Climateurope2

Guidelines on how to enhance data tools and knowledge for climate impacts, extremes and risks through standardisation of climate services

Deliverable 2.10

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This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056933.

Document Information

GRANT AGREEMENT	101056933
PROJECT TITLE	Supporting and standardizing climate services in Europe and beyond
PROJECT ACRONYM	Climateurope2
PROJECT START DATE	01/09/2022
RELATED WORK PACKAGE	WP2
RELATED TASK(S)	T2.4
LEAD ORGANIZATION	Ramboll
AUTHORS	Lilian Loyer, Rutger Dankers, Xavier Domingo, Andrea Taylor, Suraje Dessai, Charlotte Pascoe, Gwendoline Lacressonniere
SUBMISSION DATE	APR-26
DISSEMINATION LEVEL	Final

History

DATE	SUBMITTED BY	REVIEWED BY	VISION (NOTES)
07-04-2026	Lilian Loyer	Jorge Paz Jimenez	Draft
30-04-2026	Lilian Loyer	Jorge Paz Jimenez	Final

Please cite this report as: Loyer, L., Danker, R., Domingo, X., Taylor, A., Dessai, S., Pascoe, C., Lacressonniere, G., (2026), Guidelines on how to enhance data tools and knowledge for climate impacts, extremes and risks through standardisation of climate services, D2.10 of the Climateurope project
Disclaimer: *Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.*

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About Climateurope2

Timely delivery and effective use of climate information is fundamental for a green recovery and a resilient, climate neutral Europe, in response to climate change and variability. Climate services address this through the provision of climate information for use in decision-making to manage risks and opportunities.

The market and needs for climate information have seen impressive progress in recent years and is expected to grow in the foreseeable future. However, the communities involved in the development and provision of climate services are often unaware of each other and lack interdisciplinary and transdisciplinary knowledge. In addition, quality assurance, relevant standards, and other forms of assurance (such as guidelines, and good practices) for climate services are lagging behind. These are needed to ensure the saliency, credibility, legitimacy, and authoritativeness of climate services, and build two-way trust between supply and demand.

Climateurope2 aims to develop future equitable and quality-assured climate services to all sectors of society by:

- Developing standardization procedures for climate services
- Supporting an equitable European climate services community
- Enhancing the uptake of quality-assured climate services to support adaptation and mitigation to climate change and variability

The project will identify the support and standardization needs of climate services, including criteria for certification and labelling, as well as the user-driven criteria needed to support climate action. This information will be used to propose a taxonomy of climate services, suggest community-based good practices and guidelines, and propose standards where possible. A large variety of activities to support the communities involved in European climate services will also be organized.

Executive Summary

This report, developed within the Climateurope2 project, provides guidelines to enhance the quality, usability, and standardisation of climate services for assessing climate impacts, extremes, and risks. This report seeks to identify commonalities and extract recommendations that could feed into standardisation for climate risk assessment, covering the full workflow from the design of climate services to communication and decision support. It is structured into nine sections, each addressing a key step in the assessment process.

A key challenge identified is the lack of harmonisation across climate risk assessment methodologies, definitions, and tools. This fragmentation limits comparability, transparency, and trust in climate services. To address this, the report proposes a structured and standardised approach grounded in internationally recognised frameworks, particularly the IPCC framework, which defines climate risk as the interaction between hazard, exposure, and vulnerability.

The report covers the full climate risk assessment workflow. It begins with problem framing, emphasising the importance of consistent definitions, alignment with regulatory frameworks, and clear scoping based on objectives, system boundaries, and time horizons. Increasing regulatory expectations, including those related to disclosure and risk management, reinforce the need for transparent, scientifically robust, and auditable approaches.

A central component of the report is the assessment of climate hazards, including their identification, prioritisation, and quantification. The guidelines recommend the use of standardised hazard classifications, multi-scenario and multi-horizon analyses, and explicit consideration of uncertainty. The importance of addressing compound and cascading risks is also highlighted, reflecting the interconnected and dynamic nature of climate impacts.

The report further outlines approaches for analysing exposure and vulnerability, recognising that risk is context-specific and requires integrating spatial, socioeconomic, and adaptive capacity dimensions. It also highlights current limitations in data availability and methodological consistency, particularly in relation to vulnerability and indirect exposure.

Ensuring data quality, scientific robustness, and transparency is identified as a critical requirement throughout the assessment process. The report emphasises the need for clear documentation of data sources, methods, assumptions, and limitations, as well as the application of criteria such as suitability, credibility, and legitimacy.

The integration of hazard, exposure, and vulnerability into overall risk evaluations is complemented by guidance on effective communication. The report promotes user-centred approaches that present complex information in accessible ways while maintaining scientific integrity, including clear communication of uncertainty.

Finally, the report highlights the role of climate risk assessment in supporting decision-making and adaptation. By linking risk analysis to actionable outcomes, it contributes to strengthening resilience and informing strategic planning across sectors.

Keywords

Standardization, Climate Risk Assessment, Climate Impacts, Climate Extremes, Climate Services.

Recommendation for the standardisation of climate service for climate risk assessment

RECOMMENDATION	RATIONALE	SOURCE
Adopt the IPCC definition of climate risk and a controlled taxonomy aligned with EU frameworks	Inconsistent definitions of "risk," "hazard," "exposure," and "vulnerability" undermine comparability and quality assurance. Adopting the IPCC framework and aligning hazard categories with EU guidance establishes a common language across projects and improves defensibility for clients and regulators. Use a stakeholder-checked glossary, apply clear distinctions (e.g., multi-hazard vs. multi-risk), and mandate consistent use across deliverables and training.	Loyer et al, (2024), White et al, (2025), DG CLIMA
Mandate end-to-end methodological transparency and documentation to	Explainable, auditable, and reproducible assessments require clear documentation of methods, assumptions, data provenance, validation, limitations, and versioning across the full processing chain. Disclose climate models and data sources	A Buyer's Guide, Breitenstein et Al. (2022), ECB

ensure regulatory readiness and defensibility	used (e.g. GCMs, RCMs, reanalysis, etc) and selection rationale, key processing steps (e.g., bias correction, downscaling, exposure/vulnerability construction, aggregation), and whether climate change risk approaches are qualitative/quantitative and entity/sector-level. Set minimum transparency standards for vendors and provide accessible technical documentation and support to enable scrutiny and integration in regulated settings.	(2022), CFRF (2024)
Build on scientifically rigorous, validated methods and disclose key techniques and limitations across the processing chain	Using physically realistic models, appropriate bias correction and scientifically defensible downscaling, and validation against observations and historical events improves reliability and trust. Clear disclosure of technique choices, rationale, and known limitations, and when possible expert review allows users to judge fitness-for-purpose and traceability.	Jupiter Intelligence (2025)
Explicitly quantify and communicate uncertainty across all stages of the assessment	Future climate and risk information is inherently uncertain. Quantifying and communicating uncertainty (e.g., multi-model/ensemble spread, scenario variation, confidence intervals) supports better decisions and avoids false precision across hazards, exposure, vulnerability, and methods. Identify and document key uncertainty sources and provide clear confidence statements so users can understand limits and caveats.	Loyer et al., (2024), Jupiter (2025), Poljansek et al., (2021), UNDRR and WMO (2023)
Use multi-scenario, multi-horizon analyses anchored to a clear baseline and treat scenarios as plausible futures, not predictions	Integrate present conditions with short-, medium-, and long-term projections, referenced to an explicit baseline (e.g., climate normals), and use multiple IPCC-consistent scenarios (or GWL framing) to characterize uncertainty. Treat scenarios as plausible narratives rather than forecasts, focus on relative differences and robustness, and align time horizons with asset or planning lifecycles.	Loyer et al., (2024), Tavares et al., (2023), Poljansek et al, (2021), UNDRR and WMO (2023), CLIMAAX. (2026)
Where relevant to the context, account for compound, cascading, and dynamic interrelationships among hazards and impacts, and develop indicators and storylines to capture them	Real-world losses often arise from interacting hazards and evolving exposure/vulnerability. Assess dependencies (e.g., joint and conditional probabilities), consider cascading pathways and feedbacks, and complement statistical analysis with plausible multi-hazard storylines. Develop and integrate indicators that quantify these interrelationships to provide a more realistic and actionable view of risk.	Gill et al, (2022), White et al., (2025), Loyer et al, (2024), Simpson et al., (2021), Jupiter (2025), Ward et al, (2026)
Select hazards and data sources to be fit-for-purpose	Applying structured selection criteria, suitability (hazards, spatial/temporal scope, time horizons match the decision), credibility (scientific robustness and methodological	Tavares et al., (2023), CFRF (2024)

	soundness), and legitimacy (transparent, impartial sources), ensures the assessment fits its context. Document the choices and trade-offs so stakeholders can understand applicability and limitations.	
Adopt user-centred design and communication practices to reduce cognitive load while preserving scientific integrity	Co-produced, accessible outputs improve understanding and use. Provide simple, audience-appropriate views backed by robust detail; ensure visuals carry one key message, match text to graphics, use intuitive colour/salience, ensure accessibility, and supply clear context and explanations. This reduces misinterpretation without oversimplifying.	Interviews, Craig et al. (2025), Kause et al, (2020), DG CLIMA

1 Introduction

Climate change is reshaping physical, social, and economic systems across Europe and beyond, creating urgent demand for reliable, decision-ready information on climate impacts, extremes, and risks. In this context, climate services play a critical role in supporting the management of climate-related risks and the impacts of extreme events. While a wide range of data, tools, and knowledge is already used by scientists and practitioners to assess potential climate impacts, progress in harmonising approaches and ensuring the use of quality-assured data and tools has lagged behind.

Climateurope2 addresses this gap by aiming to advance equitable and quality-assured climate services for all sectors of society. This is achieved through the development of standardisation procedures, the strengthening of an inclusive European climate services community, and the promotion of the uptake of high-quality climate services to support both adaptation to and mitigation of climate change and variability. Within this framework, WP2 (Data and Processes) focuses on developing guidelines to enhance the salience and usability of data, tools, and knowledge for assessing climate impacts, extremes, and risks. The present report provides these guidelines, including recommendations for standardisation, informed by a comprehensive review of existing literature, relevant projects, and international initiatives to identify best practices and remaining gaps

1.1 Objectives and scope of the report

This report seeks to identify commonalities and extract recommendations that could feed into standardisation for climate risk assessment, covering the full workflow from the use of climate services to communication and decision support. It is structured into nine sections, each addressing a key step in the assessment process.

Following this introduction, Section 2 outlines the preliminary phases of the assessment, including definitions of climate risk, regulatory expectations and requirements, and the scoping phase. Section 3 focuses on climate hazards, including their identification, selection, and assessment under present and future conditions, as well as compound and cascading hazards. Section 4 describes approaches to assessing exposure and vulnerability. Section 5 explains how to identify and select relevant data for the assessment. Section 6 presents methodologies for integrating these components to derive risk. Section 7 addresses the communication of climate risk. Section 8 explores how climate change risk assessments can inform decision-making and adaptation measures. Finally, Section 9 highlights tools that support the assessment of climate risks.

1.2 Recommendations

The recommendations presented in this report were developed through a mixed-methods approach combining multiple complementary sources of evidence and expertise. This included the identification of best practices and gaps based on the previous report of the Climateurope project D2.5 “Inventory of data tools and knowledge for climate impacts, extremes and risks for the formulation of standards that can increase their quality and usefulness” (Loyer et al. (2024)), alongside a systematic review of academic and grey literature to capture recent methodological developments and emerging trends. These insights were further enriched through stakeholder interviews, which provided practical perspectives on user needs, constraints, and priorities from private climate services, as well as through expert workshops that enabled the validation of the recommendations for standardisation.

While the recommendations presented in this report reflect best practices for robust and comprehensive climate risk assessments, their implementation in climate services should be guided by the principle of proportionality. Not all climate services have the same objectives, resources, or constraints, and it may not be feasible or necessary to apply all recommendations in every context. Developers and practitioners should therefore prioritise actions based on user needs, decision context, available resources, and practical feasibility. A transparent and fit-for-purpose approach is essential to ensure that climate services remain usable, efficient, and sustainable.

2 Framing the Problem

2.1 Definition of a climate risk

Table 1. Recommendation for the definition of climate risk

RECOMMENDATION	RATIONALE	SOURCE
Standardize definition of risk and its components	The IPCC is the leading authority on climate change and most recent standards refer to IPCC reports, it makes sense to adopt the IPCC's definition of risk for climate change risk assessments to avoid inconsistent use of vocabulary.	Loyer et al. (2024)
Integrating Physical and Transition Risks	Most standards or guidelines focus exclusively on physical risk, with a few considering both risks. Standards and guidelines from economic and financial sectors are more likely to address transition risk, whereas those from other sectors often do not.	Loyer et al. (2024)
Aligned with the IPCC framework	The IPCC AR5 and AR6, define risk as the composite of three components: exposure, hazard and vulnerability.	Loyer et al. (2024), DGs Quotation

This guide follows the framework developed by the Intergovernmental Panel on Climate Change (IPCC). This approach is now widely used across scientific assessments, public policy, financial regulation, and climate services (Loyer et al. (2024)) because it provides a clear and decision-relevant way to understand how climate change can affect assets, systems, organisations, and societies.

In the IPCC framework, climate risk refers to the interaction of three components:

- Hazard: *The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.* (IPCC)

- 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)

- Vulnerability: *The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.* (IPCC)

Risk is the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems (IPCC). Risk emerges from dynamic interactions between all three components.

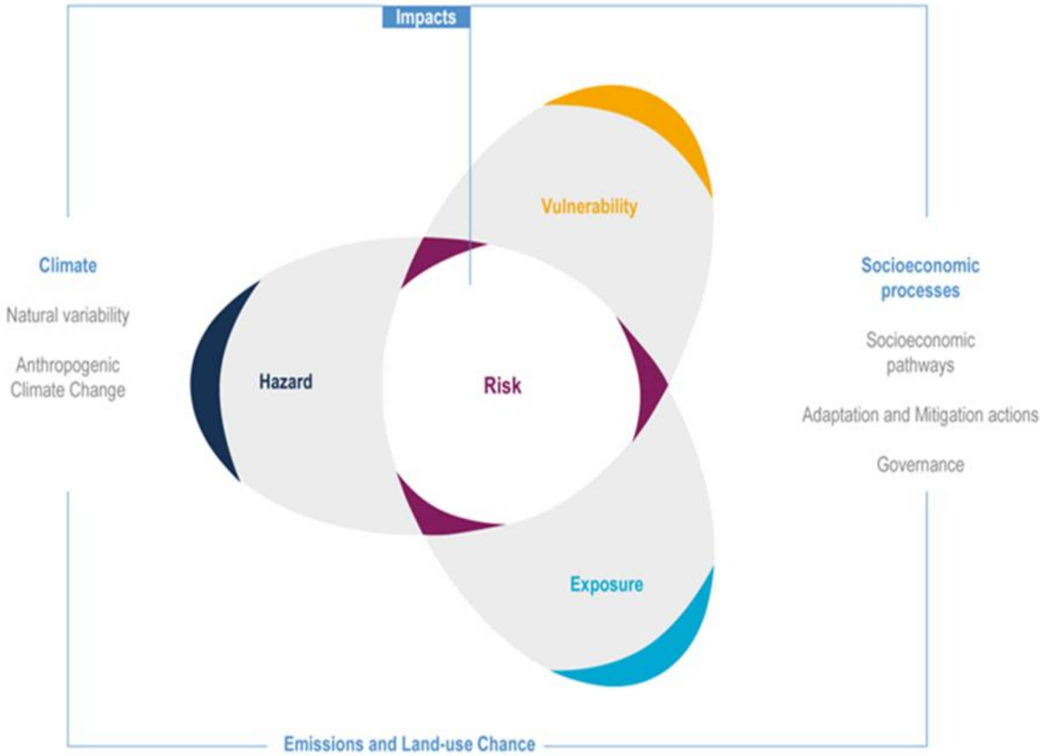

Figure 1. The IPCC conceptual framework with risk at the center from figure 1.5 of Climate Change 2022: Impacts, Adaptation, and Vulnerability

A severe hazard does not automatically imply high risk if exposure is low or vulnerability is limited. Conversely, even moderate hazards can lead to high risk when highly vulnerable and exposed systems are involved.

