU adaptation policy and practice. The objectives of Climate-ADAPT are (1) to facilitate the collection, sharing and use of information on climate change impacts, vulnerability and adaptation, and build a consistent and updated knowledge base; (2) to assist the effective uptake of the relevant knowledge by decision-makers; and (3) to contribute to a greater level of coordination among sectors and institutional levels. The platform includes a database that contains quality checked information that can be easily searched.

Adaptation knowledge portal[9] - is an online resource of the UNFCCC Knowledge-to-Action Hub for Climate Adaptation and Resilience (also called as the Nairobi work programme (NWP)), providing free and open access to adaptation knowledge resources. It builds on the contributions of policy makers, practitioners and researchers to offer informed and credible adaptation knowledge and learning. In addition, there is a platform to share the latest news and resources on adaptation under the UNFCCC process and from NWP partner organisations.

EU Mission on Adaptation to Climate Change[5] - A wide range of projects directly funded by the Mission on Adaptation undertakes research and develops innovative approaches and options for climate adaptation and associated guidance, tools, data, and case studies to help regional and local authorities deliver the Mission. A database and a summary of each project is offered enabling users to explore synergies, identify transferable approaches, and gain valuable insights into how these projects are building climate resilience on the ground.

CLIMAAX[10] - CLIMAte risk and vulnerability Assessment framework and toolboX (CLIMAAX) is the flagship project of the EU Mission on Adaptation to Climate Change and is designed to contribute to the harmonisation and consolidation of the practice of climate risk assessment, leaving a legacy for upcoming European initiatives. The Climate Risk Assessment Toolbox contains data, projections and risk assessment algorithms designed to support the compilation of regional climate multi-risk assessments and comes with datasets of pan-European hazard, exposure, and vulnerability data for the implementation of the different risk assessment methods.

DRMKC[11] *- The European Commission Disaster Risk Management Knowledge Centre* integrates existing scientific multi-disciplinary knowledge and co-develops innovative solutions for existing needs. Activities of the EC DRMKC support the translation of complex scientific data and analyses into usable information and provide science-based advice for disaster risk management (DRM) policies. The risk data hub is an Interactive platform for geospatial data exploration of disaster risk components across Europe (see also Chapter 4.2).

Existing guidance on specific elements of climate change adaptation:

The *Guide for Adaptation and Resilience Finance (2024)*[12] sets out what constitutes adaptation and resilience finance. It includes a practical roadmap for financing over 100 investable activities, including climate-resilient crops, public hospital infrastructure investment, and mangrove conservation and replanting.

Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience (2020)[13] offers a guide to effective climate change adaptation, containing hands-on guidance to the design, implementation and monitoring of national adaptation strategies. This guide shows that each country needs to tailor these actions to its specific needs and priorities. To guide this process, Adaptation Principles offers

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[8] Climate-ADAPT: https://climate-adapt.eea.europa.eu/en
[9] UNFCCC Adaption Knowledge Portal: https://www4.unfccc.int/sites/NWPStaging/Pages/Home.aspx
[10] CLIMAte risk and vulnerability Assessment framework and toolboX (CLIMAAX): CLIMAte risk and vulnerability Assessment framework and toolboX
[11] DRMKC Risk Data Hub: https://drmkc.jrc.ec.europa.eu/risk-data-hub/
[12] Guide for Adaptation and Resilience Finance: https://www.undrr.org/quick/84482
[13] Adaptation Principles: https://hdl.handle.net/10986/34780

concrete and practical tools such as, screening questions to identify the most urgent and effective actions, toolboxes illustrating common datasets and methodologies to support decisions, indicators to monitor and evaluate progress, and case studies.

The text offers a comprehensive exploration of various approaches, frameworks, and perspectives, enabling municipalities to develop meaningful RVA strategies tailored to their unique context, resources, and priorities. Frequently asked questions and common doubts are answered through the text. Moreover, each section and step of the RVA process is illustrated through real best practices and the case of a fictional city, Rivertown, serving as inspiration and helping to simplify more complex concepts (see Box 2 below).

Box 2. Rivertown: overview

Rivertown is a small municipality located in the heart of Europe, with a population of approximately 50 000 residents. The municipality is characterised by its charming historic centre, a river that flows through its core, and the surrounding lush countryside known for its vineyards and agriculture. Rivertown experiences a temperate climate with distinct seasons, but in recent years, it has faced increasing challenges with extreme heat during summers and significant flooding due to intense rainfall and overflowing of the river.

Rivertown has joined the Covenant of Mayors and recognised the need to conduct a comprehensive RVA to address these climate-related issues and to develop an effective climate adaptation plan.

2 Understanding risk and vulnerability assessment concepts

The risk and vulnerability assessment (RVA)[14] serves to assess the level of risk of a municipality looking at assets and communities living, working and accessing the territory. Several frameworks and methodologies exist to perform RVAs. Before starting the process for the RVA, having a clear understanding of the key concepts and terminology is crucial as it enables municipalities to make correct assumptions, complete analysis and set up collaborations to prepare a relevant and suitable RVA.

2.1 RVA definitions and terminology

A clear and common terminology is of great importance for developing a well-defined and accurate RVA in line with the conceptual evolution and the need of a common framework. The key terms are reported below with a concise definition. Through this document, these concepts will appear often, together with further insights and details.

— **Climate hazard**. The potential occurrence of a natural or human-induced physical event, trend or physical impact 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. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts (IPCC, 2022a).

— **Climate exposure**: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2022a).

— **Climate vulnerability**:

- For population groups: climate vulnerability describes the extent to which a population group is vulnerable to harm from climate related events. This can be influenced by factors such as socio-economic status, health, age, location, and access to resources. Vulnerable groups might include older people, low-income communities, or those with pre-existing health conditions.

- For sectors: climate vulnerability for sectors refers to the vulnerability of economic sectors (like agriculture, water resources, or energy) to climate variability and extremes. This can depend on sector-specific factors such as technology, infrastructure, market dynamics, and regulatory frameworks.

— **Adaptive capacity**: adaptive capacity is the ability of a system, community, or organisation to adjust to climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. This includes elements such as resource availability, technology, information and skills, infrastructure, institutions, and equity.

[14] Also referred to as: climate risk and vulnerability assessment (CRVA) or climate risk assessment (CRA).

- **Climate impact**: climate impact refers to the effects of climate variability and change on natural and human systems. Impacts can be positive or negative and can result from both gradual changes (like temperature rise) and extreme events (like hurricanes). These impacts often lead to changes in the functioning and services provided by these systems.
- **Climate risk**: the potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk results from the dynamic interaction of hazard, vulnerability, exposure of human and ecological systems (IPCC, 2022a).
- **Action/response/measure**: in the context of climate change, an action, response, or measure refers to the steps taken or strategies implemented to address and manage climate risks. This can include adaptation measures to reduce vulnerability and enhance adaptive capacity. These actions can range from policy changes and infrastructure improvements to community-based initiatives and technological innovations.

Box 3. Section 2 frequently asked questions

1 (Climate) Hazard vs risk?

- *Climate hazard:* a climate hazard refers to a potentially damaging natural event or phenomenon that may cause harm to human life, property, livelihoods, and the environment. Climate hazards are the physical events themselves and can include: extreme weather events (e.g., hurricanes, heatwaves, floods, droughts), sea-level rise, glacial retreat and loss of ice cover, increased variability in weather patterns, long-term changes in climate conditions (e.g., warming temperatures, changing precipitation patterns). Climate hazards are characterised by their location, intensity, frequency and duration, and are often evaluated independently of the exposure or vulnerability of human systems.
- *Climate risk:* climate risk, on the other hand, is the likelihood of harmful consequences or expected losses resulting from interactions between climate hazards and the vulnerable conditions of exposed elements such as people, economies, and ecosystems. Climate risk is a function of three components: climate hazards (as mentioned above), exposure (the presence of people, assets, and ecosystems in places that could be adversely affected by hazards), and vulnerability (the propensity or predisposition of these exposed elements to be adversely affected). Climate risk is a more comprehensive concept that takes into account not just the physical hazard but also the social, economic, and environmental factors that determine how much damage the hazard might cause. It is the combination of the probability of a climate event and the impact it would have due to the vulnerability and exposure of the affected system.

2 (Climate) Hazard vs Threat?

- A *hazard* is a potential source of harm or adverse effect that is typically associated with natural events, such as heatwaves, floods, or hurricanes. It is a situation that poses a level of threat to life, health, property, or the environment.
- A *threat,* on the other hand, can refer to both natural and human-induced actions or events that have the potential to cause damage or loss. This term is used in security and risk contexts: a threat is often associated with a deliberate intent to cause harm, such as cyber-attacks, terrorism, or other malicious activities.

In summary, while a hazard, a term used in climate change context, is generally natural and can lead to a threat, a threat is used in the security field and general risk contexts and encompasses a wider range of hazards, including those that are human-made and may involve a deliberative intent to cause harm.

3 (Climate) Adaptation vs mitigation?

While climate *mitigation* focuses on reducing the causes of climate change, namely GHG emissions reduction to prevent the rise of temperature, climate *adaptation* is concerned with managing the impacts and being able to cope with the changes (see the main document Davide et al., 2025). Tackling climate change requires integrating mitigation and adaptation. Consistent and effective mitigation action will help reduce the need for adaptation action in the future (see also the next question).

4 (Climate) Adaptation vs hazard mitigation?

- *Climate adaptation*: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2022a). The focus is on dealing with the changes that are occurring or are projected to occur in the climate system. It includes actions like altering infrastructure, adjusting agricultural practices, and developing drought-resistant crops to cope with the new climate realities.
- *Climate hazard mitigation*: This specifically addresses the reduction of risks associated with climate-related hazards, such as extreme weather events driven by climate change. It involves strategies and actions to minimise the impacts of these hazards, such as reinforcing buildings to withstand stronger storms, improving flood defences in response to heavier precipitation events, and implementing water management strategies to combat droughts exacerbated by climate change.

Both climate adaptation and climate hazard mitigation are concerned with addressing the impacts of climate change, but climate adaptation is broader and includes adjustments to a range of climate change effects, while climate hazard mitigation is more focused on specific strategies to reduce the risks and potential damages from climate-related hazards. To avoid confusion with climate mitigation, only climate adaptation is used in this report.

5 (Climate) Adaptation vs disaster risk management (DRM)?

- *Disaster* is defined as a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts[15]. Events can become disasters once they surpass thresholds in at least one of three dimensions: spatial; temporal and intensity of impact on the affected population. Disaster risk management (DRM) is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses. Extreme weather and climate events will lead to disaster if: 1) communities are exposed to those events; and 2) exposure to potentially damaging extreme events is accompanied by a high level of vulnerability (a predisposition for loss and damage). On the other hand, disasters are also triggered by events that are not extreme in a statistical sense. High exposure and vulnerability levels will transform even some small-scale events into disasters for some affected communities (Lavell et al., 2012). Disaster risk management addresses a wider range of acute hazards, including earthquakes, industrial accidents, and pandemics, focusing on preparedness, response, and recovery efforts to minimise their immediate impacts.
- *Adaptation* is a goal to be advanced and DRM supports and advances that goal. Adaptation to climate change and DRM both seek to reduce factors and modify environmental and human contexts that contribute to climate-related risk, thus supporting and promoting sustainability in social and economic development. Climate adaptation targets the gradual, cumulative, and often chronic impacts of climate-induced changes, such as sea-level rise, increased temperatures, and altered precipitation patterns,

[15] United Nations Office for Disaster Risk Reduction (UNDRR). 2017. The Sendai Framework Terminology on Disaster Risk Reduction. "Disaster". Accessed 5 March 2025.

integrating these elements into urban planning and infrastructure development to mitigate their long-term effects on urban systems.

These strategies are complementary; climate adaptation can enhance disaster risk management by promoting sustainable development practices and nature-based solutions that reduce vulnerability, while disaster risk management can provide immediate response and recovery strategies that should be incorporated into adaptation planning. A closer integration of DRM and adaptation, along with the incorporation of both into local, national, and international development policies and practices, will provide benefits at all scales.

2.2 RVA scope and applicability

2.2.1 Objectives of RVA

The overarching goal of a risk and vulnerability assessment is to systematically evaluate the municipality's risk, due to the combination of various climate change hazards, vulnerabilities and exposure. This includes assessing the probability and magnitude of climate-related hazards, as well as understanding which aspects of the municipality—such as infrastructure, populations, ecosystems, and economic sectors—are most vulnerable and exposed. The assessment aims to provide a clear picture of the municipality's vulnerabilities to inform strategic planning and decision-making. This ensures that the municipality can prepare for, respond to, and recover from climate-related impact, ultimately safeguarding the well-being of its residents and the integrity of its critical systems in the face of a changing climate.

2.2.2 Expected outcomes of RVA

The expected outcome of an RVA is a report that provides a risk profile, which identifies and ranks climate-related hazards such as extreme weather events, sea-level rise, and temperature changes, along with their potential frequency and severity. The assessment can include a vulnerability map that illustrates which geographic areas and sectors within the municipality are most susceptible to these hazards, taking into account social, economic, and environmental factors. The RVA can also deliver an impact assessment that analyses the possible effects on the municipality's critical infrastructure, public health, local economy, natural resources, and vulnerable populations. Additionally, it evaluates the municipality's adaptive capacity, examining the current ability to cope with and adapt to the impacts of climate change and the effectiveness of existing measures, while considering the potential for new strategies. This comprehensive analysis informs the municipality's understanding of its vulnerabilities, laying the groundwork for a targeted climate adaptation action.

2.2.3 Challenges

A risk and vulnerability assessment is essential to support and guide evidence-based climate adaptation policymaking. However, developing RVAs involves several challenges related to complexity and uncertainty. RVAs are inherently characterised by uncertainty, which arises from climate science, climate modelling, data availability, and the science–policy interface. The interplay between factors in natural system and socio-economic drivers contributes to the complexity of climate risks and their assessment. In researching, organising and structuring the knowledge available on events, processes and scenarios, risk and vulnerability assessments require reliable data, specialised skills and expertise, transparency, and good communication. Scenarios are used to represent diverse future pathways helping analyse these interdependencies and interactions. A major bottleneck in understanding risk lies in the limited availability and relevance of existing data. Furthermore, expert judgment remains central to the assessment process as it is essential for evaluating different sources of evidence and communicating confidence levels (Adger et al., 2018; IPCC, 2022b).

The uncertainty driven by these factors, can be reduced through innovative methods and actions that enhance knowledge flows from diverse sources, promote broader participation and communication, and ensure continuous monitoring and evaluation. However, acknowledging that a degree of uncertainty is unavoidable and building upon this aspect to inform action, marks a critical advancement in risk and vulnerability assessment.

2.2.4 Guiding principles

This section outlines crucial principles, norms, and best practices central to an RVA that is fair and sound, taking uncertainties into consideration. Adopting these principles involves a cooperative approach with diverse stakeholders, local officials, and community participating in climate planning, underscoring the importance of engagement and related methods.

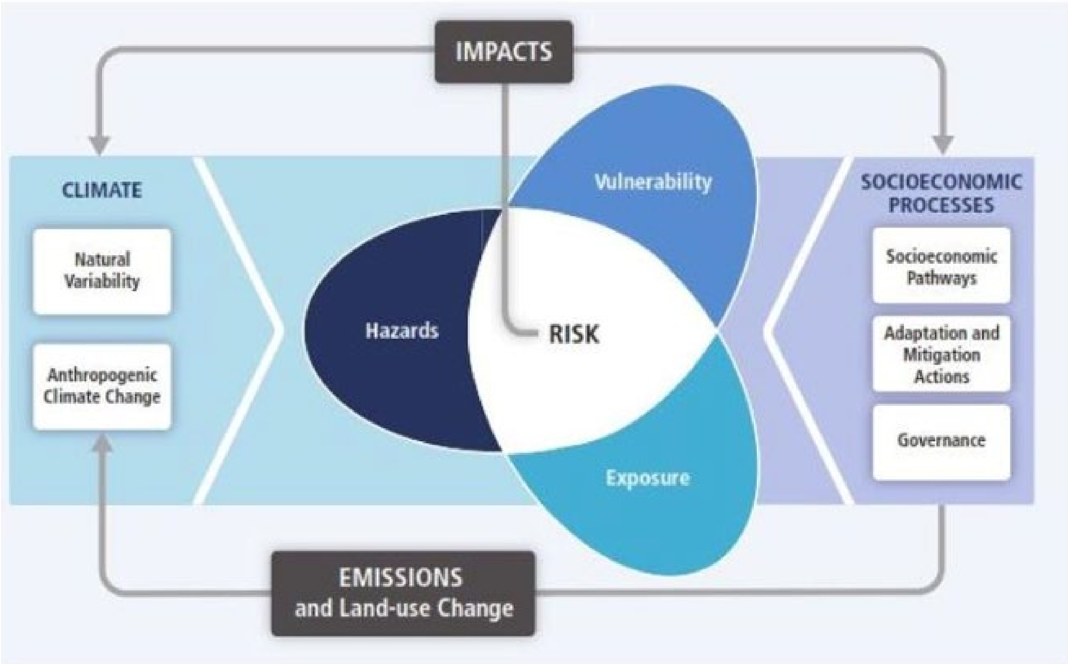
- **Social justice, equity, and inclusivity.** The impacts of and responses to climate change differ across communities, with some groups facing heightened vulnerability to climate risks or unequal benefits or burdens from mitigation and adaptation measures. Vulnerability is shaped by variables such as age, health, gender, socio-economic status, ethnicity, and social connections. The objective is to cater to the specific needs of at-risk and marginalised groups to ensure inclusivity and equitable distribution of both the burdens and benefits of climate action. A shared approach promotes justice and encourages inclusive participation.
- **Quality, rigour, and transparency.** An RVA must uphold quality and transparency to ensure its results are reliable, comparable, and open to validation and standardisation. When taking the responsibility for developing the RVA, municipalities set up an open and transparent process with citizens and stakeholders. Adhering to high-quality guidelines and practices, supported by scientific research and international standards, is vital to ensure accuracy and robustness. In addition, by utilising local data and connecting with regional data resources increases specific knowledge and reliability.
- **Precautionary approach.** RVAs encounter uncertainties due to evolving conditions within climate change and local contexts. Integrated pathways for managing climate risks will be most suitable when so-called 'low-regret' anticipatory options are established jointly across sectors in a timely manner and are feasible and effective in their local context. Approaches that break down adaptation into manageable steps over time and use pathway analysis to determine low-regret actions for the near-term and long-term options are a useful starting point. Therefore, incorporating flexibility and mechanisms to mitigate uncertainties both in the risk and vulnerability assessment, and in the planning and implementation of actions is essential. In situations where evidence is scarce, it is better to take a precautionary stance rather than to choose inaction. For instance, when gathering data for the RVA is challenging, stakeholder engagement and risk evaluation processes can become a relevant source of information to identify the most prominent risks, or vulnerable sectors and population groups. Likewise, when the risk level against a hazard can be understood as medium or high while the supporting evidence is for the time being scarce, it is advisable to strategically plan actions against this risk while data becomes available.

2.3 The need for a common RVA approach

The EU strategy on Adaptation to climate change (COM/2021/82) pursues the establishment of a common set of methods and indicators to assess the performance of adaptation projects and monitor the evolution of risk and vulnerabilities. In the literature, there are very different definitions and ways to assess climate change risks and vulnerabilities.

Scholars from different knowledge domains apply different approaches, often generating misunderstanding in interdisciplinary research on climate change (Füssel, 2007). The fragmentation of methods and frameworks creates challenges in coordinating responses and evaluating the effectiveness of initiatives. The IPCC Fourth Assessment Report (IPCC, 2007) proposed a formal conceptualisation of vulnerability as a function of a system's exposure and sensitivity to climate stressors and capacity to adapt and cope with their impacts. The Fifth Assessment Report (IPCC, 2014) introduced a slightly different terminology and moved to a climate change risk framework which is the one used through this report (Figure 2) by incorporating concepts from the disaster-risk community (Lavell et al., 2012). Different RVA approaches - based on diverse explicative variables and ways of handling indicators - can make the comparison/benchmarking between cities' RVA scores unsound or invalid.

Figure 2. Climate change risk framework



Sources: IPCC (2014)

Building the RVA entails the challenge of how to move from a conceptual framework to a quantitative assessment in a site-specific context. Judgements and approximations have to be made to translate the existing information about the municipality – such as climate parameters, biophysical and socio-economic attributes, governance and institutional capacities, among others – into knowledge that triggers a realistic RVA. This challenge and related intricacy may hinder municipalities' potential of understanding their climate change impacts, vulnerabilities and risks. This is particularly true in small and mid-size municipalities, which usually rely on limited technical skills and resources. Therefore, a harmonised framework including the main concepts, methodologies and indicators for adaptation -

as in the case of mitigation – has been conceived to make RVAs easy to handle and inform policy-making, while keeping the flexibility and autonomy of municipalities to select most appropriate solutions. The framework is harmonised at the global level, through the Global Covenant of Mayors for Climate and Energy (GCoM) Common Reporting Framework (CRF)[16], which outlines the essential elements for climate action plans, with the risk and vulnerability assessment (RVA) being a mandatory element of the climate change adaptation plan.

2.3.1 Benefits of a common approach for the RVA

A common approach for the risk and vulnerability assessment framework brings several key benefits:

- **Standardisation**: it provides standardised methodologies and indicators for assessing risks and vulnerabilities, which allows for consistency in data collection, analysis, and reporting across different regions and entities.
- **Comparability**: standardised assessments enable comparison of risks and vulnerabilities between different areas, which can be critical for prioritising actions, sharing best practices, and mobilising resources at regional, national, or international levels.
- **Efficiency**: a unified approach reduces duplication of efforts and allows for the sharing of tools, resources, and expertise, making the process more efficient and cost-effective.
- **Collaboration**: it enables collaboration and knowledge exchange among cities, regions, and countries, which can lead to more innovative and effective adaptation strategies.
- **Data integration**: the framework can facilitate the integration of various types of data, including local and indigenous knowledge, which enriches the assessment and makes it more relevant to specific contexts.
- **Capacity building**: a common framework offers a blueprint for training and capacity building, helping to raise the competencies of stakeholders involved in climate risk assessments.
- **Informed decision-making**: by providing a clear and coherent structure for assessing climate risks, a unified RVA framework supports evidence-based decision-making and policy development.
- **Public awareness and engagement**: a consistent assessment framework can enhance communication and the public understanding of climate risks and the rationale behind adaptation measures, leading to greater community engagement and support.
- **Scalability**: a harmonised framework can be adaptable to various scales, from local to global, allowing for flexibility in its application while maintaining core principles and standards.

