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D1.2
Handbook of Multi-hazard, Multi-Risk Definitions and Concepts

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D1.2/Handbook of Multi-Hazard, Multi-Risk Definitions and Concepts

Lead by the British Geological Survey

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Abstract

This report is the first output of *Work Package 1: Diagnosis* of the MYRIAD-EU project: Handbook of Multi-hazard, Multi-Risk Definitions and Concepts. The aim of the task was to (i) acknowledge the differences and promote consistency in understanding across subsequent work packages in the MYRIAD-EU project, (ii) improve the accessibility of our work to a broad array of stakeholders and (iii) strengthen consensus across the hazard and risk community through a common understanding of multi-hazard, multi-risk terminology and concepts. The work encompassed a mixed-methods approach, including internal consultations and data-generating exercises; literature reviews; external stakeholder engagement; adopting and building on a rich existing body of established glossaries. 140 terms are included in the glossary, 102 related to multi-hazard, multi-risk, disaster risk management and an additional 38 due to their relevance to the project, acknowledging the need for a common understanding amongst an interdisciplinary project consortium. We also include extended definitions related to concepts particularly of relevance to this project deliverable, including 'multi-hazard', 'hazard interrelationships', 'multi-risk' and 'direct and indirect loss and risk'. Underpinned by a literature review and internal consultation, we include a specific section on indicators, how these might be applied within a multi-hazard and multi-risk context, and how existing indicators could be adapted to consider multi-risk management. We emphasise that there are a number of established glossaries that the project (and risk community) should make use of to strengthen the impact of the work we do, noting in our literature review a tendency in papers and reports to define words afresh. We conclude the report with a selection of key observations, including *terminology matters* – for all aspects of disaster risk management, for example communication, data collection, measuring progress and reporting against Sendai Framework targets. At the same time, we discuss *when is it helpful to include 'multi-' as a prefix*, questioning whether part of the paradigm shift needed to successfully address complex challenges facing an interconnected world is through inherently seeing vulnerability, exposure and disaster risk through the lens of multiple, interrelated hazards. We emphasise that there is likely to be an *evolution of the terminology* throughout the project lifetime as terms are emerge or shift as the project evolves. Finally, we propose a roadmap for developing and testing draft multi-risk indicators in MYRIAD-EU.

The WP1 team would like to acknowledge all the contributions of the consortium on this task and the feedback from the External Advisory Board, in particular the chair of the board Virginia Murray, Head of Global Disaster Risk Reduction at the UK Health Security Agency, and the contribution of Jenty Kirsch-Wood, Head of Global Risk Management and Reporting at UNDRR, for her reflections on the findings of this work.

Dissemination level of the document

☒ Public

☐ Restricted to other programme participants (including the Commission Services)

☐ Restricted to a group specified by the consortium (including the European Commission Services)

☐ Confidential, only for members of the consortium (including the European Commission Services)

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1 Introduction

1.1 Background

Risk managers and other decisions makers are faced with several obstacles when addressing real-world challenges, including: how to consider the interrelated effects between hazards; how to better account for the dynamic feedbacks between risk drivers; and how to account for the trade-offs and synergies across sectors, regions, and hazards? Despite huge scientific advances in understanding natural hazard related risk, and the shift from managing disasters to managing disaster risk, research and policy is still dominated by single-hazard, single-sector perspectives (Ward et al. 2022).

MYRIAD-EU's vision is to catalyse the paradigm shift in which science and practice move from a single-hazard, single-sector, risk perspective towards a multi-risk, multi-sector, systemic approach (Ward et al., 2022). To achieve this vision, the project includes this first objective:

> Develop a common baseline and understanding on multi-hazard and multi-risk definitions, indicators, functions, methods, tools and policies (work package 1). Part of this objective includes the development of a *Handbook of Multi-Hazard, Multi-Risk Definitions and Concepts*

The importance of a baseline and common understanding of definitions and concepts is essential to reporting progress on key international agreements including the Sendai Framework for Disaster Risk Reduction (2015-2030), the Paris Agreement on climate change and the Sustainable Development Goals of Agenda 2030. Disaster risk terminology has received a lot of attention over the last decades and there have been several international endeavours to develop a common understanding of disaster risk related terminology led by intergovernmental bodies (e.g. UNDRR, ISC, IPCC, WHO, WMO).

In the last decade, a number of terms related to multi-hazard and multi-risk have emerged across the literature. Improving consensus around definitions and would help to improve communication and ensure that multi-(hazard-)risk management approaches meet the expectations of the Sendai Framework. Indeed, recommendation 3 of the recent UNDRR Technical Working Group on the Hazard Definition Classification Review is "Engaging with users and sectors for greater alignment and consistency of hazard definitions" (UNDRR & ISC, 2020).

An essential first step of the MYRIAD-EU project is to build a common understanding of the current state of play of multi-hazard and multi-risk terminology, identify and recommend existing terminology to adopt, and identify gaps and opportunities for further terminology evolution. The outputs of this work have key importance for both the MYRIAD-EU project process (interdisciplinary working) and impact of the project.

1.2 Aims and Scope

This *Handbook of Multi-Hazard, Multi-Risk Definitions and Concepts* (referred to as 'Handbook' from hereon) aims to (i) acknowledge the differences and promote consistency in understanding across subsequent Work Packages in the MYRIAD-EU project (and their outputs), (ii) improve the accessibility of our work to a broad array of stakeholders, and (iii) strengthen consensus across the hazard and risk community through a common understanding of multi-hazard, multi-risk terminology and concepts. It characterises current work on indicators, and sets out options for their development, testing, and use through the MYRIAD-EU project.

To achieve the aims above, the Handbook builds on existing work, using a multi-method approach to bring together data and insights from across and beyond the consortium (including literature reviews and curation of existing established glossaries). Where possible, we adopt language from established, intergovernmental glossaries to ensure our work and outputs align with national and international efforts to implement the Sendai Framework for Disaster Risk Reduction 2015–30 (UNDRR, 2015). We discuss these further in section 2.

1.3 Structure of the Deliverable

The remainder of this Handbook is structured as follows: **Section 2** outlines methods and overview of data collection. **Section 3** presents definitions for multi-hazard, multi-risk terminology and concepts, including a glossary of terms and then expanded definitions and literature review for key concepts. **Section 4** summarises the current application of indicators in the context of multi-hazard, multi-risk management. **Section 5** presents additional terminology and concepts used within the work packages of MYRIAD-EU and the project as a whole, aiming to improve accessibility of the work being conducted in MYRIAD-EU to all those involved. The section includes a glossary of terms and some expanded definitions for key terms and concepts as selected by the consortium. We conclude in **Section 6** with a summary of key observations from this work and their relevance to MYRIAD-EU and wider risk management community, including a proposal for multi-risk indicators to be further developed and tested and setting out a road map for this work. This deliverable also includes **five Appendices**. Images and figures presented in the report are reproduced according to the permissions by the author or *as per* permissions stated in the original document.

2 Methods and Overview of Data

This deliverable draws on data gathered from (i) internal consultations and data-generating exercises, (ii) literature reviews, and (iii) external stakeholder engagement. Data was synthesised and integrated to compile glossaries, concept descriptions, and draft indicators set out in **Sections 3** to **5** respectively.