A common source of confusion is the tendency to treat these concepts as interchangeable (Loyer et al. (2024)):

- Risk describes potential for adverse consequences, not hazards.
- Hazards describe climate phenomena, not impacts.
- Exposure describes what is in harm's way, not how badly it will be affected.
- Vulnerability describes how damage occurs, not how often hazards happen.

Keeping these distinctions, clear helps avoid misinterpretation, supports transparency and comparability, and enables targeted risk reduction strategies.

A special mention should be made of Annex II of the IPCC Sixth Assessment Report (AR6), which introduces a fourth component of climate risk: the response to adaptation (Simpson et al. (2021)). This component refers to the consequences, intended or unintended, arising from adaptation actions, including potential maladaptation and associated residual risks (Simpson et al. (2021)). Although the concept is beginning to emerge in the literature (ECB (2022), Breitenstein et Al. (2022)), it remains insufficiently developed and consolidated to be formally integrated into this report for standardization purposes.

In applied and regulatory contexts, the framework for climate risks can be distinguished into two broad categories:

- Physical risks: which arise from the direct impacts of climate change on natural and human systems. These include:
  - Acute Hazards from extreme events such as storms, floods, or heatwaves.
  - Chronic Hazards from long-term trends such as rising temperatures or sea-level rise.

- Transition risks: arise from the societal response to climate change and the transition towards a low-carbon and climate-resilient economy. These risks are not driven by physical climate processes themselves, but by:
  - regulatory changes
  - technological disruption
  - shifts in markets,
  - reputational impacts

This guide focuses primarily on physical climate risks, as these require explicit integration of climate data. Transition risks are acknowledged where relevant, but they are not treated in depth, as they rely on different analytical approaches and non-climate data sources.

2.2 Regulatory and disclosure expectations

Table 2. Recommendation for regulation and disclosure

RECOMMENDATION	RATIONALE	SOURCE
Integrating Physical and Transition Risks	Most standards or guidelines focus exclusively on physical risk, with a few considering both risks. Standards and guidelines from economic and financial sectors are more likely to address transition risk, whereas those from other sectors often do not.	Loyer et al. (2024), DRFIP (2022)
Model Transparency	Disclosing the specific Global Climate Models (GCMs) used, justifying their selection, and providing end-to-end documentation detailing how model bias was corrected and how the results should be interpreted for decision-making	Jupiter (2025)
Regulatory Readiness and Defensibility	The methodology must be transparent and well-documented with clear assumptions and scientific references, enabling the organization to justify the outputs to third parties, boards, and regulators	Jupiter (2025)
Provide Access and Support	Comprehensive technical documentation must be readily available, as the data needs to be understood, stress-tested, and integrated into workflows, particularly in high-stakes, regulated environments	Jupiter (2025)
Data Quality and Transparency	Provide transparency on the methodologies, criteria, and assumptions employed in both internal reports and public disclosures, and regularly reassess the appropriateness of their data sources	ECB (2022)

Disclose Climate Risk assessmentModels and Methods	Providing information on, data, rating criteria, transparency on the models and methods used for Climate Change Risk assessments, including whether these are of a qualitative or quantitative nature and whether these were conducted at the entity or sector level, would allow the user to better understand the conclusion on relevance and materiality of Climate Change Risk	Breitenstein et Al. (2022)
Ensure Clear Deliverables	Ensure that deliverables are clear and comprehensive, tailored to each specific element of the organisation, consistent with regional or national risk assessments, use the best available knowledge, are up-to-date and easily accessible to senior leadership and relevant staff.	Tavares et Al. (2024)
Aligned with standards	Choose tools and approaches that align with standards and frameworks (e.g., ISO 31010, ISO 14091)	Poljansek et Al. (2021)
Aligned with EU Taxonomy	Aligned with the definition of acute & chronic hazards	DGs Quotation
Aligned with the IPCC framework (Exposure, Hazard, Vulnerability)		DGs Quotation

Climate change risk assessments are increasingly shaped by regulatory expectations and disclosure requirements across financial, corporate, and public sectors. Over the past decade, regulators have moved from voluntary sustainability reporting towards more structured and enforceable frameworks designed to improve transparency, comparability, and accountability in climate risk management. In the European context, the Corporate Sustainability Reporting Directive (CSRD) significantly expands the number of companies required to disclose climate-related risks, both physical and transition.

Several regulatory and methodological frameworks guide how climate risks should be assessed and disclosed. These include international standards for risk assessment (e.g., ISO 14091 and ISO 31010), regulatory frameworks such as the EU Taxonomy, and disclosure-oriented frameworks including the Task Force on Climate-related Financial Disclosures (TCFD), Equator Principles (EP4) and European Sustainability Reporting Standards (ESRS). These frameworks encourage organisations to systematically identify climate-related hazards, evaluate exposure and vulnerability, and communicate results transparently to stakeholders (Loyer et al. (2024)).

Most climate risk standards follow the conceptual framework developed by the Intergovernmental Panel on Climate Change (IPCC), which defines risk as the interaction between hazard, exposure, and vulnerability. This framework is widely adopted across climate change risk assessments and policy guidelines in general because it provides a structured method for analysing how climate hazards affect specific systems or assets (Loyer et al. (2024)).

Regulatory bodies increasingly expect organisations to integrate climate risks into their governance, risk management, and reporting processes. Supervisory authorities such as the European Central Bank (ECB) require banks to incorporate climate risk into stress-testing frameworks and strategic planning. Climate risk stress tests evaluate both physical climate hazards (e.g., floods, heatwaves, droughts) and transition risks associated with policy changes, technological shifts, and market transformations during the transition to a low-carbon economy (ECB (2022)). Despite this progress, regulatory expectations are still evolving, and approaches remain heterogeneous across institutions. For example, assessments of climate risk in credit ratings reveal considerable differences in methodologies, definitions, and disclosure practices between rating agencies using the same framework (Breitenstein et Al. (2022)).

Despite growing expectations, many organisations still face significant challenges in implementing a climate risk assessment. A key gap identified in existing guidance is the imbalance between the treatment of physical and transition risks. Most climate risk standards provide detailed methodologies and tools for evaluating physical risks, while comparatively few offer robust frameworks for assessing transition risks independently. As a result, transition risk assessments are often less structured and more qualitative (Loyer et al. (2024)). Even though some standards expect to evaluate both categories of risk. Climate stress-testing exercises, for example, incorporate multiple scenarios covering acute physical hazards alongside short-term and long-term transition pathways. Another example is the Principle of the Equator which requires both a physical and transition risk for a project with a GHG emission above 100,000 tCO2/year threshold (EP4 (2023)).

Another common gap is insufficient methodological transparency. Organisations sometimes rely on proprietary or “black-box” assessment approaches without fully documenting assumptions or methodological choices (UNEP FI (2023)). This limits the ability of regulators and stakeholders to evaluate the credibility of results.

Another recurring challenge is data availability and quality. climate change risk assessments often rely on proxy data due to limited corporate disclosures, particularly regarding climate exposures and vulnerabilities. As a result, institutions frequently produce inconsistent estimates and modelling results.

As regulation grows, regulators increasingly expect climate change risk assessments to be transparent, scientifically grounded, and auditable. Several common expectations emerge across regulatory guidance and supervisory reviews:

- Organisations must be able to clearly explain the analytical methods, assumptions, and data sources used in climate risk assessments. Providing information on data inputs, rating criteria, and methodological approaches (Breitenstein et Al. (2022)).
- Regulatory frameworks emphasise the importance of disclosing the models, data sources, and analytical methods used in assessments. This includes documenting the climate models used, justifying their selection, data limitations, methodological assumptions, and describing how biases in model outputs were corrected and interpreted (Jupiter (2025))[1].
- Organisations are expected to conduct comprehensive climate change risk assessments covering physical and in some cases transition risks, using scenario analysis and transparent disclosure of methodologies and material risks.
- Climate risks are expected to be integrated into broader organisational processes such as strategy, risk management, and capital allocation. Climate change risk assessments should be accessible and understandable for decision-makers. Reports must clearly communicate key findings, assumptions, and uncertainties, ensuring that outputs can support strategic planning and risk mitigation (ECB (2022), European Commission (2021)).

2.3 Setting the scope before the assessment

[1] INTERVIEW, ELENA MAKSIMOVITCH, 17/09/2026

Table 3. Recommendation for setting the scope

RECOMMENDATION	RATIONALE	SOURCE
Setting the scope of the assessment	All standards and guidelines emphasize the need for a properly defined climate risk assessment. A climate risk assessmentis always relevant to its subject, whether it is an asset, a system, an organisation or a community. Climate change is a complex issue, and the preparation should correctly consider the location of the site, the objectives of the assessment (screening, risk assessment, adaptation measure, etc), the lifespan of the system or activity, and whether to consider chain values. Additionally, data and expertise on exposure and vulnerabilities should be gathered, and experts and stakeholders should be identified	Loyer et al. (2024)
Scenario analysis	Most standards agree that a scenario analysis of the likelihood and magnitude of hazards, at least based on the current and future climate projections over the lifespan of the system, is a fundamental requirement. It would be preferable to have multiple scenarios to evaluate the uncertainties associated with climate projections, but many standards do not require this. However, a high-level emission scenario is often required by standards and guidelines for such analysis. The time horizon (short-, medium-, long-term) should be adapted to the lifespan of the system or activity, generally over a period of 20 or 30 years.	Loyer et al. (2024)
Define Scope, Objectives, and Risk Criteria	A good scoping phase means to design a risk assessment in such a way that it supports decision-making and planning by taking into account existing objectives, goals, values, and the existing policy and planning framework	UNDRR and WMO (2023)
Define the scope of the assessment	All standards and guidelines emphasize the need for a properly defined climate risk assessment. A climate risk assessmentis always relevant to its subject, whether it is an asset, a system, an organisation or a community. Climate change is a complex issue, and the preparation should correctly consider the location of the site, the objectives of the assessment (screening, risk assessment, adaptation measure, etc), the lifespan of the system or activity, and whether to consider chain values. Additionally, data and expertise on exposure and vulnerabilities should be gathered, and experts and stakeholders should be identified.	CLIMAAX. (2026)
Is the system well-defined for which the CRA is being done?		CLIMAAX. (2026)

Before conducting a climate risk assessment (CRA), it is essential to clearly define the scope and objectives of the analysis (Scoping Phase). A well-defined scope ensures that the assessment is relevant, decision-oriented, and aligned with the system being evaluated (UNDRR and WMO (2023), Adelphi et al. (2023)). Climate change risk assessments are always context-specific and may focus on a wide range of subjects, including a single asset, a portfolio of assets, an organisation, or a territorial system such as a municipality, region, country, etc. Defining the system boundaries at the outset helps determine which hazards, exposures, and vulnerabilities should be analysed and ensures that the assessment remains focused on relevant risks (Loyer et al. (2024)). International guidelines emphasise that an assessment must be explicitly linked to a well-defined system to produce meaningful and actionable results.

In the scoping phase of the CRA, it is necessary to clearly identify the project, system, sector, territory or activity that the assessment is intended to support. Defining the project involves clarifying its geographic location, operational boundaries, and expected lifetime, as these elements determine the types of climate hazards, exposures, and vulnerabilities that should be analysed. A clear project definition also helps determine the appropriate scale of the assessment, including whether the analysis should focus on a specific asset or a portfolio, an interconnected system with dependencies, such as supply chains, or a broader territorial or transboundary context. Establishing these elements at an early stage ensures that the subsequent risk assessment is relevant (UNDRR and WMO (2023), EP4 (2023), ISO 14091:2021, CLIMAAX. (2026), Loyer et al. (2024), Adelphi et al. (2023)).

Climate change risk assessments are part of a global process for adaptation. The scoping phase should clarify the purpose of the assessment, such as supporting strategic planning, identifying adaptation measures, aligning with regulatory requirements (EP4, IFC, EU Taxonomy, CSRD, etc), or conducting a high-level screening (Loyer et al. (2024)). Defining the decision context during the scoping phase ensures that the level of detail, choice of methodology, and results of the assessment are appropriate for its intended use. For example, a high-level screening assessment may be sufficient to identify potential impacts from climate change, while a more detailed CRA is required when evaluating adaptation measures or meeting regulatory requirements.

Once the objectives and system boundaries have been established, the scoping phase should incorporate which future climate conditions use through scenario analysis. Scenario analysis of climate projection is widely recognised as a fundamental component of CRA. It enables to evaluate how the likelihood and magnitude of climate hazards may change under different future climate conditions. In practice, however, scenario selection should remain proportionate to the objectives of the assessment and aligned with regulatory requirements. Many guidelines recommend using a number of climate scenarios, most often a moderate emissions scenario and a high-emissions scenario, to capture the range of potential future conditions (Loyer et al. (2024)).

Closely related to scenario selection is the definition of appropriate time horizons for the assessment. Typical CRA evaluate risks across short-, medium-, and long-term periods, often extending over several decades. For this reason, Climate change risk assessments should consider time horizons that correspond to the lifespan of the asset or system being analysed. Selecting appropriate time horizons ensures that the analysis captures how hazards may evolve over these periods, allowing decision-makers to understand how risk levels may change during the lifetime of the system or activity being assessed (Loyer et al. (2024)).

Finally, climate scientists, sector specialists, risk analysts, and operational experts may all contribute to understanding how climate hazards interact with exposure and vulnerability within the system being analysed. Engaging stakeholders early in the process helps identify critical assets, operational dependencies, and potential vulnerabilities that may not be evident from data alone. It also improves the relevance and credibility of the assessment outcomes, as stakeholders can help validate assumptions and interpret results (UNDRR and WMO (2023)).

3 Assessing Climate Hazards

3.1 Relevant Climate Hazards

Table 4. Recommendation for selecting relevant climate hazards

RECOMMENDATION	RATIONALE	SOURCE
Standardize definitions of hazard and indicators	Regulations associated with the EU Taxonomy (e.g., delegated acts) provided a list of 28 climate related hazard (chronic and acute) which are required to be analyzed through different european standards such as the CSRD, Equator principle, etc. This list of climate related hazards does not define the hazard or the indicators that should be associated with each hazard.	Maksimovitch, E. 17/09/2022
Screening before assessment	Some standards or guidelines propose an initial step to identify hazards that could pose the greatest risk. This can be done through a stakeholder and expert roundtable on sensitivity of the system to climate-related hazards, or by reviewing available climate data at a regional level. This screening serves two key purposes: first, it provides an overview of all potential climate risks, and second, it validates focusing the risk assessment on the most critical threats.	Loyer et al. (2024)
Require Comprehensive Hazard Consideration	Risk assessment tool must account for all climate hazards relevant to the sector/organization/asset, considering non-trivial impacts.	Tavares et Al. (2024)
Aligned with EU Taxonomy	Aligned with the definition of acute & chronic hazards	DGs Quotation

One of the key components to analyse in a physical climate risk assessment is the hazard. One should note that according to the definition a hazard (see Section 2.1) only makes sense in the context of its potential impact. One of the key challenges in risk assessment is to define the impact that we want to study in such a way that we can establish a link between an impact and a climate phenomenon that causes it, which is sometimes not obvious. In addition, the degree of impact along with thresholds that enable decision-making or post-processing also need to be determined. Establishing these is an arduous coproduction process between climate information providers and decision-makers.