[16] Global Covenant of Mayors Common Reporting Framework (CRF) available at: https://www.globalcovenantofmayors.org/our-initiatives/data4cities/common-global-reporting-framework/

3 Laying the Foundations for RVA

3.1 Establishing the RVA team

3.1.1 Identifying resources

Assessing resource needs and availability is critical for effective adaptation planning. Given that the resources required may vary based on the specific management and institutional context, it is important to take stock of human, technical, and financial resources to inform the policy cycle:

— **Human resources:** evaluate the skills and staffing levels within the organisation through surveys, interviews, and competency assessments. Identify any skill gaps to target training and capacity-building efforts.

— **Technical resources:** assess the technical tools, equipment, and technology that support day-to-day operations. Map existing resources to determine if they meet current organisational needs and identify areas where new technology is necessary.

— **Financial resources:** establish financial viability by exploring various funding options available from different sources, such as EU programmes, national and regional institutions, private sector contributions, or mixed sources. Utilise guidance from resources like the Climate-ADAPT to navigate EU adaptation funding[17]. Consider mainstreaming adaptation into sectoral policies to create synergies and reduce costs.

3.1.2 Formation of the RVA team

To effectively conduct an RVA, it is crucial to establish a dedicated core team within the municipality and set up collaboration with external stakeholders. This team's primary responsibility is to develop and oversee the RVA, focusing on the shared identification of climate hazards, risks, and vulnerabilities.

— **Core team composition:** the core adaptation team should be multidisciplinary, drawing on expertise from departments that handle sectors particularly vulnerable to climate change impacts or that are integral to delivering adaptation solutions. This includes professionals from health, civil protection, transport, energy, water management, agriculture, spatial planning, finance, forestry, and local or regional development. Each member brings a sector-specific perspective to the table, ensuring a comprehensive assessment that covers all critical areas of concern.

— **Leadership and coordination:** an 'adaptation officer' should be appointed to lead the RVA team. This individual will act as a central coordinator, facilitating communication and collaboration across the various departments involved and ensuring that the RVA aligns with the organisation's overall adaptation goals. To ensure broad departmental engagement, it is essential that there is a clear political will legitimising the process and the action of the officer, while allowing readjusting priorities within the organisation and across the departments. The adaptation officer will also be responsible for clarifying roles within the team and establishing clear lines of accountability.

[17] https://climate-adapt.eea.europa.eu/en

— **Defining objectives and tasks:** the team should collaboratively determine its members, define the objectives of the RVA, clarify individual and collective tasks, and develop work programmes that outline the assessment process in detail. This includes identifying the climate hazards of greatest concern, the vulnerable sectors and population groups, and the methodologies to be used in the assessment. External relevant entities, such as protection agencies, should be involved in each step.

— **Collaborative structures:** establish effective collaboration structures that enable the core team to work together seamlessly. This could involve regular meetings, shared digital workspaces for data and document management, and joint fieldwork when necessary. Organising dedicated workshops will ensure all stakeholders are involved providing data and filling information gaps, providing feedback and owning the results.

— **Documentation and transparency:** maintain thorough and transparent documentation throughout the RVA process. This includes records of meetings, data analyses, interim findings, and the final assessment report. Transparent documentation not only aids in the decision-making process but also ensures that the rationale and evidence behind adaptation strategies are clear to all stakeholders.

It is advisable to retain the RVA development task internally within the municipality, as this would ensure continuity, facilitate seamless data access and need for updates. In addition, having an in-house process fosters a sense of ownership and ensures effective progress monitoring phases.

Box 4. Rivertown: RVA team

The first step for Rivertown municipality is to create a team dedicated to the development of the RVA. By forming a well-structured RVA/Adaptation team with clear leadership, defined roles, and a tailored approach, Rivertown lays a solid foundation for a successful risk and vulnerability assessment that will inform its climate adaptation strategies. The *Adaptation team* in Rivertown has been created involving key personnel from the municipal departments dealing with sectors affected by climate risks: the built environment; emergency services, disaster response planning; public works, for infrastructure resilience, particularly water management and drainage systems; social sector and public health. An *Adaptation Officer* from the urban planning department, with experience in project management and a strong understanding of climate issues, has been appointed as leader of the *Adaptation team*. After a thorough evaluation of the human, technical, and financial resources, Rivertown has decided to conduct the RVA internally since the key skills are available within the team. This way, continuity can be maintained in the assessment process, ensuring that any future inquiries or updates to the RVA can be managed by the in-house team. Moreover, by developing an internal RVA team, Rivertown fosters a sense of ownership over the analysis, which will be a strength during the monitoring phase, facilitating easier access to and retrieval of necessary data. However, for key scientific expertise, the municipality has thought to explore collaborations with external experts. Ideally, the team formation and identification of missing skills would be set up in 1-2 months from the start of the process, considered as coinciding with joining the CoM.

3.2 Stakeholder identification and engagement

Stakeholder identification and engagement is an activity that goes through the whole SECAP process, considering all CoM pillars (see Main Document, Davide et al., 2025). However, there are certain nuances that are specific to climate adaptation. Effective climate adaptation requires plurality of views that goes beyond the knowledge of municipality and includes the perspectives and knowledge of those with a legitimate stake, including private sector, research institutions, non-governmental organisations and residents who may influence, or be influenced by the SECAP climate adaptation actions. Stakeholder engagement adds value in identifying vulnerable subsystems and interlinkages of vulnerabilities, hazards and cascading effects. Incorporating stakeholder inputs in the process support setting priorities and selecting/developing tailored indicators.

The main goal of stakeholder and citizen involvement is to diversify the perspectives while building trust, thereby achieving stronger outcomes through the whole planning process. Hence, stakeholder engagement should be carried out from the assessment phase to the later steps of planning, implementation and monitoring of policies (Corral & Hernandez, 2017). This seamless engagement ensures that the adaptation plan (or the adaptation part of the SECAP) is informed by both technical and non-technical knowledge, and that all phases are linked and coherent. An ample information provision in the initial steps of the policy cycle is of great importance to ascertain major conflicting values and to find compromise solutions at a later stage.

The engagement of stakeholders and citizens brings mutual benefits. On one hand, the active engagement of stakeholders enables building local capacity and knowledge, increasing trust towards decision-makers, and at later steps, building co-designed climate adaptation strategies and solutions with higher legitimacy. On the other hand, the contribution of stakeholders and citizens can introduce new knowledge into the climate adaptation RVA process and related scientific findings, can confirm analysis and outcomes, identify barriers and may suggest novel methods or approaches (Palermo & Hernandez, 2020). In addition, engaging a wider user and stakeholder group allows these actors to design and propose inclusive, context-specific solutions that are adequate responses to the hazards and risks posed.

One of the key elements of stakeholder engagement is deciding who is to be engaged, namely who counts as a relevant stakeholder. The first step is the stakeholder mapping and identification, the process run to identify who has a stake, responsibility, interest or is and will be influenced by climate change impacts and adaptation solutions. Although there is no overall agreement on who or what qualifies as a stakeholder in sustainability science (Lemke et al., 2024), stakeholder mapping is frequently used with different approaches, tools and methods. It is upon the municipality to define the best approach that suits its local context, availability of resources, and specific goals. In fact, when working on the hazards, exposure and vulnerabilities analysis, some adjustments in defining who has a legitimate stake may be required to make sure that the needs and contributions are best placed and relevant to the topic developed. Any mapping process should respond to the principles of diversity, inclusiveness and transparency to limit the knowledge bias, thereby identifying a sufficient number of stakeholders with a legitimate stake, including diverse and marginalised voices through a rigorous and transparent process. Municipalities should aim to address these principles as much as possible, even though some challenges may occur such as availability of involved people, experience, and expert knowledge. There are several methods to identify the first pool of stakeholders, including basic desk research activities, focus groups, surveys, open call and self-identification, and snowball mapping[18]. A crucial aspect is to be aware of and address potential conflicts of interests and power positions. A combination of methods widens the arena of the actors involved and helps reducing subjectivism[19].

Mapping stakeholders is not necessarily a fully top-down process, instead it could be subject to some iterative mechanisms coming from the bottom. Further adjustments, for example increasing the representativeness of the groups, or involving additional groups previously neglected, can be made building on the contributions of selected stakeholders during the first meetings. Municipalities, after having identified the stakeholders and citizens to be involved, can consider organising preliminary meetings to assess if the mapping exercise they made was complete and satisfactory, or if it could be improved through the additional insights they gathered.

Box 5. Stakeholder mapping in Paris

IMPETUS4CHANGE (I4C)[20] is a Horizon Europe project aiming at improving the quality, accessibility and usability of near-term climate information and services at local to regional scales to strengthen and support end-user adaptation planning and action.

In Paris, one of the four demonstrators, I4C combines the urban climate response with urban planning to guide strategies to address urban heat island impacts, by co-assessing health impacts and stakeholder needs for urban planning based on existing knowledge.

The stakeholder map and group of prioritised users is specific to the local context in which the affected decisions will be taken and the overarching or high-level goal of the climate service to be developed. In Paris, the goal is how to reduce the health impacts of heatwaves. Two main actors were identified during the proposal stage given existing interests in heat-related health issues and support for urban redevelopment strategies, *Santé Publique France* (SPF) and the *Institut Paris Région* (IPR). The Paris team has then expanded the stakeholder panel, based on a call for expressions of interest. A dozen stakeholders with diverse profiles from the institutional, voluntary, and private sectors agreed to participate. Subsequently, each stakeholder was interviewed to understand their organisation's missions, interests, expectations and needs regarding climate data, climate and impact indicators, data type and format, spatial coverage, resolution, and timeframes. From these interviews, the interest and needs of stakeholder is variegated, ranging from need for climate data, to maps supporting planning and decision-making process for climate change adaptation. Webinars and workshops followed to foster stakeholder dialogue with researchers and to present the first sets of climate data produced.

Once stakeholders are identified, specific areas of focus and questions relevant to the stakeholders and the climate adaptation process are to be defined. These serve as guidance for the identification of key issues, concerns, and priorities and requires to be thoughtfully designed in a flexible way, so that the contribution of stakeholders can influence the process in a continuous improvement. The themes of discussions can focus on the hazards, perceptions, the challenges encountered, methodologies, ideas for the future. Framing the topics also determine the approaches, tools and methods that will be used to involve stakeholders to ensure the relevance of the RVA process and then of the adaptation strategy. Stakeholder involvement processes are not "pre-packaged". On the contrary each

[18] Snowball mapping asks the initially identified stakeholders to identify new stakeholder categories and to provide further contacts.

[19] RESIN – Climate Resilient Cities and Infrastructures. European Union's Horizon 2020 research and innovation programme grant agreement no. 653522, Deliverable 6-1

[20] https://impetus4change.eu/the-project/ I4C- Impetus4Change. European Union's Horizon Europe research and innovation programme, grant agreement no. 101081555, Deliverable 6.2

time suitable and adaptable strategies and methods are to be considered, depending on and according to the specific topics and context. For instance, the [DIY Manual on Engaging Stakeholders and Citizens in Climate Adaptation: Tools, Good Practices and Experiences][21] (Wehbe et al., 2024) developed in the context of the EU Mission Adaptation to Climate change proposes a series of steps and observations in the context of adaptation.

Some examples of commonly used methods are reported below, but broad literature exists on stakeholder involvement and participatory methods. Municipalities can further explore these and select the cases that best fit their purposes (some additional resources are reported in annex 4).

- Thematic focus groups or workshops can help identify and prioritise or validate climate vulnerabilities and risks.
- Cross-thematic/cross-sectoral workshops can help identify any cross-cutting climate vulnerabilities and risks across themes/sectors through.
- Useful dialogue and deliberation to better identify risks and vulnerabilities from vulnerable groups.
- Stakeholder interviews to corroborate findings and feed in new ideas.
- Serious games that help increase knowledge and awareness, steer the discussion and identify barriers.
- Target communications activities to build citizens' understanding or awareness of climate vulnerabilities and risks (i.e., an information awareness campaign).

Box 6. Co-creation pathway for urban nature-based solutions (NBSs)

The Clever Cities[22] project investigated and implemented nature-based solutions (NBS) to address urban challenges and promote social inclusion in nine cities across Europe, South America, and China with Hamburg, London, and Milan being the frontrunners. The project developed approaches to co-design and co-implement NBS in shared-governance processes. Co-creation in urban-greening projects enhances the awareness and knowledge of citizens and stakeholders around NBS, the inclusivity in decision-making for urban transformation, supports the quality of regeneration interventions. (Mahmoud & Morello, 2021).

In Hamburg, a green corridor was planned to increase biodiversity and increase or upgrade nature in the city. The CLEVER Cities team designed a new wayfinding system in the district of Neugraben-Fischbek to provide information on place-specific nature-based interventions in the area, establish connections between them, offering orientation, while at the same time embedding them into existing paths. In March 2021, the district office of Harburg kicked off a co-creation process to get residents and local stakeholders involved in designing the new system, linking different elements to develop the corridor. Through the co-design process, involved participants were able to define five further spots of local significance to be integrated into the wayfinding system. Several participatory workshops were organised allowing to identify and further refine potential locations for nature-based interventions. The launch events brought together ten local stakeholders from various institutions in Neugraben-Fischbek such as the Loki-Schmidt Foundation, the Cornelius Parish, the beekeeping association Harburg-Wilhelmsburg, the primary school Ohrnsweg, the culture and history associations Falkhus eV and Fischbek, the high school Süderelbe, and the production facility Süderelbe.

[21] EU Missions - Adaptation to climate change: DIY Manual on Engaging Stakeholders and Citizens in Climate Adaptation: Tools, Good Practices and Experiences https://climate-adapt.eea.europa.eu/en/mission/external-content/pdfs/2024-eumissions-diy-manual-vfinal.pdf/

[22] https://clevercities.eu/the-project/

Box 7. Rivertown: stakeholder and citizen engagement and initial data gathering

Developing an RVA is not a linear process, initial steps require a preliminary assessment of data available to understand the context and the stakeholders to be involved. The *Adaptation team* of Rivertown, based on information available, works on mapping stakeholders to identify individuals or groups whose interests and activities are affected by climate risks and who possess/control information, resources and expertise needed for developing a sound assessment. Regional climate experts, such as those at nearby universities or government agencies, are reached out to assist with climate data analysis and projections. These experts can participate as consultants or advisors to the RVA team. In addition, Rivertown's *Adaptation team* invites a residents' association to represent community interests. The *Adaptation team* organises a series of meetings with interested residents and stakeholders, to share the intention and the programme of the RVA process and to share and gather local knowledge useful for informing the RVA.

In parallel, the public works representative starts exploring available data on flooding events and current drainage system capacities. The public health official compiles health records related to past heatwaves. The *Adaptation team* conducts two focus group sessions with residents from flood-prone and heat-affected areas to gain local insights.

Moreover, with the help of the experts, the team also participates in a specialised workshop on climate data analysis and GIS mapping, thereby bridging any skills gaps in these areas, which are relevant for several steps of the RVA.

Ideally, these steps are taken within six months.

3.3 Defining RVA framework, tools, methodologies

The third main element towards laying the foundations to draft the RVA, is determining the framework to be used. This includes analysing the geographical scope to be covered, the temporal scale (short and long term) and the corresponding tools and methodologies.

3.3.1 Determining the geographical scope

While jurisdictional boundaries are clearly defined, physical and natural elements, as well as infrastructures, often transcend these boundaries. Climate events disregard administrative borders, but the responses are determined by administrative decisions and tied to specific geographic areas. This highlights the need for collaborative efforts horizontally and across different levels of governance. This is why understanding the geographic scope and the interconnections of an RVA for a municipality is a crucial step, as it sets the stage for data collection, analysis, and subsequent planning.

- **Jurisdictional boundaries:** the administrative boundaries of the local government, which may include the municipality limits, county lines, or other delineations of political authority. These boundaries define the area for which the local government is responsible and has the authority to implement adaptation measures.
- **Interconnectedness:** the interconnectedness of the local area with neighbouring regions is a key concept for the assessment of risks and vulnerabilities. Infrastructure networks cross administrative borders and well represent the geographical and administrative interconnectedness of local governments and other interested bodies. Impacts of climate related events hit irrespectively of administrative definitions and reciprocal effects can occur.

- **Regulatory requirements:** regulatory frameworks or guidelines may dictate the geographical scope of risk assessments for local governments. Some regions may have specific requirements that need to be adhered to, i.e. specific regulations for protected areas.
- **Physical and natural boundaries:** in some cases, physical features such as rivers, watersheds, or ecosystems may extend beyond jurisdictional lines but still impact the local area. Where relevant, these natural boundaries should be considered to fully understand the sources and pathways of climate risks.
- **Infrastructure and assets:** key infrastructures and assets within the local government's area critical to community function are to be identified as they may be at risk from climate hazards, inducing serious interruptions which may affect the community, particularly in case of emergency. This can include transportation networks, utilities, public buildings, and cultural heritage sites.
- **Socio-economic factors:** the socio-economic characteristics of the population within the administrative boundaries are a determinant of RVAs. It highlights areas, sectors and population that may be disproportionately affected by climate impacts and municipalities can decide to pay closer attention to specific areas that are more vulnerable.
- **Climate data availability:** climate data can be at different resolutions. High-resolution data may allow for a more detailed and localised RVA, while less granular data may necessitate a broader geographical scope. The availability of this data may influence the RVA structure (se 3.3.2 and 3.3.3).

3.3.2 Setting the temporal scale

Setting the temporal scale of an RVA involves determining the time frame over which climate risks are evaluated. The chosen time frame should align with the goals of the assessment, the expected lifespan of key infrastructure and assets, and the planning horizons for adaptation measures. Below some key elements to consider for setting the temporal scale for an RVA are reported:

- **Short-term vs. long-term risks:** clearly identify and assess immediate, short-term risks that might occur within the next few years, such as those associated with weather variability, or long-term risks that account for climate change projections over decades (100 years).
- **Climate projections:** use climate projection data that provide insights into future trends. This can include near-term projections (up to 2040), mid-century (2040-2070), or end-of-century (2070-2100) scenarios, depending on the resolution of available data and the planning needs.
- **Stakeholder expectations:** engage with stakeholders to understand their time horizons for risk perception and management, ensuring that the RVA aligns with community and business planning processes.
- **Life cycle of assets:** consider the expected service life of critical infrastructure and assets within the jurisdiction of the municipality. For example, if a municipality is planning a new bridge or a flood defence system, the RVA should cover the entire anticipated lifespan of these structures.
- **Regulatory requirements:** review any regulations or guidelines that may prescribe specific time frames for conducting RVAs and ensure compliance with these requirements at different levels of governance.

— **Adaptation pathways:** establish time frames that allow for the implementation and evaluation of adaptation pathways[23], including the ability to adjust strategies as conditions change or new information becomes available.

— **Policy and planning cycles:** when feasible, align the temporal scale with relevant policy and planning cycles, such as the terms of elected officials, the timing of comprehensive municipality plans, or the schedules of climate action plans.

In practice, it is also common to set multiple temporal scales within a single RVA to establish priorities and guide investments.

3.3.3 Scoping phase: methodologies, tools and techniques

To systematically evaluate the municipality's vulnerability to the various climate change hazards, the RVA involves making informed technical choices that encompass the selection of timeframes, climate change scenarios, climate data sources, and the degree of local data integration. This can take the form of a single assessment, or various assessments undertaken per hazard or per vulnerable sector.

As climate risk not only depends on climate-related hazards but also on the exposure and vulnerability of a region/community to the respective hazard, the final step combines hazard data with exposure and vulnerability to assess risk according to the equation:

$$\textbf{Risk} = \textbf{Hazard} \times \textbf{Exposure} \times \textbf{Vulnerability}$$

Information and analysis of past climate hazards and impacts are essential to understand the context and the actual status of the municipalities and to gain insights into the relationships between climate and the environmental and socio-economic elements of the municipality. RVAs also look at the future to assume and forecast the trends and potential hazards municipalities will be prone to, requiring the use of climate models, scenarios and projections. This will also enable to plan adaptation actions that meet the actual and future need of the communities.

The approaches that municipalities can employ to identify and assess climate change hazards, vulnerabilities, and impacts within their territory and to develop their RVAs can have increasing levels of detail, data, and technical complexity. These approaches can range from simple to complex, and can vary in their level of sophistication, data requirements, and technical expertise needed. To develop their RVA, municipalities can make use of a combination of climate models, scenarios and projections based on various sources of data, creating indicators, maps and other outputs useful to set the scene, inform other models and support the development of climate adaptation strategies.

Models covering hazards, exposure, and socio-economic vulnerabilities are increasing, many of them are interrelated with the output of one modelling phase often serving as the input for another (Ebrey et al., 2020; European Commission et al., 2021)[24]. Models can be informed by a wide range of data, from statistically available dataset to robust geodatabases. Proxies can be used to address lack of reliable or accessible information at local level, despite introducing additional levels of uncertainty. Substantial research streams are dedicated to developing regional and sector specific climate models in support to local administrations. Moreover, the advancement of climate modelling has also seen

[23] Adaptation pathways are sequences of actions that can be implemented progressively depending on how the future unfolds and the development of knowledge (Werners et al., 2021)

[24] A detailed review of climate adaptation is available at: European Commission: Directorate-General for Climate Action, CMCC, IVM, PWA, Ebrey, R. et al., Study on adaptation modelling – Comprehensive desk review – Climate adaptation models and tools, Publications Office, 2021, https://data.europa.eu/doi/10.2834/280156

an increased availability of ready-to-use maps and tools with user interfaces based on more complex models, supporting municipalities in their analytical efforts. For instance, the Risk Data Hub (RDH) of the Disaster Risk Management Knowledge Centre (DRMKC)[11] is a platform centralising and standardising relevant data at a pan-European level, to support risk assessment and risk analysis processes. EU-funded projects under Horizon 2020 and Horizon Europe focused on the advancement of climate services can also support municipalities in defining the RVA. The project VALORADA[25] aims to develop customisable data-manipulation tools to access available climate datasets and to enable the sharing, community validation and use of locally socio-economic, demographic and Earth observation data. CLIMAAX[10] provides a toolbox for conducting risk analyses, which hosts data, models and utilities and provides access to European and global open data archives integrated with local data and procedures. PROVIDE[26] developed an interactive online tool making available detailed information on different future global warming scenarios and expected impacts on the climate, natural, and human systems.