2.1.1 Initial Data Collection and Generation (Internal Consultation activities)

The MYRIAD-EU consortium was invited to complete forms (**Appendix A**), collating information on relevant terms, suggested definitions, and links to existing glossaries and publications that may inform this work. Eight forms were returned with approximately 110 unique terms suggested for inclusion in the Handbook. After merging closely related terms (e.g., disaster and catastrophe, compound hazards and compound events), this list was reduced to 93 terms.

This dataset formed the basis for two activities at the hybrid MYRIAD-EU kick off meeting (Milestone 1.1, 29 September to 1 October 2021), with the in-person component taking place in Zandvoort, the Netherlands:

1. *Activity A.* Participants worked in small groups (**Figure 1**) to organise 93 terms by their similarity, express which terms could be excluded from the handbook (e.g., due to perceived lack of relevance), and suggest additional terms to those initially suggested. Some groups focused on a sub-set of terms, whilst others organised all terms and suggested some additional terms for inclusion. This feedback was used to update the dataset of terminology and concepts for task 1.1.
2. *Activity B.* Participants reviewed definitions of a selection of terms via an online tool (Mentimeter) expressing the extent to which they agreed with the definition (**Figure 2**). These definitions were pre-selected by Gill, Duncan and Ciurean owing to their relevance to work package 1, the project and their application across the different work packages (based on early understanding of the project overall). Whilst we acknowledge that there are other terms that could have been selected for this exercise, the aim of the activity was to get participants thinking and talking about definitions and the commonalities and differences across different disciplines and sectors, which was achieved. For each definition participants picked one of three options: ‘generally agree’, ‘don’t know and/or not relevant to my work’ or ‘would prefer this to be edited’. For these terms, participants then had opportunity to edit existing definitions or suggest alternative definitions. The definition of ‘systemic risk’, for example, received a number of suggestions for alternative definitions, with feedback that it was too long and difficult to understand (see **Appendix B**).

Figure 1: Images of the participatory group discussions on terms to include in the handbook (Source: BGS © UKRI. The online post it notes discussion was carried out in Miro.com)

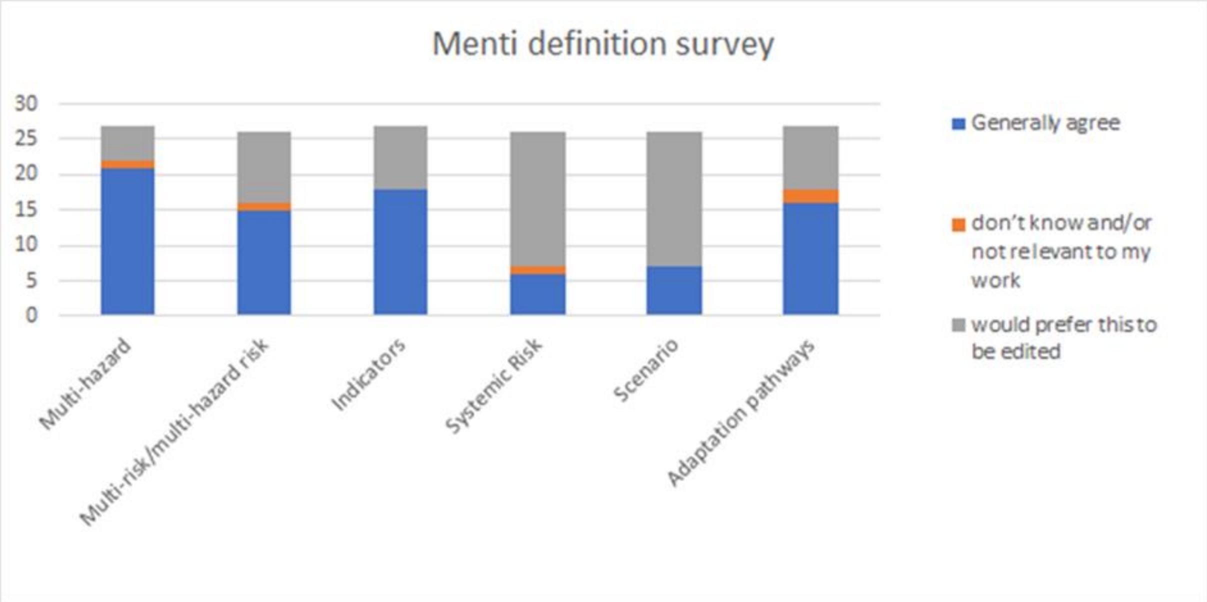

Figure 2: Results from the Mentimeter.com survey on definitions (results reflect a combine voting from online and in-person participants) (Source BGS © UKRI).

Activities A and B, above, informed our understanding and refining of the terminology required in the Handbook. Subsequent discussions highlighted that some words have very specific definitions in different sectors, making it challenging to achieve consensus. Being aware of differences, however, makes it easier for steps to be taken to ensure clarity of communication between different partners.

Further engagement with the MYRIAD-EU consortium took place during a series of online meetings. On the 12 November 2021, we ran an online exercise using the collaborative tool 'Padlet', to gather information on (i) what *technical glossaries* participants use or refer to in their work, (ii) *how we may use indicators* for multi-hazard risk management, and (iii) whether there are any *good examples of indicators* (especially, but not exclusively for risk management). The results of this exercise are included in **Appendix C.** In later WP1 meetings, the consortium shared perspectives on specific definitions and additional glossaries of interest.

Finally, specific content was requested from the MYRIAD-EU consortium to populate this Handbook, including definitions and short descriptions of key terms and concepts. Here, contributions focused on technical terms and language describing the structure of activities in specific work packages. This supports both internal partners and external groups to understand the work being done in MYRIAD-EU, recognising that we are a community coming from multiple different disciplinary and sectoral backgrounds. Sectoral Representatives contributed brief descriptions of the scope of their 'sector', articulating the groups that make these up, key metrics that help to characterise this sector in the European context, and other useful information of relevance to the project.

2.1.2 Literature Reviews

Two literature reviews informed the development of **Sections 3** and **4** of this Handbook.

In the context of **Section 3**, a review of multi-hazard and multi-risk literature (including both peer-reviewed and 'grey' literature) focused on two questions:

1. What terms are explicitly defined, and are these self-generated definitions or do they reference existing glossaries or definitions in other sources?
2. To what extent does this body of literature use and define terms preceded by 'multi-hazard' or 'multi-risk' (e.g., multi-hazard exposure, multi-hazard response, multi-risk preparedness, multi-risk prevention)?

To address these questions, we selected multi-hazard literature from 2015 to 2021 (i.e., post agreement of the Sendai Framework for Disaster Risk Reduction) using Google Scholar. We completed four searches (see **Table 1**), each using a search term to identify multi-hazard or multi-risk literature (i.e., multi-hazard, multihazard, multi-risk, multirisk) and a search term to identify those papers that explicitly defined key terms. As of December 2021, these searches generated a total of 1151 results, with some articles likely to be returned in more than one of the searches.