The first step of the assessment consists of identifying and prioritizing the relevant hazards which are most likely to cause significant impacts, which depends on several factors, including the sector, site typology, geographic context of the assets, as exposure to climate hazards varies significantly across regions and infrastructure types. Consequently, a physical risk assessment should start from the most comprehensive list of potential climate hazards, allowing to systematically screen and identify the most relevant and priority hazards.

To support this initial screening process, the EU Taxonomy[2] provides a list of 28 climate-related hazards, covering chronic (i.e., long-term trends such as rising temperatures or sea-level rise) and acute (i.e., extreme events such as storms, floods, or heatwaves) hazards (See section 2.2).
This list notably covers the following four categories of hazards:

- Temperature-related hazards: extreme heat (heatwaves, very high temperatures, temperature variability), cold events (frost, cold waves), and forest fires
- Water-related hazards: drought and water stress, extreme precipitation, flooding (pluvial, fluvial, coastal, groundwater)
- Wind-related hazards: strong winds and storms, cyclones, tornados
- Solid-mass related hazards: coastal erosion, landslides and other types of ground movements.

The classification of climate hazards defined in the EU Taxonomy provides a common reference point to conduct an initial hazard screening. It already serves as a common reference framework and is relied upon by several regulatory and financial standards, including the Corporate Sustainability Reporting Directive (CSRD) through the ESRS E1 standard, as well as international frameworks such as the Equator Principles. In this context, it can be considered a minimum set of hazards to be reviewed in a climate risk assessment.

However, this list should not be interpreted as exhaustive or prescriptive. Some hazards included may be complex to assess in practice or may not be relevant for all contexts. Therefore, organisations and practitioners should complement this reference framework with context-specific hazard identification processes, ensuring that the selection and prioritisation of hazards remains proportionate to the scope, data availability, and feasibility of the assessment. In practice, this means that while all hazards should be considered at a screening level, detailed analysis should focus on those that are most relevant and material for the system under study.

Beyond data availability at regional scale, which sometimes limit the range of hazards considered, this initial screening should be conducted in alignment with operational relevance and validated through stakeholder and expert consultations (such as roundtables, site visits and on-site assessments for assessing the sensitivity of the system or assets to different climate-related hazards).

At this stage, it's important to differentiate between natural climate variability and climate change. According to the IPCC AR6 glossary climate variability represents the

> *Deviations of climate variables from a given mean state (including the occurrence of extremes, etc.) at all spatial and temporal scales beyond that of individual weather events. Variability may be intrinsic, due to fluctuations of processes internal to the climate system (internal variability), or extrinsic, due to variations in natural or anthropogenic external forcing (forced variability).*

On the other hand, climate change is

> *A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic*

[2] Delegated Act 2021/2139, Annex 1, Appendix A, European Commission 2021

eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. …

It's important to highlight this difference, because **the assessment of climate hazards is an essential risk assessment exercise even without the presence of anthropogenically induced climate change.**

At the end of this step, the relevant hazards have been identified and prioritised, the subsequent stages of the climate risk assessment can focus on quantifying these hazards.

3.2 Quantify Climate Hazards

Table 5. Recommendation for quantifying climate hazards

RECOMMENDATION	RATIONALE	SOURCE
Contextualise a climate hazard to make it fit-for-purpose	Without a thorough contextualisation, a climate hazard can't become part of a service that is fit-for-purpose. This contextualisation is sometimes a result of an arduous co-production process, and may take many iterations, but it's essential in order to provide data that is meaningful and actionable.	
Don't fall into the simplification trap and embrace uncertainty	Predicting the future is not a simple task, especially when the system you're trying to predict is as complex as the Earth's atmosphere. Consequently, climate modelers employ different strategies to translate this complexity into uncertainty, which is sometimes quantifiable, but not always. Decision-makers should not hide from understanding this uncertainty, as it's an integral part of climate information, and should thus learn to make decisions based on a probabilistic approach.	
Use scenarios and pathways as stories, not predictions	Climate scenarios and pathways weren't designed to be predictions of the future, but rather stories representing plausible futures, and should thus be used as such. Multiple scenarios should be used in conjunction to account for different alternatives, and analyse relative differences between them.	
More expensive doesn't mean more fit-for-purpose	Multiple methodologies exist to simulate the Earth and calculate predictions, and they all have their pros and cons. Users shouldn't mistrust a service because it's cheaper, or vice versa, but rather try to understand their applicability and its limitations in the context of their service.	
Always aim for a comprehensive understanding of the applicability and limitations of data	Users shouldn't blindly trust the quality of data. An honest and detailed validation report should always be provided along with data in a language that everyone can understand. Such reports should be particularly transparent about the applicability and limitations of data.	

The diversity of climate hazards and the way to quantify them is as diverse as the impacts they are associated with. Thus, contextualisation is unavoidable. In addition, as the field of climate science continues to grow and new tools and datasets become available, also change the methodologies for the quantification of hazards. It's important to highlight that climate information has the particularity that it involves the analysis of both the past and the future. Since we can't be sure about the future (nor up to a certain extent about the past), we are forced to deal with probabilities and uncertainties.

In this section, instead of providing specific methodologies for certain contexts, which would be a never-ending endeavour, we would like to highlight some key aspects that lead to the quantification of a climate hazard, or rather the choice of tools and datasets to analyse it.

3.2.1 Temporal scale

The selection of temporal scale should be driven by the context and intended use of the assessment. In particular, time horizons should be aligned with the lifespan of the asset or system under consideration. For example, providing projections until 2100 may not be relevant for assets with a lifetime of 10–15 years, whereas long-term projections are critical for infrastructure such as dams or hydropower systems with lifespans exceeding several decades.

Usually the first analysis of a hazard comes from taking a look at historical observations. Historical observational datasets can be produced from single instruments like satellites or in situ monitoring stations, a combination of instruments, or even a combination of instruments and weather forecasting models, which produce the so called reanalysis products. Understanding the past is an essential step to establish a baseline with which to compare the predicted future, identify trends, and perform attribution studies to try to explain them.

Each relevant climate hazard should be evaluated based on its projected evolution across different time horizons (mid-century, end-century) or global warming levels (such as 2°C, 3°C and 4°C of warming) , with the choice of horizons remaining consistent with the decision context and the lifespan of the asset or system under study.

Regarding the prediction of the future, there are many options depending on the frequency and duration of a climate hazard. Another important concept is lead-time, which we define as the length of time between the moment a forecast is issued and the actual occurrence of the predicted event. For example, if we are analysing monthly average temperature in February and we issue the forecast in January, that corresponds to a lead-time of one month.

Future temporal scales are usually divided into climate predictions and climate projections. Climate predictions evaluate the variability of climate variables over near-term future timescales and can be further divided into sub-seasonal (1-4 weeks), seasonal (1-15 months), and decadal (1-10 years). On the other hand, climate projections provide information about the variation of atmospheric variables over the coming decades and up to the end of the century.

At the scale of climate projections, it's impossible to know for sure how society will evolve and thus continue impacting the climate. Therefore, and particularly in the context of the IPCC, four important concepts were used to agree on plausible stories about how the future might evolve: scenarios, pathways, Representative Concentration Pathways (RCP) and Shared Socioeconomic Pathways (SSP).

A scenario is defined by IPCC AR6 glossary as

A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts, but are used to provide a view of the implications of developments and actions.

In simple words, a scenario is a "snapshot of a plausible world" and a pathway is the "step-by-step directions" to get there, or more formally

The temporal evolution of natural and/or human systems towards a future state. …

In IPCC AR5 RCPs were presented as a

step-by-step evolution of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover …

given an assumption of how radiative forcings might evolve. Radiative forcing is a measure of the Earth's energy budget, which in simple terms means that it measures the difference between the incoming solar energy absorbed by the Earth and the energy radiated back out of space, and it is measured in Watts per square meter (W m-2). For example, RCP2.6 is a pathway where radiative forcing peaks at approximately 3 W m-2 and then declines to be limited at 2.6 W m-2 in 2100.

In IPCC AR6, SSPs were introduced to complement RCPs with the effects of socio-economic development on emissions and concentrations, resulting in a joint SSP-RCP framework. In more detail, SSPs define societal conditions that Integrated Assessment Models (IAMs) combine with mitigation efforts (policy responses) to reach the RCP objective at least cost. Examples of societal rules include population growth, education, urbanization, trade, technology, and diet. Examples of mitigation efforts include carbon pricing, subsidy reforms, fuel switching, carbon capture and storage, electrification, etc. Given the uncertainty in future societal development, this SSP-RCP framework enables the production of storylines about the climate consequences of different plausible futures.

3.2.2 Spatial scale

Unfortunately, temporal and spatial scales are not separable—one influences the other naturally. Therefore, the choice of temporal scale also limits the choice of spatial scale to some degree. Additionally, there is the concept of spatial (in)dependence. Some climate events have consequences over the entire globe, while others have a more local effect. In this regard, teleconnection refers to a causal link between weather or climate patterns occurring in widely separated regions of the globe.

Taking this into account and regarding the spatial scale there are two main types of climate models:

- Global Climate Models (GCM): They simulate the entire planet's climate system by covering the globe with grid cells ranging from 100 km to 250 km in size. Currently, there are efforts to provide GCM data at a much higher resolution of 5 to 10 km, for example, by the DestinationEarth initiative .

However, higher resolution comes with a higher computational cost, which will be discussed in the following sections.

- Regional Climate Models (RCMs): Because GCMs have grid cells that are large, they often miss small-scale features such as specific mountain ranges or coastlines. An RCM takes a subset of the world and simulates it at higher resolution (about 5–50 km). RCMs don't run in isolation; they are nested inside GCMs. In other words, RCMs require the data from GCMs to run.

Beyond models operating at different spatial and temporal scales, there are techniques to increase spatial resolution, known as downscaling . These techniques, like climate models, can be either dynamic or statistical. The former use the laws of physics, while the latter use mathematical patterns found in historical or simulated data and are much faster and less computationally expensive.

3.2.3 Uncertainty and skill

Climate models can lead to different predictions depending on many factors like the initial state of the atmosphere and the parameterization of physical laws. Climate modelers run a model with multiple combinations of plausible parameters to create model ensembles. The diversity of results coming from such ensembles represent the uncertainty of the climate prediction. In addition, Climate modelers can also use multiple models that simulate the climate differently to create multi-model ensembles. This is the key of multi-model initiatives, such as the Coupled Model Intercomparison Project (CMIP) .

Producing prediction ensembles has a high computational cost because multiple model runs are needed. This is a challenging bottleneck for high-resolution models, which are already computationally expensive. A potential solution suggested in the literature is the use of emulators. These are statistical models (including AI models) that learn to imitate a dynamic model, and run much faster, thus enabling an efficient creation of ensembles.

When choosing a dataset, users should be aware of the uncertainty of the data, define the amount of uncertainty that is allowable for decision-making, and how they would work with it. Once this working methodology has been established, historical model runs can be used to test how effective it is. Historical runs are model simulations that start within the period of available observations and can therefore be compared with them. Climate modelers provide historical runs to evaluate model accuracy, commonly referred to as skill.

One should note that selecting the members of ensembles is not a trivial process, and that observational data also has uncertainty. For more information and recommendations on how to deal with both uncertainty quantification and communication the interested reader is referred to Climateurope2 Work Package 2 Deliverable D2.8 - Guidelines for climate uncertainty quantification and communication.

3.2.4 Rarity and extreme events

Analysing extreme events can be very subtle, because climate change can shift the mean state and variability of the climate in which extreme events were observed in the past. Consequently, the statistics of extremes derived from historical data may not be applicable on future climate conditions. To deal with this issue climate modelers use detrending techniques or simply shift the baseline in time. For example, WMO recommends using spans of 30 years to find out the mean state and variability of the climate, and the start of this 30-year span shifts as we move forward in time. It is currently between 1991 and 2020.

Other methodologies of analysing the occurrence of extreme events in the future include the use of ensembles, and also more recently, the concept of nudging in high-resolution models. Nudging is used to recreate extreme atmospheric conditions in the context of different climates, and thus analyse how extremes would differ in future warmer climates, for example.

3.2.5 Economic and technical capacity

Computational resources are expensive, and these directly influence the price of a service. For example, statistical downscaling is much cheaper than dynamical downscaling. Nevertheless, more expensive doesn't necessarily mean more fit-for-purpose. Users should select datasets and tools not only based on their budget but also on fitness for their needs.

Moreover, users should be aware of data complexity and avoid oversimplification. Climate modelers also have a responsibility to document data properly and provide learning resources.

In addition, the long-term sustainability of climate services themselves should be considered. Many climate services are developed within research projects or public funding frameworks, but their continuation depends on viable business models that balance operational costs with user demand and value creation.

3.2.6 Trust

Perhaps the biggest challenge of selecting a dataset is that users sometimes don't fully understand what they need or the limitations of what is available. Adding to this complexity is the presence of the private sector and the fact that they need to protect their proprietary knowledge, which includes the methodologies they use.

Even though it is with systems of trust that society can grow, users should always aim for a clear understanding of the limitations of the data, the validation it has gone through, and its uncertainty.

For further information on quality control and verification, interested readers are referred to Climateurope2 Work Package 2 Deliverable D2.9 - Common procedures for data verification, certification and quality management, and for information on traceability to Deliverable D2.7 - Good practices in provenance of processing methodologies and ways to communicate it in a user-friendly manner.

Finally, this evaluation could rely on a scoring framework or criticality scale (for example, ranging from low to critical), which reflects the potential change in hazard intensity, frequency, or occurrence over time. Applying this scoring approach helps to compare hazards consistently and to determine which ones present the highest level of concern.

3.3 Compound and multi-hazards

Table 6. Recommendation for compound and multi-hazard assessment

RECOMMENDATION	RATIONALE	SOURCE
Require Comprehensive Hazard Consideration	Risk assessment tools must account for all climate hazards relevant to the sector/organization/asset, considering non-trivial impacts.	Tavares et Al. (2024)
Incorporate Hazard Interrelationships	Risk assessments must move beyond "multi-layer single hazard" approaches (which treat hazards as independent) to account for how one hazard affects another and potential feedbacks.	Gill et Al. (2022)
Consider interactions in impacts as well as hazards	Interrelationships exist not only between hazards but also between (potential) impacts, and these should be considered as well.	White et Al. (2025)
Model Risk as a Dynamic System	Rather than seeing risk as a static product of hazard, exposure, and vulnerability, it should be viewed as a dynamic system with interrelationships between the individual components that are evolving over time.	Gill et Al. (2022), Stalhandske et Al. (2024)
Develop indicators that capture interrelationships	Many existing hazard and risk indicators focus on individual hazards or multiple single hazards. While combining indicators for multiple hazards allows for a multi-hazard perspective, it may sometimes be necessary to develop indicators that capture or quantify the hazard interrelationships.	Gill et Al. (2022), White et Al. (2025)
Adopt clear and consistent terminology	Adoption of clear and consistent terminology in the definition and usage of terms such as “multi-hazard”, “multi-risk”, as well as the terms to describe hazard interrelationships is necessary to avoid ambiguities and confusion. The terminology should be checked with relevant stakeholders as well.	White et Al. (2025)
Account for dependencies in frequency analysis	Probabilistic or frequency analyses of hazardous events should account for the dependencies between different types of events.	Ward et Al. (2026)
Supplement statistical approaches with plausible multi-hazard storylines	Multi-hazard storylines allow for an exploration of cause-and-effect relationships in multi-risk situations, as well as for an examination of cascading effects, critical thresholds, emerging risks and indirect impacts.	Ward et Al. (2026), Cocuccioni et Al. (2025)

In recent years, there has been an increasing recognition of the importance of compound and multi-hazard events in shaping climate risk. Traditional risk assessments have largely focused on single hazards, yet many high-impact events arise from the interaction or co-occurrence of multiple drivers across time and space. While this is still an area of active research that has not yet fully been translated into operational practice, a number of general principles and good practices are emerging.