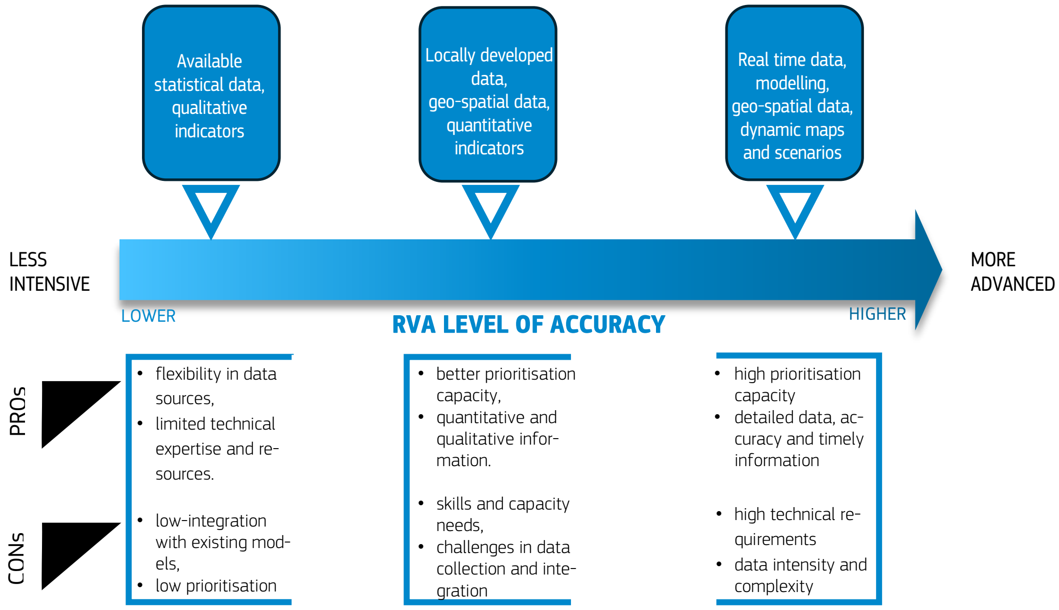
However, depending on the availability of data and models in the municipality, the RVA can vary in its level of detail and approach with different ranges of expertise and skills. The IPCC Fifth Assessment Report (IPCC, 2014) specifies that risk can be understood either qualitatively or quantitatively. Useful approaches for managing risk do not necessarily require extremely accurate assessments, unless the information is available. Therefore, municipalities can develop their RVA according to their desired level of detail and available expertise and resources. By leveraging advancements in data collection and modelling, building specific indicators and maps, different level of accuracy can be obtained depending on the available supporting data and modelling techniques. This flexibility allows municipalities to develop RVAs that meet their specific needs and capabilities, ranging from simple to complex assessments, ultimately enabling them to produce assessments that are valid, reliable, and suitable for informing subsequent planning, decision-making, and implementation steps (Figure 3). The figure shows how RVAs can be built using qualitative data not requiring advanced modelling skills and that the accuracy of the RVA increases with more elaborated methodologies and data.

A proposed list of considerations to select the RVA methodologies and approaches can be observed in Table 1**.**

A summary of the RVA development steps is reported in Figure 4.

[25] Validated Local Risk Actionable Data for Adaptation (VALORADA) https://climate-adapt.eea.europa.eu/en/metadata/projects/validated-local-risk-actionable-data-for-adaptation
[26] PROVIDE https://climate-risk-dashboard.iiasa.ac.at/about

Figure 3. Approaches for developing the RVA.



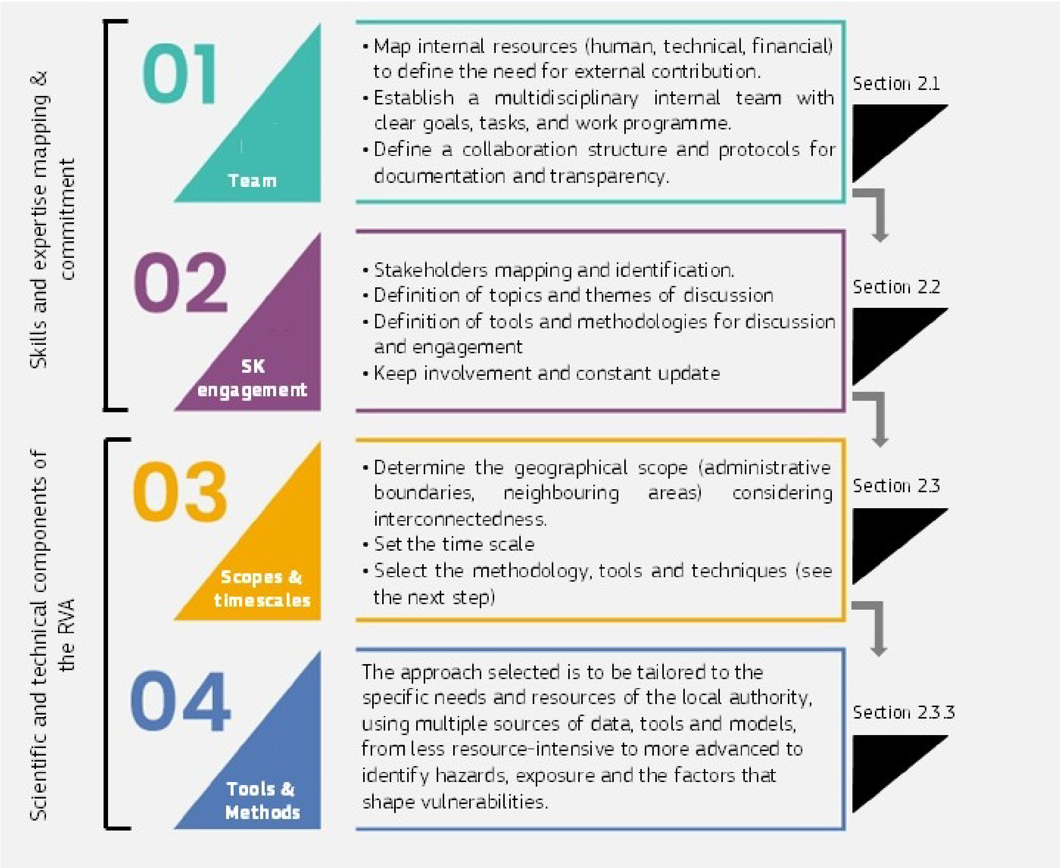
Source: JRC elaboration

Table 1. List of considerations to select the RVA methodology

Considerations	**Description**
Choose a timeframe	The choice of time horizon for scenario analysis and modelling is important; short-term horizons are relevant for immediate risk assessment, while longer-term horizons are necessary for understanding future trends. Near-term projections are less sensitive to the choice of scenario, while for mid-century and beyond, the scenario choice becomes more significant in determining climate outcomes.
Select climate scenarios	Climate scenarios, which include both greenhouse gas emissions trajectories and socio-economic trends, are crucial for understanding future conditions and developing resilient climate risk management strategies.
Use climate models	The RVA uses different models and ensembles to understand the range of possible future climates and assess the robustness of adaptation options. The output from these models, while not predictions, provides scenarios of what the future climate might look like under various socio-economic pathways. Additionally, through modelling, the RVA considers global warming levels and how incremental temperature increases can affect climate hazards. This approach helps communicate climate risks in terms that are relatable to stakeholders.
Integrate local data	The integration of high-resolution local data allows for a more detailed and accurate picture of potential risks and impacts, helping to identify vulnerable populations and tailor the assessment to local conditions. The RVA combines hazard, exposure, and vulnerability data to comprehensively assess risk. Thus, depending on how the assessment is framed, local data suitable to the analysis can be considered when analysing each of the risk components.
Account for uncertainties	Data selection is subject to limitations including availability, inherent uncertainties, and the spatial scale of analysis. The RVA must navigate these challenges by carefully selecting datasets and accounting for uncertainties, such as scenario uncertainty, model uncertainty, and natural variability. While high-resolution local data are preferred for regional or local assessments, challenges such as data gaps, short time series, and scale mismatches can occur and need to be managed to ensure a comprehensive understanding of the uncertainties involved in the assessment.

Source: JRC elaboration

Figure 4. Summary of RVA development steps



Source: JRC elaboration

Box 8. Rivertown: establishing the RVA framework

To conduct a comprehensive RVA, Rivertown's *Adaptation team* needs to determine the framework that will guide the assessment process. This involves analysing the geographical scope, temporal scale, and selecting appropriate methodologies, tools and techniques.

Determining the geographical scope: Rivertown's *Adaptation team* recognises that the municipality's jurisdictional boundaries are clearly defined, but physical and natural elements, such as the river and surrounding countryside, transcend these boundaries. The team decides to focus on the municipality's administrative boundaries, and the neighbouring areas that may be impacted by climate events.

The team considers the following factors to determine the geographical scope:

- Jurisdictional boundaries: Rivertown's municipality limits and neighbouring regions.

- Physical and natural boundaries: the river and surrounding countryside.

- Interconnectedness: the municipality's connection to neighbouring regions and the potential for reciprocal effects.

- Infrastructure and assets: key infrastructure, such as transportation networks, utilities and public buildings (hospitals).

- Socio-economic factors: residential areas, business districts, and industrial zones, as well as areas with vulnerable populations.

- Climate data availability: the availability and resolution of climate data for the local area.

Setting the temporal scale: Rivertown's *Adaptation team* decides to adopt a dual approach to the temporal scale, recognising the need to address both immediate and future climate-related challenges. The team considers preliminarily two timeframes:

- short-term assessment (2025-2035): this timeframe will focus on extreme heat events, which the municipality is currently experiencing.

- medium-term assessment (2035-2065): with a focus on floods, which are likely to increase in the future.

The initial observations on the hazards frequency and intensity will need to be corroborated with appropriate data in the hazard identification step.

Scoping phase: selecting appropriate methodologies, tools and techniques: Rivertown's *Adaptation team* decides to use a combination of approaches to assess the municipality's risks. For extreme heat events, the team chooses to use an indicator-based assessment approach. This approach allows the team to assess the municipality's vulnerability to heatwaves using a set of indicators, such as: heatwave frequency and duration, population density and demographics, urban heat island effects, access to cooling infrastructure and services. These indicators will serve to characterise the hazard, understand the vulnerability and exposure of sectors and population groups, as well as to assess their adaptive capacity.

For floods, the team chooses to assess the municipality's vulnerability to flooding using spatially explicit data, as it will vary depending on the proximity to the river. For this, the municipality plans to use: flood hazard maps, elevation data, land use and land cover data, and infrastructure and asset locations. This approach will enable the team to identify areas of high flood risk and develop strategies to enhance flood resilience, including infrastructure upgrades and land-use planning.

By choosing a combination of approaches, the team can leverage the strengths of different methods to provide a comprehensive understanding of the municipality's climate risks and vulnerabilities.

4 Identifying climate hazards

4.1 Climate hazards

Hazards may be single, sequential or combined in their origin and effects. Each hazard is characterised by its location, intensity, frequency and probability (UNDRR, 2017).

Covenant of Mayors' signatories can assess the following climate hazards; however, municipalities have the flexibility to assess relevant hazards to their local contexts even though they are not listed here.

Extreme heat: marked warming of the air over a large area over a period of time with temperatures that significantly exceed the average for a region. Heatwaves are extreme heat events defined as a period where local excess heat accumulates over a sequence of unusually hot days and nights (Nairn & Mason, 2025).

Extreme cold: marked cooling of the air over a large area lasting from a few days to a few weeks. It can also be referred to as cold wave or cold spells, defined as a prolonged period of abnormally cold weather, often lasting several days or weeks.

Heavy precipitation: this precipitation happens in a relatively short period of time and can be in the form of heavy rainfall, heavy snowfall, or hail and can have different thresholds depending on the climatic zone considered. The increase in frequencies and intensities of extreme precipitation can lead to floods.

Floods: pluvial floods can be either flash floods (associated with short, high-intensity rainstorms) or surface floods (due to rainfalls when the volume of rainwater cannot be drained away through existing drainage systems or by filtering in the ground). River floods occurs when the water level in a river, lake or stream rises and overflows onto neighbouring land and coastal floods are the inundation of land along the coast by seawater. Groundwater floods are the emergence of groundwater at the ground surface away from perennial river channels or the rising of groundwater into man-made ground, under conditions where the 'normal' ranges of groundwater level and groundwater flow are exceeded [27].

Sea level rise: is the increase in sea level, globally or locally, due to (1) changes in the shape of the ocean basins, (2) changes in the total mass and distribution of water and land ice, (3) changes in water density, and (4) changes in ocean circulation. The expansion of warm ocean water and melting polar ice are the primary causes of today's rising sea levels.

Droughts: period of abnormally dry weather, long enough to cause a serious hydrological imbalance. Droughts are caused by precipitation deficits that can lead to agricultural, ecological and hydrological droughts and can be exacerbated by concurrent extreme temperatures or heatwaves, accelerating evaporation rates. Droughts interact and manifest in complex ways in urban areas, in some cases leading to urban water scarcity.

[27] UNDRR: https://www.undrr.org/understanding-disaster-risk/terminology/hips/mh0008#:~:text=Definition,exceeded%20(BGS%2C%202010) and British Geological Survey: https://www2.bgs.ac.uk/groundwater/flooding/groundwater_flooding.html

Water scarcity: occurs when the amount of water available cannot meet all the different sectorial needs. When there is lack of water resources to meet the different demands, public water supply is normally given the highest priority while other sectors may suffer water shortages (e.g. energy, agriculture, industry).

Storms: different types of storms include severe wind, tornado, storm surge (in coastal areas), lighting /thunderstorm, tropical storm, extratropical storm, and cyclones (hurricane / typhoon). The largest possible type of storm are hurricanes that very rarely arrive to Europe. However extra-tropical and tropical storms, the second and third largest types of storms, can affect Europe.

Mass movement: these are any type of downslope movements of earth material in the form of landslides, avalanches, rock fall, and subsidence mainly in clay soils that can shrink, crack, dry out and shift in hot, dry weather, causing unstable ground.

Wildfires: these can affect both forests (forest fire) or other types of ecosystems (land fire) and although many are human induced, to occur, they require specific meteorological conditions linked to soil moisture, temperature and wind.

Chemical change: these types of hazards can be in the form of saltwater intrusion, intended as the mixing of saltwater with freshwater; ocean acidification, due to decreasing pH of the ocean over an extended period, atmospheric CO_2 concentrations with effects on the environment and human living conditions.

Biological hazards: most common biological hazards are water-borne disease, vector-borne disease, airborne disease, and insect infestation. Although biological hazards already exist, they can expand geographically or be exacerbated due to climate change.

4.2 Data and tools

The hazard can be estimated either through pre-calculated, large-scale European hazard maps or through individual, local data hazard maps.

In case municipalities have access to local climate-relevant data, i.e. meteorological stations, projects developed by universities or research centres, this should be the primary source for the development of the RVA. This aspect also highlights again the importance of stakeholder engagement and collaboration.

However, municipalities often do not have to directly retrieve hazard data, as regional or higher-level governments and environmental agencies may handle this task; instead, municipalities can focus on downscaling the information to their specific territory and incorporating local data for exposure, vulnerability, and historical impactful events into their analysis (see section 5).

The Copernicus Climate Change Service (C3S) Climate Data Store (CDS)28 offers a wealth of climate-related data, including observations, re-analyses, and model projections. These datasets undergo strict quality control and adhere to the FAIR principles, ensuring they are findable, accessible, interoperable, and reusable. For past climate data, the E-OBS29 dataset provides gridded observational data across Europe, while ERA5-Land[30] offer monthly global atmospheric reanalysis with high-resolution

[28] https://cds.climate.copernicus.eu/datasets

[29] Download page for the ENSEMBLES daily gridded observational dataset for precipitation, temperature and sea level pressure in Europe called E-OBS: https://www.ecad.eu/download/ensembles/download.php

[30] https://cds.climate.copernicus.eu/datasets/reanalysis-era5-land-monthly-means?tab=overview

coverage of land areas. UERRA[31] (Uncertainty in Ensembles of Regional Analysis) complements these with detailed regional reanalysis for Europe, including uncertainty estimates for climate variables. The Copernicus Emergency Service (CEMS)[32] and the Disaster Risk Management Knowledge Centre (DRMKC) Risk-Data Hub (RDH)[11] are other sources of information regarding specific past hazards (e.g. droughts, floods, wildfires, and specific mapping of a number of climate hazards using Earth observation data).

Looking at the **future**, CMIP5[33] and CMIP6[34] datasets deliver global climate model simulations under various emission scenarios, and EURO-CORDEX[35] offers high-resolution regional climate projections for Europe. Users can access these datasets in multiple formats supporting a broad range of applications in research, policy-making, and beyond. While these datasets contain the most up-to-date current information on climate projections, the continuous evolution of climate models provides new improved data every few years. Hence, municipalities are recommended to regularly monitor the datasets used to ensure their analysis are updated.

The DRMKC Risk Data hub[11] is an extensive tool that explores disaster risk and vulnerability, provides resources in a learning and training space as well as automated access to data.

The IPCC Interactive Atlas[36] is a valuable resource to access and explore observations, reanalyses and observational products. This is a novel tool for flexible spatial and temporal analyses of much of the observed and projected climate change information underpinning the assessment of the physical basis of climate change, including a regional synthesis for the climatic impact-drivers assessed in the report. This product has been extended and incorporated into the Copernicus Climate Change Service (C3S) to become the Copernicus Interactive Climate Atlas (C3S Atlas)[37]. It facilitates global and regional in-depth assessment of past trends and future changes in key variables and (extreme) indices for different periods across emission scenarios or for different policy-relevant global warming levels (e.g. 1.5°C, 2°C, 3°C and 4°C). Different graphical climate products such as maps and time series (or stripes) can be interactively customised to display temporally- or spatially-aggregated values (or changes relative to different baselines) over flexible seasons, periods and regions.

Further data spaces and hubs of interest may be: Climate Data Explorer[38], index-based interactive EEA report[39], Climate Solutions Explorer[40], European Drought Impacts Database EDID[41], European Drought Risk Atlas EDRA[42], or JRC PESETA programme[43].

The following table (Table 2) presents a summary of the main tools mentioned here where municipalities may retrieve information of interest regarding past and future climate hazards.

The European Climate Risk Assessment (EUCRA)[1] also contains information on hazards and is an insightful source of information for developing the RVA. The Taxonomy Regulation ((EU) 2020/852;

[31] https://cds.climate.copernicus.eu/datasets?q=UERRA
[32] https://emergency.copernicus.eu/
[33] https://cds.climate.copernicus.eu/datasets/projections-cmip5-daily-single-levels?tab=overview
[34] https://cds.climate.copernicus.eu/datasets?q=CMIP6
[35] https://cds.climate.copernicus.eu/datasets/sis-hydrology-variables-derived-projections?tab=overview
[36] https://interactive-atlas.ipcc.ch/
[37] https://atlas.climate.copernicus.eu/atlas
[38] https://climexp.knmi.nl/start.cgi
[39] https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1
[40] https://www.climate-solutions-explorer.eu/
[41] http://edid-test.eu/#/home
[42] https://drought.emergency.copernicus.eu/tumbo/edra
[43] https://joint-research-centre.ec.europa.eu/projects-and-activities/peseta-climate-change-projects_en

(EU) 2021/2139) also provides an indicative list of the most widespread hazards to be considered. Further insights into the EUCRA and the Taxonomy Regulation approach to hazards is included in Annex 1.

Box 9. Barcelona, Spain: using insurance data to improve resilience to climate change

The city of Barcelona partnered with Cetaqua and other institutions in the RESCCUE[44] project to use insurance data to improve resilience to climate change. The project aimed to develop a methodology that prioritises adaptation measures and contributes to the updated version of the Barcelona Climate Plan. The city's main focus was on the water sector, as water-related risks can have a significant impact on urban services and energy supply. Barcelona uses a multi-scale, multi-sectorial and multi-hazard methodology to evaluate risks. The city combined data collected by the City Council and the Spanish Insurance Compensation Consortium to assess economic damage for properties. The project also developed flood depth-damage curves tailored for Barcelona, which helped estimate the economic impact of floods and revealed the most vulnerable areas. The results of the project have provided the city with the knowledge and the necessary information to update and enhance the Barcelona Climate Plan and have been used to plan climate adaptation actions, such as retention tanks to absorb rainwater in future weather events.

[44] RESCCUE - RESilience to cope with Climate Change in Urban arEas - a multisectorial approach focusing on water: https://cordis.europa.eu/project/id/700174 and CoMO library: https://eu-mayors.ec.europa.eu/sites/default/files/2022-10/202005_CoMo_CaseStudy-Barcelona_EN.pdf

Table 2. Main tools for retrieving information on past and future [45]

Platform	Spatial Resolution	Temporal coverage	Parameters	Data visualisation	Data download	Data format
C3S Copernicus Interactive Climate Atlas	Variable (0.05-2.0 decimal degrees)	1940-2100	Heat & cold, Wet & dry, Drought, Wind & radiation, Snow & ice, Ocean, …	Yes	Yes	NetCDF-4
E-OBS gridded dataset	0.1-0.25 decimal degrees	Past (1950-present)	Temperature, Precipitation	No	Yes	NetCDF-4
ERA5-Land monthly	0.1 decimal degrees	1950-present	Temperature, Precipitation, Evaporation, …	No	Yes	NetCDF-4
Copernicus Emergency Service (CEMS)	Variable	Variable (Past-Present)	Droughts, Hot/Cold spells, Floods, Wildfires, Exposure	Yes	Yes	Variable (e.g.: GRIB2, NetCDF-4, GEOTIFF)
Risk-Data Hub (RDH) Atlas	Variable	Variable (Past-Present-Future)	Droughts, Floods, Wildfires, Storms, Extreme temperatures, Sea level rise, Exposure, Vulnerability	Yes	Yes	Variable (e.g.: GeoJSON, CSV)
European Climate Data Explorer (ECDE)	Variable (e.g. NUTS2)	1991-2100	Heat and cold, Wet and dry, Wind, Snow and ice, Coastal, Oceanic	Yes	Yes	CSV
OECD Local Data Portal	Variable (e.g. NUTS3)	1981-present 2041-2060	Temperature, Hot days, Tropical nights, Icing days, Precipitation, Droughts, Flooding, Fires	Yes	No	-

Source: JRC elaboration

[45] Some of the platforms also provide additional information on exposure or vulnerability (e.g. Risk-data Hub or CEMS)

Box 10. Section 4 frequently asked questions

6. Heavy Precipitation vs Floods vs Storms?

Heavy precipitation can be often confused with floods. Heavy precipitation refers to the occurrence of a significant amount of precipitation in a relatively short period of time. This can cause damages locally if the soil or the drainage systems cannot absorb the precipitation. *Floods,* instead, can be caused by heavy precipitations in a short period of time (e.g. flash floods) but can also be caused by precipitation that, despite not being heavy, may occur during a sufficient period that leads to overflow and inundation of water basins (e.g. river floods). *Storms* are characterised by severe winds and can also lead to flooding as a secondary effect, particularly after events like storm surges in coastal regions.