Table 1: Literature Review Search Terms (Multi-Hazard, Multi-Risk Terminology and Definitions)

Search Term	Total Returned Results
"multi-hazard" AND "we define"	598
"multihazard" AND "we define"	177
"multi-risk" AND "we define"	312
"multirisk" AND "we define"	64

We acknowledge that this search was not exhaustive, and that other relevant publications may exist that were not returned with the combinations of search terms set out in **Table 1**. However, the boundaries placed on this review (both temporal and through the selection of search terms) enabled the rapid identification and analysis of a highly relevant sample of literature, to inform the production of this deliverable alongside data from engagement activities.

For each accessible result (i.e., English language, not behind a paywall) of these searches, we identified any terminology that included a stated definition in the publication. The review identified 660 definitions relating to more than 300 individual terms. We used the results of this review to augment and refine the list of terms included in the glossary and to improve proposed definitions. Wider observations from the review process are captured in **Appendix D**, commenting on themes such as the use of existing well-established definitions vs. generating a new definition, the pre-fixing of existing terms with 'multi-hazard' or 'multi-risk' (e.g., hazard assessment vs. multi-hazard assessment), and opportunities to strengthen consensus on multi-hazard, multi-risk terminology and definitions.

In the context of **Section 4**, an additional literature review (including both peer-reviewed and 'grey' literature) explored the use of indicators for multi-hazard, multi-risk management, and the extent to which the concept of 'multi-hazards' is embedded into existing indicators. The review was undertaken between December 2021 and February 2022, using Google Scholar. We completed 14 searches (**Table 2**), each with a term to identify multi-hazard or multi-risk literature and a search term relating to indicators, with no time filter and excluding citations from the search results. The combinations of search terms were designed to exclude literature of peripheral interest (i.e., those using the word 'indicator' in a different context).

Table 2: Literature Review Search Terms (Indicators)

Search Term	Total Returned Results
"multi-hazard indicators"	7
"multihazard indicators"	1
"multi-risk indicators"	31
"multirisk indicators"	0
"multi-hazard" AND "disaster risk indicators"	53
"multihazard" AND "disaster risk indicators"	10

Search Term	Total Returned Results
"multi-risk" AND "disaster risk indicators"	9
"multirisk" AND "disaster risk indicators"	1

Again, while not an exhaustive set of possible search terms, the boundaries placed on this review ensured our analysis focused on the most relevant papers, with supplementary examples provided from engagement activities. For each accessible result (i.e., English language, not behind a paywall), we read the contents to assess relevance. Some relevant papers described the differing use of or characteristics of good indicators, and others described examples. For the latter, we examined the purpose of indicators, the types of indicators used, and evidence of uptake.

2.1.3 Building upon Existing Work

To support alignment with global policy mechanisms, initial preference was given to definitions within existing, well-established international glossaries, including those compiled by intergovernmental organisations (e.g. the World Meteorological Organisation – WMO, the UN Office for Disaster Risk Reduction – UNDRR) and intergovernmental panels (e.g. Intergovernmental Panel for Climate Change – IPCC). Examples of established international glossaries include:

IPCC (2022) 6th Assessment Report Working Group II Glossary. The glossary defines some specific terms as the Lead Authors of the Working Group intend them to be interpreted in the context of the Working Group II Report: Impacts, Adaptation and Vulnerability.

UNDRR (2016) Disaster Risk Reduction Terminology. This terminology is available on the UNDRR website, but also in the 'Report of the open-ended intergovernmental expert working group on indicators and terminology related to disaster risk reduction. Experts were nominated by States and supported by the United Nations Office for Disaster Risk Reduction. Within this work, it was also decided that the group should act upon the recommendations of the Scientific and Technical Advisory Group of the United Nations Office for Disaster Risk Reduction on the update of the publication entitled "2009 UNISDR Terminology on Disaster Risk Reduction" (UNDRR, 2016). Notable additions to the terminology include 'multi-hazard'.

UNDRR-ISC (2020) Hazard Definition and Classification Review. Following extensive scientific consultation, the United Nations Office for Disaster Risk Reduction (UNDRR) and the International Science Council (ISC) published in 2020 the UNDRR/ISC Hazard Definition and Classification Review – Technical Report (UNDRR/ISC, 2020). This was followed by a supplement containing 302 hazard information profiles (HIPs), published in 2021 (Murray et al., 2022). The work reviewed existing glossaries and involved experts across hazards. We discuss this work further in **section 3**.

WHO (2020) Glossary of Health Emergency and Disaster Management Terminology. The development of the glossary drew upon WHO's work with partners and countries led by WHO country and regional offices and respective regional directors. It was drafted from existing glossaries and refined using virtual consultation and a face-to-face technical workshop. Within this glossary, there are references to other glossaries of disaster risk terminology in, for instance, the UNDRR 2016 terminology.

WMO (1992) International Meteorological Vocabulary. Published 25 years after the first edition, it takes account of the definitions approved by the WMO technical commissions or other constituent bodies.

2.1.4 External Stakeholder Engagement

We accessed broad understanding of external perspectives on terminology, definitions, concepts, and indicators through exploration of the published literature (including both peer-reviewed and 'grey' literature). Perspectives on terminology and concepts from external stakeholders were also captured through participation of the External Advisory Board at the first and second General

Assemblies (29 Sep – 1 Oct, Zandvoort; 7 – 8 Apr, Austria, Laxenburg) and through the presentation of WP1 findings and a break-out session with external experts at the WP1/WP2 workshop at IIASA, Laxenburg (11–12 April 2022). Between these meetings, we had discussions with the chair of the External Advisory Board regarding work package 1. We also shared an advanced draft (particularly section 5) just prior to submission with the External Advisory Board and the Head of Global Risk Management and Reporting, UNDRR.

2.1.5 Data Synthesis and Integration

Our approach to data integration can be characterised as "pragmatic and iterative" (Wachinger *et al.,* 2013). Starting from an initial list of terminology proposed by the consortium, as well as key terms identified within the MYRIAD-EU description of work, we integrated information from the multiple internal consultation exercises, literature review, and external stakeholder engagement. Through this integration, we developed and refined lists of terminology and definitions, and an overview of approaches to developing and using indicators in MYRIAD-EU.

2.2 Ethics and Data Management

A description of the research informing this deliverable was reviewed by the British Geological Survey (BGS) Research Ethics Committee (*Ref: BGSREC-2021-009*). It adheres to the principles set out in D8.1 (Quality, Ethics, and Risk Management Plan).

Data are shared in the Google Drive for the purposes of collective engagement and input across the WP1 team. The same data are also saved on the secure BGS server, which is regularly backed up. No personal data was collected or shared during the work of D1.2. The work adheres to the principles set out in D8.3 Data Management Plan, for instance, regarding recommended data formats following the literature review work ('tabular data with minimal metadata' as an MS Excel file).

3 Definitions of Key Multi-Hazard, Multi-Risk Terms and Concepts

Table 3 includes 106 terms, selected for inclusion based on (i) their relevance to the field of multi-hazard, multi-risk disaster management, and (ii) their relevance to the work being undertaken in the MYRIAD-EU project. Included terms were either proposed by one or more beneficiary organisations (and their inclusion ratified by the wider consortium) or identified during literature review activities.

The following points are set out to help the reader understand the contents of **Table 3**, the exclusion of certain information, and our approach to ensuring this information remains relevant within and beyond the project.