As highlighted in a recent study, even a common understanding and definition of concepts related to multi-hazards and multi-risk has been missing until recently (Ward et Al. (2026)). The United Nations Office for Disaster Risk Reduction (UNDRR) has included a definition of the term “multi-hazard” since 2016[3]:

1) the selection of multiple major hazards that the country faces, and (2) the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects.

This definition can be generalised beyond the focus on countries to include any location (or indeed system) that may be impacted by multiple hazards. A key element in this definition is the focus on potential interactions between hazards and/or their impacts.

A key first step is therefore to comprehensively evaluate not only all the hazards that may impact a location or system, but also their potential interactions. Different terms have been used to describe these relationships; here we follow the Horizon 2020 project MYRIAD-EU (Gill et Al. (2022)) that characterised three types of hazard interrelationships:

- Triggering: One hazard cause another to occur, creating cascades or chains (e.g., heavy rainfall triggering a landslide);
- Amplification: One hazard increases the likelihood or magnitude of a future hazard (e.g., a forest fire increasing the likelihood of debris flows during rain);
- Compound: Two or more hazards impacting the same region and/or the same time period (or in close succession of each other), leading to impacts greater than the sum of their individual parts.

Hazards may interact not only directly, but also through the impacts they have on a region or system, as each event has the potential to change the exposure and/or vulnerability to the impacts of any successive events (Gill et Al. (2022)). The sequence of events - the progression of a location or system through a series of multi-hazard events - therefore becomes important as well and may give rise to different risk scenarios or pathways. Instead of a static concept, risk should therefore be seen as dynamic, with each of the components - hazard, exposure, and vulnerability - interacting and evolving over time (Gill et Al. (2022)). For example, a dynamic approach allows to include assumptions on the recovery of the vulnerability and exposure over time following an event (Stalhandske et Al. (2024)).

Further recommendations on multi-hazard risk assessment and the development of indicators can be found in White et Al. (2025) and Ward et Al. (2026). These include the adoption of mixed-method approaches, integrating quantitative data (e.g., historical hazard frequencies, exposure metrics), qualitative insights (e.g., community perceptions) and expert judgement to comprehensively reflect the complexity and interdependencies of risk drivers. Multi-hazard and multi-risk indicators should be co-developed through interactive and participatory processes involving relevant stakeholders, ensuring that they are meaningful, practical, and tailored to decision-making needs in disaster risk management and climate adaptation (White et Al. (2025)).

Also within the framework of the MYRIAD-EU project, Hochrainer-Stigler et Al. (2023) proposed a six-step framework for multi-risk assessment and management with the following steps:

1) Finding a system definition;

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[3] REPORT OF THE OPEN-ENDED INTERGOVERNMENTAL EXPERT WORKING GROUP ON INDICATORS AND TERMINOLOGY RELATING TO DISASTER RISK REDUCTION.

2) Characterisation of direct risk;
3) Characterisation of indirect risk;
4) Evaluation of direct and indirect risk;
5) Defining risk management options
6) Accounting for future system state

Each step is accompanied by a “guidance protocol”, which is essentially a set of questions to be asked when working through a specific step of the framework. The same project (MYRIAD-EU) has also developed a toolkit for the definition of plausible multi-hazard scenarios (Ward et Al. (2026)). This includes probabilistic approaches, for example based on the statistical properties of historical observations but extended to account for the dependencies between different types of events, as well as storylines, focusing on plausibility rather than probability. Building on the concept of climate storylines (Shepherd et Al. (2018)), multi-hazard storylines allow stakeholders to explore cause-and-effect relationships in multi-risk situations, and supports an understanding of complex events as well as the development of forward-looking decision pathways (Ward et Al. (2026)). A storyline approach also allows for the examination of cascading effects, critical thresholds and emerging risks, including an evaluation of indirect impacts such as disrupted supply chains that may cause economic losses outside the directly affected area (Cocuccioni et Al. (2025)).

In practice, increasing methodological complexity should be carefully balanced against the marginal value it provides for decision-making. Therefore, the level of complexity should be aligned with the intended scope of the assessment.

4 Exposure and Vulnerability

4.1 Exposure

Table 7. Recommendation for exposure assessment

RECOMMENDATION	RATIONALE	SOURCE
Use standardised definition of exposure	As with other components of risk, using a standard definition of exposure aligned with the IPCC definition promotes consistency of understanding.	DGs Quotation
Be aware of the strengths and limitations of exposure datasets	Some exposure datasets for indicators of specific sectoral interest may be low resolution, while others may be high resolution but have limited coverage. Integration of different region level datasets may improve granularity.	CLIMAAX. (2026)
Do not disregard uncertainties	Exposure to hazards is not static. In addition to uncertainties about observed exposure, be aware that exposure projections are based on assumptions (e.g. regarding population).	CLIMAAX. (2026)
Consider indirect exposure	While formal procedures for assessing indirect exposure require further development, indirect exposure may be qualitatively integrated into climate impact assessment through mapping of transmission across supply chains and macroeconomic channels.	DRFIP (2022)

This conceptualisation of exposure (see section 2.1) also covers cases where the impact of climate is indirect (e.g. through effects on supply chains of food or goods). In many cases, physical climate risk exposure data may be inherently tied to vulnerability (e.g. distribution of elderly populations). In operational terms, assessing direct exposure may involve layering spatial data about infrastructure, population, land use and other types of asset location onto hazard information using datasets such as the Global Human Settlement Layer.

At a European level the Climaax Handbook (CLIMAAX. (2026)) indexes a corpus of exposure datasets that may be used in this way, as well highlighting their respective pros and cons (CLIMAAX. (2026)). As with hazard data, selecting an appropriate resolution for the purposes of decision support is important. Where region level data does not provide sufficient granularity to support risk assessment, multiple sources may be combined (DRFIP (2022)). As emphasised in Section 3.3 and 5.1 exposure, along with hazard and vulnerability are dynamic and this should be considered in CRA. Information about uncertainty in exposure and vulnerability is often less well accounted for than the hazard component of risk.

While assessing direct exposure to physical climate risk typically involves spatial mapping, assessing indirect exposure can require additional approaches. Here assessment of exposure is often not possible to disaggregate from impact assessment. Approaches to assessing indirect exposure may include qualitative mapping of transmission of impacts across supply chains and macroeconomic channels, as well as macroeconomic modelling approaches (DRFIP (2022)). However, at the time of writing specific guidance on procedures for doing this requires further development.

4.2 Vulnerability

Table 8. Recommendation for vulnerability assessment

RECOMMENDATION	RATIONALE	SOURCE
Consider both the sensitivity and adaptive capacity of vulnerability	Vulnerability is characterised by the IPCC as comprising sensitivity of systems to harm combined with the extent to which these harms can be mitigated through adaptation. Both should therefore be considered in	DGs Quotation
Ensure that indicators are unambiguously aligned with underpinning vulnerability	Indicators should meet the criteria of being valid, relevant, reliable and credible, precise in their meaning (i.e. agreement on what it is measuring), clear in their direction (i.e. change in value unambiguously positive or negative with relation to the underlying vulnerability component) and comes from an accessible source	MOEFCC. (2023), IFRS (2024)
Consider the level of specificity needed	In some cases generic vulnerability indicators (e.g. sociodemographic variables such as aging population) may be sufficient for decision making (e.g. urban planning for heat risk). In others a more sector/asset specific indicator may be needed, particularly where adaptive capacity is heavily influenced by key decision makers' willingness to engage with adaptation.	DGs Quotation , MOEFCC. (2023)

The formal definition of Vulnerability by the IPCC is presented in Section 2.1. Sensitivity here relates to the extent to which people, ecosystems and assets are affected by climate variability and change, while adaptive capacity relates to the ability to mitigate harms and respond to risk (IPCC).

Country-level indices such as ND GAIN (ND-GAIN (2025)) and INFORM (INFORM (2025)) provide national indicators of vulnerability. However, these may not have the granularity needed for subnational and sectoral CRA. While fewer sub-national datasets exist for vulnerability versus exposure, geospatial indicators of social vulnerabilities, demographics and socioeconomic measures exist that can be integrated with hazard and exposure information (CLIMAAX. (2026)). However, while these generic indicators may be useful for decision making in some contexts (e.g. urban heat health risk assessment) where broad indicators of social deprivation and demographic concentrations may be useful for guiding local authority decision making, in other cases sensitivity and adaptive capacity may be less well reflected in these Loyer et al. (2024)). For instance, willingness to engage in adaptive measures may require a subjective judgement based on region or sector (MOEFCC. (2023)).

The GIZ Vulnerability Sourcebook (MOEFCC. (2023), IFRS (2024)) specifies that indicators should meet the criteria of being valid and relevant, reliable and credible, precise in its meaning (i.e. agreement on what it is measuring), clear in its direction (i.e. change in value unambiguously positive or negative with relation to the component) and comes from an accessible source (IFRS (2024)).

5 Managing Data and Scientific Quality

5.1 Data Selection and Management

Table 9. Recommendation for data selection and management

RECOMMENDATION	RATIONALE	SOURCE
Gathering climate data (current and future climate)	All standards agree on gathering the highest-quality data available as a best practice. Standards acknowledge the disparity in the quality of climate data and other data between regions and countries around the world. As such, if no high-quality data is available, current and future climate data at the finest resolution available are the minimum requirements for a climate risk assessment. Many services and data portals provide access to quality-controlled climate data and hazard indicators, often at a global resolution.	Loyer et al. (2024)
Quality assurance	Few climate services provide readily accessible information on data quality, such as validation details for impact simulations. To what extent the data provided to the FAIR principles (Findability, Accessibility, Interoperability, and Reusability; Wilkinson et al., 2016) is often not obvious to a user. Many of the available tools do not explicitly provide provenance metadata or information on quality assurance, which creates challenges for transparency and quality assessment	Loyer et al. (2024)
Addressing and mitigating uncertainties	While most climate data-oriented portals provide information from one or more ensembles of climate models, it is sometimes left to the user to ensure that this uncertainty information is taken into account. The same rigour in providing uncertainty information is often not found in services and tools supporting other parts of the risk assessment process, such as the provision of data on impacts, exposure and vulnerability.	Loyer et al. (2024)
Downscaling and Resolution	Scientifically defensible downscaling techniques (such as statistical, dynamic, or hybrid ML-based approaches) and involve physical scientists in validating the results to ensure realism and traceability	Jupiter (2025)
Data Selection Methodology	Assess tools and data sources using the criteria of Suitability (does it match the time horizon, region, and hazard?); Credibility (is it robust, peer-reviewed, and theoretically underpinned?); and Legitimacy (is the source impartial and transparent about funding/peer review?)	CFRF (2024)
Gaps and Constraints	Process should involve explicitly identifying and addressing gaps in climate data (time series, scale, etc.), regulatory frameworks, or human capacity, which limit the quality of integrated plans	UNDRR and WMO (2023)

Climate change risk assessments should rely on the highest-quality data available, including datasets describing climate hazards, exposure, and vulnerability. These may include historical climate observations, future climate projections, as well as information on assets, infrastructure, populations, ecosystems, and their susceptibility to climate impacts. International guidelines consistently emphasise that the reliability of the assessment depends on the quality and transparency of the data used. Where possible, datasets should be derived from recognised scientific sources, such as climate services, national meteorological agencies, official statistical databases, sectoral inventories, or peer-reviewed research. When high-resolution or locally validated datasets are not available, the minimum requirement is to use the best available data at the finest spatial and temporal resolution accessible for the region, hazards, and systems being analysed. Ensuring traceability of the data sources, documenting model assumptions, and clearly identifying the climate models or datasets used are essential to maintain scientific credibility and support transparency in the risk assessment process Loyer et al. (2024)).

Within this context, climate data used in risk assessments are produced at different spatial scales, each serving a specific purpose. Global climate models (GCM) (see section 3.2) provide projections of future climate conditions at a planetary scale and are commonly used to assess long-term climate trends and emission pathway scenarios. However, these datasets typically operate at relatively coarse spatial resolution and may not adequately capture local climatic conditions or hazards. Regional climate models (RCM) coupled to GCM improve spatial resolution by downscaling global projections to regional scales, allowing more detailed analysis of climate patterns within a specific geographic area. At the local level, observational datasets and site-specific climate studies provide the most detailed information on climatic conditions and hazards affecting individual assets or territories (EP4 (2023)). To obtain high-resolution projections at local scale, data could be further downscaled using dynamical approaches, which use RCM at finer resolution to simulate climate processes, or statistical methods that translate large-scale climate signals into locally relevant variables. In both approaches, bias correction methods are commonly applied to adjust systematic errors in climate model outputs by comparing model simulations with historical observations.

Given the diversity of available datasets, selecting appropriate datasets for CRArequires a structured evaluation of available data sources. Several guidelines recommend assessing datasets according to three key criteria: suitability, credibility, and legitimacy (CFRF (2024)). Suitability refers to whether the dataset corresponds to the geographic area, hazards, and time horizons relevant to the assessment. Credibility relates to the scientific robustness of the dataset, including whether it is based on established climate models, validated methodologies, or peer-reviewed research. Legitimacy concerns the transparency and impartiality of the data source, including whether methodologies, assumptions, and funding sources are openly disclosed. The FAIR principles (Findability, Accessibility, Interoperability, and Reusability) provide a widely accepted framework for ensuring that these conditions are met. The FAIR principle ensure that scientific data can be reliably accessed, shared, and reused Loyer et al. (2024)). Applying these principles in data for climate change risk assessments involves ensuring that datasets are clearly documented, stored in accessible repositories, and accompanied by metadata describing their origin, methodology, and limitations.

Despite the growing availability of climate information, important data limitations remain common in climate risk assessments. These limitations may include limited historical observations, insufficient spatial resolution for local hazard analysis, incomplete time series, or lack of datasets describing exposure and vulnerability [16]. In many cases, climate services provide extensive information on climate hazards but relatively limited information on downstream impacts, vulnerability factors, or exposure. Identifying these gaps is an important part of the assessment process. Good practice involves explicitly documenting any limitations in the available data, including missing datasets, uncertainties in projections, or assumptions made to compensate for missing information. Transparent documentation of these limitations helps ensure that the results of the risk assessment are interpreted appropriately and allows decision-makers to understand the potential implications of data constraints Loyer et al. (2024)).

5.2 Scientific Robustness and Transparency

Table 10. Recommendation for robust climate data

RECOMMENDATION	RATIONALE	SOURCE
Standardize Bias-correction methodology for risk assessment with ERA5-Land data	Many climate service vendors overlook bias correction, causing misaligned historical vs. future series and unrealistic jumps.	Maksimovitch, E. 17/09/2022
Model Transparency	Disclosing the specific Global Climate Models (GCMs) used, justifying their selection, and providing end-to-end documentation detailing how model bias was corrected and how the results should be interpreted for decision-making	Jupiter (2025)
Scientific Rigor	Build their analytics on well-established scientific methods, use physically realistic models, apply proper bias correction, and validate outputs against observed data and historical events	Jupiter (2025)
Uncertainty Handling	Explicitly quantify uncertainty, including confidence intervals, probabilistic outcomes, and scenario-based variation using a broad ensemble of GCMs	Jupiter (2025)
Data Quality and Transparency	Provide transparency on the methodologies, criteria, and assumptions employed in both internal reports and public disclosures, and regularly reassess the appropriateness of their data sources	ECB (2022)
Standards and Transparency for Vendors	Standards and assurance be created for third-party climate risk data providers, or, at a minimum, require transparency on evidence sources, methodology, and assumptions and enable independent and expert academic assessment of quality by experts	CFRF (2024)

Ensuring scientific robustness and transparency is essential for producing credible climate change risk assessments (CCRA). Because these assessments rely on complex datasets, modelling frameworks, and analytical assumptions, the methodologies used must be clearly documented and scientifically defensible. Guidance emphasises that climate change risk assessments should rely on transparent modelling frameworks, validated scientific methods, and well-documented assumptions to ensure that results can be interpreted and reviewed by decision-makers, regulators, and external stakeholders (ECB (2022)). Without such transparency, organisations may struggle to justify their results and integrate them into governance, reporting, and risk management processes.