7. Drought vs Water scarcity?

While *drought* is a more or less prolonged period of abnormal low precipitation that can lead to agricultural, ecological or hydrological water shortage, *water scarcity* is linked to the lack of water availability to meet the demand side of different sectors such as agriculture, energy, industry and public water supply.

8. Urban heat island (UHI) vs Extreme heat vs Heatwave vs Increasing temperatures

Urban heat islands are localised areas, typically in built-up areas, where temperatures are significantly higher than surrounding rural areas/vegetated areas, due to human activities and modifications of the landscape. This effect can make people more vulnerable to a warming climate if appropriate adaptation measures are not taken. *Extreme heat* refers to periods of unusually high temperatures that significantly exceed the average for a region, often leading to health risks and infrastructure stress. *Heatwave* is the local cumulative excess heat over a sequence of unusually hot days and nights (from two days to months). Heatwaves involve cumulative and sustained heat. The temperature excess is often defined with reference to a relative temperature threshold (Nairn & Mason, 2025). In contrast, *increasing temperatures* refer to the long-term trend of rising average global temperatures attributed to climate change, affecting both urban and rural areas and exacerbating phenomena like UHI and extreme heat events.

9. Multi-hazards vs Cascading effect?

- *Multi-hazard* is the co-occurrence of more than one hazard such as a tropical storm that can be accompanied by floods and landslides.

- *Cascading effects* occur when a single hazard (e.g. drought) can lead in more or less time to another hazard (e.g. wildland fires due to reduced soil/vegetation moisture), and later on it provokes another hazard (e.g. floods and landslides might happen due to the burning of the trees and shrubs that leave the soil surface unprotected from heavy precipitation).

10. Coastal floods vs Sea level rise?

- *Coastal floods* are linked to an increase of precipitation together with the occurrence of high tides and storm surges in coastal areas.

- *Sea level rise* is the continuous slow rising of the seas due to anthropogenic climate change; it contributes not only to reducing the land area above the sea level but also exacerbates coastal floods.

11. Future expected change timeline

When referring to future expected changes in hazards, the following timeline is commonly considered within the CoM framework:

Short-term = next few years
Mid-term = mid-century
Long-term = end of century

Box 11. Rivertown: hazards identification

As the foundational stage of Rivertown's comprehensive RVA, a meticulous process was undertaken to identify the specific climate hazards that the municipality faces. This hazard identification was crucial to understanding the nature and extent of the risks that would later be mapped through the exposure and vulnerability analysis.

Methodology: The hazard identification process involved collecting and analysing historical climate data, ongoing weather patterns, and future climate projections. The RVA team aimed to pinpoint the types of climate hazards that could impact Rivertown, focusing on their characteristics and potential changes over time. The level of probability assigned to a hazard—whether high, moderate, or low—reflects how likely it is to occur based on available evidence, past events, expert judgment, and projected trends. A high probability indicates the hazard is occurring regularly or increasingly. A low probability reflects that the hazard is unlikely to occur, though it may still be possible. The level depends on the specific context and hazard.

Key Steps:

Historical climate data review: the team examined records of past weather events, such as temperature highs and lows, precipitation patterns, and instances of river overflow of the last 20 years. This retrospective analysis helped to establish a baseline understanding of the climate hazards Rivertown has historically experienced, and to highlight past occurrences suggesting the hazard is likely. This screening showed no instances of significant wildfires, droughts, biological hazards, storms, extreme cold events. Extreme heat was analysed based on historical temperature data showing an increasing number of days under heatwave, while floodplain maps were retrieved to model the river inundation areas. Since the floodplain maps were 10 years old, a specialised hydrological study obtained from a commissioned analysis on the river's impact on a critical highway bridge, further informed the assessment. The analyses documented an average of three days per year with temperatures surpassing 35°C. However, recent trends based on data analyses from a hydrometric station showed an increase to five days annually. The municipality also recorded 10 significant flooding events over the last 20 years, with an unprecedented three occurrences in the last year only.

Climate projections analysis: employing regional climate services' RCP8.5 high-emission scenario models[46], the team reported a potential doubling of extreme heat days' frequency (and 10% increase in number of days with temperatures surpassing 35°C days). Additionally, the team reported a 20% increase in flood events' frequency by 2050 and expected days with water level above 10 cm will increase 10% by 2050. Projections showed no significant occurrence of wildfires, droughts, biological hazards, storms, and extreme cold events.

Hazard characterisation: for each identified hazard, the team summarised the information gathered and characterised its frequency, intensity, duration/timeframe, and spatial extent. Based on the available information on each hazard, the *Adaptation team* followed a more advanced approach making use of spatial data to analyse and track the flood risk. Extreme heat was assessed through indicators, specifically focusing on the average number of days per year exceeding 35°C and the associated health effects on vulnerable population groups. The team also identified areas where urban heat island effect is likely to intensify in the future, and hence, decided to consider expanding the analysis with more advanced tools and data as they become available.

[46] Representative Concentration Pathways (RCP) are a set of scenarios including emissions and concentrations of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover. There are four RCPs, each defined in terms of its radiative forcing reached by the end of 21st century. RCP 8.5 (one high pathway which leads to >8.5 W m−2 in 2100) is a high greenhouse gas emissions scenario in the absence of policies to combat climate change, leading to continued and sustained growth in atmospheric greenhouse gas concentrations (IPCC, 2019, 2022a).

Hazard mapping: the team created hazard maps highlighting areas of Rivertown that have been affected by past climate events and those that are likely to be impacted in the future. These maps were developed using GIS and incorporated topographical data to visualise hazard-prone areas. The analysis pinpointed that flooding risks were shown to have expanded by roughly 15% beyond previously mapped floodplain areas.

Results:

River Floods

- Hazard categorisation: floods (under Hazard category: Flood & sea level rise)

- Main indicator: days with water level above 10 cm (data from hydrometric station)

- Current hazard probability: 10 significant events in the last 20 years, 3 significant events in the last year > high

- Current hazard impact: 15 buildings damaged, economic damages to infrastructure estimated at EUR 5 000 000

- Expected change of frequency: 20% increase by 2050

- Expected change of intensity: 10% increase by 2050

Extreme heat

- Hazard categorisation: extreme heat

- Main indicator: average number of days per year with temperatures exceeding 35°C = 3

- Current hazard probability: average of 3 days per year, increasing to 5 days per year > high

- Current hazard impact: 10 heat-related illnesses reported in the last year

- Expected change of frequency: 100% increase by 2050 (doubling of the number of days with extreme temperature)

- Expected change of intensity: 10% increase by 2050

Conclusion: the hazard identification stage has provided Rivertown with an essential, data-driven understanding of the main hazards. Armed with this knowledge, the municipality is well-prepared to scrutinise the exposure of its assets, systems, and populations. This detailed insight will enable the *Adaptation team* to conduct thorough vulnerability and adaptive capacity analyses, forming a solid foundation for Rivertown's robust climate adaptation planning.

5 Assessing exposure, vulnerability, and adaptive capacity

5.1 Conducting exposure analysis

As explained earlier, “exposure” refers to the presence of people, ecosystems and species, economic, social and cultural assets, and services in places and settings that could be affected by climate hazards (IPCC, 2014). This implies that for population or assets located in areas not subjected to specific hazards, the related climate risks will be negligible. Therefore, different geographical locations can be exposed to different climate hazards. This highlights how exposure expresses the geographical and spatial component of climate risks, which is context-specific and how vulnerability is linked to exposure. While it is possible to be exposed but not vulnerable, the opposite is not true. To be vulnerable to an extreme event, it is necessary to also be exposed (IPCC, 2014, 2022b). Taking the example of river flood hazards, the exposed assets and people are those located/living in the flood prone area. Those living in other areas of the municipality, far from the river and its surroundings, will not be physically impacted and are therefore not considered vulnerable to this hazard. In addition, those assets and individuals who are exposed to the flood but have the means to avoid or mitigate losses, i.e. by specific infrastructures or building characteristics, will not be considered as vulnerable.

Understanding which areas within the municipality’s boundaries are exposed to hazards is essential to predict consequences, build scenarios and plan adaptation actions. The accuracy and relevance of the assessment improve with specific data at the local level. While there is not a unique method to analyse exposure, exposure spatial mapping and indicators are powerful, easy-to-use tools. Exposure maps can show information about the location and characteristics of relevant city assets, such as buildings, roads, historical monuments, and population density. Depending on the capacity and resources of the municipality, maps can be developed in a geographic information systems (GIS) platform and data can be collected taking advantage of residents’ and stakeholders’ knowledge on environmental features, buildings, infrastructures, and assets. However, if there is sufficient knowledge of the spatial component of exposed people and assets, this piece of information can be directly used and there is no need to produce additional maps. The knowledge can also be gained and increased through the development of specific indicators that are related to specific geographical areas of the municipality. Combining the exposure data with each climate-related hazard (overlapping the layers), and, subsequently, with vulnerability information enables to identify hot-spot areas in the city.

5.1.1 Exposed assets and infrastructure

Mapping assets and infrastructures allows identifying the areas exposed to the hazards. By overlapping the layers of each hazard and the layer of existing assets and infrastructures in a GIS tool, it is possible to build exposure maps related to each climate hazard. The maps can be of different types, i.e., they can use graded colours showing the increased exposure of the elements.

5.1.2 Exposed population

Maps on exposed population can be prepared having at disposal information on the population distribution, or density to be then spatialised. If this data is not already available for the municipality, there are multiple approaches that can be followed. For example, census or other complete population data can be disaggregated from national to lower levels. Alternatively, estimates can be conducted about the average population per building. Additionally, questionnaires and surveys can be submitted to residents, depending also on the scale of the study. In addition, the Global Human Settlement layer (GHSL)[47] provides spatialised data on population, urbanisation and built-up areas with a world coverage. Exposure maps are strictly interconnected to vulnerability assessment, in particular when dealing with population and social factors.

Box 12. Rivertown: exposure analysis

As part of Rivertown's comprehensive RVA, an exposure analysis was conducted to determine which assets, systems, and population groups are at risk from extreme heat and flooding. The analysis aimed to map the spatial distribution of these elements and assess their level of exposure to the climate hazards previously identified.

Methodology: the exposure analysis combined data from various sources, including geographic information systems (GIS), land use maps, demographic data, temperature records, and infrastructure records. The RVA team focused on the two primary hazards identified – extreme heat and flooding – which have become increasingly prevalent in Rivertown.

Key steps:

Data collection and integration: the RVA team compiled topographical data from Rivertown's GIS management system, which provided detailed elevation and terrain information crucial for understanding flood dynamics and heat distribution. They sourced land use patterns from the municipality's urban planning documents to identify areas of high-density development, green spaces, and industrial zones. Population density figures were extracted from the municipal demographic records, highlighting where the population reside. The team also pinpointed the precise locations of critical infrastructure, including bridges, hospitals, and power stations, using the GIS system to assess which vital services and facilities were in areas subjected to the identified climate hazards. Local knowledge stemming from the meetings with the community was integrated to the data.

Heat exposure analysis: the team identified urban heat islands within the municipality, particularly in the historic centre with its dense construction and limited green space, while the industrial area is less affected. The analysis considered the locations with high density of population using demographic indicators, integrating this information with the hottest areas of the municipality, gathered through data on temperature from temperature sensors located within the municipality (including private premises). The areas where these two indicators were highest were highlighted into a map showing the municipality’s hotspots.

Assets and infrastructure - flood exposure mapping: the team overlaid floodplain maps (available from regional plans and studies) with land use (current and planned) and population data to identify potential flooded areas. A specific hydrology study that was commissioned from a highway bridge on the river was also used. The exposure map showed that low-lying agricultural lands and the residential neighbourhoods along the riverbanks were exposed to the river that bisects Rivertown. Additionally, the map showed that the proposed new developments would be exposed to recurrent floods.

Population - flood exposure mapping: utilising floodplain maps derived from available regional hydrological studies the team conducted an overlay analysis with current and projected land use data, as well as population demographics. This overlay revealed potential areas exposed to inundation during flood events. Because the floodplain maps were 10 years old, a specialised hydrological study obtained from a commissioned study on the river's impact on a critical highway bridge, further informed the assessment. The resulting exposure map highlighted the exposure of the low-lying agricultural zones and residential neighbourhoods adjacent to the river that cuts through Rivertown. The map also indicated that planned future developments, if not carefully sited, could face exposure to recurrent flooding.

[47] Copernicus - Global Human Settlement Layer (GHSL): https://human-settlement.emergency.copernicus.eu/

Findings:

Some areas of the historic centre were found to be highly exposed to extreme heat, which could lead to increased health risks and decreased tourism during the summer months.

Some areas of the riverbanks and adjacent neighbourhoods were identified as exposed to flooding, which could endanger lives, disrupt services, and cause significant property damage.

Critical infrastructure, including the main hospital and a power substation, were located within the flood zone, indicating a high level of exposure and potential for cascading impacts on the wider municipality during flood events.

Conclusion: the exposure analysis provided Rivertown with a clear understanding of where and how its assets and population are exposed to extreme heat and flooding.

The next step involves assessing the vulnerability of these exposed assets and population groups to determine their potential to withstand and recover from these climate hazards.

5.2 Evaluating vulnerability factors

The definition of vulnerability by IPCC Sixth Assessment Report (IPCC, 2022a, 2022b) is: "The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt". Vulnerability varies over space and time due to the multiple factors (such as poverty, inequality, health, access to resources and social status), which influence how individual communities and systems respond to climate change. Moreover, vulnerability depends on the type of hazards, as certain groups would be deemed vulnerable to a specific hazard, and not to others (Brooks, 2003) and is unequal across different regions and socio-economic groups (COM/2021/82, 2021). The same hazard event may, hence, be experienced in different ways by different people, which is the core of the concept of vulnerability.

5.2.1 Vulnerable groups: socio-economic considerations

The human dimension of vulnerability is covered in the IPCC definition reported above. Some authors refer to the perspective of social vulnerability (Otto et al. 2017), when looking at the combination of social, cultural, economic, political, and institutional factors leading to the differential experience of hazards. Depending on the factors considered, social vulnerability can be intended as **internal**, when factors such as sex, age, religion, disability, and health status are accounted, and **external**, when factors relate more to the socio-economic sphere (Otto et al., 2017). These are key elements to consider when identifying the communities that are vulnerable to specific hazards. Often those most affected tend to be those already at a disadvantage, and without consideration of equity in adaptation, the existing inequalities may be reinforced, or new inequalities may arise (European Environment Agency, 2022b). Identifying vulnerable groups and communities and understanding what underpins their vulnerability, help to inform and tailor the response, including their specific needs in the adaptation strategies, frameworks, and institutional arrangements. Common communities and groups considered vulnerable to climate change are described below.

Women and girls: different roles and responsibilities in households, the structure of the labour market, and income disparities result in distinct experiences of climate change impacts between men and women (EIGE, 2012). This effect is especially pronounced in many parts of the world, though it is also evident in Europe. This was highlighted during the opening day of COP29 in Baku, where the European

Union and its Member States issued a joint statement reaffirming their commitment to strengthening gender integration in global climate action (DG-Clima & DG-Communication, 2024).

Looking for example at heat related hazards, women have specific health needs, besides social circumstances, linked to pregnancy and childbirth which make women more vulnerable to heat stress (WHO Europe, 2021). Higher temperatures and heatwaves have harmful effects on older people and children, but women are a segment of the population statistically spending much time on providing care for children, older people and sick (EIGE, 2012), hence being indirectly affected and carrying the burden of the climate change effect. Finally, disasters can disrupt essential services such as care services, impacting women and girls.

Children and youth: children and adolescents in Europe face direct and indirect effects from climate change due to several factors, including their physiology, their dependency from adults, their development and growth processes. In addition, climate change-related events can have psychosocial effects on children (European Climate and Health Observatory, 2022)

For example, during flooding events, children may be in contact with contaminated water sources which contributes to water and foodborne disease infections. Children and young people are susceptible to psychological trauma and mental disorders such as anxiety, depression, and post-traumatic stress disorder (PTSD) are often observed after floods (Graber et al., 2024). In addition, climate anxiety is a growing concern with impacts that can affect daily functioning and activities (Hickman et al., 2021).

Older people: older adults are more vulnerable to extreme weather events due to aging immune systems and propensity for dehydration (Kriebel-Gasparro, 2022). Moreover, limited mobility and access to resources, such as transportation and digital communications, exacerbate their vulnerability to climate change (Birkmann et al., 2022; Hajat et al., 2014; Haq, 2023; Katey & Zanu, 2024; Pillemer et al., 2021).

For example, in case of wildfires emergency plans, older people may not be able to receive timely warnings and communications, due to their limited access to media, phones and other digital communication technologies. Therefore, they may not be aware and ready for evacuation.

Marginalised groups: marginalisation embraces factors such as material deprivation, inadequate housing, low educational levels, high unemployment, poor health as well as discrimination and prejudice, and /or a combination of these factors (van Lierop, 2016). Marginalised communities often lack access to basics services and infrastructure, a situation that can be exacerbated in case of an extreme event.

For example, extreme weather events (e.g., heatwaves, heavy rain, and flooding) exacerbate challenges for people experiencing homelessness further complicating their access to basic services. Heavy rains and floods put at risk the life of people experiencing homelessness, who have limited or no protection, and need to look for shelters in public services and shops. Also, their equipment can be damaged, amplifying and lengthening the impacts. Floods also have adverse health implications, as public water sources may be contaminated (Anthonj et al., 2024).

People with disabilities: people with disabilities are often among those most adversely affected during extreme events. These vulnerabilities can take diverse forms and are linked to multiple factors, such as physical conditions, dependence from others, socio-economic conditions, accessibility. For example, people of all ages with some physical disabilities experience greater pain and fatigue on hot days (Sleap, 2024). Often, they are affected by accessibility issues that exacerbate climate related challenges. Infrastructure damage can have a dramatic impact on how people with disabilities are able to recover from a disaster, i.e., accessing shelters or care and treatments in hospitals (Gutnik & Roth, 2018). In addition, climate events lead to economic losses across the community, but people with disabilities tend to have more difficulties in recovering from the loss implying further marginalisation and creating a cycle that reinforces social and economic exclusion and increases vulnerability.

People with chronic diseases: climate events exacerbate the perceived effects in persons having specific needs or diseases. For example, people with cardiovascular and respiratory diseases are more affected by heat, and these people are often at higher risk of heat-related death (European Environment Agency, 2018, 2019, 2022b).

Low-income households and people living in sub-standard housing: low-income households usually have fewer assets and less access to funding, technologies and political influence leading to limited resources to adapt to climate change impacts (Birkmann et al., 2022). Moreover, low-income residents may live in settlements more exposed to hazards, with lower building standards, e.g., dwellings that cannot be cooled to comfortable levels during summer, or neighbourhoods lacking sufficient green spaces leading to less associated cooling benefits. These people are particularly vulnerable to risks from increasing heatwave in European cities. It is also harder for many from low-income areas to rebuild after an extreme event and to invest in adaptation measures that might lower their exposure or vulnerability.

Unemployed people: the increase in frequency and extent of extreme weather events may lead to job and work productivity losses. Disasters take lives away and destroy infrastructure, resulting in job and productivity losses (International Labour Office, 2018). Moreover, unemployed individuals experiencing short-term or long-term unavailability of resources may struggle to afford the costs of adaptation, repairs, or reconstruction following extreme weather events, making it harder for them to recover and build future resilience.

Migrants and displaced people: refugees and migrants remain among the most vulnerable members of society and are often faced with discrimination, substandard living, housing and working conditions, often living and working in the shadows lacking access to shelter, food, and other basic services (World Health Organisation, 2025). These factors may compromise their ability to adapt to events and affect the susceptibility to heat and cold extremes.

Outdoor workers: outdoor workers, including seasonal workers, are exposed to extreme temperatures, heat stress, and other climate hazards, which impact on their labour capacity and performance, and on their health (Turhan et al., 2015; Watson et al., 2023). For examples, due to the nature of work, outdoor workers may suffer from heat-related illness. Seasonal agricultural workers are among the most vulnerable groups as they work in one of the sectors most exposed to climate change, adding socio-economic related implications. For example, further temperature rises will make some agricultural areas unproductive, displacing a large number of workers (International Labour Office, 2019).

5.2.2 Vulnerable sectors

Vulnerable sectors refer to areas and systems affected by the adverse impacts of climate change which have also a limited capacity to adapt. These sectors are also those where it is needed to intervene and municipalities can dedicate efforts, spend resources, and identify priorities. Key affected sectors and systems considered vulnerable to climate change are described below[48].

Buildings: refers to any structure or groups of structures, surrounding spaces, permanently constructed or erected on its site. Buildings can be vulnerable in their structures and in the indoor conditions. For example, the building may be impacted by floods causing permanent structural damages or the indoor temperature is not comfortable for the dwellers in case of extreme heat or extreme cold events.

Transport: the sector includes transport networks and related infrastructure. The vulnerability often refers to the interruption of the service, which in turn questions its reliability and safety, caused by climate events. Transport infrastructures are vulnerable to weather-induced hazards, such as changing precipitation patterns, temperatures, sea levels, coastal and river floods (European Environment Agency, 2024). For example, heatwaves in 2015 and 2018 caused road melting, railway asset failures and speed restrictions to reduce the likelihood of track buckling (Bednar-Friedl et al., 2022) (Bednar-Friedl et al., 2022). Moreover, severe weather events may lead to infrastructure failures with cascading events to other regions and sectors.

Energy: it refers to the energy supply service and related infrastructure. Power plants may be less efficient or damaged during extreme events. Similarly to the transport sector, an interruption in the energy supply may have critical cascading effects on other sectors and on the community. For example, power outages or telecommunications interruptions may hinder timely communication and alerts to citizens.

Box 13. Critical infrastructures

Transport and energy supply, together with health and other services and sectors, are part of the so-called "critical infrastructures," facilities and infrastructures delivering key services to the society, a failure of which can have cascading impacts on other services and on the functioning of the society. As described in the IPCC AR6 (IPCC, 2022b), key infrastructure refer to 'critical nodes and arteries' that comprise urban energy, food, water, sewerage, health, transport and communication systems.

Critical infrastructures play a key role in enabling individuals coping with risks, especially during disasters in which the services of transport infrastructure, communication technologies or energy are particularly needed. However, these infrastructures are themselves exposed and vulnerable to adverse climate events, and, hence, they are to be prioritised in any climate adaptation strategy as an interruption or damage to them may hinder the capacity to adapt of the whole society.