- *Definitions of Individual Hazards.* The UN Office for Disaster Risk Reduction and International Science Council completed a substantial piece of work reviewing hazard definitions and classifications, published in a technical report (UNDRR/ISC, 2020), and supplementary material (Murray *et al.*, 2021). The latter provides a description of 302 hazards, or 'hazard information profiles (HIPs), developed through consultation with the global science community and other experts. The 302 hazards are categorised within clusters under eight hazard types (**Figure 3**). Each HIP contains the name of the specific hazard, a reference number, a definition, selected annotations, key references and the name of the UN agency or organization that issues guidance relating to the hazard. Given the existence of this substantial, comprehensive, and systematic work, we do not include definitions for specific hazards in the glossary (**Table 3**), but instead we refer readers directly to Murray *et al.* (2021) for referenced information on specific hazards, including definitions, synonyms, a scientific description, metrics, and drivers, outcomes, and risk management. For convenience, the link to this reference is: https://www.undrr.org/publication/hazard-information-profiles-supplement-undrr-isc-hazard-definition-classification.
- *Variations in Use Between Communities.* We recognise that some groups (be they a sector, discipline, network, or community of practice) may have different definitions for the same

term or use different terms to mean the same thing (as identified during our internal consultation). We are not suggesting that every group adopt all the terms and definitions included in this Handbook. While there are clear benefits from greater consensus and consistency in terminology, we recognise that there are often well-established reasons for divergence. In the MYRIAD-EU project, an approach is needed that allows effective interdisciplinary, multi-sectoral work. This approach includes making deliberate efforts to clarify and move towards a shared understanding to ensure we can effectively communicate within and between teams and across disciplines.

- *Expected Evolution of Glossary.* We acknowledge that this glossary is unlikely to be complete, and that other terms linked to multi-hazard risk management may exist. We also recognise that our use of terminology or specific definitions may evolve as the MYRIAD-EU project develops over time (see section 6). This Handbook should therefore be considered our starting point for a shared understanding of multi-hazard, multi-risk concepts, and updated as required (see section 6 for processes for updating the terminology).
- *Language.* The definitions in Table 3 are in English. We recognise that this will hinder accessibility to those who do not have English as a first language. In Appendix E, we include links to some lists of terminology and associated definitions, which happen to be available in other languages (French and Spanish).

Figure 1: UNDRR/ISC hazard information profiles according to eight hazard types
Note: CBRNE = chemical, biological, radiological, nuclear and high-yield explosives
Source: Reproduced from Fahad S Malik and Anna Schwappach, UK Health Security Agency

Figure 3: UNDRR/ISC hazard information profiles according to eight hazard types. Source: Murray et al. (2022), used with permission from the lead author of the report (personal communication, Virginia Murray, 27 May 2022).

Table 3: Glossary of Disaster Risk and Resilience Terminology and Concepts

A B C D E F G H I L M N O P R S T U V

Term	Definition	Source	Additional Notes
A			
(Climate change) Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.	IPCC (2014)	
Adaptation Tipping Point	An adaptation tipping point is the moment when the magnitude of change is such that a current management strategy can no longer meet its objectives. As a result, adaptive management is needed to prevent or postpone these ATPs	Nanda et al. (2018)	See also: *Adaptation Pathways*, *Tipping Point*
Adaptive Capacity	The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.	IPCC (2014)	
Asynergies (in Disaster Risk Reduction measures)	Potentially unwanted effects of measures that reduce the impacts of disasters across different hazards. Traditionally, those measures are aimed at decreasing the risk a building faces of a single hazard type despite their potential of having unwanted effects on other hazard types. For example, building on stilts is an often-used measure to decrease a building's flood vulnerability, however, it simultaneously increases a building's earthquake vulnerability.	De Ruiter *et al.* (2021)	See also: *Disaster Risk Reduction*
B			

Term	Definition	Source	Additional Notes
Bayesian (Belief) Network	Graphical models that communicate causal information and provide a framework for describing and evaluating probabilities when we have a network of interrelated variables. A key feature of Bayesian Belief Networks (or simply Bayesian Networks) is that they discover and describe causality rather than merely identifying associations.	McClean (2003)	See also: *Graphical Models*
C			
Capacity	The combination of all the strengths, attributes, and resources available within an organisation, community, or society to manage and reduce disaster risks and strengthen resilience.	UNDRR (2016)	See also: *Disaster Risk; Resilience*
(Coping) capacity	The ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities contribute to the reduction of disaster risks.	UNDRR (2016)	See also: *Capacity*
Complexity	A causal chain with many intervening variables and feedback loops that do not allow the understanding or prediction of the system's behaviour on the basis of each component's behaviour.	Aven (2019)	
Confidence	The robustness of a finding based on the type, amount, quality and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and on the degree of agreement across multiple lines of evidence.	Mastrandrea et al., (2010)	
D			
Deterministic Event Modelling	Modelling of single, specific events (simulated or real observed)	WP5 (MYRIAD-EU)	See also: *Deterministic Risk*; *Model*;

Term	Definition	Source	Additional Notes
Disaster	A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.	UNDRR (2016)	See also: *Capacity*; *Exposure*; *Hazard*; *Vulnerability*
Disaster damage	Disaster damage occurs during and immediately after the disaster. This is usually measured in physical units (e.g., square meters of housing, kilometres of roads, etc.), and describes the total or partial destruction of physical assets, the disruption of basic services and damages to sources of livelihood in the affected area.	UNDRR (2016)	See also: *Direct economic loss*
Disaster Forensics	A process to understand the root causes of disasters (rather than focusing exclusively on the dynamics of individual disaster events and response efforts), often yielding 'systemic' strategies for managing disasters.	Masys (2016); Keating et al. (2016); French et al. (2020)	See also: *Disaster*; *Systemic Perspective*
Disaster Impact	The total effect, including negative effects (e.g., economic losses) and positive effects (e.g., economic gains), of a hazardous event or a disaster. The term includes economic, human and environmental impacts, and may include death, injuries, disease and other negative effects on human physical, mental and social well-being.	UNDRR (2016)	See also: *Disaster*
Disaster Management	The organization, planning and application of measures preparing for, responding to, and recovering from disasters.	UNDRR (2016)	See also: *Disaster*
Disaster Recovery	The restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and "build back better", to avoid or reduce future disaster risk.	UNDRR (2016)	See also: *Disaster*; *Disaster Risk*; *Sustainable Development*

Term	Definition	Source	Additional Notes
Disaster Response	Actions taken directly before, during or immediately after a disaster to save lives, reduce health impacts, ensure public safety, and meet the basic subsistence needs of the people affected.	UNDRR (2016)	See also: *Disaster*
Disaster Risk	The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society, or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.	UNDRR (2016)	See also: *Disaster; Capacity; Exposure; Hazard; Vulnerability*
Disaster Risk Assessment	A qualitative or quantitative approach to determine the nature and extent of disaster risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend.	UNDRR (2016)	See also: *Disaster Risk; Exposure; Hazard; Vulnerability*
Disaster Risk Drivers	Processes or conditions, often development-related, that influence the level of disaster risk by increasing levels of exposure and vulnerability or reducing capacity.	UNDRR (2016)	See also: *Disaster Risk; Capacity; Exposure; Vulnerability*
Disaster Risk Management	The application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses.	UNDRR (2016)	See also: *Disaster Risk; Disaster Risk Reduction; Residual Risk; Resilience*
Disaster Risk Reduction	Preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development.	UNDRR (2016)	See also: *Disaster Risk; Residual Risk; Resilience; Sustainable Development*
Disaster Risk Governance	The system of institutions, mechanisms, policy and legal frameworks and other arrangements to guide, coordinate and oversee disaster risk reduction and related areas of policy. Annotation: Good governance needs to be transparent, inclusive, collective and efficient to reduce existing disaster risks and avoid creating new ones.	UNDRR (2016)	See also: *Disaster Risk; Governance*