Climate change risk assessments commonly rely on high resolution climate data originating from the Coupled Model Intercomparison Project (CMIP), which were downscaled using dynamics or statistical approaches. Another critical component of high resolution data approaches is Bias-Correction techniques. Climate models may produce systematic deviations from observed climate conditions, which can lead to unrealistic transitions when downscaled, if not properly addressed.

Downscaling and Bias-correction techniques are therefore widely used for climate data which would be used in a climate risk assessment. Proper and transparent methodologies are particularly important when downscaling climate data, as inconsistencies can produce unrealistic changes in hazard indicators (EP4 (2023)). Transparency in the modelling process and limitations are also essential to avoid "black-box" climate risk assessments, where the underlying assumptions and methodologies are not clearly disclosed.

In recent years, the growth of third-party climate data providers has raised concerns that some climate data may rely on proprietary models without sufficient documentation or scientific validation or robust downscaling and bias correction methodologies. Guidance therefore recommends that climate data and tools providers disclose the evidence sources, modelling approaches, and assumptions underlying their outputs and allows independent experts to evaluate the scientific quality (CFRF (2024)). Transparent documentation helps ensure that climate data reflect the broader scientific consensus and allows users to understand how the results should be interpreted in a climate risk assessment context.

Uncertainty may arise from several sources related to the underlying datasets and modelling processes, including differences between climate models, limitations in observational data, spatial resolution constraints, and methodological choices such as downscaling or bias correction. Good practice therefore involves explicitly quantifying and communicating these sources of uncertainty when interpreting climate hazard indicators or derived risk metrics. Rather than relying on single deterministic projections, assessments should incorporate ensembles of climate models and present ranges of possible outcomes or probabilistic estimates (ECB (2022), Loyer et al. (2024)).

6 Integrating and Evaluating Climate Risk

Table 11. Recommendation for evaluating climate risk

RECOMMENDATION	RATIONALE	SOURCE
Hybrid Qualitative–Quantitative Assessment Strategy	Since existing CRAs can be qualitative, quantitative, or mixed, adopting a hybrid approach increases robustness. It allows combining data-driven analysis (Risk Analysis) with contextual judgement (Key Risk Assessment), especially where data gaps or uncertainties exist.	
Multi-Hazard and Risk Interaction Integration	Climate risks are often interacting, compounding, or cascading, not isolated. Incorporating multi-hazard analysis improves realism in Risk Exploration and Analysis, preventing underestimation of systemic risks.	
Severity and Urgency-Based Risk Prioritisation	The Key Risk Assessment step evaluates risks based on severity and urgency, enabling prioritisation into key vs. less urgent risks. This directly supports actionable climate risk management decisions.	

There is no universal or one-size-fits-all approach to climate risk assessment (CRA) because of the heterogeneity of contexts, spanning different geographies (from global to local risks), temporalities (past, present and future), sectors (e.g., infrastructure, finance, agriculture, etc.) amongst other dimensions. Existing approaches to climate risk assessment can be qualitative, quantitative or a mixture of both.

The earliest climate risk assessment frameworks (Jones, (2001)) share many elements with the most recent ones (e.g., CLIMAAX framework); see Figures below.

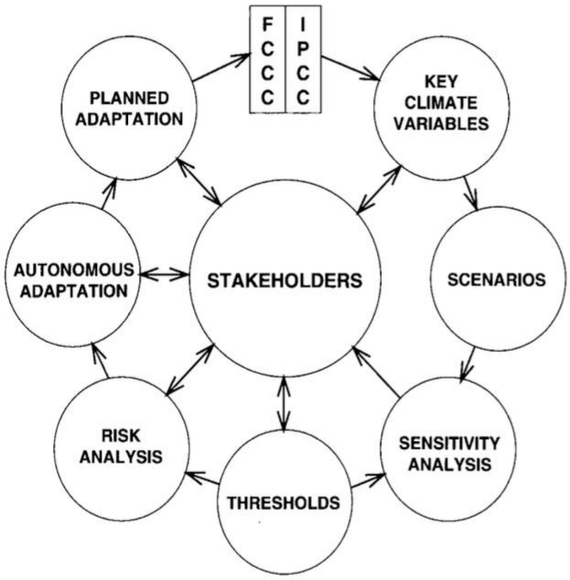

Figure 1. Risk assessment framework for assessing climate change impacts (Jones, (2001)).

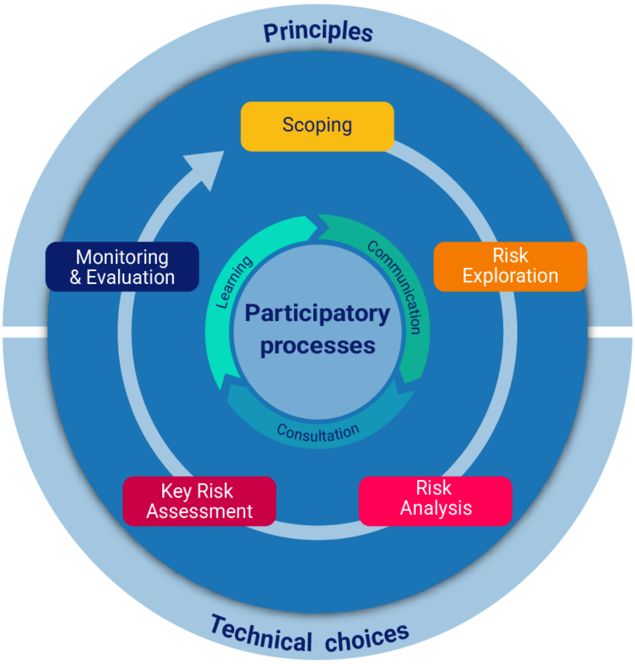

Figure 2. The framework is based on established principles (related to social justice, equity, transparency), technical choices to be made (e.g., for parameters, climate scenarios, time horizons etc.), and participatory processes (learning, communication, consultation).

These three conceptual dimensions frame the CRAsteps and lead, through continued implementation, to information on climate risk that can support adaptation and climate risk management planning. Source: CLIMAAX Consortium.

Considering state-of-the-art knowledge, relevant concepts and existing CRAframeworks, the CLIMAAX CRAFramework was developed as an inclusive, up-to-date, and standardised yet flexible approach designed to enhance the regional and local assessment of climate risks.

We briefly explain the conceptual background to this framework:

- Principles: considerations of social justice, equity and inclusivity; quality, rigour and transparency to guarantee applicability, comparability, validation, and the possibility of standardisation.
- Technical choices: considerations of relevant scenarios, time periods, climate datasets (observations, reanalyses, models), and the extent of data integration.
- Participatory processes: engaging in bidirectional learning, communication, and consultation.

This framework identifies five operational steps: Scoping, Risk Exploration, Risk Analysis, Key Risk Assessment and Monitoring & Evaluation. The Scoping phase defines objectives, sets the context, and identifies stakeholders and risk ownership. Risk Exploration is strongly informed by the Scoping step as it sets the conditions of analysis: selection of future scenarios, or relevant risk workflows by exploring hazard, exposure, and vulnerability. After the risk workflow application in the Risk Analysis step, the individual risk outcome (possibly composed of several hazards, risk workflows or the application of various scenarios) is evaluated and contextualised in the Key Risk Assessment step (severity and urgency of risk resulting in key and less urgent risks), thus identifying potential entry points for climate risk management and risk reduction. Monitoring & Evaluation puts emphasis on summarising the

CRAprocess and surveilling climate risks while gathering knowledge and data that is relevant for a learning process.

While recent developments include multi-hazard approaches, risk tolerance integration, and the concept of Climatic Impact-Drivers (CID), managing complexity and uncertainty remain the main operational challenges (Higuera Roa et al. 2025).

Climate risks are not limited to individual impacts resulting from individual hazards. They are often complex with multiple hazards interacting, compounding or cascading. Cascading climate risk can be conceptualised as "…chains of risk in which adverse climatic impact or trend triggers or amplifies a set of risks". The assessment and management of interacting, compounding and cascading climate risks remain a particularly challenging area to address precisely because of the complexity.

7 Communicating Climate Risk Effectively

Table 12. Recommendation for communicating climate risk

RECOMMENDATION	RATIONALE	SOURCE
Use communication about uncertainty to build trust	Be transparent about the uncertainty evaluation of the information.	Pascoe et Al. (2025)
Match the complexity of information to the user's climate education	• Use simple messages and intuitive graphics in public communication. • Be clear about what the uncertainty information refers to. • Provide information about why climate projections are intrinsically uncertain. • Only use technical language and complex graphics with sophisticated users. • If jargon is necessary, it should be explained.	Pascoe et Al. (2025) [2, CFRF (2024)
Understand existing narratives before introducing climate uncertainty into risk analysis.	Understand how people are thinking about risk and decision making. Work with humility and transparency to co-create new climate narratives or storylines of plausible futures.	Pascoe et Al. (2025)
Be aware that the framing of risk and uncertainty matters	Frame an uncertain situation in terms of risk reduction through action to increase intention to act.	Corner et Al. (2015)
Frame climate impact information in terms of 'when' rather than 'if'	Frame climate impacts in terms of uncertainty about when they will occur.	Corner et Al. (2015)
Ratios, return periods and percentages	Use consistent denominators to communicate ratios and combine return periods with percentage expressions.	Craig et Al. (2025), Grounds et Al. (2018)
Embrace deep uncertainty with Storylines	Use storylines to explore deep uncertainty in a traceable and physically plausible, event-oriented manner that is aligned with how people perceive risk.	Pascoe et Al. (2025), UNDRR and WMO (2023), DGs Quotation, Grounds et Al.

		(2018), Iturbide et Al. (2018)
Move from the abstract to the concrete	Link climate uncertainty to concrete risks from specific impacts with individual relevance or highlight analogies with other types of familiar risk. Use case studies and personal narratives to engage people who do not have direct experience of extreme events.	Corner et Al. (2015)
Incorporate uncertainty into graphs and charts	Where uncertainty measures are available, show the data, but also their uncertainty, by incorporating the uncertainty into the visualisation method. The choice of chart-type depends on the data pattern: ● a line chart communicates the development over time of a statistic ● a bar chart communicates the comparison of sizes and ● a point chart communicates differences in value **Error bars** have the benefits that the visual focus is on the point estimate and that the confidence interval is a detail. Error bars allow the comparison of the sizes of the uncertainty intervals for different estimates. Many academics have been trained to use plots with error bars, making them a popular well understood method. **Error bands** on line charts are essentially continuous error bars and convey the variation of uncertainty over time. Describe their range as "showing uncertainty" with narrower ranges as showing "greater certainty". **Box plots and violin plots** are useful for visualising distributions but are less useful for depicting uncertainty, because they have no central point estimate. **The Gradient approach** encodes probability using colour intensity (the more likely, the more intense the colour) and is a popular choice for time series, especially for future predictions. **Cross section graphs such as the bar graph** can also be used to convey an uncertainty distribution via the application of a complementary cumulative distribution which shapes the tips of the bars. **'Spaghetti' plots** (Hypothetical Outcome Plots) explicitly plot multiple outcomes and are useful for showing prediction uncertainty. They make it clear that the future (or estimation) is not set, and that one of multiple outcomes is possible. Such plots do not encode the full uncertainty distribution but work well to convey the presence of uncertainty. **Frequency Distribution plots show** the likelihood of occurrence (probability) of events of a certain magnitude (which can be absolute, or a difference from the mean) that occur over a certain period. Such distributions generally form a bell-shaped curve with the mean (average) located in the middle.	Pascoe et Al. (2025), Loyer et al. (2024), Craig et al. (2025), Jupiter (2025), David et Al. (1956)

Use consistent visualisation methods for both historical past and projected future	Present historical data and data for the projected future using the same method.	Pascoe et Al. (2025), Loyer et Al. (2024), CFRF (2024), David et Al. (1956)
Present an even number of climate projections	Recommendation: Present an even number of climate projections to avoid the misattribution of likelihood. Rationale:	Pascoe et Al. (2025), Loyer et Al. (2024), Kause et al. (2020)

Uncertainty should be actively managed and normalised within climate communication rather than hidden. Its presence should not be interpreted as a weakness, but as a reason to engage more deeply with information, particularly where vulnerabilities or risks are involved. Awareness of uncertainty enables more critical risk assessment, and even where uncertainty is high, action may still be required if the potential consequences are severe or unacceptable (Pascoe et Al. (2025)). In this sense, uncertainty is not a barrier to decision-making but an inherent feature of it.

Despite this, users differ significantly in how they interpret and respond to uncertainty. Some users prefer clear, categorical answers about whether an event will occur and may view probabilistic forecasts as an attempt to avoid responsibility or to "hedge bets." In the absence of a definitive yes/no answer, they may translate probabilities into binary outcomes themselves. These users are less likely to understand the sources of uncertainty and tend to favour simple messages and graphics. In contrast, more sophisticated users are aware of the underlying reasons for uncertainty and can engage with technical language and more complex visualisations, provided that any necessary jargon is clearly explained (CFRF (2024)). Across all user groups, a key challenge remains ensuring that probabilities are clearly understood—whether they refer to a specific point, a spatial area, or a time period (Maksimovitch, E. 17/09/2025, CFRF (2024)).

Given these differences, user education plays an important role in improving understanding of uncertainty, particularly because climate science is not an exact discipline. Co-production processes provide valuable opportunities to build this understanding. Where such education is not possible, communications should aim to support an intuitive grasp of uncertainty.

At the same time, people rely on narratives to interpret complex evidence. Until existing narratives and the ways in which people think about risk and decision-making are well understood, it is difficult to introduce actionable climate information and related services. Once these narratives are identified, it becomes possible to build trust through mutual learning, embrace diverse and sometimes conflicting perspectives, and co-create new climate risk narratives or plausible future storylines with humility and transparency (Pascoe et Al. (2025)).

The way information is framed has a significant influence on how it is received. Functionally identical information can lead to different responses depending on how it is presented. For example, framing an uncertain situation in terms of risk reduction through action (e.g. a lower probability of impact if action is taken) has been shown to increase willingness to act compared to framing in terms of risk from inaction (Corner et Al. (2015)). While climate services may aim to remain neutral, it is essential to recognise that framing can shape interpretation and decision-making. Similarly, climate impacts may be perceived as more concrete and less psychologically uncertain when communicated as a time range within which an impact will occur, rather than as a probability tied to a specific point in time (Corner et Al. (2015)).

Clarity and consistency in expressing likelihood are also critical. Using a common denominator when comparing probabilities (for example, “1 in 10” versus “2 in 10”) improves comprehension, whereas mixing formats (such as “1 in 10” and “1 in 5”) can create confusion (Craig et Al. (2025)). However, communicating risk solely through return periods (e.g. “1 in 100-year event”) can lead to misinterpretation, particularly if an event has occurred recently, creating a perception that a similar event is either less likely or “due.” Supplementing return periods with percentage probabilities can help reduce this effect (Grounds et Al. (2018)).