Water: it refers to the water supply service and related infrastructure. It also covers water use and water management system, which includes sewers, drainage, and treatment systems. Climate change affects water availability, with cascading impacts on interconnected sectors, e.g., agriculture and crops production, energy production, industry, and health.

[48] Further details and insights are available at Adaptation in EU policy sectors (https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/sector-policies).

Waste: it includes activities related to the management of various forms of waste, as well as contaminated sites. Extreme weather leading to floods can create a large quantity of waste and can make transporting the waste very difficult if transportation networks are flooded (Winne et al., 2012).

Land use planning: it indicates the process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, and the subsequent formulation and promulgation of plans or regulations that describe the permitted or acceptable uses. Climate change impacts this sector as it represents a challenge, cumulating with other existing ones, requiring new approaches and strategies to develop resilience. Land use planning can intervene in the urban ecosystem, with actions dedicated to green space to address the urban heat island effect or to permeability of surfaces to increase natural drainage systems.

Agriculture & forestry: it includes land classified/designated for agriculture & forestry use, and organisations and industries linked to it. Drought, water scarcity, heavy rains, variability in winter weather conditions affect this sector in multiple ways. Crop productivity and species are expected to change. For example, the use of water for irrigation in case of drought and heatwaves could be limited by water availability, leading to loss in agricultural production and related economy (Bednar-Friedl et al., 2022).

Environment & biodiversity: it refers to green and blue landscapes, air quality, including urban hinterland and to the variety of life in a specific region, measurable as the variety within species, between species, and the variety of ecosystems. Climate change is one of the major drivers of biodiversity loss and ecosystem degradation. For example, prolonged heat and changes in precipitation affect land use and nutrients and favour the proliferation of invasive alien species into new habitats (Habibullah et al., 2022). However, biodiversity loss is strictly linked also to non-climate related drivers and actions, including deforestation and soil sealing, therefore it is crucial for municipalities to adopt an integrated lens when dealing with environmental and biodiversity concerns.

Health: it refers to the geographical distribution of dominance of pathologies, information on well-being and includes the health care service and related infrastructure. Climate change can amplify health problems and generate new health risks, it challenges the health of workers exposed to extreme climate conditions. As mentioned, climate change impacts on health are felt most by the most vulnerable. For example, during heatwaves, an increased incidence of heat exhaustion and heat stroke; exacerbated circulatory, cardiovascular, and respiratory and kidney diseases are recorded. Moreover, climate change can impact the delivery of health care services due to the lack of trained health workforce, and predisposition to inadequate energy supplies (World Health Organisation, 2020).

Civil protection & emergency: it refers to the operation of the civil protection and emergency services by or on behalf of public authorities and includes local disaster risk reduction and management. Emergency planning deals specifically with preparing for events and immediate recovery from them and complements other adaptation measures. As per the land use planning, climate change will impact civil protection and emergency increasing pressures on incident and emergency management, and on the staff and resources involved (Arnell, 2022). New procedures, skills and tools can be developed to be better integrated into other areas of disaster risk reduction also including a longer-term perspective. For example, early warning systems, improved forecasts and planned measures for wildfires, droughts and heatwaves can help ensure timely responses and mitigate harm civil protection systems to the consequences of climate change, in terms of prevention, preparedness, response and recovery (European Environment Agency, 2024).

Tourism: it refers to the activities of individuals travelling to and staying in places outside their usual environment for not more than one year for leisure, business and other purposes not related to the exercise of an activity remunerated from within the place visited. Climate change adverse events can lower the attractiveness of places and change the dynamics of the competitiveness of the sector. For example, due to reduced snow availability and hotter summers, changes in patterns of touristic destination can occur and touristic locations may suffer from economic losses.

Education: it refers to the process of learning or giving instructions in formal or informal settings. It includes the system and facilities. Extreme weather events are increasingly disrupting schooling, resulting in school closures, but also in missed learning opportunities due to hot temperatures (Venegas Marin et al., 2024). In addition, education facilities are often impacted by extreme events such as flooding and windstorms causing the interruption of the provision of education services. These effects are considered as more significant compared to other public buildings (European Environment Agency, 2024), having implications on the development of future societies.

ICT: it refers to information & communication technologies. Extreme climate events such as storms, droughts and heatwaves can damage ICT infrastructures and assets by destroying or disabling the physical assets affecting telecommunications. In addition, ICT can be compromised by gradual changes such as greater exposure to temperature extremes, longer sustained hot temperatures, more rapid temperature variation, and higher humidity, with impacts occurring in longer periods. This may imply the need of upgrading, repairing, or replacing the assets more often than in the past, with increased financial burden.

Box 14. Rivertown: vulnerability analysis

Once the assessment of exposure is completed, the *Adaptation team* can focus on vulnerability, which is one of the factors composing the risk. To conduct the analysis of vulnerability the *Adaptation team* needs to assess the level of vulnerability of exposed assets and population groups, through the combination of multiple data, to determine their potential to withstand and recover from these climate hazards.

The analysis focused on physical and social vulnerabilities. The former refers to the physical characteristics of the exposed areas, and the latter to socio-economic characteristics of people living and using those areas.

Extreme heat:

The team collected data on the tourist flows of the last five years at regional and provincial levels from regional governments and on hotels permanence thanks to the collaboration with the local section of business associations. A meeting with interested hotels and guest services in the historical centre was also held to collect further information and impressions. The records were then elaborated to assess whether high temperatures of last years have impacted on tourism presences during summer.

The results showed that in the last five years the touristic flows did not change drastically, with some expected fluctuations. However, the representatives from the sectors highlighted the need to install air conditioning. Therefore, tourism cannot be considered a vulnerable sector in the short-term, but there are indications that it may become more vulnerable in the future.

The team also worked on the data collected from the health department and population distribution in the exposed areas, to cross check the age of residents in neighbourhoods affected by heat island with the incidence of cardio-vascular problems during the days with the highest temperature.

Results showed that 30% of the population living in the affected neighbourhood has an age above 60 years, and that reported cardio-vascular disorders increased during the past summers, with most cases related to people aged above 60. Therefore, the older people living in the historic centre are to be considered a vulnerable group to heat stress.

Flooding:

The team assessed the conditions and characteristics of the buildings located in the residential neighbourhoods along the riverbanks. For each building, the number of floors, the presence of underground floors, the destination of ground floors, the status of conservation of the building were assessed. This exercise was conducted with the support of master's degree students.

Results showed a hundred buildings with underground floors (60%), used in all cases for storage. Moreover, aligned with the predominantly residential land use of the area, the ground floors are used for residential purposes in the 85% of cases. The remaining 15% is dedicated to small retail activities and local services. In addition, the assessment of buildings characteristics showed that 25% of buildings have poor building characteristics, with a need for refurbishment. Therefore, in case of floods many buildings in the neighbourhood are deemed vulnerable, as the underground and ground floors are highly impacted and the buildings with poor standards may experience further damages due to their already degraded conditions.

The team also worked on the data on population and social conditions in the exposed areas, to cross-check the magnitude of potential impacts on the residents living in the flood prone areas and the economic capacity to react in case of the adverse climate event. It resulted that out of 500 people living in the flood prone area, 10% are facing economic constraints and could not afford any cost to repair their dwelling within damaged buildings. Therefore, this group is deemed vulnerable to floods. In addition, there are 10 persons with disabilities, who face great constraints to run their daily activities and eventually escape in case of floods. In a later step, tailored actions are to be planned to reduce these vulnerabilities, with a view on prevention rather than only disaster management. See Complementary document 4 (Hernández Moral et al., 2025) (Corral & Hernandez, 2017) for key insights.

Finally, the team evaluated the vulnerability of low-lying agricultural lands to flooding, leveraging high-quality crop data and the exposure map, and identified floods as a driver for crop production losses. By calculating the ratio of inundated area to total area for each crop type, the team found that vineyards are disproportionately prone to flooding compared to other crops.

This critical insight enables the planning of targeted measures to counteract climate-induced impacts and ensure the continuity of wine production, minimising losses for producers. See Complementary document 4 for further details on action planning (Hernández Moral et al., 2025).

5.3 Determining adaptive capacity

5.3.1 Identifying current adaptive capacity

The IPCC provides the following definition for adaptive capacity: "The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC, 2022a). From this definition, it emerges that adaptive capacity has a positive connotation, it refers to diverse actors highlighting their capacity to face potential damaging events with minimum losses, through social, natural, financial resources. Adaptive capacity of cities and their systems (physical, ecological, social, and economic) is particularly important in the context of climate change as a requisite for future adaptation actions. The adaptation process requires the capacity to learn from previous experiences to cope with current climate, and to apply these lessons to cope with future climate (Brooks & Adger, 2005; Klein, R.J.T. et al., 2014). In essence, a high adaptive capacity helps to minimise the severity and / or frequency of adverse consequences stemming from climate-related hazards.

However, there might be barriers hindering adaptive capacity, which need to be identified to ensure a robust and successful adaptation process. Examples include political barriers, when the political will to act is limited, or financial ones, when there is a lack of resources that impede investments and actions in adaptation solutions.

Box 15. Section 5 frequently asked questions

12. (Climate) Adaptation vs Resilience?

Often used interchangeably, they are complementary concepts with different nuances.

- *Adaptation* is a process or action to increase the capability to adapt/survive in a changed environment/context.
- *Resilience* is a property/characteristic of the system that indicates the capacity to cope with and recover from changes.

Adaptation and resilience are connected, and adaptation responses can help to build resilience, but they can also undermine it. For example, when adaptation processes and actions focus on the symptoms of a problem, rather than addressing the root causes of vulnerability or neglect social and ecological interdependencies. Therefore, it is essential to ensure integrated approaches when developing adaptation strategies and actions considering the interactions between social, economic, and environmental systems.

13. Vulnerability vs Sensitivity

- *Sensitivity* is defined as: "The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (IPCC, 2022a))
- *Vulnerability* is defined as "The propensity or predisposition to be adversely affected". Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2022a).

14. Coping capacity

Coping capacity is defined as the capacity of a system to properly face adverse consequences in the short term, and adaptive capacity as a longer-term process which includes adjustments in the system as part of a learning, experimentation, and change process.

15. (Climate) Adaptive capacity vs Adaptation action?

The concepts are interrelated.

- *Adaptive capacity* refers to the ability of a system to adjust to potential damages, to take advantage of opportunities or respond to consequences. The adjustment may be of any kind, with factors influencing the capacity of the system being the determinants of the adaptive capacity.

- *Adaptation actions* aim at increasing the capacity of the system to cope better with the stresses induced by climate change.

While adaptive capacity can include spontaneous actions by individuals or communities, such as farmers purchasing insurance coverage or installing rainwater tanks in drought-prone areas driven by immediate needs and local knowledge, adaptation actions are planned and structured efforts, like municipal projects to improve water network leakages, requiring coordinated planning and resource allocation.

16. Maladaptation

The IPCC AR6 defines "*Maladaptation*" as actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas emissions, increased or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence (IPCC, 2022a).

Therefore, maladaptation occurs when adaptation actions and strategies go against the planned direction, creating conditions that worsen the original status. With growing experience of adaptation, it has become clear that poorly designed adaptation strategies are often the drivers of maladaptation (Schipper, 2020).

Maladaptation can lead to “rebounding vulnerability”, when an adaptation strategy aimed at a group of people makes them more vulnerable to climate change. Maladaptation could also occur in the form of “shifting vulnerability”, when the adaptation strategy redistributes vulnerability, by making a non-beneficiary group of people more vulnerable to climate change than before the strategy was implemented. Maladaptation can also create “negative externalities”, adverse outcomes of projects that introduce new problems, which are not necessarily linked with increasing vulnerability to climate change (Schipper, 2020).

As adaptation has a strong local component, likewise the adaptive capacity is strongly linked to the local context, with different actors experiencing different constraints, which result in differential adaptive capacities and preferences for adaptation options (Klein et al., 2014).

5.3.2 Identifying factors supporting/challenging adaptive capacity

There are various dimensions of adaptive capacity, indicating the ability of different systems (economic, social, technical, institutional, …) to react. All dimensions contribute to adaptation and there are several factors influencing adaptive capacity. The dimensions as well as the factors are interrelated; however, these are often assessed singularly to ensure an in-depth analysis and a focused approach.

Several categorisations may be possible when analysing the adaptive capacity factors. Within CoM EU the following adaptive capacity factors are considered, and examples of indicators are provided:

- **Access to services:** reflects the accessibility of residents and organisations to services, such as infrastructures, transport networks in view of, during and after a climate-related adverse event. E.g. percentage of population with access to emergency services within 30 minutes (unit: %).
- **Socio-economic:** reflects the social component in the capacity of the individuals and households to face and recover from adversities, including health. It also considers the extent of resources available and the capacity to employ these to prevent, plan actions and react to adverse climate-related events. E.g. average annual household income (unit: €/year).
- **Governmental & institutional:** the capacity of the institutions to anticipate, provide and improve their responses for climate change, highlighting how well they learn, innovate, and modify existing policies and practices to reduce vulnerability and are able to mobilise resources and adopt decision-making. E.g. number of climate change-related policies and plans adopted by local government per year (unit: n. policies/year).
- **Physical & environmental:** represents the capacity of the physical system (assets, buildings, network) and the environment to maintain key functions during the adverse climate-related event. E.g. number fireproof buildings (unit: n of buildings.).
- **Knowledge & innovation:** the available knowledge and awareness which can support adaptation and set the basis for learning from experience and the enabling environment fostering innovation for solutions supporting adaptation. E.g. number of climate change-related research projects conducted by local universities and research institutions (unit: projects/year).

These factors can inform or support adaptive capacity and be reflected in adaptation actions that in turn can enhance the existing adaptive capacity. However, as mentioned above, there are also negative factors that hinder adaptive capacity. For example, communities with limited ability to act collectively and low decision-making (governmental).

Box 16. Rivertown: adaptive capacity analysis

With the support of the Social Science department of the university, the *Adaptation team* assessed the adaptive capacity of Rivertown for the identified hazards. Structured interviews of 60 residents, who were selected randomly, were conducted to understand their considerations and experiences. Through the analysis of the interviews, information on risk perceptions, needs, and ability to alleviate risks, outcomes of actions were collected.

On extreme heat: the results showed that the access to adequate air conditioning was limited. Results also indicated that the emergency response system, set up by Rivertown in the past year to inform individuals about the weather conditions and recommendations, required more than 1 hour to be activated and consequently for the notifications to reach the residents. These insights highlighted room for improvement of governmental and physical adaptive capacity.

On floods: when asked whether, assuming the current economic conditions, the interviewed would have been able to afford refurbishments or interventions on the buildings to recover from damages, responses tended to show low capacity to face the damages, low level of insured buildings and businesses, and the need to recur to loans or personal savings. This underscores a low socio-economic adaptive capacity.

In addition, the *Adaptation team* discussed with the responsible departments of the main hospital and the power substation located within the prone area. The team assessed that in both cases several measures are already in place to continue the activities during adverse climate events and floods.

Finally, the results of the surveys together with the outputs of spatial analysis and models, showed that the accessibility of residents and organisations to services and infrastructures from the potentially flooded neighbourhood during and after the event, could be improved, as some key routes would be impacted but a line of access would remain available in case of floods.

Reflecting on these aspects supports developing solutions, setting up processes and collaborations to manage effectively resources, steering education and awareness raising, developing future-oriented planning, and innovation in governance, technologies, and partnerships to enhance the capacity of individuals, communities, institutions, businesses, and systems to face climate change impacts.

5.4 Identifying exposure, vulnerability and adaptive capacity indicators

Indicators are a common and easy-to use metric to provide information about specific conditions (both quantitative and qualitative) which are used to evaluate the effect of climate change. For exposure, indicators can focus on the elements (inhabitants, assets, infrastructures, etc.) at stake and determine the scale and thresholds of impacts. The degree of exposure can be expressed by absolute numbers, densities or proportions of the elements at risk. Indicators need to be specific to the local context and identified hazards.

As described before, vulnerability has different dimensions, from physical to social and economic. These aspects could be assessed and measured through the use of indicators and proxies, which are key for assessing actual and future adverse consequences of climate change (Birkmann et al., 2022; Hinkel, 2011; Meza et al., 2019). Similarly, adaptive capacity has several dimensions and is dependent on the hazard.

While not a panacea, methodological approaches based on indicators help assess, compare, and monitor complexities and theoretical concepts in simpler terms, being both quantitative and qualitative. Indicators describing vulnerability in its dimensions (but also exposure and adaptive capacity) support a better understanding of the relations among the factors and can inform policy making, hence, require careful validation and identification of their limits and assumption behind. For example, in case of floods, the area potentially affected by flooding/inundation represents the "exposure". Similarly, people living in that area (officially registered residents) would be exposed but also vulnerable. The inhabitants directly vulnerable are those living on the ground or first floors of the buildings in the prone area, while those living on upper floors might suffer from indirect discomfort due to the flooding. However, this indicator (people living in the area exposed to floods -officially registered residents) serves as a proxy of potential vulnerable persons to the floods, as no concrete information is available on the people who will be in the buildings during the event (Swart et al., 2012). In terms of physical assets, all buildings in the area are exposed, but only those which have determined characteristics will be most impacted.

Examples of exposure indicators include: percentage of cropland exposed to extreme precipitations; number of inhabitants exposed to a number of days identified as a hot day. Numerous indicators are available, municipalities can make use of those or develop ones relevant and suitable to their specific conditions. Useful exposure indicators to be used at the local level have been developed by the OECD (Maes et al., 2022)[49] and by the EEA (European Environment Agency, 2021)[50].

Looking at the wild-fire hazard, for example, the areas prone to wild-fire (exposure) can be determined through models summarising the climatic conditions that may determine the occurrence of fires. The vulnerability of the exposed settlements is determined by factors such as the type of vegetation in the surroundings, the building system employed and standards used, the population of 65 year-old and above, which can be used as a proxy, given that this group shows higher probability to cardio-vascular diseases which can be in turn exacerbated by fire smoke (Swart et al., 2012).

For assessing adaptive capacity, proxies are often used. Examples could be: the GDP, or income level at municipal or neighbourhood levels, pertaining to the socio-economic factor, the degree of institutional capacity of the municipality to cope with climate change, linked to the governmental and institutional factor. In addition, factors are often interlinked, and, hence, the indicators, e.g., the percentage of farmers who have experienced changes due to climatic events (knowledge and social factors); appropriate emergency response (physical, institutional, innovation). Often indicators for exposure, vulnerability and adaptive capacity are used interchangeably. For example, inverting the direction of the indicator in case it is the capacity to react (adaptive or coping capacity) instead of vulnerability that is intended to be measured.

There is not a single fit for all indicators, but the identification of the most suitable and relevant indicators is determined by the local conditions and factors. Knowing the territory, its characteristics and potential is key to build and select good indicators and ultimately develop a tailored risk and vulnerability assessment. However, common conditions, similarities and closeness make it possible to share useful indicators. These can also serve as inspiration and starting point for assessing vulnerability and exposure. Therefore, commonly used and useful indicators for climate change adaptation are often available in scientific literature, documentations and the CoM reporting platforms. For

[49] The working paper provides a list of useful exposure indicators for seven climate hazards: extreme temperature, extreme precipitation, droughts, wildfire, wind threats, river flooding and coastal flooding.

[50] The EEA report "Europe's changing climate hazards - an index-based interactive EEA report" explores 32 indices related to 16 hazards aggregated into 6 classes: heat and cold, wet and dry, wind, snow and ice, coastal, open ocean.

example: Number or % of (public/residential/tertiary) buildings damaged by extreme weather conditions/events, Number of people injured/evacuated/relocated due to extreme weather event(s) (e.g. heat or cold waves).

Key aspects to be considered when selecting or developing indicators are:

- Specificity, tailored to local conditions and to the element to be measured.
- Time and spatial coverage, clearly defined its applicability in terms of space and time.
- Replicability, possibly applied several times including for timely monitoring.
- Metrics and direction, defined system of measurement and interpretation (how it can be measured and what the desired direction is).

The table below proposes examples of indicators per identified factors. Other examples of indicators can be found in Annex 2.

Table 3. Examples of indicators.

Factors	**Examples of indicators [unit]**
Exposure	The area potentially affected by flooding/inundation in the time frame of 100 years [square meters]
Vulnerability	Number of people living in the ground or first floors of buildings within the area prone to flood [n]
Adaptive capacity	Appropriate emergency response in place [y/n] Number of people reached through the system within 1 hour [n]

Source: JRC elaboration

Box 17. Murcia, Spain: measuring social vulnerability and sectoral adaptive capacity

Murcia (Spain) developed a climate adaptation plan that assesses not only climate risks but also social vulnerability and adaptive capacity of different sectors[51]. Murcia measured exposure, vulnerability and sensitivity of different sectors every 15 years to plan for long-term scenarios. The municipality assessed climate risk by calculating potential impact, exposure, and vulnerability indicators, which also measure adaptive capacity and sensitivity.

Murcia identified priority sectors, such as water, health and urban planning, and conducted expert interviews and panel discussions to verify the accuracy of the analysis and collect concerns from stakeholders. The municipality also measured social vulnerability in reference to the health and land use planning sectors, evaluating indicators such as population poverty rate and unemployment rate. The municipality's approach to analysing adaptive capacity is comprehensive, with multiple inputs by different stakeholders and aims to build resilience and address social vulnerability.

[51] Murcia's Adaptation Strategy: https://energia.murcia.es/index.php/estrategia-adaptacion-2030 and CoMO library: eumayors-case study-Murcia-2020-en.pdf

6 Risk analysis, impacts and prioritisation

Once climate hazards have been identified, and exposure, vulnerability and adaptive capacity of sectors and population groups have been analysed, it is possible to analyse risks and impacts. Risk can arise from the dynamic interactions among climate-related hazards, the exposure and vulnerability of affected human and ecological systems. The IPCC Sixth Assessment Report defines risk as "the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems". The word "potential" marks the uncertainty underlying the concept of risk. On the other hand, "impacts" are defined as "the consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather / climate events), exposure and vulnerability". The assessment of risks, impacts, and their prioritisation are described in this section.

6.1 Risks identification and characterisation

To identify risks, it is essential to consider the climate-related hazards over the short, medium and long term (as a driver of risk) and its interaction with the exposure and the vulnerability of the system affected. This can be achieved through various methodologies, which often combine top-down and bottom-up approaches and quantitative or qualitative analysis. As described in the previous chapters, the selection of the approach and type of analysis depends on data and resources availability.

Quantitative analysis uses numerical methods, relying on sufficient data to support the analysis itself, while qualitative analysis uses non-numerical methods and are useful when data is limited, or the risk is difficult to quantify.