Term	Definition	Source	Additional Notes
(Consecutive) Disasters	Two or more disasters that occur in succession, and whose direct impacts overlap spatially before recovery from a previous event is completed.	de Ruiter et al. (2020)	See also: *Section 3.3*
E			
Early Warning System	An integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events. **Multi-hazard early warning systems** address several hazards and/or impacts of similar or different type in contexts where hazardous events may occur alone, simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects. A multi-hazard early warning system with the ability to warn of one or more hazards increases the efficiency and consistency of warnings through coordinated and compatible mechanisms and capacities, involving multiple disciplines for updated and accurate hazards identification and monitoring for multiple hazards.	UNDRR (2016)	See also: *(Hazard) Forecast*
Ecosystem Services	Ecological processes or functions having monetary or non-monetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or biodiversity maintenance, (2) provisioning services such as food or fibre, (3) regulating services such as climate regulation or carbon sequestration, and (4) cultural services such as tourism or spiritual and aesthetic appreciation.	IPCC (2018)	

Term	Definition	Source	Additional Notes
Ecosystem-Based Adaptation (EbA)	The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. EbA aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change.	CBD (2009)	See also: *Ecosystem Services*; *Resilience*; *Vulnerability*
Ecosystem-Based Disaster Risk Reduction (Eco-DRR)	The sustainable management, conservation, and restoration of ecosystems to reduce disaster risk, with the aim to achieve sustainable and resilient development.	Estrella and Saalismaa (2013)	See also: *Disaster Risk*; *Sustainable Development*
Environmental Degradation	The reduction of the capacity of the environment to meet social and ecological objectives and needs. Degradation of the environment can alter the frequency and intensity of natural hazards and increase the vulnerability of communities.	PreventionWeb (n.d., *a*)	See also: *Ecosystem Services*
Exposure	The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.	UNDRR (2016)	See also: *System, System of systems, Systemic Perspective*
Extreme Event	A time and place in which weather, climate, or environmental conditions—such as temperature, precipitation, drought, or flooding—rank above a threshold value near the upper or lower ends of the range of historical measurements.	Herring (2020)	Though the threshold is subjective, some scientists define extreme events as those that occur in the highest or lowest 5% or 10% of historical measurements. Other times they describe events by how far they are from the mean, or by their recurrence interval or probability.
F			
Feedback Loops	Part of a system in which some portion (or all) of the system's output is used as input for future operations.	Fitzgibbons (2022)	See also: System
(Hazard) Forecast	Hazard forecasts provide information on the physical event characteristics, such as the location, timing, and magnitude of a potentially damaging event.	Merz et al. (2020)	See also: *Early Warning System*
G			

Term	Definition	Source	Additional Notes
Governance	The structures, processes, and actions through which private and public actors interact to address societal goals. This includes formal and informal institutions and the associated norms, rules, laws, and procedures for deciding, managing, implementing, and monitoring policies and measures at any geographic or political scale, from global to local.	IPCC (2022)	
H			
Hazard	A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation.	UNDRR (2016)	See also: *Anthropogenic Hazards; Biological Hazards; Environmental Hazards; Geological /Geophysical Hazards; Hydrometeorological Hazards; Natural Hazards; Technological Hazards*
Hazard Interrelationships[1]	The mode in which one hazard affects another hazard.	WP1 (MYRIAD-EU)	In the context of MYRIAD-EU, we identify four types of relationship, each defined in this glossary: *Triggering*, *Amplification*, *Compound* relationships. See also: ***Section 3.2***
(Cascading) Hazard	Cascading hazard processes refer to an initial hazard followed by a chain of interrelated hazards (e.g., earthquake triggering landslide, landslide triggering flooding, flooding triggering further landslides).	Adapted from UNDRR (2019)	See also: *Triggering Relationships*; ***Section 3.2***
(External) Hazards	Hazards originating from sources located outside the site area of interest	IAEA SSG-3 (2010)	See also: *Hazard*
(Natural) Hazards	Hazards that are predominantly associated with natural processes and phenomena.	UNDRR (2016)	See also: *Hazard*

[1] 'Interrelationships' and 'relationships' tend to be used interchangeably

Term	Definition	Source	Additional Notes
(Hydrometeorological) Hazards	Hydrometeorological hazards are of atmospheric, hydrological, or oceanographic origin.	UNDRR (2016)	See also: *Hazard* Examples are tropical cyclones (also known as typhoons and hurricanes); floods, including flash floods; drought; heatwaves and cold spells; and coastal storm surges. Hydrometeorological conditions may also be a factor in other hazards such as landslides, wildland fires, locust plagues, epidemics and in the transport and dispersal of toxic substances and volcanic eruption material.
(Technological) Hazards	Technological hazards originate from technological or industrial conditions, dangerous procedures, infrastructure failures or specific human activities.	UNDRR (2016)	See also: *Hazard* Examples include industrial pollution, nuclear radiation, toxic wastes, dam failures, transport accidents, factory explosions, fires and chemical spills. Technological hazards also may arise directly as a result of the impacts of a natural hazard event.
(Anthropogenic) Hazards	Hazards that are induced entirely or predominantly by human activities and choices. This term does not typically include the occurrence or risk of armed conflicts and other situations of social instability or tension which are subject to international humanitarian law and national legislation.	UNDRR (2016)	May also be termed: *Human-Induced Hazards* See also: *Hazard*

Term	Definition	Source	Additional Notes
(Environmental) Hazards	Environmental hazards may include chemical, natural, and biological hazards. They can be created by environmental degradation or physical or chemical pollution in the air, water, and soil. However, many of the processes and phenomena that fall into this category may be termed drivers of hazard and risk rather than hazards in themselves, such as soil degradation, deforestation, loss of biodiversity, salinization, and sea-level rise.	UNDRR (2016)	See also: *Environmental Degradation*; *Hazard*
(Biological) Hazards	Biological hazards are of organic origin or conveyed by biological vectors, including pathogenic microorganisms, toxins and bioactive substances.	UNDRR (2016)	See also: *Hazard* Examples: bacteria, viruses or parasites, as well as venomous wildlife and insects, poisonous plants and mosquitoes carrying disease-causing agents.
(Geological / Geophysical) Hazards	Geological or geophysical hazards originate from internal earth processes.	UNDRR (2016)	See also: *Hazard*; *Hydrometeorological Hazards* Examples: hazards associated with earthquakes, volcanic activity, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses and debris or mud flows. Hydrometeorological factors are important contributors to some of these processes. Tsunamis are difficult to categorise: although they are triggered by undersea earthquakes and other geological events, they essentially become an oceanic process that is manifested as a coastal water-related hazard.
I			