Alongside probabilistic approaches, storylines provide a valuable complementary method for communicating uncertainty. They are descriptive narratives of plausible, physically consistent future climates and events, emphasising qualitative understanding rather than quantitative precision. By framing risk in an event-oriented way, storylines align more closely with how people perceive and respond to risk, and they strengthen decision-making by focusing on specific vulnerabilities or decision points while incorporating both physical and human dimensions of climate change. They are particularly suited to contexts of deep uncertainty, where robust rather than optimal decisions are required. In practice, storylines have been used to explore contrasting precipitation futures in the Netherlands, to develop multi-level hazard scenarios for civil protection in Switzerland, and to stress-test exposure in the insurance and reinsurance industries using historical or modified events (Pascoe et Al. (2025), UNDRR and WMO (2023), DGs Quotation, Grounds et Al. (2018), Iturbide et Al. (2018)).

Although uncertainty is not an inherent barrier to decision-making, climate change itself can appear abstract. It is therefore important to link climate change to concrete risks with individual relevance or to draw analogies with more familiar types of risk, enabling people to better weigh the costs and benefits of action versus inaction. Experiences of extreme weather events can reduce the psychological distance between individuals and climate change, making the issue more tangible and relatable for affected communities (Corner et Al. (2015)).

Finally, visual communication plays a crucial role in shaping understanding. Presenting historical and projected climate data using different formats can be confusing, so applying consistent visual methods improves interpretability. For example, using the same approach for both historical and projected data, or applying consistent thresholds in distribution plots, can make changes in extremes more intuitive to interpret (Pascoe et Al. (2025), Loyer et Al. (2024), CFRF (2024), David et Al. (1956)). Care must also be taken to avoid unintended bias: audiences often interpret central projections as the most likely outcome, even when no such likelihood is assigned. Presenting an even number of projections can help mitigate this bias by encouraging more critical evaluation of the information (Pascoe et Al. (2025), Loyer et Al. (2024), Kause et al. (2020)).

8 From Risk Assessment to Action

8.1 Climate Risk to Support Decision-Making

Table 13. Recommendation for supporting decision-making

RECOMMENDATION	RATIONALE	SOURCE
Ensure alignment between decision needs and initial scoping to ensure alignment	As specified in Section 2.3, the initial scoping phase should take into account the decision context or context in terms of the selection of criteria, indicators and thresholds.	
Ensure consideration of physical and transition risk under multiple scenarios	Assessment of the materiality of transition and physical risks should consider a range of scientifically determined climate change pathways across multiple timescales. These may be represented using a series of matrices or heat maps to characterise material risk at different timescales.	
Support decision making under uncertainty through consideration of multiple scenarios aligned with risk tolerance	The CFRF Aim-Build-Contingency framework represents one approach to building multiple scenarios into planning. With Aim representing a target state (1.5°C), Build as the state budgeted and built for (2.0°C) and Contingency as plans for states exceeded this (2.5°C)	
Involve all relevant decision makers in the CCRA	Align with ISO14090: 2019 by involving relevant decision making authority across affected areas of the business, organisation or system in CCRA. This will facilitate prioritisation and ranking of risk by urgency for adaptation as well as alignment with regulatory frameworks	

The ultimate goal of climate risk assessment(CCRA) is to support decision making, whether in terms of long-term planning or identifying nearer-term risk that requires immediate operational changes. As outlined in 2.3, appropriately setting the scope of the assessment is critical to ensure alignment with decision making. Decision relevant parameters and thresholds should be integrated into the assessment from the outset, though the level of specificity may depend on the scope and granularity (e.g. national, regional, local, sector specific, organisation specific). Even within sectors there may exist organisational differences in the materiality of transition and physical climate risks, as well as organisational risk appetite.

Specific guidance on how to determine materiality thresholds to support stress testing and risk management decision making does not currently exist (IFRS (2024)). However, finance sector guidance exists on defining and assessing materiality (e.g. defining the context of business exposure, the potential impacts of climate risk on areas of exposure, and the likelihood and material consequence of these) to feed into sensitivity analysis and stress testing, with matrices and heat maps being used to identify and characterise material risk (EIOPA (2022)). This guidance emphasises the importance of considering both transition and physical risks, under a range of scientifically determined climate change pathways across multiple timescales.

To support decision making under uncertainty and integrate multiple scenarios, the ABC (Aim Build Contingency) framework outlined by the CFRF may be adopted to address a range of possible states, through specifying a target (aim), building for a middle scenario (build) and planning for scenarios that exceed this (contingency). The following example is given by CFRF:

- Aiming for 1.5°C (a suitable proxy for this is the IPCC's Shared Socioeconomic Pathway 1-1.9 (SSP1-1.9) scenario and taking the median climate response).
- Building and budgeting for 2°C by 2050 (the best proxy for this is the IPCC's SSP2-4.5 scenario and taking the median climate response).
- Contingency planning for 2.5°C by 2050 (this is represented by the IPCC's SSP3-7.0 scenario and taking the 95th percentile of the climate response).

To support decision making more broadly, guidance emphasises that CRAshould involve those with relevant decision making authority across affected areas of the business, organisation or system; facilitate the prioritisation or ranking of risk by urgency for adaptation; enable decision making to be stress tested across multiple scenarios ; and facilitate alignment with regulatory frameworks[4] (e.g. ISO14090: 2019). The integration of climate risk assessment into decision support for adaptation and mitigation may utilise multi-criteria decision analysis tools or storyline to capture a range of possible futures [see section 9].

In addition to risk management and reporting frameworks, there is an emerging trend towards integrating climate information directly into engineering and technical standards. For example, ongoing developments in the Eurocodes aim to incorporate climate projections into the definition of design parameters such as thermal loads and extreme events (Rianna et al. (2023)). This reflects a broader shift towards embedding climate data into infrastructure design and operational standards. As a result, climate services are increasingly expected to provide information that is not only decision-relevant but also compatible with engineering specifications and standardised design processes.

8.2 Adaptation

Table 14. Recommendation for adaptation

RECOMMENDATION	RATIONALE	SOURCE
Provide CRAto facilitate the prioritisation of adaptation	ISO14090: 2019 identifies the need for risk assessment to facilitate the prioritisation of adaptation based on likelihood and consequence of risks. Adaptation actions should be considered in the scoping phase of risk assessment.	
Multiple scenarios and timescales to reduce risk of maladaptation	Maladaptation, where attempts to adapt to and cope with climate change impacts lead to increased exposure and vulnerability, may result from considering too few potential futures or insufficient	

[4] 2015-11-09-SUMMARY-OF-CCRA-RESEARCH-PROJECTS.PDF

	timeframes. Ensuring that a sufficient range of scenarios are considered can enable stress testing of different adaptation options and the identification of robust and low-regret options. In an organisational context ensuring that consideration of future timeframes is aligned with the lifespan of exposed assets is important.	
Consider how adaptation may affect underpinning risk (hazard, exposure, vulnerability)	While response to adaptation has been identified as a new dimension of risk in IPCC AR6 guidance on formal procedures for assessing this remains under-developed, a holistic approach encompassing both mitigation and adaptation strategies could benefit decision-makers by helping them validate whether their chosen adaptation measures effectively mitigate climate risks while avoiding unintended consequences	
Consider metrics that might help to prioritise adaptation actions	At a quantitative level, metrics to assess return on investment from adaptation measures, can support prioritisation of actions.	

For CRAto most effectively support adaptation, it should be readily linked to adaptation options. ISO14090: 2019 Adaptation to Climate Change specifies a requirement for a "systematic assessment of organizational climate vulnerability and risk as foundation for adaptation planning" to inform a risk-based approach to climate adaptation that prioritises actions to address the risks posed those hazards that are most likely and most consequential. To achieve this, an assessment of exposure and sensitivity precede an assessment of adaptive capacity, evaluating the organisation or region's ability to adapt and adjust through, for instance, financial, technical/technological and knowledge systems or flexibility and diversity of systems. As noted in Section 2.3, adaptation actions should be considered in the scoping phase of the risk assessment. ISO14090: 2019 specifies that they should also be prioritised in terms of effectiveness, feasibility, efficiency, equity, co-benefits, urgency of risk, as well as flexibility (i.e. given uncertainty surrounding future risk)

Awareness of the potential for adaptive actions to lead to maladaptation, which actions taken to adapt to or cope with climate impacts serve to increase exposure and vulnerability is also a critical consideration. Maladaptation can result from adaptation actions running counter to mitigation goals (e.g. increased demand for air condition systems), actions cause a negative knock-on effect elsewhere (e.g. coastal defences in one location leading to greater erosion elsewhere) as well as planning for a limited range of future scenarios or considering effectiveness under climate change at an insufficient range of timescales. To avoid failure to plan for a range of possible futures, multiple scenarios must be considered, under which possible adaptation actions can be stress tested[5] and no regret and low regret options identified[6]. Likewise, multiple timescales consistent with the lifecycle of assets exposed to climate risk should be considered, considering changes in assets over time (Poljansek et Al. (2021)). CRAto support adaptation should facilitate the identification of adaptation measures that are robust across multiple scenarios, as well as enabling the consideration of how these adaptation options may

[5] 2015-11-09-SUMMARY-OF-CCRA-RESEARCH-PROJECTS.PDF

[6] 4.3 PRIORITISING ADAPTATION OPTIONS | GETTING STARTED | DISCOVER THE KEY SERVICES, THEMATIC FEATURES AND TOOLS OF CLIMATE-ADAPT CLIMATE-ADAPT

affect level of risk (e.g. development of early warning systems affecting vulnerability and exposure). For instance, by simulating how specific measures (e.g. flood barriers or insulation upgrades) change risk outcomes over time. At a quantitative level, metrics to assess return on investment from adaptation measures, may support prioritisation (Jupiter (2025)). Nonetheless, it is important to note that the question of how to assess the impact of adaptation measures on risk itself remains nascent with further research needed to identify guidelines.

Speaking to the issue of maladaptation and the need to balance adaptation and mitigation, the IPCC has introduced "responses to adaptation" as a new dimension of risk in AR6, though existing standards and guidelines have yet to incorporate this new element. A holistic approach encompassing both mitigation and adaptation strategies could benefit decision-makers by helping them validate whether their chosen adaptation measures effectively mitigate climate risks while avoiding unintended consequences. Scenario-neutral approaches to climate impact and risk assessment have been proposed in the literature (e.g., Prudhomme et al., 2010) but have yet to find their way into guidelines and standards.

9 Tools

9.1 Climate Risk Tools

Table 15. Recommendation for climate risk tools

RECOMMENDATION	RATIONALE	SOURCE
Adopt user-centred design principles	User-centred design can increase the credibility and usefulness of climate risk tools, greater attention to post-creation tool use, and better integration of tool development into broader project lifecycles. It may also be beneficial to build on or improve existing tools and platforms rather than developing new ones for each project, in order to foster greater continuity, efficiency, and long-term impact in the science-policy interface.Part of the user-centred design process also involves a rigorous user testing to evaluate how users interpret the information and identify where misunderstandings occur.	Houtkamp et al. (2025), Terrado et al. (2022)
Follow existing standards for accessibility and digital inclusion	The European Accessibility Act (EAA) requires certain digital products and services to be accessible to people with disabilities. Even if not mandated by law, it is recommended to comply with accessibility standards such as the Web Content Accessibility Guidelines (WCAG) developed by the World Wide Web Consortium (W3C) in order to reduce barriers and improve digital inclusion.	European Commission (2025), W3C
Provide context	Embedding data visualisations into a narrative context can help audiences make sense of complex information. Examples of this include describing relevant changes or trends that can be spotted in the data or combining graphs for easy comparison..	Terrado et al. (2022), Kause et al. (2020)
Provide relevant metadata and documentation	Providing comprehensive metadata and documentation enhances the credibility, usability and long-term impact of data and tools. Well-defined and structured metadata adhering to existing standards and conventions enables data and digital services to be findable, accessible, interoperable, and reusable, supporting discovery, understanding, and long-term use by both humans and machines. Documentation should not only cover technical data details but also provide contextual guidance for both expert and non-expert users, including potential limitations to the data and models.	Wetzel et al. (2024), Houtkamp et al. (2025),
Useability of uncertainty information	While most climate data-oriented portals provide information from one or more ensembles of climate models, it is sometimes left to the user to ensure that this uncertainty information is taken into account. The same rigour in providing uncertainty information is often not found in services and tools supporting other parts of the risk assessment process, such as the provision of data on impacts, exposure and vulnerability.	Pascoe et al. (2026)

Adhere to best practices in visualisation	Climate risk tools and services should adhere to best practices in communication and data visualisation, including practical recommendations such as avoiding jargon and acronyms; using consistent terminology; focusing on one key message per visualisation; matching the messages in the visualisation with text; integrate legends within charts; use descriptive titles; selecting accessible colour palettes; and leveraging intuitive colour associations (such as red for heat/danger, blue for cold/precipitation, green for safe, etc.)	Terrado et al. (2022), Kause et al. (2020), Pascoe et al. (2026)
Define indicators and visualizations tailored to and actionable for decision-making	Many services offer information in the form of indicators, most often representing single climate hazards only. Many of the standard indicators may be useful for comparisons across regions or provide an indication of changes in extremes but could potentially be inadequate in a formal risk assessment as they may not represent the relevant hazards at the local scale of interest. For climate risk tools and services, indicators should be co-developed with the relevant stakeholders to ensure they are meaningful, relevant, practical and tailored to the decision-making needs of the users	Loyer et al. (2024), White et al. (2025)

The increasing need for climate change risk assessments has led to a proliferation of services and tools to support this process. The previous deliverable D2.5 (Loyer et al. (2024)) provided an overview of the different types of services and tools available at the time. While "service" and "tool" are often used interchangeably, Loyer et al. (2024) distinguished between data and information providers (services) and tools requiring user input for personalised risk assessments. These diverse services and tools were categorised into eight distinct categories based on their functionality. The following types of services were distinguished based on the data or information provided:

1) Climate data or information only (not including data repositories);
2) Climate indicators on extremes relevant to climate hazards;
3) Data and information on impacts;
4) Data for risk evaluation, including exposure and vulnerability;
5) The outcomes of a risk evaluation, such as a risk index.

In addition, three different types of tools were identified:

6) Software tools to process climate data (not including general software libraries);
7) Models or software tools to evaluate impacts and/or risk;
8) Stepwise methodologies or templates for the risk evaluation process.

These categories represent only a first attempt to categorise the various services, tools and products relating to climate risk that are on offer, and indeed not all services neatly fall into one of these categories. Different categorisations may be conceivable, for example according to the target audience or user; however the target audience for a service or tool is not always clear from its description.

In spite of this diversity, a number of general recommendations can be derived from the literature as well as interviews with stakeholders. Key gaps and obstacles often identified include the following (Houtkamp et Al. (2025), Terrado et Al. (2022), Kause et Al. (2022)):

- Tool proliferation and fragmentation: many tools are developed as part of a research project and/or within a disciplinary “silo”, leading to a confusing landscape for users where tools often only address a minor part of a larger problem;
- Lack of continuity: because development is often project-based, there is frequently insufficient attention to long-term maintenance and uptake;
- Focus on products over process: climate services often prioritize the delivery of a tangible "product" (datasets or models) while neglecting the social processes necessary for sustained use, such as ongoing stakeholder engagement, translation, and evaluation;
- Misalignment of priorities: researchers, funders, and users often have diverging, sometimes even conflicting priorities: researchers for example typically prioritise scientific depth, funders may focus on visibility, while users may seek concise, actionable insights to support daily workflows rather than complex, raw data. As a result, many tools are too complicated for independent use by non-expert users such as practitioners [e.g., Palutikof et Al. (2019)];
- Relevance to user needs: many tools are supply-driven, reflecting research outputs rather than real user needs. Often tools are expected to serve diverse audiences, but their design fails to support different types of information-seeking behaviour;
- Tool usability: even when a tool addresses relevant problems, its usability can pose barriers. Effective tools must align with the expertise and workflow of their intended users.