Municipalities with extensive data on climate-related hazards, exposure and vulnerability can use quantitative methods to characterise the risk. However, municipalities with limited data may need to rely on qualitative methods, such as expert judgement or stakeholder engagement. In cases when municipalities have access to spatial data, detailed risk maps can be developed to assess the risk at a specific location.

6.1.1 Developing risk indicators and constructing matrices

To translate risk analyses into actionable insights, quantitative or qualitative risk indicators can be developed. These indicators allow assessing the level of risk and can be developed by combining data on hazard, exposure, and vulnerability.

<u>Quantitative risk indicators:</u> would result from the advanced analyses undertaken (i.e. the use of spatial information, the outcomes of models, numerical methods) to calculate the level of a risk. For example, a risk indicator can be developed by combining data on flood frequency and intensity (hazard) with data on asset location and value (exposure) and social and economic characteristics of the affected population (vulnerability). The resulting risk indicator could be a metric such as potential or expected damage from flooding.

<u>Qualitative risk indicators</u>: would result in categorical rating such as "high", "medium" or "low" risk.

Municipalities can develop effective risk indicators by using a combination of available data, quantitative and qualitative methods. For example, a municipality may use historical climate data to estimate the likelihood of a hazard, while using expert judgement to estimate the potential impact of the hazard on the municipality's infrastructure and population, or proxy indicators, such as population density, to estimate the level of exposure and vulnerability.

Risk matrix is a simple, graphical tool that plots two different values and compares them among each other and can be used to synthesise the results of the risk. The resulting matrix can be divided into different zones (the cells of the matrix), each representing a distinct level of risk, such as minor, moderate, or significant. Risk determined via quantitative indicators or qualitative ones can be plotted in the matrix, which can be quantitative, semi-quantitative, and qualitative. In a qualitative risk matrix, there is no explicit risk measure, but a categorisation. Looking at the matrix, decision-makers can quickly identify and prioritise the most critical risks and allocate resources accordingly.

Table 4. Example of a qualitative risk matrix

		Exposure x Vulnerability			
		Low	Medium	High	Not known
Hazard	Low	Insignificant	Minor	Moderate	
	Medium	Minor	Moderate	Significant	
	High	Moderate	Significant	Severe	
	Not known				

Source: JRC elaboration

The example shown in Table 4 generally refers to a non-specified hazard. Risk matrices of this kind can be prepared for different hazards and exposure/vulnerabilities. To develop these matrices some intermediate steps are required, for example to combine vulnerability and exposure (as it appears in the example). The risk matrix provides a clear and visual way to communicate the relative priority of different risks, facilitating decision-making and resource allocation. For instance, in an area with high exposure and vulnerability (e.g. substandard buildings in a flood-prone area) and a high probability of a specific hazard (e.g. floods expected to increase in the short term), the overall risk would be classified as "severe". In contrast, risks characterised by low exposure, vulnerability and hazard likelihood, would be considered as insignificant and, hence, of low priority not requiring immediate action.

Risk is sometimes defined as the probability of a consequence multiplied by the magnitude of that consequence. Within this perspective the matrix can take the shape represented below in Table 5.

Table 5. Risk matrix combining likelihood and magnitude of impacts

		Impact[52]			
		Low	Medium	High	Not known
Likelihood	Low	Insignificant	Minor	Moderate	
	Medium	Minor	Moderate	Significant	
	High	Moderate	Significant	Severe	
	Not known				

Source: JRC elaboration

Box 18. Extracting relevant risks using increasing levels of analysis: extreme heat case in Helsinki

To determine the heat risk in the Helsinki metropolitan area (Finland) a recent study[53] combined indicators with more advanced approaches for all risk components. The approach involved several steps, including: (1) selecting indicators representing different aspects of heat risk, such as economic and health status, and physical environment, based on expert judgement and data availability; (2) mapping these indicators to understand their spatial distribution, using data sources such as Statistics Finland and CORINE; (3) combining the indicators into an index to offer an overall impression of the spatial distribution of vulnerability and heat risk; and (4) projecting future trends of individual indicators, such as the share of older people living alone, using a participatory scenario approach and shared socio-economic pathways (SSPs). The approach used in Helsinki allows urban planners and policymakers to identify areas with high heat risk and target specific interventions. A comprehensive understanding of the risk is gained through a combination of advanced techniques and less intensive analysis, of qualitative and quantitative methods, using expert elicitation to define indicators and scenario trends, and then quantifying these trends using observed data and SSP-based projects. This also provides a framework for assessing and projecting heat risk in other regions.

Box 19. The risk and vulnerability assessment in the SECAP of Parma

The risk and vulnerability assessment of the municipality of Parma[54] (Italy) is based on its Local Climate Profile, which draws on long-term meteorological series (dating back to 1881), regional datasets from the Regional Agency for Prevention, Environment and Energy (ARPAE Emilia-Romagna), and the *Local Climate Emergency Plan*. The RVA identifies key climate-related risks associated with floods, drought and water scarcity, and extreme heat and heatwaves. The RVA was developed through an integrated, multi-source approach. For instance, it combines exposure maps from the Emilia-Romagna Region's *Flood Risk Management Plan*, data and insights from specific research projects led by the University of Parma. In relation to drought and water scarcity, the municipality used monitoring data on the duration of drought events, the condition of subsurface watercourses, and the status of water suppliers to characterise and assess the hazard. For extreme heat and heatwaves, the studies developed in a PhD thesis from the University of Parma

[52] Risk is sometimes defined as the probability of a consequence, multiplied by the magnitude of that consequence (Begum et al., 2022). Some frameworks adopt matrices showing the "likelihood" in the columns and the "magnitude" of impacts in the rows. The DIY manual "Assessing Climate Change Risks and Vulnerabilities" (Smithers et al., 2023) indicates to rate the magnitude of impacts in a "climate-related impact matrix", by combining vulnerabilities and exposure, and then to combine the likelihood of future potential climate-related impacts with the rating of their magnitude, to rate the risk.

[53] ETC/CA Report 1/2024 Guidelines to quantify climate change exposure and vulnerability indicators for the future: an example for heat stress risk across scales: https://www.eionet.europa.eu/etcs/etc-ca/products/etc-ca-products/etc-ca-report-1-2024-guidelines-to-quantify-climate-change-exposure-and-vulnerability-indicators-for-the-future-an-example-for-heat-stress-risk-across-scales

[54] SECAP of the municipality of Parma - Sustainable Energy and Climate Action Plan, 2021

were central to determining the risk of heatwaves on residents over 65 years. Thus, Parma has adopted a collaborative approach to develop its risk and vulnerability assessment, drawing on scientific expertise and existing regional data, ensuring a shared and robust foundation for understanding local climate risks and for developing effective adaptation strategies.

6.2 Impact analysis

When the hazard occurs, climate risks will become an actual impact[55], affecting key areas of living, with damages to the economy, society, and environment. While all previously described steps for the assessment are crucial to understand and determine climate risk in a given context, data on impacts represents key information for decision-making as it reflects tangible effects. According to the IPCC, "impacts generally refer to effects on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes and can be adverse or beneficial" (IPCC, 2022a). However, in this context it mainly refers to negative consequence, in line with the definitional choices of the IPCC. Impacts are also referred to as consequence of hazard, whose severity will depend on the vulnerability of affected human and ecological systems. For these reasons, the concepts of risks and impacts need to be jointly observed.

The IPCC also refers to the concept of "losses and damages" both economic and/or non-economic, which is linked to adverse observed impacts and/or projected risks (IPCC, 2022b). Assets and infrastructure, and vulnerable population would be suffering from the impacts of the risk realisation. Thus, impact analysis can be performed at sectoral or population group level. Impacts can be classified as:

— **Social:** climate change is having far-reaching social impacts, affecting the health, well-being and livelihoods of individuals and communities worldwide. Rising temperatures, changing precipitation patterns, and increased frequency of extreme weather events on exposed and vulnerable populations are all contributing to a range of social impacts, including health-related illnesses, respiratory problems, and mental health issues such as anxiety and trauma (European Environment Agency, 2022a; World Health Organisation (WHO), 2018, 2021). Additionally, climate change is exacerbating existing social inequalities (Ajibade, 2022), disproportionately affecting vulnerable populations (Otto et al., 2017) such as the poor, older people (Katey & Zanu, 2024) and young children. Social cohesion is being tested, as communities face increased competition for limited resources (Lager et al., 2023). In this context, food security is also a major concern, as changing weather patterns and rising temperatures affect agricultural productivity and distribution (Loboguerrero et al., 2019; Marino et al., 2023). Moreover, impacts may also occur on cultural heritage[56] with communities being forced to leave their lands and traditions behind, and buildings or areas with cultural values being irreversibly damaged due to climate change events. Limited resources and infrastructure have indirect effect on education, as educational premises may be subject of damages being unable to provide the services or cannot be reached due to damages to the network infrastructures and pathways and hence, struggle to provide adequate facilities and resources in the face of climate-related challenges.

[55] Consequences of climate change https://climate.ec.europa.eu/climate-change/consequences-climate-change_en
[56] Cultural heritage https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/sector-policies/cultural-heritage

— **Economic:** climate change is also having significant economic impacts, which affect industries, businesses, governments and individuals. Climate-related events are altering the availability of natural resources, disrupting supply chains and damaging infrastructure (including roads, bridges and buildings (European Energy Defence Agency, 2023; Forzieri et al., 2018)). Hurricanes, floods or wildfires may result in significant economic losses, damage to property and loss of productivity. These economic impacts can be felt across different vulnerable sectors and can also affect the competitiveness of businesses (Locatelli et al., 2015; United Nations Framework Convention on Climate Change (UNFCCC), 2022), particularly those that rely on natural resources.

— **Environmental:** climate change has a strong impact on the environment, affecting ecosystems and causing loss of biodiversity (Brooker et al., 2007; Elliot et al., 2022; Nunez et al., 2019; Secretariat of the Convention on Biological Diversity, 2009). Rising temperatures and changing weather patterns affect the distribution of plants and animals, disrupting delicate systems. Climate change also affects the availability and quality of water, which also contributes to exacerbating droughts and floods and altering the patterns of weather extremes. Environmental impacts of climate change are being felt across various ecosystems, including coral reefs, alpine areas, polar regions or forests. Additionally, oceans are also being affected, i.e., ocean acidification, warming of waters and consequently, changing the ocean circulation patterns (Cooley et al., 2016).

As a result from the social, economic and environmental analysis, relevant indicators can be defined to measure the impact in relation to the most relevant hazards. Some examples linked to specific hazards, vulnerable assets or vulnerable population groups are presented below (and in Annex 2).

Table 6. Impact indicators examples

Impact indicator [Unit]	Type	Hazard	Vulnerability (sector or population group)	Exposure
Number of heat-related illnesses per 100 000 citizens [cases/100 000]	Social	Extreme heat	Older people, young children, people with medical conditions	Buildings located in the historical centre, in particular urban heat islands
Number of people affected by water scarcity [n. persons]	Social	Drought and water scarcity	Low-income households, rural communities	Municipal water supply infrastructures
Loss in tourism revenue due to beach erosion [million €]	Economic	Coastal erosion/ sea level rise	Tourism sector	Coasts composed of soft sediment and narrow sand areas.
Damage to transport infrastructure due to landslides [million €/km of roads affected]	Economic	Mass movement [landslides]	Transport sector	Transport infrastructures located within the area of landslide inventory maps
Number of threatened species due to habitat loss [n. species]	Environmental	Drought and water scarcity	Environment and biodiversity sector	Ecosystems subjected to drought

Source: JRC elaboration

The social, economic and environmental impacts of climate change are interconnected and can have compounding effects. For instance, climate-related displacement can lead to further social (such as loss of livelihoods) and economic impacts (such as strain on community resources). Environmental impacts, such as loss of biodiversity and ecosystem disruption, can also lead to economic and social impacts, such as loss of ecosystem services and effects on human health. Moreover, these impacts can also exacerbate the initial climate conditions. Therefore, understanding the interconnection of climate change impacts is essential for developing effective adaptation strategies that address the complex and far-reaching consequences of a changing climate. To this aim impact chains (Zebisch et al., 2022) can be developed. An impact chain is a sequence of events that describes how a climate-related stressor (such as increased temperature or precipitation) affects a system or sector, leading to a range of potential impacts. It is a causal chain that links the initial climate stressor to the ultimate consequences, including social, economic and environmental effects.

Box 20. Impact levels

High level can be associated to severe consequences leading to serious interruptions to day-to-day life, irreversible changes and cascading effects.
Moderate level can be associated to adverse consequences leading to significant interruptions to day-to-day life, with limited cascading effects.
Low level can be associated to consequences resulting in less significant/insignificant changes to day-to-day life.
Not known - There is not experience, data or past records.

Source: JRC elaboration

6.3 Risk assessment and prioritisation considerations

Assessing climate-related risks is complex not only because of the interplay of its three main factors, but also due to their uncertainty, in terms of magnitude, frequency, and in terms of socio-economic changes. In addition, uncertainty lays in data and process understanding. Consequently, climate risks cannot be assessed deterministically. The following considerations are useful when assessing and prioritising risks:

— The "dynamic" nature of risks: the three factors shaping the risk (hazard, vulnerability and exposure) are not constant, but subject to change over time. Changes can be driven by various factors, including climate changes or socio-economic shifts, and can be natural, unintended or deliberate (for example through risk management). See section 9 on monitoring the RVA.

— The linkage to human and ecological systems: the Sixth Assessment Report of IPCC (IPCC, 2022b) highlights that the concept of risk applies only to "human or ecological systems", consequently, it should not be used to describe outcomes within physical systems only. For example, the term "extreme heat risk" should not be used if it only describes changes in the frequency and intensity of heat events; it would need to be linked explicitly to the consequences of such events for human or ecological systems (Reisinger et al., 2020). For instance, "the risk from extreme heat to human health" or "the risk from extreme high ocean temperatures to coral reef system and ecosystems", both of which clearly link the physical phenomenon of extreme heat to its potential impacts on human or ecological systems.

— The diversity of values and objectives: individuals will assess the potential consequences on human and ecological systems from different perspectives, placing varying importance on material, cultural, aesthetic and/or spiritual values, as well as the intrinsic value of ecological systems. This means that risk can affect not only tangible aspects, but also intangible ones, and can affect systems that might not have direct human value but still hold significant importance for certain individuals or groups.

When prioritising risks, it is essential to consider additional factors, such as urgency and reversibility. Urgency can be driven by already occurring impacts that are projected to worsen over time, while reversibility is critical for identifying serious risks that could have irreversible consequences for the municipality, such as sea-level rise or other extreme weather events. In these cases, prioritising actions that can mitigate these threats is crucial.

Existing mechanisms, such as emergency response plans can also be leveraged to maximise the effectiveness of prioritisation efforts. Furthermore, policy makers may need to prioritise risks that seem lower in terms of likelihood or impact but are still crucial due to other factors. For example, areas that have recently experienced adverse events may require urgent attention to prevent further damage, or interventions that require significant time to implement may need to be prioritised to ensure timely action.

The prioritisation process can be informed by the analysis performed, as well as the mandate of the municipality and the stakeholders engaged. Municipalities can draw on a range of decision-making tools and methods, including cost-benefit analysis, multiple-criteria analysis (Kong et al., 2025; Ozkiper et al., 2024), decision trees or scenario planning. These tools enable systematic evaluation and prioritisation of climate-related risks, taking into account a range of factors defined by the municipality (such as likelihood, impact and urgency) that can be weighted and/or aggregated (Hazel et al., 2012). By applying these tools, municipalities can ensure that the most critical challenges are addressed in a timely and effective manner, and that resources are allocated efficiently to mitigate the risks.

Finally, it is crucial to recognise that assessing and responding to climate change is not a single action, but rather it requires an ongoing and continuous process (iterative risk management) (Begum et al., 2022).

Box 21. Observations: reporting data on the RVA according to the CRF

Within the CRF, the risk is intended as the result of the combination of *Probability of Hazard* and the *Consequence of hazard*. As described before, the impact is intended as the consequence of the climate event or hazard and is linked to exposure and vulnerability. The impact represents the realisation of the risk driven by the hazard, the exposure, and the vulnerability. When reporting data on the RVA according to the CRF, the level to assign to the "impact of hazard" or "consequence of hazard" intrinsically takes into consideration the exposure and vulnerability analysis conducted, as vulnerable sectors and population groups reported per each identified hazard, will be those that are also exposed.

Box 22. Rivertown: risks and impacts analyses

As part of the climate change adaptation planning process for Rivertown, a comprehensive risks and impacts analysis was conducted. The analysis aimed to identify, assess and prioritise potential climate-related risks to the municipality's infrastructure, economy and social systems. The risk analysis was conducted using a combination of quantitative and qualitative methods. Quantitative methods involved analysing historical climate data. The city had available and reliable data starting from the last 20 years, including temperature highs and lows, precipitation patterns, and instances of river overflow. The analysis also used future climate projections from regional climate services' RCP8.5 high-emission scenario models, which indicated a potential doubling of extreme heat days and a 20% surge in flood events by 2050. Qualitative methods, including stakeholder engagement and expert judgment, were used to assess the potential consequences of these hazards on the municipality's critical infrastructure, economy, and social systems (this is a way to consider both the vulnerability and exposure).

Developing risk indicators

To support the risk analysis, a set of risk indicators was developed to measure the municipality's vulnerability to climate-related hazards. These indicators considered the results of hazard identification (**Box 11**), exposure analysis (**Box 12**), vulnerability analysis (**Box 14**), and adaptive capacity analysis (Error! Reference source not found.).

For extreme heat, the team created a heat stress index based on the average number of days with temperatures exceeding 35ºC, as well as the urban heat island effect (UHI). The heat stress index was calculated as the product of the average number of heatwave days and the percentage of vulnerable population living in areas with high urban heat island effect.

For flooding, the indicators were based on the spatial analysis of flood-prone areas, using floodplain maps and hydrological studies. The flood risk index was calculated as the ratio of the area of flood-prone zones to the total area of the municipality.

Constructing risk matrices

The risk indices developed were used to construct risk matrices, which helped to prioritise the municipality's climate-related risks. The risk matrices allow policymakers to identify the most critical risks and develop targeted adaptation strategies.

The heat stress index and flood risk index were used to estimate the potential impact of each hazard on the municipality's infrastructure, economy, and social systems.

Prioritising the risks

Based on the risk matrix, the highest priority risks for Rivertown are those falling under "high" rating, namely flooding and extreme heat leading to heat-related illnesses and mortality, and disruption of essential services. These risks should be addressed first as they have the potential to cause significant harm to people, assets, and infrastructure. The next priority regards the "moderate" risk, including the risk from extreme heat to agriculture leading to crop damage. These risks should be addressed next as they still have the potential to cause harm but are less likely to occur or have a lower impact than the high priority risks. Notably, no risks were considered as low priority, highlighting the need for proactive measures to mitigate the potential impacts of climate-related hazards in Rivertown.

The municipality decided to gather all the analysis in the following table (Table 7):

Table 7. Climate impacts in Rivertown on different sectors / population groups based on example results from RVA (hazards, exposure, vulnerability, risk)

Sector / population group	Hazard	Exposure level	Vulnerability level	Impact example	Type of impact	Impact indicator [Unit]	Likelihood level	Impact level	Risk level
Buildings	Flood	High	High	Economic damage on residential buildings due to floods	Economic	No. of buildings damaged [n.]	High	High	High
	Extreme heat	Medium	Medium	Increased energy consumption Increased heat-related illnesses	Economic / social	Energy consumption increase [%] No. of hospitalisations due to heat-related illnesses [n.]	Medium	Medium	Moderate
Agriculture and forestry	Flood Extreme heat	High	High	Reduced crop yield Economic loss	Economic / environmental	Decrease in crop yield from past years [%] Economic loss [€]	Medium	Medium	Moderate
Critical energy infrastructure	Flood	High	High	Service interruption Economic loss	Economic / social	Service interruption duration [hours]	High	High	High
Older people	Extreme heat	High	High	Increased mortality and morbidity	Social	Heat-related mortality rate [n. per 100 000]	High	High	High
Low-income households	Extreme heat	High	High	Increased energy expenditure Increased heat-related illnesses	Economic / social	Energy expenditure increase [%] No. of hospitalisations due to heat-related illnesses [n.]	High	High	High

Source: JRC elaboration

7 Setting adaptation goals

Climate adaptation goals are commitments that address the most important identified risks and vulnerabilities and provide measurable targets for increasing community resilience to climate change. For adaptation, the specificities of the municipalities are to be considered already at the goal setting stage, as local conditions determine what the most relevant hazards are, the exposure level of assets and population groups, as well as their vulnerability level. Goals are based on municipalities' long-term visions and on the outcomes of the risk and vulnerability assessments. They should be quantifiable and formulate the intention to reduce potential impacts. This can be achieved by:

- decreasing the overall risk level (e.g. through risk management).
- decreasing exposure.
- decreasing sectors' vulnerability.
- decreasing population groups' vulnerability.
- increasing adaptive capacity (factors).

Adopting the SMART framework (specific, measurable, achievable, relevant and time-bound) would increase the effectiveness of adaptation goals.

- **Specific**: climate adaptation goals should be clearly defined. Increasing the specificity would avoid ambiguities, keep the focus on precise challenges and tailor the strategies. Example of a specific goal would be "to reduce the annual loss resulting from river floods".

- **Measurable**: to track progress and assess the effectiveness of adaptation strategies. For instance, "decrease the number of forest fires/hectares of land burned to max 5% of land" provides a clear metric that can be measured and evaluated.

- **Achievable**: while being ambitious, climate adaptation goals must be realistic, considering the available resources, technology, and time. Setting an achievable goal might mean starting with gradual targets to be reached in the next few years.

- **Relevant**: adaptation goals must align with the broader objectives of the communities and needs of the ecosystems they aim to protect. A relevant goal takes into account the local context, such as "reduce the economic loss of drought-prone agricultural areas to ensure food security".

- **Time-bound**: goals should have a timeframe in which they are expected to be achieved. Specific timeline and deadlines help maintain momentum and urgency in climate adaptation efforts. A time-bound goal could be "reduce to zero damages on the building stock as a result of storms by 2030". This creates a clear timeline for planning, execution, and review.

As a consequence, adaptation goals should refer to the main climate hazard identified, include indicators, units, base year value, and target value for monitoring the progresses.