Term	Definition	Source	Additional Notes
(Cascading) Impacts	Cascading impacts are those in which the impact of a physical event or the development of an initial technological or human failure generates a sequence of events in human subsystems that results in physical, social or economic disruption. Thus, an initial impact can trigger other phenomena that lead to consequences with significant magnitudes.	Adapted from Pescaroli and Alexander (2015).	See also: *Disaster Impact*
(Cross-Boundary) Impacts	Event impacts (either social and/or economic) which occur over two or more spatial units, where there are often feedbacks between these regions.	WP5 (MYRIAD-EU)	May also be termed: *Interregional Risks*
Indicators	Indicators are observable and measurable characteristics that can be used to simplify information to help understand the state of a concept or phenomenon, and/or to monitor it over time to show changes or progress towards achieving a specific change.	Adapted from Ivčević et al. (2019) and Scotland's International Development Alliance (n.d.)	See also: **Section 4**
Insurance	A family of financial instruments for sharing and transferring risk among a pool of at-risk households, businesses, and/or governments.	IPCC (2022)	
L			
(Economic) loss	Total economic impact that consists of direct economic loss and indirect economic loss.	UNDRR (2016)	See also: *Disaster Impact*
(Direct economic) loss	The monetary value of total or partial destruction of physical assets existing in the affected area. Direct economic loss is nearly equivalent to physical damage. Direct economic losses usually happen during the event or within the first few hours after the event and are often assessed soon after the event to estimate recovery cost and claim insurance payments. These are **tangible** and relatively easy to measure.	UNDRR (2016)	See also: *Economic loss*, *Disaster Damage*

Term	Definition	Source	Additional Notes
(Indirect economic) loss	A decline in economic value added as a consequence of direct economic loss and/or human and environmental impacts. Indirect economic loss includes **microeconomic impacts** (e.g., revenue declines owing to business interruption), **mesoeconomic impacts** (e.g., revenue declines owing to impacts on natural assets, interruptions to supply chains or temporary unemployment) and **macroeconomic impacts** (e.g., price increases, increases in government debt, negative impact on stock market prices and decline in GDP). Indirect losses can occur inside or outside of the hazard area and often have a time lag. As a result, they may be **intangible** or difficult to measure.	UNDRR (2016)	See also: *Economic loss*, *Direct economic loss*
Non-economic loss	Non-economic losses refer to a broad range of losses that are not in financial terms and not commonly traded in markets. They may impact individuals (e.g. loss of life, health, mobility), society (e.g. loss of territory, cultural heritage, indigenous or local knowledge, societal or cultural identity) or the environment (e.g. loss of biodiversity, ecosystem services)	UNFCCC (n.d)	See also: *Economic Loss*
M			
(Hazard Impact) Mitigation	The lessening of the potential adverse impacts of a hazardous event (including those that are human-induced) through actions that reduce hazard, exposure, and vulnerability.	IPCC (2014) and UNDRR (2016)	See also: *Exposure; Hazard; Vulnerability; Disaster Risk Reduction*
(Climate Change) Mitigation	A human intervention to reduce emissions or enhance the sinks of greenhouse gases.	IPCC (2022)	
Multi-Hazard	The selection of multiple major hazards that the country faces, and the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects.	UNDRR (2016)	See also: *Hazard*, ***Section 3.1***
Multi-Hazard Risk	Risk generated from multiple hazards and the interrelationships between these hazards (but not considering interrelationships on the vulnerability level).	Zschau (2017)	See also: *Hazard*; *Hazard Interrelationships; Multi-Hazard; Disaster Risk; Vulnerability*

Term	Definition	Source	Additional Notes
Multi-Risk	Risk generated from multiple hazards and the interrelationships between these hazards (and considering interrelationships on the vulnerability level).	Zschau (2017)	See also: *Hazard*; *Multi-Hazard*; *Disaster Risk*; *Vulnerability*; ***Section 3.3***
Multi-Layer Single Hazards	More than one hazards are considered, but not the interrelationships between these (i.e., they are treated as discrete, independent).	Gill & Malamud (2014); Zschau (2017)	See also: ***Section 3.1***
Multi-Hazard Event Sets	A list of multi-hazard events over a given time period.	WP5 (MYRIAD-EU)	See also: *Multi-Hazard*
N			
NATECH Events	Technological accidents triggered by a natural hazard or disaster which result in consequences involving hazardous substances (e.g., fire, explosion, toxic release)	European Commission Joint Research Centre (2021)	See also: *Natural Hazard*, *(Cascading) Hazard*
Natural Resources	Actual or potential sources of wealth that occur in a natural state, such as timber, water, fertile land, wildlife and minerals.	PEDRR (2010)	
Nature-Based Solutions	Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.	IUCN (2021)	
O			
Opportunity Tipping Points	Points at which a particular action becomes feasible or attractive, for example because of lower costs of actions or technical developments.	Haasnoot et al. (2019) *in* Marchau et al. (2019)	See also: Adaptation pathways
P			
Paired Disaster Study	A type of empirical case study, that analyses changing conditions, and changes in the impacts of consecutive disasters that occurred in the same region over time.	Kreibich et al. (2017)	

Term	Definition	Source	Additional Notes
Pathway	The temporal evolution of natural and/or human systems towards a future state.	IPCC (2022)	Pathway concepts range from sets of quantitative and qualitative scenarios or narratives of potential futures to solution-oriented decision-making processes to achieve desirable societal goals. Pathway approaches typically focus on biophysical, techno-economic, and/or socio-behavioural trajectories and involve various dynamics, goals, and actors across different scales.
(Adaptation) Pathways	A series of adaptation choices involving trade-offs between short-term and long-term goals and values. These are processes of deliberation to identify solutions that are meaningful to people in the context of their daily lives and to avoid potential maladaptation	IPCC (2022)	See also: *Adaptation*, *Pathway*
Preparedness	The knowledge and capacities developed by governments, response and recovery organizations, communities, and individuals to effectively anticipate, respond to, and recover from the impacts of likely, imminent, or current disasters.	UNDRR (2016)	See also: Capacity
Probabilistic Event Modelling	Modelling a series of simulated events, accounting for the probability of those events over time (stochastic event set) or using the classical method (probabilistic model).	WP5 (MYRIAD-EU)	See also: *Model*; *Probabilistic Risk*
Probable Maximum Loss	The maximum loss that an insurer would be expected to incur on a policy.	Society of Actuaries (2022)	
R			
Risk Perception	The subjective judgment that people make about the characteristics and severity of a risk.	IPCC (2022)	
Risk Dynamics	A term used to encompass the interrelationships between and evolution through time of hazard, exposure, and vulnerability, and underlying risk drivers	WP1, WP4 (MYRIAD-EU)	See also: *Disaster Risk*; *Disaster Risk Reduction*