User-centred design offers a structured approach to addressing these challenges by embedding user needs throughout development (Houtkamp et Al. (2025)). Applying user-centric design principles such as early user involvement, iterative prototyping, and usability testing, can help create tools that are not only technically robust but also practical, relevant, and widely used. Continuous stakeholder engagement, involving users from initial scoping to final testing is central this approach, which typically follows a number of steps: specifying the context of use, defining user requirements, creating design solutions and prototypes, and conducting rigorous evaluations with actual stakeholders.

To create effective tools and services, it is also important to integrate insights and expertise from disciplines beyond climate science, including fields such as psychology and behavioral sciences, user experience and interaction design, and social sciences and humanities. Guidelines and best practices are available to ensure that online tools and platforms are accessible and inclusive[7], the communication of uncertainties (see Pascoe et Al. (2026) and references therein), as well as the design of effective data visualisations (Terrado et Al. (2022), Kause et Al. (2022), Pascoe et Al. (2026)). Although much of this is very context-dependent, it is usually beneficial to embed visualisations into a narrative context that can help the user make sense of complex information, for example by describing in the accompanying text relevant changes or trends that can be seen in a graph or map.

In addition to user-focused considerations, climate risk tools and services should also consider technical aspects, such as the provision of comprehensive metadata and documentation to ensure the credibility, usability and long-term impact. Well-defined and -formatted metadata can also enhance the findability and usability of data being provided (Wetzel et Al. (2024)). Documentation should not only cover technical data details but also provide contextual guidance for both expert and non-expert users, including potential limitations to the data and models (Houtkamp et Al. (2025)).

[7] ***WEB CONTENT ACCESSIBILITY GUIDELINES***

Many services provide information about indicators about risk or its components, and in particular hazard indicators (Loyer et al. (2024)). Indicators contain observable and measurable characteristics to simplify information to understand the state of a concept or phenomenon, and/or to monitor it over time (White et Al. (2025)). Many climate hazard indicators are based on or sometimes variants of, the standard indicators of the Expert Team on Climate Change Detection and Indices (ETCCDI) (Klein Tank et Al (2009)). An additional set of 50 indices highlighting characteristics of climate change in Europe has been proposed by the European Climate Assessment & Dataset project (ECA&D)[8]. While the generic nature of these indicators means they can easily be compared across regions and timescales, they may not always be appropriate or useful to inform a risk assessment, as they are not tailored to local conditions and may not always represent extremes at the scale and location of interest. Interactions between multiple hazards are often not accounted for. When the intention is to use in a climate risk assessment, it is important that indicators are co-developed with the relevant stakeholders to ensure they are meaningful, relevant, practical and tailored to the decision-making needs of the users (White et Al. (2025)).

While the recommendations presented above reflect best practices identified in the literature and stakeholder consultations, their implementation should be adapted to the specific context in which a climate risk tool is developed and used. In practice, developers are required to prioritise and make trade-offs between different dimensions of tool design, including the level of scientific complexity (e.g., number of scenarios, models, or representation of multi-hazard interactions), usability, computational cost, and the capacity of users to interpret results. Adopting a fit-for-purpose approach is therefore essential. This implies aligning the level of complexity and functionality of a tool with its intended use and the needs of its users.

9.2 Transparency and Defensibility

Table 16. Recommendation for transparency of climate risk tools

RECOMMENDATION	RATIONALE	SOURCE
Provide information about methods and models used	Disclosing the specific Global Climate Models (GCMs) and other models and methods used, justifying their selection, and providing end-to-end documentation detailing how model bias was corrected and how the results should be interpreted for decision-making promotes transparency and trust.	JUPITER (2025)
Provide quality assurance information	Few climate services provide readily accessible information on data quality, such as validation details for impact simulations. To what extent the data provided to the FAIR principles (Findability, Accessibility, Interoperability, and Reusability; Wilkinson et al., 2016) is often not obvious to a user. Many of the available tools do not explicitly provide provenance metadata or information on quality assurance, which creates challenges for transparency and quality assessment	Loyer et al. (2024), D2.9
Regulatory Readiness and Defensibility	The methodology must be transparent and well-documented with clear assumptions and scientific references, enabling the user to	JUPITER (2025)

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	justify the outputs to third parties, boards, and regulators. The risk assessment method must align with the standard climate risk frameworks.	
Addressing and mitigating uncertainties	While most climate data-oriented portals provide information from one or more ensembles of climate models, it is sometimes left to the user to ensure that this uncertainty information is taken into account. The same rigour in providing uncertainty information is often not found in services and tools supporting other parts of the risk assessment process, such as the provision of data on impacts, exposure and vulnerability.	Loyer et al. (2024)
Follow best practices in software quality assurance	When developing a climate risk tool, following widely-accepted practices in software quality assurance can help ensure that the tool is robust, transparent and reliable.	

Many of the recommendations on scientific robustness, transparency and defensibility of climate services discussed earlier in this report also apply to climate risk tools, often even with greater urgency and practical relevance. Transparency and reproducibility of the results are obviously key concerns when the outputs of a tool are supposed to support decision-making by stakeholders, yet the level of quality assurance applied to the underlying software libraries and models is often not clearly documented or transparent (Loyer et al. (2024)). When developing climate risk tools, following widely accepted software quality assurance practices, such as logical and unit testing, version control, code review and clear documentation, help ensure that the tools are robust, transparent and reliable. Examples exist of provenance metadata models that facilitate traceability and reproducibility of the results (Iturbide et Al. (2019)).

Users of a tool should assess whether a climate risk tool is transparent, scientifically robust, validated against observations or other reference data, and appropriately represents uncertainty, while also meeting basic standards of software quality assurance, usability, and relevance to the decision context. In addition, they should evaluate the governance, sustainability, and credibility of the tool, addressing questions such as: who developed the tool? Is there institutional backing or a peer-reviewed basis? Is the tool actively maintained and updated? And is there a clear contact point or user support available?

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Climateurope2

The objective of this workshop is to bring together experts to discuss and identify actionable recommendations for the standardization of climate services in support of climate risk assessments.

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Recommendation	Source	Owner	Rationale	Discussion	Comments						Evidence	Result	Vote						
Standardize definition of risk and its components	Loyer et al, (2024)	Lilian	While most current standards or guidelines agree with the IPCC's definition of risk, they do not always use the same definition. The definition of risk in standards can be found to be "uncertainty in the outcome" or "the likelihood or potential outcome of climate related hazards." The IPCC's definition of risk is based on exposure, hazards, and vulnerability. As the IPCC is the leading authority on climate change and most recent standards refer to IPCC reports, it makes sense to adopt the IPCC's definition of risk for climate risk assessments. A similar inconsistent use of vocabulary is also found for the components of risk, especially with regards to the concept of vulnerability.									Validated	Validate	Validate	Validate	Validate	Validate	Validate	Validate
Non-expert users need simple, standardized outputs	Interview D2.10 - Elena Maksimovitch	Lilian	Heatmap-style matrices showing hazards (aligned with TCFD/IFRS categories), historical vs. future periods, and scenarios. Creating such simplicity requires careful normalization across hazards, locations, periods, and scenarios, and excluding outliers (e.g., Arctic/high mountains) to avoid skewing distributions.	This can be used to represent different things in the document, could create confusion. Could left to 2.8. Rationale to specific, more general point on using appropriate form of visualisation. To be refined not complete discarded if not as specific. Could discard because does like to define what user needs or something simple. Not a good phrasing								Refined	Discard	Refine	Refine	Discard	Refine	Discard	
Try to reduce the mental load of interpretation	Craig et al. (2025), Kause et al, (2020)	Lilian	The review has found that many people, including experts and scientists, misinterpret probabilities and statistics. When communicating uncertain future climate information, it is important to try and reduce the mental load of interpretation for all involved, including scientists. In a study with participants from climate-adjacent UK organizations, 79% and 46% of participants described probability estimates as a feature that hindered their understanding of maps and graphs, respectively (Kause et al. 2020). When communicating climate projection probabilities and statistics (such as relative change or percentiles) care should be taken to explain them and not assume that they will be correctly interpreted by people, even those who are in the field of climate change.	Could enhanced to the education needed + documentation from developers. Making sure users undertand how to use the service ... CRA are broads it could high-level or more in-depth but we do be simple but to simple. Summaru with key information - progressifs disclosure of information fitness for purpose								Refined	Validate	Refine	Refine	Refine	Refine	Refine	
Scenario analysis	Loyer et al, (2024)	Lilian	Most standards agree that a scenario analysis of the likelihood and magnitude of hazards, at least based on the current and future climate projections over the lifespan of the system, is a fundamental requirement. It would be preferable to have multiple scenarios to evaluate the uncertainties associated with climate projections, but many standards do not require this. However, a high-level emission scenario is often required by standards and guidelines for such analysis. The time horizon (short-, medium-, long-term) should be adapted to the lifespan of the system or activity, generally over a period of 20 or Disclosure of climate change risk in credit ratings years.	- Some recommendation about the analysis on present (timeseries, where are the assets), for the future to need to caracterize and manage uncertainty (using multiple scenarios) - Miminal requirement using climate data for the present and future projection. Multiple scenarios or worst case scenario ? D2,8 have a recommendation for multiple scenario Recommendation for looking in the past, and the future including multiple projection. use of GWL to avoid having to look into multiple scenarios - could be covered by projection time horizon is important -								Refined	Refine	Refine	Refine	Discard	Refine	Discard	
Addressing and mitigating uncertainties	Loyer et al, (2024)	Lilian	A few standards address the issue of uncertainties. The suggestion for addressing uncertainties is to be transparent about the confidence level and to use multiple model ensembles and multiple scenarios to consider a range of possible futures. This gap is further explored in another deliverable of Climateurope2, specifically "D2.3: Preliminary Best Practices in Climate Uncertainty Quantification and Communication".	D2.8? Provide guidelines - Should not ignore uncerntainties and look in D2,8. Could have a disclaimer assuming the data is right. Uncertainty is not a well established practices. People should try to manage uncertainty. Could reformulate to something like: be transparent about uncertainties and limitations in the risk assessment.								Refined	Refine	Refine	Refine	Discard	Refine	Discard	
Response to adaptation	Loyer et al, (2024)	Lilian	The current assessment AR6 introduces "responses to adaptation" as a new dimension of risk. However, existing standards and guidelines have yet to incorporate this new element. A holistic approach encompassing both mitigation and adaptation strategies would significantly benefit decision-makers by helping them validate whether their chosen adaptation measures effectively mitigate climate risks while avoiding unintended consequences. Scenario-neutral approaches to climate impact and risk assessment have been proposed in the literature (e.g., Prudhomme et al., 2010), but have yet to find their way in guidelines and standards.	New not a lot of literrature, more on risk management then risk assessment, more on residuel risk. Science is still developing. Fit for purpose targeting, not a recommendation at this stage. Try to include responsive in the CRA approach. Research gap instead of recommendation?								Refined	Discard	Refine	Discard	Refine	Refine	Refine	

Compound and cascading risks	Loyer et al, (2024),Simpson et al, (2021)	Lilian	The compound and cascading nature of physical climate risks and their interplay with transition risks as well as those related to economy and biodiversity, is increasingly recognised as a critical consideration for climate risk management. Indeed, a recent report by the Network for Greening Financial Systems (NGFS) has highlighted the need to take this into account in climate scenario planning within the financial sector, citing examples of institutions that are already integrating this into planning. However, there are currently no publicly available tools and guidelines for assessing compound and cascading risks, with the NGFS highlighting the need to develop methodologies and toolkits. While Simpson et al. (2021) have identified a potential framework for classifying complex risk in terms of interactions between 1) the determinants of risk, 2) the drivers of determinants of risk and 3) risk themselves, this is yet to be operationalised as a tool	To generic, emerging area - should be included - We recommended people try to asses compound and cascading risk in the assesment. Should include something. Research gap ? Important but no concrete guidances, could be grouped as a recommendation important but not adressed yet. Should be written in D2,10								Refined	Refine	Refine	Refine	Refine	Refine	Refine
Addressing and mitigating uncertainties	Loyer et al, (2024)	Lilian	While most climate data-oriented portals provide information from one or more ensembles of climate models, it is sometimes left to the user to ensure that this uncertainty information is taken into account. The same rigour in providing uncertainty information is often not found in services and tools supporting other parts of the risk assessment process, such as the provision of data on impacts, exposure and vulnerability.	Same as 46 - Making sure uncertainties is used -								Refined	Refine	Refine	Refine	Refine	Refine	Refine
Common language	Interview D2.10 - Anonymous A	Lilian	Standardization/taxonomy can help establish a common language	Should be included in 34, disagree to obvious, could be joined to standardized definition								Refined	Refine	Refine	Refine	Refine		Refine
Model Transparency	A Buyer's Guide to Evaluating Physical Climate Risk Data	Lilian	Disclosing the specific Global Climate Models (GCMs) used, justifying their selection, and providing end-to-end documentation detailing how model bias was corrected and how the results should be interpreted for decision-making	Could not be possible because of properties manage, high-level description of what they do. Disclose different then open source the user will decide if good enough Should be included in 63								Refined	Refine	Refine	Refine	Refine		Refine
Scientific Rigor	A Buyer's Guide to Evaluating Physical Climate Risk Data	Lilian	Build their analytics on well-established scientific methods, use physically realistic models, apply proper bias correction, and validate outputs against observed data and historical events		I would put revise should be used but it would be better for it to be transparent, documented and the limitations clearly defined		I would be generally supportive of a recommendation that climate services should be based on well-established scientific principles etc. But it would need some rephrasing. What should be included, all steps of the processing chain? Should it also mention the *latest* scientific insights? Probably it can be merged with some of the other recommendations.					Refined	Refine	Refine	Refine	Refine		Refine
Uncertainty Handling	A Buyer's Guide to Evaluating Physical Climate Risk Data	Lilian	Explicitly quantify uncertainty, including confidence intervals, probabilistic outcomes, and scenario-based variation using a broad ensemble of GCMs	Should be included in a recommendation adressing uncertainties	Similar to 46 but I think we do need a recommendation of multi-ensenble approach for risk assessment		Merge with other uncertainty recommendations			Same as 46		Refined	Refine	Refine	Refine	Refine		Refine
Downscaling and Resolution	A Buyer's Guide to Evaluating Physical Climate Risk Data	Lilian	Scientifically defensible downscaling techniques (such as statistical, dynamic, or hybrid ML-based approaches) and involve physical scientists in validating the results to ensure realism and traceability		I would reformulate to have a recommendation to disclose downscaling techniques and limitations		To some extent this overlaps with 57 - use bias correction techniques that are scientifically sound/defensible. There could be a separate recommendation on disclosing key steps/methods.					Refined	Refine	Refine	Refine	Refine		Refine
Peril and Compound Risk Modeling	A Buyer's Guide to Evaluating Physical Climate Risk Data, Simpson et al, (2021)	Lilian	Understands how multiple hazards interact (e.g., combining wind and different types of flooding)	Should be included with 49	Similar to 49		Yes, but there will be similar recommendations further down			Same as 49		Refined	Refine	Refine	Refine	Refine		Refine
Regulatory Readiness and Defensibility	A Buyer's Guide to Evaluating Physical Climate Risk Data	Lilian	The methodology must be transparent and well-documented with clear assumptions and scientific references, enabling the organization to justify the outputs to third parties, boards, and regulators		I would agree that climate services should provide documentation, assumptions and limitation for their data or information	Others recs can be folded into this one	Extend this to all steps of the processing chain?					Validated	Validate	Validate	Validate	Validate		Validate
Access and Support	A Buyer's Guide to Evaluating Physical Climate Risk Data	Lilian	Comprehensive technical documentation must be readily available, as the data needs to be understood, stress-tested, and integrated into workflows, particularly in high-stakes, regulated environments	Should be included with 63	Goes with 64	The most important points seem to be in 63	To some extent, overlaps with 63. It also depends on the budget/time available, in some contexts this may be overkill?			With 63		Refined	Refine	Refine	Refine	Discard		Refine
Data Quality and Transparency	2022 climate risk stress test	Lilian	Provide transparency on the methodologies, criteria, and assumptions employed in both internal reports and public disclosures, and regularly reassess the appropriateness of their data sources	Should be included in 63	Same as 64	Agree with merge with 63	Merge with 63			Same as 63		Refined	Refine	Refine	Refine	Refine		Refine
Transparent Uncertainty Management	Technical Guidance on Comprehensive Risk Assessment and Planning in the Context of Climate Change	Lilian	Future risks, are subject to a high degree of uncertainty, performing a qualitative assessment of uncertainty sources and documenting the confidence level of main statements	Should be included in a recommendation adressing uncertainties	Perhaps already in D2.8	Agree that this merges with the others	Merge with other uncertainty recommendations (46?)					Refined	Discard		Refine	Discard		Discard
Standards and Transparency for Vendors	MOBILISING ADAPTATION FINANCE TO BUILD RESILIENCE	Lilian	Standards and assurance be created for third-party climate risk data providers, or, at a minimum, require transparency on evidence sources, methodology, and assumptions and enable independent and expert academic assessment of quality by experts	Should be included with 64	Goes with 64, but I do like a minimun requirement or quality assessment by experts	Can it be integrated with 63-65	Agree with Lilian, but in some circumstances this could be overkill (or unrealistic). As a general recommendation on transparency of data sources etc. it can be merged with similar requirements			Same as 63		Refined	Refine	Refine	Refine	Refine		Refine