For example, in case of floods, the goal *Reduce to zero the number of buildings severely damaged by floods by 2030* focuses on decreasing the vulnerability of buildings exposed to floods. A key indicator to measure this goal is 'Number of buildings damaged', measured in absolute terms with the unit "number of buildings". In addition, to enhance the precision of this metric, damage levels can be classified to clearly distinguish between the buildings that cannot be used after the flood event and those that require minor interventions to be safe. The municipality, can, therefore, assess the progress and check whether the base value [e.g. 50 buildings] in the reference year [e.g. 2022] is brought to zero in the target year [2030].

Box 23. Section 7 frequently asked questions

17. Adaptation goals vs adaptation actions

Adaptation goals reflect **what** the objectives that are pursued to enhance climate change adaptation are, whereas *adaptation actions* reflect **how** these objectives are pursued. As a consequence, for every adaptation goal, there should be one or more adaptation actions addressing them.

The following Table 8 clarifies the difference between adaptation goals and adaptation actions by providing some examples. On the contrary, Table 9 presents examples of adaptation goals missing some of the key parameters that are fundamental in their definition. Further examples of well-defined adaptation goals can be found in Annex 3.

Table 8. Well-defined adaptation goals examples and potential adaptation actions

Adaptation goal	Main objective	Hazard	Indicator [Unit]	Base year value	Target value	Potential adaptation actions (non-exhaustive)
Reduce the annual expected loss due to floods in the city by at least 80% by 2025	Decrease the overall risk level	Floods	Annual expected loss [€]	€10 000 000	€2 000 000	(1) implementing flood protection infrastructure, (2) adaptive planning and zoning, (3) establishing early warning systems
Protect the population living in high-risk coastal areas by 2030	Decrease exposure and reduce vulnerability	Sea-level rise	Number of protected people [n. persons]	None	5 000 people	(1) implement flood resilient construction standards, (2) awareness-raising campaign on sea-level rise, (3) establishing financing incentives for the relocation of population, etc.
Reduce power outages due to extreme weather events (floods, storms, extreme heat) by at least 80% by 2032	Reduce vulnerability	Floods, storms, extreme heat	Number of power outages [n. power outages]	100 power outages	20 power outages	(1) implementation of smart grid technologies, (2) implementation of energy storage, (3) distributed energy deployment, etc.
Reduce to zero the number of buildings severely damaged by floods by 2030	Reduce vulnerability	Floods, storms	Number of buildings damaged [n. buildings]	50	0	(1) implement flood resilient construction standards, (2) design nature-based solutions

Source: JRC elaboration.

Table 9. Wrongly defined adaptation goals examples and explanations (with reference to the SMART framework).

"Adaptation goal"	Goal or action	S.	M.	A.	R.	T.	Comments
Enhancing resilience in the municipality by 2030	Goal	No	No	Unknown	Unknown, vaguely defined	Yes	The defined "adaptation goal" has a clear target year. However, its formulation is neither specific nor measurable as it generically mentions "resilience" without any details on what hazard(s) is related to or how it can be measured. Similarly, the achievability and relevance cannot be assessed. The relevance of the goal would depend on the RVA performed.
Reduce damages to zero	Goal	No	No	Unknown, insufficient parameters	Unknown, vaguely defined	No	The formulation of the "adaptation goal" is very generic, as it is not clear where would the "damages" originate from (i.e. which hazard they are related to). Additionally, it does not provide any reference upon which to measure, nor establishes any target year.
Implementing rainwater tanks in municipal buildings	Action	Yes	No	Unknown, depends on scope	Unknown, depends on risks	No	The statement cannot be considered as a goal, but it represents an action linked to droughts / water scarcity. While it is specific, it is not measurable, nor time bound.
Establishing an emergency plan against floods by 2030	Action	Yes	No	Unknown, depends on the capacity	Unknown, depends on risks	Yes	The statement represents a policy-related action to enhance the preparedness of the municipality; however, it cannot be considered as a goal even when it is specific and includes a target year.
Raising awareness against heatwaves for the most vulnerable populations (older people, low-income communities, etc.)	Action	Yes	No	Unknown, depends on the scope	Unknown, depends on high risks identified	No	In the same way as the previous two statements, this "adaptation goal" is an action linked to increasing population's knowledge against a specific threat. While it is specific in identifying the addressed hazard and targeted population, it cannot be considered as a goal.
Implementing 40% of adaptation actions by 2030	Neither	No	Yes	Unknown	Unknown	Yes	This formulation differs from the previous ones, as it provides a unit of measurement to track the deployment of the actions. It cannot be considered neither as goal nor as an action, but rather the activity that should be tracked by the municipality during the monitoring process. Therefore, it cannot be considered as a goal.

Source: JRC elaboration.

Box 24. Rivertown: adaptation goals setting

At this stage, the *Adaptation team* had a clear idea of the risks and impacts that could affect the municipality in the short and medium-term. Additionally, based on the prioritisation efforts, the city was able to identify the most important challenges to be addressed.
The *Adaptation team* considers stakeholder and citizen engagement of crucial importance and establishes a review and refining stage soliciting feedback from stakeholders and residents where the results of the RVA will be discussed, as well as the adaptation objectives established.

The next step is to define the adaptation goals that would guide the identification and design of adaptation actions. The *Adaptation team* reflects on how the adaptation goals can be defined following the SMART framework based on the analyses performed so far, the data that has been used to perform the RVA (i.e. data availability), the available resources and the inputs from stakeholders. To establish a long-term vision the team considers a medium / long-term time horizon when defining the adaptation goals, but it also acknowledges the urgency to establish some short-term milestones that would enable the municipality to start adapting to potential short-term and medium-term impacts. The team clearly links each adaptation goal to the corresponding climate hazard and the main objective that is pursued (reduce exposure, reduce vulnerability, increase adaptive capacity or decrease overall impacts). Additionally, the team places close attention on how the adaptation goal can be measured and ensures that the municipality has access to data to measure the baseline value and to monitor progress in the following years. The *Adaptation team* presents the proposed adaptation goals, developed in consultation with stakeholders, to the Mayor and the municipal council, who review and approve the goals, reaching a consensus on their implementation. Rivertown's data last update dates to 2022. The team summarises the outcomes in the following table:

Adaptation goal [unit]	Climate hazard	Objective	Sector	Vulnerable population group *	Base value	Base year	Target value	Target Year
Reduce the annual heat-related hospitalisations by 80% by 2028 [n. cases]	Extreme heat	Vulnerability	Health	Older people	100	2022	20	2028
Reduce to zero damaged buildings by 2030 [n. buildings]	Floods	Vulnerability / exposure	Buildings	Low-income households, marginalised groups	50	2022	0	2030
Increase flood-resistant agricultural practices to 90% by 2030 [% practices]	Floods	Adaptive capacity	Agriculture and forestry	Low-income farmers	10	2022	90	2030
Reduce crop losses due to extreme heat by 70% by 2028 [% losses]	Extreme heat	Vulnerability / exposure	Agriculture and forestry	Low-income farmers	30	2022	9	2028
Reduce the number of energy (critical) infrastructure failures due to floods by 95% by 2028 [n. failures per year]	Floods	Impact	Energy	All*	20	2022	1	2028
Increase the proportion of transport critical infrastructure with flood-resistant design by 100% by 2030 [% infrastructures]	Floods	Adaptive capacity	Transport	All*	0	2022	100	2030

Note: "All" population groups are considered as vulnerable against floods in critical infrastructures; however, as the potential climate impacts of floods are progressively being addressed, these groups can vary and the vulnerability reduce.

8 Reporting, communication, and outreach documenting the RVA

The steps undertaken to understand the risks and vulnerabilities in the municipality allow for a better planning of actions that will reduce vulnerabilities and exposures and increase the resilience of the territory. The risk and vulnerability assessment would need to be elaborated and translated into one (or more) comprehensive RVA report, highlighting the methods and procedures followed, the analysis and main outcomes. This would ensure the monitoring and progress reporting as well as the possibility to improve and timely adapt the RVA in time in case of changes (see section 9).

Regular reporting is crucial for securing financial resources, as it provides transparency and accountability to funding agencies, banks, and other financial institutions, thereby ensuring ongoing access to the necessary funds to implement adaptation actions effectively. Reporting creates accountability and transparency, building trust with stakeholders and funding entities.

In addition, the RVA report is the mean and occasion to share the knowledge acquired and the findings with stakeholders and the public. Therefore, the RVA report should be clear and accessible. To maximise the impact and strengthen the message, municipalities can consider developing targeted communication strategies that address diverse audiences, adopting suitable communication tools, leveraging media and public forums to amplify the message. Moreover, in parallel to formal dissemination, communication through social media can help gathering wider non-technical audience and increase the involvement of residents. Setting up a dedicated website with effective visualization techniques, such as data dashboards and infographics and regular newsletters help to keep informed and engaging through easy-to-understand formats. The use of shared platforms for dialogue among various stakeholders can facilitate the process of adaptation with a full participatory approach. Communication is essential to achieve a shared understanding of any climate related issue and hence suitable language that allows people to understand and pro-actively participate in decision making is essential.

Box 25. Rivertown: reporting and communicating the RVA

The RVA report generated by the *Adaptation team* highlighted the municipality's exposure to flooding and heatwaves, identified the most vulnerable populations, including low-income households and older residents.

To communicate the findings and recommendations of the RVA report, the city of Rivertown developed a targeted communication strategy that addressed diverse audiences, including residents, businesses and stakeholders. The municipality used a range of communication tools, including:

- A dedicated website with interactive data dashboards and infographics to visualise the risks and vulnerabilities.
- Regular newsletters and social media updates to keep the public informed and engaged.
- Public forums and community meetings to gather feedback and input from residents and stakeholders.
- Collaborations with local media to amplify the message and reach a wider audience.
- Educational workshops for youth deployed in public schools.

The municipality also established a shared platform for dialogue among various stakeholders, including residents, businesses and community groups, to facilitate the process of adaptation and ensure a full participatory approach. The platform, called "Rivertown Resilience", acted as a one-stop-shop and allowed stakeholders to share information, discuss ideas and collaborate on projects focused on reducing the municipality's vulnerability to climate change. The platform was also instrumental in ensuring transparency and accountability, building trust with funding agencies, and facilitating access to the necessary funds for effective adaptation actions.

To ensure that the communication strategy was effective, Rivertown used clear and accessible language, avoiding technical jargon and complex terminology. The municipality also provided opportunities for residents and stakeholders to ask questions and provide feedback and established a system for tracking and responding to comments and concerns.

The communication strategy was successful in raising awareness and engagement among residents and stakeholders and helped to build a sense of community and shared responsibility for addressing the municipality's climate-related challenges. Some examples of the communication materials used by Rivertown include: an infographic highlighting the municipality's top climate-related risks and vulnerabilities, a video explaining the RVA process and findings, a social media campaign using the hashtag #RivertownResilience to promote the municipality's adaptation efforts and a newsletter providing updates on the municipality's progress in implementing the RVA recommendations.

By using a range of communication tools and strategies, Rivertown was able to effectively communicate the findings and recommendations of the RVA report and fully engage residents and stakeholders.

9 Monitoring and improving the RVA

Monitoring progress is a crucial part of the SECAP process. It involves every step, including the RVA, providing a key opportunity to assess changes and identify options for improvement and refined accuracy. Regular assessment is essential to understand the evolving nature of the risks identified in the RVA. Reviews will allow checking any changes in hazard probabilities coming from updated analysis or assessment, grasping whether changes in the socio-economic and territorial context occurred and reflecting these changes into vulnerabilities and exposures. The RVA can be enhanced with the integration of new insights gathered from new analysis, or analysis run for longer periods.

For climate mitigation, compiling GHG inventories on a regular basis enables monitoring and tracking the progresses towards the emission reduction targets. Likewise for adaptation, changes in the level of impact and intensity of identified climate hazards and in the identified vulnerable sectors and vulnerable population groups can be recorded in the updated version of the risk and vulnerability assessment.

The amount of data collected increases over time, allowing for more detailed assessment and forecasts. Similarly, methodologies and procedures can be refined with time, providing significant and meaningful elements for the RVA. Moreover, in every monitoring cycle the actions implemented will have already some impacts on the level of vulnerability and exposure, shaping a revised version of the RVA. As a consequence, well-defined exposure, vulnerability, adaptive capacity indicators are crucial tools to monitor any changes.

To handle this review/monitoring process, adopting flexible and adaptive management[57] practices will help municipalities in coping with the changes that may occur and become necessary due to the outcome of monitoring.

For this reason, once the RVA is ready, the process is not over. On one hand, the team identifies priorities and plans suitable adaptation actions. On the other hand, the team with the support of collaborating experts and involved stakeholders, continues collecting and elaborating data, organises purpose-specific meetings and focus groups to exchange, reflect and learn.

There could also be the case that a strong climate adverse event occurred after the submission of the RVA and the SECAP. This event may have significant impacts on different sectors of the municipality and groups of people. As a consequence, the conditions at the basis of the already submitted RVA may become quickly outdated and the need for a deep review to understand the physical, social and economic conditions of the municipality arises. In this context, the adaptive management capacity of the team is crucial to re-set the process and update the RVA.

The following steps summarises a suggested standard review process for the RVA:

- Establishment of the review cycles: while it is expected to report on the monitoring every four years after the SECAP submission, municipalities can set intermediate timelines suitable to their contexts and resources to review or check the data (or part of it) to assess if there is any relevant change and, hence, update their RVA. It is essential that the team establishes a roadmap and timeline, identifying

[57] Adaptive management is a scientific and social process, it implies flexibility in the whole process, being aware that changes in local conditions or advance in scientific research often require periodic revision of plans and strategies, refinement and improvement of outcomes according to the learning-by-doing framework.

the milestones and the data that requires a revision. The roadmap and timeline are to be shared with all members of the team, the involved departments, and stakeholders.

- Procedures for regular data updates: the team together with the experts should define the suitable protocol for the revision of the identified data and variables. The procedures can be shared among different data types, or singular approach can be applied for each data type. This really depends on the selected elements, the granularity of the data, and its variability. If for example, a research group in the university is developing a new assessment of the building stock within the municipality, revising the data collected at the time of developing the RVA in light of the recently developed data on buildings, becomes a key opportunity for increased quality and reliability. In this case, data on buildings is not highly variable, unless there are significant new development sites, but the methodology applied by the university department might be more precise than the one used for building the RVA and, hence, might enlighten new aspects previously neglected. This also shows how important it is to keep a periodic contact with all stakeholders.

In parallel, if for example, data from the health department is collected every two years, the team should take into account this timeline for data updates.

Similarly, if no changes in census data are expected within four years, the team should consider this frequency and not include the revision or update of this type of data within shorter term.

- Reassessing risks and vulnerabilities: hazards, exposures, vulnerabilities and adaptive capacity should be reviewed and updated in light of new or updated data available. The same procedure adopted at the moment of the elaboration of the RVA should be followed, to assess if any change occurs. The indicators identified and defined during the RVA elaboration for all the risk factors can be employed to highlight any modification. It is also possible that the changes in the data do not imply any adjustment in the risk factors and, therefore, no significant change occurs.

- Adjusting RVA framework based on new insights: the new insights gathered from the revision and updates are then reflected into the RVA framework and the risk assessment. The risk matrices might change accordingly, and the outcomes of the identified impact indicators will clearly reflect these changes.

Municipalities are recommended to establish regular review cycles of the RVA, in alignment with the CoM reporting requirements, i.e. every four years. Every review is the occasion to integrate any lesson learnt and should be integrated with adaptive management practices.

9.1 Planning for future assessments

Adaptation to climate change needs to be based on assessments of future impacts, associated with the changing climate conditions. To develop a long-term adaptation strategy, it is crucial to access and correctly interpret information about the long-term projected climate impacts (Climate Adapt[17]). Climate projections 100 years into the future enable analysts, policy makers and people to assess long-term impacts in critical sectors, such as human health and welfare, ecosystems and biodiversity, social systems and the economy. They also inform decisions that are sustainable, in the sense that do not prioritise immediate needs over the needs of future generations and enable benefits that may not be immediately apparent, such as: reducing maintenance, improving public health, increasing competitiveness. In addition, with the lifespan of infrastructures reaching 50-100 years or more, any related assessment of exposure and vulnerability would be partial if not considering long-term climate projections.

Climatic uncertainty is related to the climate and biophysical systems as well as to challenges associated with the social dimensions. In this context, scenarios are helpful and powerful tools showing future states and allowing to consider alternative response options (Peterson et al., 2003; Star et al., 2016). The set of alternative scenarios provides a foundation for discussions about policy development, innovation, and community visions. Therefore, scenario planning helps municipalities increase their awareness and understanding of potential future impacts and tailor decision-making and planning processes. They can better understand the potential consequences of their decisions and assess potential trade-offs and synergies.

Box 26. Rivertown: monitoring and improving the RVA

Rivertown recognised the importance of monitoring and improving the RVA process to ensure that the municipality's climate adaptation efforts remain effective and up-to-date. To achieve this, the municipality established a regular review cycle of the RVA, aligning with the CoM reporting requirements of every four years.

The municipality's *Adaptation team*, in collaboration with experts and stakeholders, defined a roadmap and timeline for reviewing and updating the RVA. The team identified the data and variables that required revision and established procedures for regular data updates. For example, the team worked with the local university to update the building stock data, which provided new insights into the municipality 's vulnerability to flooding.

The municipality also reassessed the risks and vulnerabilities identified in the initial RVA, using the same procedures and indicators. The team found that the municipality's exposure to extreme heat and flooding had increased, and that new population groups were vulnerable to these hazards. The team updated the risk matrices and impact indicators to reflect these changes.

The municipality's experience with monitoring and improving the RVA highlighted the importance of adaptive management practices. The *Adaptation team* recognised that climate change is a dynamic and evolving process, and that the municipality's adaptation efforts must be flexible and responsive to changing conditions.

The municipality's monitoring and improvement process also involved engaging with stakeholders and residents to raise awareness and build support for climate adaptation efforts. The municipality used a range of communication tools, including social media, public forums and community meetings to share information and gather feedback in the most targeted manner depending on the addressed stakeholders.

Key lessons learnt from Rivertown's experience with monitoring and improving the RVA include: (1) the importance of establishing a regular review cycle to ensure that the RVA remains up-to-date and effective, (2) the need for adaptive management practices to respond to changing climate conditions and new information, (3) the value of engaging with stakeholders and citizens to raise awareness and build support for climate adaptation efforts, and (4) the importance of using clear and accessible language to communicate complex climate-related information to non-technical audiences.

10 Conclusions

The present document outlined a comprehensive approach to defining the risk and vulnerability assessment (RVA) in a local context, which involves several steps. These steps include identifying and characterising potential hazards, assessing the vulnerability and exposure of communities and assets, understanding their adaptive capacity and evaluating the potential impacts of climate-related stressors. By following this process, municipalities can ensure that their adaptation efforts are targeted and effective, and that they are making the most of their resources.

The choices made in the adaptation process must be informed by available data, including climate projections, socio-economic trends, and local context information. This data will help to understand the potential risks in a given area associated with specific hazards and support municipalities in starting to hint towards potential adaptation actions. By using adequate data, tracking the progress as well as evaluating the effectiveness of future adaptation actions will be eased.

Involving local communities, businesses, and organisations in all phases of the RVA process, can ensure that the adaptation efforts are responsive to the needs and concerns of those who will be the most affected. The engagement of stakeholders will also help to build trust and support for adaptation efforts, and to foster a sense of ownership and responsibility among community members. Moreover, citizen and stakeholder engagement can provide valuable insights and perspectives that might not be captured through data analysis alone and can help to identify innovative and effective adaptation solutions in the future, especially through co-creation processes.

The RVA will need to be carried out within a specific timeline, with key milestones and deadlines established to ensure that progress is made and that adaptation efforts are implemented in a timely and effective manner. This can also help in communication strategies, and collaboration with stakeholders. This timeline will need to be flexible and adaptable to account for changing circumstances and new information.

After having performed the RVA, the next steps involve defining and implementing adaptation actions and continuing to monitor and assess the progress. This will require ongoing engagement with citizens and stakeholders, as well as continuous data collection and analysis to inform decision-making. Additionally, necessary resources will need to be identified and secured to support adaptation efforts and establish partnerships and collaborations with other organisations and agencies to leverage expertise and resources. Further information on the definition and planning of adaptation actions can be found in complementary document 4 "How to develop mitigation, adaptation and energy poverty actions" (Hernández Moral et al., 2025).

Box 27. Rivertown: summary of the RVA process

Rivertown's RVA process was a comprehensive and iterative process that involved multiple stakeholders and steps. The process began with the appointment of the *Adaptation officer* and *Adaptation team* in month 1 and was followed by the establishment of external partnerships and training in months 2-3.

The *Adaptation team* then conducted initial data gathering and community engagement in months 3-6, which involved collecting and analysing data on the municipality's climate-related risks and engaging with stakeholders and citizens to gather local knowledge and identify climate-related concerns.

During this period, Rivertown defined the RVA framework, by determining the geographical scope, temporal scale and choosing the most appropriate methodologies, tools and techniques.

In months 6-10, the *Adaptation team* conducted a risk identification and preliminary analysis, which involved identifying and characterising the climate-related hazards and analysing exposure and vulnerability of the municipality's assets, systems and populations to the identified climate-related hazards. The municipality also evaluated the adaptive capacity of the sectors and population groups.

In months 11-12, the *Adaptation team* drafted the RVA report, which involved synthesising the results and extracting the main risks and impacts based on the hazard identification, and vulnerability and exposure analyses. These analyses set the basis to define the adaptation goals.

The report was reviewed and refined in months 13-14, through solicited feedback from stakeholders and citizens, discussion of the findings and recommendations and revisions of the report.

The final RVA report was then finalised and presented in its final version to the community in months 15-16. In parallel, the *Adaptation team* could start working on their action planning.

Finally, the RVA report was integrated into the climate adaptation plan in month 17.

Key findings and recommendations

The RVA process identified several key findings and recommendations for Rivertown, including:

- The municipality is highly vulnerable to extreme heat and flooding, which could have significant impacts on human health, infrastructure and the economy.
- The municipality's existing infrastructure and buildings are not well adapted to the projected impacts of climate change. Additionally, there are several population groups that could be severely affected by the impacts of the detected hazards.
- The municipality incorporates the findings in terms of RVA into the SECAP.

Next steps

The next steps for Rivertown include:

- Develop climate adaptation actions based on the outcomes of the RVA.
- Continue to engage with stakeholders and citizens to raise awareness and build support for climate adaptation efforts.
- Monitor and evaluate the effectiveness of the SECAP and make adjustments as needed.