Term	Definition	Source	Additional Notes
(Deterministic) Risk	Deterministic risk considers the impact of a single risk scenario (as opposed to probabilistic risk). Assessments of deterministic risk therefore provide a single point estimate of risk at a site of concern.	PreventionWeb (n.d., *b*), OECD (2012)	See also: *Scenario*, *(Current) Scenario*, *(Future) Scenario*, *(Forward-looking) Scenario*, *(Probabilistic) Risk*
(Residual) Risk	The disaster risk that remains in unmanaged form, even when effective disaster risk reduction measures are in place, and for which emergency response and recovery capacities must be maintained.	UNDRR (2016)	See also: *Disaster Risk; Disaster Risk Reduction*
(Probabilistic) Risk	The consideration of all possible scenarios, their likelihood, and associated impacts. This method contains the idea of uncertainty because it incorporates the concept of randomness.	PreventionWeb (n.d., *b*); OECD (2012)	See also: *Scenario;*
(Individual) Risk	Risk of individual elements within a system (a bottom-up perspective).	WP2 (MYRIAD-EU)	See also: *System*, *Systemic Perspective*, *Systemic Risk*
(Emergent) Risk	A risk that arises from the intersection of phenomena in a complex system.	Oppenheimer et al. (2014)	For example, risk caused when geographic shifts in human population in response to climate change lead to increased vulnerability and exposure of populations in the receiving region.
(Systemic) Risk	Risk of a 'System' due to interaction effects of elements of a system.	WP2 (MYRIAD-EU), UNDRR (2022)	See also: *Individual Risk*, *System*, *Systemic Perspective*
(Triggering) Relationship	One hazard causing another hazard to occur Any natural hazard might trigger zero, one, or more secondary natural hazards, with these being either the same or different from the primary hazard.	Ciurean et al. (2018); Tilloy et al. (2019)	See also: *Multi-hazard* See also: **Section 3.2**
(Amplification) Relationship	The occurrence of one hazard can increase the likelihood and/or magnitude of additional hazards in the future (e.g., forest fires can amplify the triggering of debris flows during heavy rain)	Ciurean et al. (2018)	See also: *Multi-hazard*, ***Section 3.2***
(Compound) Relationships	Two different natural hazards that impact the same time period and spatial area. Compound hazards can have a footprint with spatial and temporal characteristics that differs from the component single hazards	Tilloy et al. (2021), Zscheischler et al. (2018)	See also: *Multi-hazard*, **Section 3.2**

Term	Definition	Source	Additional Notes
Resilience	The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.	UNDRR (2016)	See also: Disaster Risk Management
Robustness	The insensitivity [of a system] to future conditions and the ability to perform satisfactorily over a broad range of future conditions.	Based on Beh et al. (2017)	See also: *Robustness Conflicts*, *(Societal) Robustness*
Robustness Conflicts	The existence of unacceptable compromises to some cooperating actors in a strategy *(e.g., for risk management)*.	Gold et al. (2022)	See also: *Robustness*
(Societal) Robustness	Robustness of a system of systems might be maximized using different perspectives: a "social planner's perspective" might want to maximize the welfare for the entire system, while a 'pragmatists perspective' might be accounting for the power dynamics.	Gold et al. (2022)	See also: *Robustness*
S			
Scenario	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 (TC), prices) and relationships. Scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions.	IPCC (2022)	See also: *Current Scenario*; *Forecast; Future Scenario; Prediction*, *Adaptation Pathway*, *Forward-looking pathways*
(Current) Scenario	A hazard or risk scenario using the historical baseline or current data, for the current conditions.	Carter et al. (2001)	
(Future) Scenario	A hazard or risk scenario using the historical baseline or current data, and/or modelled climate change metrics presented in the future (after present day), for example for 2050 or 2080.	WP5 (MYRIAD-EU)	See also: *Scenario*
Site Area	A geographical area that contains assets at risk	Adapted from IAEA (2007)	See also: *Exposure*
Sustainable (or Healthy) Ecosystems	Ecosystems that are largely intact and functioning, and on which human demand for ecosystem services does not impinge upon the capacity of them to maintain future generations.	Sudmeier-Rieux and Ash (2009)	See also: Ecosystem Services

Term	Definition	Source	Additional Notes
Sustainability	Involves ensuring the persistence of natural and human systems, implying the continuous functioning of ecosystems, the conservation of high biodiversity, the recycling of natural resources and, in the human sector, successful application of justice and equity.	IPCC (2022)	
Sustainable Development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.	Brundtland (1987)	
System	A set of (partly) interconnected elements.	WP2 (MYRIAD-EU)	See also: *System of systems*, *Exposure*, *Systemic Perspective*
System of systems	A system where the individual elements of the system are treated again as systems	WP2 (MYRIAD-EU)	See also: *System*, *Exposure*, *Systemic Perspective*
Systemic Perspective	A focus on interactions between elements within a 'System' (or Systems).	WP2 (MYRIAD-EU)	See also: *System*
T			
Threshold	The level of magnitude of a system process at which sudden or rapid change occurs. A point or level at which new properties emerge in an ecological, economic or other system, invalidating predictions based on mathematical relationships that apply at lower levels.	IPCC (2007)	See also: *Tipping Point*
Tipping Point	A critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly.	IPCC (2022)	See also: *Threshold*
Trade-off	Trade-offs are defined as a decision between two desired outcomes where a gain in one requires a loss in another. The losses, or how these decisions negatively impact society, are sometimes not at the forefront of decision-making. Trade-offs are common in complex policy situations where multiple objectives, stakeholders, scales, and time-horizons collide	Tuhkanen (2020)	See also: *Adaptation Pathways*
U			

Term	Definition	Source	Additional Notes
Uncertainty	A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, incomplete understanding of critical processes, or uncertain projections of human behaviour. Uncertainty can be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts)	IPCC (2022), and references therein	See also: *(Deep) Uncertainty*
(Deep) Uncertainty	Exists when experts do not know or the parties to a decision cannot agree upon (i) the external context of a system, (ii) how a system works and its boundaries, and/or (iii) the outcomes of interest from a system and/or their relative importance. Deep uncertainty also arises from actions taken over time in response to unpredictable evolving situations.	Marchau et al. (2019)	See also: *Uncertainty*
V			
Vulnerability	The conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards.	UNDRR (2016)	See also: *Disaster Risk*
(Multi-)vulnerability	Refers to (i) a variety of exposed sensitive targets (e.g. population, infrastructure, cultural heritage, etc.) with possible different vulnerability degree against the various hazards; (ii) time-dependent vulnerabilities, in which the vulnerability of a specific class of exposed elements may change with time as consequence of different factors (e.g. the occurrence of other hazardous events).	Gallina et al. (2016) and see references therein	See also: *Vulnerability;* See also: **Section 3.3**

The following sub-sections provide expanded literature review and/or definitions for a selection of the terms and concepts presented in the glossary. The reason for the selection of these terms was due to their perceived importance to our collective understanding of multi-hazards and multi-risk, and related concepts in the MYRIAD-EU project.

3.1 Multi-Hazard vs. Multi-Layer Single Hazards

Governments and Intergovernmental Organisations have long advocated for multi-hazard approaches to disaster risk management (e.g., UNCED, 1992; UN, 2002; UNDRR, 2005; Government Office for Science (UK), 2012; UNDRR, 2015a). However, the first appearance of the term 'multi-hazard' in the UNDRR terminology was not until the 2016 update. This definition, adopted within the MYRIAD-EU project, is included in the glossary, and repeated here:

> *Multi-hazard means "(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."*

UNDRR (2016)

In this context, multi-hazard approaches are considered to include but extend beyond the collation (or overlay) of distinct information for multiple single natural hazards (or 'multi-layer single hazard' approaches), to also characterise different relationships between natural hazards.