Data Selection Methodology	MOBILISING ADAPTATION FINANCE TO BUILD RESILIENCE	Lilian	Assess tools and data sources using the criteria of Suitability (does it match the time horizon, region, and hazard?); Credibility (is it robust, peer-reviewed, and theoretically underpinned?); and Legitimacy (is the source impartial and transparent about funding/peer review?)		This would be useful for Users		Not sure if peer-reviewed is always achievable for e.g., private companies					Refined	Validate	Validate	Validate	Refine		Refine
Disclose CCR Assessment Models and Methods	Disclosure of climate change risk in credit ratings	Lilian	Providing information on, data, rating criteria, transparency on the models and methods used for CCR assessments, including whether these are of a qualitative or quantitative nature and whether these were conducted at the entity or sector level, would allow the user to better understand the conclusion on relevance and materiality of CCR	Should be included in 63	Goes with 64	Merge with 64.64,65 and 69 due to transparency overlap	Overlaps with 63			Same as 63		Refined	Refine	Refine	Refine	Refine		Refine
Require Comprehensive Hazard Consideration	Tavares et al, (2023)	Lilian	Risk assessment tool must account for all climate hazards relevant to the sector/organization/asset, considering non-trivial impacts.		Should be included in D2,10 but I do not think it is for WP1	Integrate with other multi-hazard?	Probably overlaps with other multi-hazard recommendations. As a general principle I actually think it is quite important, but maybe not in all contexts.					Refined	Discard	Refine	Refine	Refine		Discard
Address Multi-Time Horizon Projections	Tavares et al, (2023)	Lilian	Integrate short-, medium-, and long-term climate projections to understand how climate change may influence the location, duration, intensity, and frequency of hazards	Should be included with Scenario analysis	Would be the recommendation of scenario analysis, could perhaps add something for current risk	This is an important one	Depends on the context! But I agree with Lilian					Refined	Validate	Validate	Validate	Refine		Discard
Evaluate Extreme Probability Events	Tavares et al, (2023)	Lilian	The assessment should specifically include consideration of both high-impact low-probability and low-impact high-probability events				Depends on the context!					Refined	Validate	Validate	Refine	Refine		Refine
Ensure Climate Change Projections are Integrated	Poljansek et al, (2021)	Lilian	The risk identification should take into account of climate change projections and scenarios based on the Intergovernmental Panel on Climate Change (IPCC) reports, or on other validated scientific sources. Where existing, national climate risks and vulnerability assessments provide relevant projections of climate hazards and risks. The future climate scenarios used could be short-term (20Disclosure of climate change risk in credit ratings); medium-term (2050) and long-term (2100) knowing that short term scenarios tend to have a very large uncertainty.	Should be included with Scenario analysis	Same as 75	Merge with 75?	Current risk missing					Refined	Refine	Refine	Refine	Discard		Refine
Explicitly Frame Uncertainty	Poljansek et al, (2021)	Lilian	Documentation of scenarios and the analysis methods utilized to estimate the probable extent and impact of hazards is important not only for keeping track of uncertainties, but also for being able to merge and compare the results properly, Acceptable levels of uncertainty arising from the input data and models used in different stages of risk assessment should be framed.	Should be included in a recommendation adressing uncertainties	Perhaps already in D2,8		Merge with other uncertainty recommendations (46?) though I quite like this formulation					Refined	Refine	Refine	Validate	Discard		Discard
Use of Climate Indices	UNDRR and WMO (2023)	Lilian	Indices highlight specific features of variables designed for better understanding of climate hazards variations of the data they derive	Discarded		Doesn't seem to be linked to a	Not sure what the recommendation is.					Refined	Discard		Refine	Refine		Discard
Handle timescale	UNDRR and WMO (2023)	Lilian	The assessment must reference the climate normal (baseline statistics, usually 20 or Disclosure of climate change risk in credit ratings years) to identify changes in future climate (statistics,	Should be included with Scenario analysis		Specifying what is mean by normal/the baseline is important	Formulation too specific (credit rating years?). Comparing with a baseline is a good					Refined	Validate	Refine	Discard	Refine		Refine
Uncertainty	UNDRR and WMO (2023)	Lilian	Any information for the future, regardless of the timescale it covers, contains uncertainty. Since none of the available products regarding future climate states is entirely certain (forecasts, predictions, outlooks and scenarios all carry on a certain degree of uncertainty),	Should be included in a recommendation adressing uncertainties			merge with other uncertainty recommendations (79, 46?) though some of the					Refined	Validate	Refine	Refine	Refine		Refine
Identify and Assess Critical Thresholds	UNDRR and WMO (2023)	Lilian	Specific critical thresholds in weather/climate variables for the sector or area of interest, should be aligned with recommended climate indices	Discarded	Would depend of the purpose of the CRA		See my comment in line 80. For this one, I would rather say that the indices used should align with relevant thresholds in the system (rather than the other way round!)					Refined	Discard	Refine	Refine	Discard		Discard
Aligned with EU Taxonomy	DG CLIMA	Lilian	Tools should be aligned with the definition of acute & chronic hazards	Should be included in 34	Same as 36		Alignment with standards/definitions already captured I think					Refined	Refine	Refine	Refine	Refine		
Aligned with the IPCC framework (Exposure, Hazard, Vulnerability)	DG CLIMA	Lilian	Tools should be aligned with the definition IPCC framework	should be included in the 34	Same as 35		Same					Refined	Refine	Refine	Refine	Refine		
Communicate data to users	DG CLIMA	Lilian	Need to help users understand the data, ensuring it is communicated in a simple way but backed by robust information	Include in 37	Same as 37		Merge with 37 indeed					Refined	Refine	Refine	Refine	Refine		Refine
Match visualisations with matching text	Kause et al, (2020)	Lilian	Match climate risk visualisations with associated text In communicating risk using visualisations ensure that the text clearly maps onto the contents of the visualisation	Include in 37		Building on Rutger's point could this be 'adhere's to best practice in invisualisation, including ensuring that text clearly maps onto accompanying images, that the most prominent and salient features are the most relevant, that usage of colour is intuitive and that one key message is presented per image' This would merge several very specific points into a summary of what good practice looks like...though realise this may have been done in 2.8 and will be aligned with recs from that work.	Yes although maybe more a general visualisation principle, not just for climate risk tools? So maybe we should have one to say "adhere to best practices in visualisation and communication, such as ...."					Refined	Validate	Refine	Refine	Refine		Refine
Communication of one message per visualisation	Kause et al, (2020)	Lilian	Communicate one message per climate risk visualisation To avoid confusion and cognitive overload, visualisations for risk communication benefit from conveying one key message.	Include in 37		This is good visual communication practice,but not specific to risk assessment. It could relate to other recs regarding clarity.	Yes although maybe more a general visualisation principle, not just for climate risk tools?					Refined	Validate	Refine	Refine	Discard		Discard
Recommendations about climate information	Loyer et al, (2024),CLIMA AX handbook	Lilian	For the assessment multiple scenario's being considered, timeframe, level of detail, quality control / trusted data sources…)	Should be included with Scenario analysis	Same as the scenario analysis		Not sure what the recommendation is.					Refined	Refine		Discard	Discard		Discard

Storylines	Shepherd et al, (2018)	Lilian	Two human tendencies are intuitively evident in how we think about risk. It may be useful to classify them using a distinction about memory: knowing facts (semantic) versus reliving events (episodic). The conventional approach to climate change risk is semantic (e.g., what is a 1 in 1000 year event?), whereas storyline approaches are episodic (e.g. have we seen this before; and if so, what might the next event be like?). Threats from natural events sufficiently rare as to be outside the living memory of local populations and decision-makers do not so readily motivate investments in physical infrastructure (or other costly measures, such as retreat) that would reduce risk, despite good semantic understanding of the case for such investments, because the necessary episodic understanding is not present. Scientifically constructed storylines help as a complementary approach to raise risk awareness, by incorporating episodic information and making the predicted future more tangible.	Should be included with 49 - Same as 104	Storylines seems to be a great way to comminicate risk	I think that there is enough evidence of these working well as a tool for communication. I agree with Rutgers rephrasing. Integrate with the storylines recommendation lower down.	Recommendation unclear, maybe it should be something like "consider the use of storylines as an alternative to, or to supplement, quantitative approaches..." Note storylines are sometimes seen as a communication tool, and sometimes as more as a scenario (but then maybe more event based). I agree there may be benefits to using storylines... But how strong is the evidence? I think it *could* be a WP1 recommendation, if phrased appropriately.					Refined	Validate	Refine	Refine	Refine		Refine
Contextualise a climate hazard to make it fit-for-purpose		Xavi	Without a thorough contextualisation, a climate hazard can't become part of a service that is fit-for-purpose. This contextualisation is sometimes a result of an arduous co-production process, and may take many iterations, but it's essential in order to provide data that is meaningful and actionable.	Include in 37	I agree with the rationale, this goes well with the scoping phase of D2.10. Not sure if it should a recommendation for WP1		I am not quite sure what the recommendation is / implies. I am also not convinced by the rationale - a climate hazard doesn't want to be part of a service! Maybe it should say: you cannot develop a service for a hazard that is not contextualised? But then I don't know what it means. If this is about providing sufficient context to the users, then is it not about communication and education?					Refined	Discard	Refine	Discard	Validate		Refine
Don't fall into the simplification trap and embrace uncertainty		Xavi	Predicting the future is not a simple task, especially when the system you're trying to predict is as complex as the Earth's atmosphere. Consequently, developers employ different strategies to translate this complexity into uncertainty, which is sometimes quantifiable, but not always. Decision-makers should not hide from understanding this uncertainty, as it's an integral part of climate information, and should thus learn to make decisions based on a probabilistic approach.	Should be included in a recommendation adressing uncertainties	Goes with 46		Merge with other uncertainty recommendations					Refined	Validate	Refine	Refine	Validate		Refine
Use scenarios and pathways as stories, not predictions		Xavi	Climate scenarios and pathways weren't designed to be predictions of the future, but rather stories representing plausible futures, and should thus be used as such. Multiple scenarios should be used in conjunction to account for different alternatives, and analyse relative differences between them.	Should be included with Scenario analysis	Goes with the scenario analysis		Yes, an important one. But not "use as stories" but rather as "plausible narratives of the future without prior likelihood attached"					Refined	Validate	Validate	Refine	Validate		Refine
Always aim for a comprehensive understanding of the applicability and limitations of data		Xavi	Users shouldn't blindly trust the quality of data. An honest and detailed validation report should always be provided along with data in a language that everyone can understand. Such reports should be particularly transparent about the applicability and limitations of data.	Should be included in 63	Goes with disclosure	As others mentioned it overlaps with earlier recommendations on transparency	Too generic					Refined	Refine		Discard	Refine		Refine
Incorporate Hazard Interrelationships	Gill et al, (2022)	Rutger	Risk assessments must move beyond "multi-layer single hazard" approaches (which treat hazards as independent) to account for how one hazard affects another and potential feedbacks.	Should be included with 49	Goes with coumpound risk		This is probably the strongest "multi-hazard" recommendations, but it may need some reformulation, as it depends on the context					Refined	Refine		Validate	Validate		Refine
Consider interactions in impacts as well as hazards	White et al, (2025)	Rutger	Interrelationships exist not only between hazards but also between (potential) impacts, and these should be considered as well.	Should be included with 49	Goes with cascading risk		Emerging best practice?					Refined	Refine		Refine	Validate		Refine
Model Risk as a Dynamic System	Gill et al, (2022)	Rutger	Rather than seeing risk as a static product of hazard, exposure, and vulnerability, it should be viewed as a dynamic system with interrelationships between the individual components that are evolving over time.	Should be included with 49	Agreed maybe how we can provide exposure and vulnerability could be the recommendation		Emerging best practice?					Refined	Refine		Validate	Refine		Refine
Develop indicators that capture interrelationships	Gill et al, (2022),White et al, (2025)	Rutger	Many existing hazard and risk indicators focus on individual hazards or multiple single hazards. While combining indicators for multiple hazards allows for a multi-hazard perspective, it may sometimes be necessary to develop indicators that capture or quantify the hazard interrelationships.				Not quite sure to what extent this is being applied in practice. I would probably accept one of 98-100 first as a WP1 recommendation before this one.					Validated	Validate	Validate	Refine	Validate		Validate
Adopt clear and consistent terminology	White et al, (2025)	Rutger	Adoption of clear and consistent terminology in the definition and usage of terms such as "multi-hazard", "multi-risk", as well as the terms to describe hazard interrelationships is necessary to avoid ambiguities and confusion. The terminology should be checked with relevant stakeholders as well.	This recommendation should be merged with 34		Agree that this should be included, but amalgamated into the other standardised terminology recs.	Yes, but probably can be merged with other "use standard terminology" recommendations					Refined	Validate	Refine	Refine	Validate		Refine
Account for dependencies in frequency analysis	Ward et al, (2026)	Rutger	Probabilistic or frequency analyses of hazardous events should account for the dependencies between different types of events.	Should be included with 49		Does this sit broadly within 98?	In principle yes but very specific to multi-hazard studies					Refined	Refine	Refine	Refine	Refine		Discard
Supplement statistical approaches with plausible multi-hazard storylines	Ward et al, (2026), [57]	Rutger	Multi-hazard storylines allows for an exploration of cause-and-effect relationships in multi-risk situations, as well as for an examination of cascading effects, critical thresholds, emerging risks and indirect impacts.	Should be included with 49	Goes with 92	Merge with 92?	I would probably formulate 92 as something like this					Refined	Refine	Refine	Refine	Refine		Refine
User-led design		Rutger			Something perhaps like fit for purpose		Needs better formulation. But a user-cenred design is quite key...					Refined	Refine	Refine	Refine			

Accessability		Rutger		Include in 37		Earlier recommendations speak to this?						Refined	Refine	Refine	Refine			
Provide context		Rutger		Include in 37	Should be included in this assessment simarlaly to 93							Refined	Discard	Refine	Refine			
Provide relevant metadata and documentation		Rutger		Should be included in 63		Does this merge with earlier points on transparency?						Refined	Validate	Refine	Refine			
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