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List of abbreviations and definitions

Abbreviations	Definitions
CDS	Climate Data Store
CMIP	Coupled Model Intercomparison Project
CoM	Covenant of Mayors
CRF	Common reporting framework
CSV	Comma-separated values
C3S	Copernicus Climate Change Service
DRM	Disaster risk management
DRMKC	Disaster Risk Management Knowledge Centre
EEA	European Environment Agency
E-OBS	ENSEMBLES daily gridded observational dataset for precipitation, temperature and sea level pressure in Europe
ETC-CCA	European Topic Centre on Climate Change impacts, vulnerability and Adaptation
ETC-SIA	European Topic Centre on Spatial Information Analysis, the predecessor to ETC-ULS – European Topic Centre on Urban, Land and Soil Systems
EU	European Union
EUCRA	European Climate Risk Assessment
GCoM	Global Covenant of Mayors for Climate and Energy
GDP	Gross domestic product
GIS	Geographical information system
GHSL	Global Human Settlement Layer
GRIB	General regularly distributed information in binary form
ICT	Information & communication technologies

Abbreviations	Definitions
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
MCDA	Multi criteria decision analysis
netCDF	Network common data format
OECD	Organisation for Economic Co-operation and Development
RCP	Representative concentration pathway
RVA	Risk and vulnerability assessment
SECAP	Sustainable energy and climate action plan
SMART	Specific, measurable, achievable, relevant, time-bound

List of boxes

List of figures

List of tables

Annexes

Annex 1. Comparative analysis with existing frameworks at EU Level

While the list of climate hazards in the CoM is quite detailed and exhaustive, a summary of most important climate hazards can also be found for comparison in other reference documents such as in Annex II of the Taxonomy Regulation ((EU) 2021/2139, 2021) and in the European Climate Risk Assessment (EUCRA)[1].

The list of climate-related hazards presented in the Taxonomy Regulation (see Table 10 below) constitutes an indicative list of most widespread hazards that are to be taken into account as a minimum in the climate risk and vulnerability assessment and are classified by four main climate drivers (temperature, wind, water, and solid mass movements). Although each specific hazard is related to these main climate drivers some of them might be linked to more than one (e.g., wildfires appear only related to temperature, but it is also linked to wind and water since these are also important for the development of fire hazard). A comparison between the climate hazards considered within the CoM and the Taxonomy Regulation[58] can be found in Table 11**.** While most of the hazards are common in both, the biological hazards are not considered in the Taxonomy Regulation. Conversely, changing meteorological patterns and variability are not considered in the CoM.

Table 10. Classification of climate-related hazards – Taxonomy Regulation

	Temperature-related	Wind-related	Water-related	Solid mass-related
Chronic	Changing temperature (air, freshwater, marine water)	Changing wind patterns	Changing precipitation patterns and types (rain, hail, snow/ice)	Coastal erosion
	Heat stress		Precipitation or hydrological variability	Soil degradation
	Temperature variability		Ocean acidification	Soil erosion
	Permafrost thawing		Saline intrusion	Solifluction
			Sea level rise	
			Water stress	
Acute	Heatwave	Cyclone, hurricane, typhoon	Drought	Avalanche
	Cold wave/frost	Storm (including blizzards, dust and sandstorms)	Heavy precipitation (rain, hail, snow/ice)	Landslide
	Wildfire	Tornado	Flood (coastal, fluvial, pluvial, ground water)	Subsidence
			Glacial lake outburst	

[58] REGULATION (EU) 2020/852 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0852 and REGULATIONS COMMISSION DELEGATED REGULATION (EU) 2021/2139 of 4 June 2021 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 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2139

Source: Taxonomy Regulation ((EU) 2020/852; (EU) 2021/2139)

Table 11. Comparison between the climate hazards of the CoM and the Taxonomy Regulation

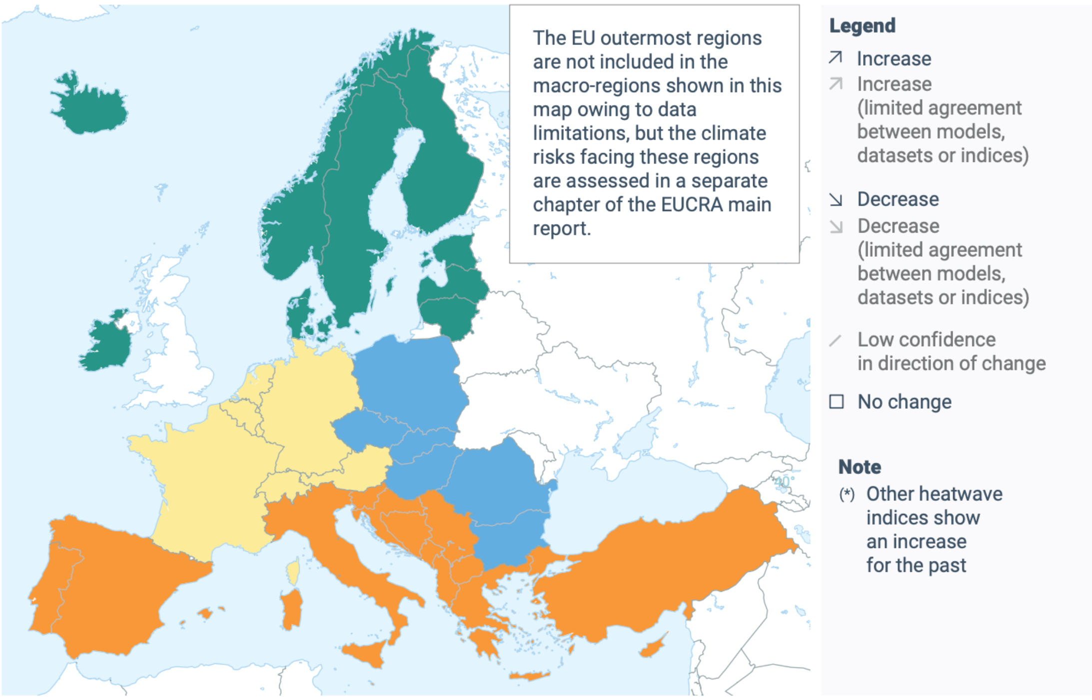
EU CoM	**Taxonomy**
Extreme heat	Heat stress Heatwave
Extreme cold	Cold wave/frost
Heavy precipitation - Heavy rainfall - Heavy snowfall - Fog - Hail	Heavy precipitation (rain, hail, snow/ice)
Floods & sea level rise - Flash / surface flood - River flood - Coastal flood - Groundwater flood - Permanent inundation	Flood (coastal, fluvial, pluvial, ground water) Glacial lake outburst Permafrost thawing
Droughts & water scarcity	Water stress Drought
Storms - Severe wind - Tornado - Cyclone (hurricane / typhoon) - Tropical storm - Extratropical storm - Storm surge - Lighting / thunderstorm	Cyclone, hurricane, typhoon Storm (including blizzards, dust and sandstorms) Tornado
Mass movement - Landslide - Avalanche - Rockfall - Subsidence	Avalanche Landslide Subsidence Solifluction
Wildfires - Forest fire - Land fire	Wildfires
Chemical change - Saltwater intrusion - Ocean acidification - Atmospheric CO_2 concentration	Ocean acidification Saline intrusion
Biological hazard - Water-borne disease - Vector-borne disease - Airborne disease - Insect infestation	

Source: JRC elaboration

While EUCRA is not addressing exhaustively climate hazards, it is an exhaustive assessment of 36 climate risks threatening energy and food security, ecosystems, infrastructure, water resources, financial stability, and public health in Europe. Nevertheless, Figure 5 below, extracted from EUCRA, shows some of the main climate hazards/drivers and how they are expected to change in the future and could be useful when preparing the climate risk and vulnerability assessments.

Figure 5. Observed and projected trends in key climatic risks drivers in different European regions

Land regions	Northern Europe			Western Europe			Central-eastern Europe			Southern Europe			European regional seas		
	Past	Future		Past	Future		Past	Future		Past	Future			Past	Future
		Low	High		Low	High		Low	High		Low	High			
Mean temperature	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	Sea surface temperature	↗	↗
Heatwave days	□(*)	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗			
Total precipitation	↗	*↗*	↗	*↗*	*⟋*	*↘*	*↗*	*↗*	*⟋*	↘	*↘*	↘	Sea level	↗	↗
Heavy precipitation	↗	*↗*	↗	↗	*↗*	↗	↗	*↗*	↗	↗	*↗*	↗			
Drought	*↗*	*↘*	↘	*↗*	*⟋*	↗	*↗*	*⟋*	↗	↗	↗	↗			



Notes: Underlying climate variables are: heatwaves (days with maximum temperatures above 35°C), heavy precipitation (maximum 1-day precipitation), and drought (using a standardised precipitation evapotranspiration index over 6 months (SPEI-6, Hargreaves' method)). Time periods and scenarios are past (1952-2021); future until the end of the century (2081-2100 relative to 1995-2014); low scenario (SSP1-2.6); and high scenario (SSP3-7.0).

Source: Copernicus Climate Change Service (C3S).

Source: EUCRA (European Environment Agency, 2024)

Annex 2. Indicators examples

Table 12. Hazard, exposure, vulnerability and impact indicators examples

Hazard	Hazard indicator [unit]	Exposure	Exposure indicators [unit]	Vulnerability	Vulnerability indicators [unit]	Impact indicator [Unit]
Extreme heat	Temperature above X for X number of days per year [n./y]	Buildings located in the historical centre	Number of buildings located in the historical centre [n.]	Older people	Number of people with age above 65 (living in buildings in the historical centre) [n.]	Number of heat-related illnesses per 100 000 citizens [n./100 000]
Drought and water scarcity	Number of days with rainfall below average per year [n./y]	Municipal water supply infrastructures	Length of municipal water supply infrastructures [km]	Low-income households	Percentage of households not able to purchase water [%]	Number of people affected by water scarcity [n. persons]
Coastal erosion/sea level rise	Number of coastal flooding events per year [n./y]	Coasts composed of soft sediment and narrow sand areas	Length of coasts composed of soft sediment and narrow sand areas [km]	Tourism	Number of touristic business (located along the coast) that have ceased operation [n.]	Loss in tourism revenue due to beach erosion [million €]
Mass movement [landslides]	Number of landslides per year in a given area [n./y]	Transport infrastructures located within the area of landslide inventory maps	Total length of roads located within the area of landslide inventory maps [km]	Education / transport	Number of students that could not reach education facilities [n.] Number of days of road closure [n.]	Damage to transport infrastructure due to landslides [million €/km of roads affected]
Wildfires	Amount of burned area [square meter]	Population located in areas prone to fires	Percentage of population located in areas prone to fires [%]	People with disabilities	Percentage of residents with disabilities [%]	Number of evacuated people with post fires pathologies [n.]
Floods	Occurrences of floods per year [n./y]	Built-up area exposed to flooding with a specific return period	The built area potentially affected by flooding/inundation in the specific period [square meters]	Residents in the ground or first floors of buildings	Number of people living in the ground or first floors of buildings within the area prone to flood [n.]	Number of households with buildings permanently damaged [n.]

Source: JRC elaboration

Annex 3. Adaptation goals examples

This annex complements section 7 supporting the definition of adaptation goals.

Table 13. Adaptation goals examples and related adaptation actions[59]

Adaptation goal	Main objective [Main Adaptation sectors]	Hazard	Indicator [Unit]	Base value [year]	Target value [year]	Potential adaptation actions
Decrease the risk of heat-related illnesses in the community by 40% by 2030	Decrease overall risk level [Civil protection & emergency, Buildings]	Extreme heat	Number of heat-related illnesses [n. cases]	100 cases [2020]	60 cases [2030]	(1) Establish a heatwave early warning system, (2) conduct public education campaigns, (3) provide cooling centres (e.g. public buildings), (4) improve building design / refurbishment actions, etc.
Reduce the risk of landslides in the mountainous region by 35% by 2028	Decrease overall risk level [Land use planning, Environment & Biodiversity, Civil protection & emergency]	Mass movement	Number of landslides [n. cases]	20 landslides [2020]	13 landslides [2028]	(1) Implement land use planning measures, (2) clear vegetation and debris from landslide-prone areas, (3) develop evacuation plans, (4) develop landslide risk reduction plans, (5) implement reforestation and afforestation programmes, (6) community-based landslide risk management, etc.

[59] Further insights into adaptation actions can be found in Covenant of Mayors Guidebook | Complementary document 4 JRC142138

Adaptation goal	Main objective [Main Adaptation sectors]	Hazard	Indicator [Unit]	Base value [year]	Target value [year]	Potential adaptation actions
Decrease the risk of waterborne diseases in the community by 40% by 2030	Decrease overall risk level [Water]	Biological	Number of water-borne disease cases [n. cases]	100 cases [2024]	60 cases [2030]	(1) Implement a water quality monitoring plan and climate-resilient water treatment systems, (2) improve water infrastructure, (3) implement wastewater management systems, (4) develop rainwater harvesting systems, etc.
Protect 80% of the agricultural land in the flood-prone area by 2030	Decrease exposure, Reduce vulnerability [Land use planning, Agriculture and forestry]	Floods	Area of agricultural land protected [hectares]	None of the total 5 000 hectares [2024]	4 000 hectares [2030]	(1) Design and plan flood-control measures (levees, dikes, floodwalls…), (2) develop climate-resilient agricultural practices, (3) develop a flood warning system, (4) implement natural flood-control measures (wetlands, floodplains, etc.)
Protect 90% of the (critical) energy infrastructure in the flood-prone area by 2027	Decrease exposure, reduce vulnerability [Buildings, Civil protection & emergency, Water, Land use planning]	Floods	Area of critical infrastructure protected [square meters]	None of the total 10 000 square meters [2019]	9 000 square meters [2027]	(1) Design and plan flood-control measures (levees, dikes, floodwalls…), (2) develop a flood emergency response plan, (3) implement temporary flood protection measures (sandbags, portable flood barriers, etc), (4) elevate critical infrastructure, (5) refurbish with the use of flood-resistant materials, (6) implement smart flood monitoring systems, etc.
Protect 85% of the coastal ecosystem from the impacts of sea-level rise and storm surges by 2031	Decrease exposure, Reduce vulnerability [Environment and biodiversity, Civil protection & emergency, Land use planning]	Sea-level rise, storms	Area of coastal ecosystem protected [hectares]	None of the total 10 000 hectares [2020]	8 500 hectares [2031]	(1) Restore natural barriers (e.g. mangroves, dunes), (2) develop a storm surge warning system, (3) develop a coastal erosion management plan, (4) implement a coastal protection program, etc.

Adaptation goal	Main objective [Main Adaptation sectors]	Hazard	Indicator [Unit]	Base value [year]	Target value [year]	Potential adaptation actions
Reduce water scarcity by 20% by 2030	Reduce sector's vulnerability (and/or exposure) [Water]	Drought and water scarcity	Days with water scarcity in a year [n. days]	50 [2018]	37 [2030]	(1) Implement water saving measures, (2) develop and implement water recycling and reuse systems, (3) implement rainwater harvesting systems, (4) implement water pricing strategies and incentives to encourage water conservation and efficiency, etc.
Reduce the number of road closures due to landslides by 50% by 2029	Reduce sector's vulnerability and exposure [Transport, Civil protection & emergency, Land use planning]	Mass movement	Number of road closures [n. cases]	50 closures [2019]	25 closures [2029]	(1) implement landslide mitigation measures (slope stabilisation, retaining walls, drainage improvements, etc), (2) upgrade road infrastructure, (3) use landslide-resistant materials, (4) develop emergency response plans, (5) enforce building codes and regulations, etc.
Reduce medical supply chain disruptions due to storms and floods by 60% by 2031	Reduce sector's vulnerability and exposure [Health, Civil protection & emergency, Land use planning]	Storms and floods	Number of medical supply chain disruptions [n. cases]	20 disruptions [2017]	8 disruptions [2031]	(1) Develop supply chain risk management plans, (2) develop emergency stockpiling plans and facilities, (3) develop alternative logistic routes and establish partnerships with logistics providers, (4) implement flood-proofing measures, (5) establish emergency response teams and communication networks, etc.
Reduce crop failure of small-scale farmers due to drought by 75% by 2032	Reduce population groups' and sector's vulnerability [Agriculture and forestry, Water, Other (insurance)]	Drought and water scarcity	Number of crop failures [n. cases]	100 failures [2023]	25 failures [2032]	(1) Promote and disseminate drought-tolerant crop varieties through seed distribution, (2) implement conservation agriculture (e.g. no-till or reduced-till farming), (3) promote cover cropping, (4) promote efficient irrigation systems and water harvesting, (5) promote climate-smart agriculture (e.g. agroforestry), (6) develop weather-based insurance products, etc.

Adaptation goal	Main objective [Main Adaptation sectors]	Hazard	Indicator [Unit]	Base value [year]	Target value [year]	Potential adaptation actions
Reduce hypothermia of vulnerable populations due to extreme cold to zero by 2029	Reduce population groups' vulnerability and exposure [Health, Education, Civil protection & emergency]	Extreme cold	Number of hypothermia cases among vulnerable populations [n. cases]	20 cases [2020]	0 cases [2029]	(1) Provide financial assistance for home insulation, (2) promote energy-efficient appliances and heating systems, (3) develop emergency preparedness plans, (4) establish emergency shelters, (5) provide emergency heating and cooling assistance, (6) conduct public education campaigns and hold workshops, (7) conduct home visits and assessments, etc.
Reduce the incidence of waterborne diseases in indigenous communities due to heavy precipitation and flooding by 80% by 2032	Reduce population groups' vulnerability and exposure [Health, Water, Education]	Biological hazards	Number of waterborne disease cases among indigenous communities [n. cases]	50 cases [2023]	10 cases [2032]	(1) Improve water treatment infrastructure, (2) develop emergency water treatment protocols, (3) implement rainwater harvesting systems, (4) implement flood protection measures, (5) conduct community education and awareness campaigns, (6) provide health and social services, (7) establish community shelters, etc.
Enhance the capacity of the municipality to respond to droughts, floods and heavy precipitation emergencies by 50% by 2026	Increase sectors' adaptive capacity (factors) [Civil protection & emergency, Land use planning]	Droughts, floods, heavy precipitation	Number of trained personnel [n. persons]	10 people [2024]	15 people [2026]	(1) Develop a comprehensive emergency response plan and conduct regular emergency response drills, (2) establish an emergency operations centre, (3) conduct regular training exercises / establish a mentorship programme, (4) establish a data management system, (5) develop a geographic information system (GIS), etc.
Increase the number of climate-resilient touristic infrastructure by 30% by 2033	Increase sectors' adaptive capacity (factors) [Tourism, Buildings, Civil protection & emergency, Water,]	Extreme heat, water scarcity, floods	Number of climate-resilient touristic infrastructure [n. infrastructures]	100 infrastructures [2024]	130 infrastructures [2033]	(1) Design and refurbish buildings to be climate-resilient, (2) implement water-saving measures and energy-efficient systems, (3) develop/adapt transport systems to make them resilience to climate change (elevated roads, reduced impervious surfaces in cycle lanes, etc), (4) implement climate-resilient tourist management practices (crowd control, emergency preparedness plans), etc.

Adaptation goal	Main objective [Main Adaptation sectors]	Hazard	Indicator [Unit]	Base value [year]	Target value [year]	Potential adaptation actions
Enhance the adaptive capacity of the transport infrastructure to extreme weather events (floods and mass movement) by 30% by 2030	Increase sectors' adaptive capacity (factors) [Transport Civil protection & emergency, Other]	Flood, mass movement	Length of climate-resilient transport infrastructures [kilometres]	500 Km [2024]	650 Km [2030]	(1) Develop and implement climate-resilient construction standards for transport infrastructure, (2) implement asset management practices to prioritise maintenance and repair of transport infrastructure, (3) develop and implement emergency response plans for transport infrastructure (minimise disruption), (4) research new technologies and materials to enhance resilience of transport infrastructure, etc.
Reduce the economic loss of tourism sector due to climate-related disasters by 40% by 2026	Decrease overall impacts [Buildings, Land use planning, Other (insurance)]	Floods	Economic loss [€]	€ 100 million [2020]	€ 60 million [2026]	(1) Develop climate-resilient policies and regulations, (2) provide funding and resources to support climate-resilient initiatives, (3) implement climate-resilient financial instruments (e.g. climate-risk insurance), (4) upgrade critical infrastructure, etc.
Reduce the number of invasive species by 40% by 2035	Decrease overall impacts [Environment and biodiversity, Civil protection & emergency, Land use planning, Other (research)]	Extreme heat	Number of invasive species [n. species]	12 species [2018]	7 species [2035]	(1) Develop early warning systems, (2) implement biosecurity measures (quarantines and inspections of invasive species), (3) implement control and eradication efforts, (4) restore degraded habitats promoting native species, (5) conduct research on invasive species, etc.
Protect 80% of cultural heritage sites from climate-related damage derived from heavy precipitation and storms by 2032	Decrease overall impacts and reduce vulnerability [Buildings, Land use planning, Water, Education, Other]	Heavy precipitation and storms	Number of heritage sites protected [n. sites]	None of the total 10 heritage sites [2024]	8 heritage sites [2032]	(1) Upgrade drainage systems, (2) use climate-resilient materials, (3) implement conservation measures (waterproofing, stabilisation), (4) engage local communities in conservation efforts, (5) provide funding to support climate-resilient conservation and management of cultural heritage sites.

Source: JRC elaboration

Annex 4. Additional resources

- CoMo_Case Studies library: https://eu-mayors.ec.europa.eu/en/resources/library
- Abad, J., Booth, L., Baills, A., Fleming,K., Leone, M., Schueller,L., Petrovic, B (2020).Assessing policy preferences amongst climate change adaptation and disaster risk reduction stakeholders using serious gaming, International Journal of Disaster Risk Reduction, Volume 51, ISSN 2212-4209, https://doi.org/10.1016/j.ijdrr.2020.101782.
- Corporate Guidance on Citizen Engagement: https://cop-demos.jrc.ec.europa.eu/resources/corporate-guidance-citizen-engagement
- EU research contribution to IPCC Working Group II on Impacts, Adaptation and Vulnerability. Providing solutions, enabling resilient environment (2022): https://cinea.ec.europa.eu/publications/eu-research-contribution-ipcc-working-group-ii-impacts-adaptation-and-vulnerability_en
- Full policy brief on Stakeholder Engagement in Climate Adaptation: https://ec.europa.eu/newsroom/clima/items/866100/
- IAP2 International association for public participation: https://www.iap2.org/page/pillars
- International Disaster Database: https://www.emdat.be/
- OECD Guidelines for Citizen Participation Processes | OECD https://www.oecd.org/en/publications/oecd-guidelines-for-citizen-participation-processes_f765caf6-en.html
- OECD Local Data Portal: https://localdataportal.oecd.org/
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