This definition aligns with some (but not all) uses of the term 'multi-hazard' in the literature. The inclusion of 'country' as opposed to 'given spatial region' (e.g. Gill and Malamud, 2014) within the UNDRR definition arguably applies a geographical constraint that excludes the fact that hazards (and risks) can be transboundary (cross-border), which is an important consideration for the MYRIAD-EU and its multi-country pilot projects. The emphasis upon 'major' deviates from some definitions in the literature, which instead bound multi-hazards by the inclusion of 'all relevant hazards' regardless of their magnitude (e.g. Kappes et al., 2012; Gill and Malamud, 2012).

Some authors have used the term 'multi-hazard' to describe the independent analysis of multiple different hazards and others to refer to the superimposition of various hazard layers to identify areas of spatial overlap (Gill and Malamud, 2014). Such approaches build on Hewitt and Burton's (1971) concept of the "hazardousness" of a place, highlighting the need for an "all-hazards-at-a-place" approach. The identification of possible, spatially relevant hazards is important, but the failure to consider hazard interrelationships can distort management priorities, increase vulnerability to other spatially relevant hazards, or result in an underestimation of risk. In the next section we explore the characterisation of different relationships between hazards.

3.2 Types of Multi-Hazard Interrelationship

In MYRIAD-EU we have adopted "interrelationship" as the collective noun for the links between hazards. We recognise that this term and other terms are used in the literature, for example "interrelations", "interactions" and "interconnections" (e.g. Delmonaco et al. 2006; Greiving 2006; Tarvainen et al. 2006; de Pippo et al. 2008; Marzocchi et al. 2009; Duncan et al. 2016; Perles Roselló and Cantarero Prados, 2010; Zuccaro and Leone 2011; Gill and Malamud, 2014; Tilloy et al., 2019; de Angeli et al., 2022). We acknowledge the existence of these other terms and their similar application for collectively describing processes that can link hazards spatially or temporally. The adoption of "interrelationship" within MYRIAD-EU, reflects the evolution of thinking in multi-hazard research and practice regarding the processes and relationships between hazards and their pathways.

As noted in **Section 3.1**, multi-hazard includes in its definition *"…the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects"* (UNDRR, 2016). Just as there is variation in terminology for how the links between hazards are collectively referred to, there is also variation in the terminology used to define different types of hazard interrelationship (Kappes et al., 2012; van Westen et al., 2014; Duncan et al., 2016; Tilloy et al., 2019; Simpson et al., 2021; de Angeli et al. 2022).

A review of different classifications in the academic literature by Ciurean *et al.* (2018) identified many commonalities between these, with three emerging types of hazard interrelationship. These are described below, with examples included and mapped against examples of similar and related terms used in the literature.

- *Triggering Relationships.* One hazard causes another hazard to occur, which can result in hazard chains, networks, or cascades. For example, heavy rain results in the destabilisation and collapse of a slope (a landslide). A landslide blocks a river and causes a flood. In addition to including triggering relationship in the glossary, we also include a specific definition for 'cascading hazard' (table 3) owing to its suggestion for inclusion during Activity A at the first General Assembly (see section 1.2.1) and its inclusion in the UNDRR's (2016) definition of multi-hazard.
  - Related concepts: *domino or cascades* (e.g. Delmonaco et al., 2006; Marzocchi et al. 2009; Garcia-Aristizabal and Marzocchi, n.d.)*; chains* (Xu, et al. 2014)*; causation* (Duncan et al. 2016)*; consecutive disasters* (de Ruiter et al., 2020 – **see section 3.3**)

- *Amplification Relationships.* One hazard can change the likelihood and/or magnitude of additional hazards in the future. For example, drought increases the likelihood of wildfires. Wildfires increase the likelihood of floods and debris flows.
  - Related concepts: *alteration of the disposition* (Kappes et al. 2012); *change conditions* (Tilloy et al., 2019); *association and amplification* (Duncan et al., 2016)

- *Compound Relationships.* Two or more hazards may impact the same region and/or time period with impacts different (greater, lesser) than their sum. These compound relationships can take different forms, including (i) a primary hazard triggering multiple secondary hazards simultaneously, and (ii) two independent hazards impacting the same region and/or time period (or in close succession). For example, (i) a storm could trigger floods and landslides simultaneously or a volcanic eruption can produce and trigger multiple hazards that could occur simultaneously; (ii) an earthquake followed by a period of extreme cold (resulting in those forced to sleep outdoors due to damaged homes being more susceptible to the impacts of the low temperatures)
  - Related concepts: *compound events* (Zscheischler et al., 2018; 2020); *coinciding hazards* (EC, 2011); *coupled hazards* (van Westen et al. 2014); *compound hazard (association)* (Tilloy et al. 2019); *independence* (Tilloy et al. 2019); *consecutive disasters* (de Ruiter et al., 2020 – **see section 3.3**)

Tilloy et al. (2019) also discuss the negative dependence between hazards 'mutual exclusion', for instance heavy rain and fire. We acknowledge the existence of these relationships in the literature (see also 'alleviation' Duncan et al. 2016) but argue that these effects are less likely to be the focus of risk assessment and management, which tend to adopt a conservative approach (Gill and Malamud, 2014).

The interrelationship types described above can combine in any individual scenario, thus developing a complex multi-hazard situation. For example, lightning may *trigger* wildfires, which in turn *amplify* the likelihood and magnitude of debris flows if heavy rain occurs soon after. Heavy rain can *trigger* both debris flows and landslides simultaneously (*compound relationships*), both drawing on a limited response capacity. In the next section we discuss current terminology and understanding of disaster risk and how interrelationships across hazards, exposure and vulnerability require that disaster risk incorporates a dynamic, multi-risk perspective.

3.3 From Multi-Hazard Risk to Multi-Risk

A typical representation of disaster risk in the literature demonstrates it to be the product of hazard, exposure, and vulnerability (each defined in the glossary, table 3)), as illustrated in **Figure 4**.

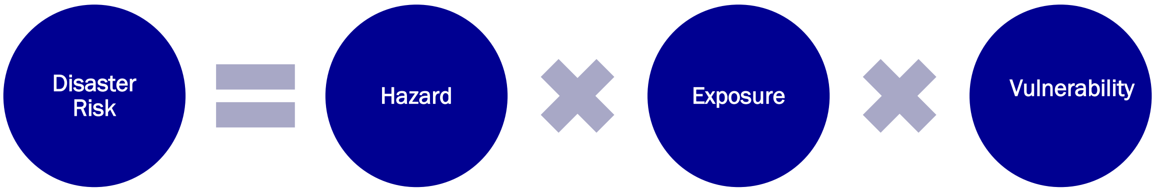

Figure 4 Typical Representation of the Risk Equation (e.g., PreventionWeb, n.d., c) Source: Gill et al. (2021) CC BY 4.0

Some risk equations (and following our adopted definition of disaster risk in table 3) divide vulnerability by capacity (or coping capacity) to represent disaster risk. Each of these components of risk is *dynamic* (i.e., they change over time) and therefore so too is the resulting disaster risk. Variations in exposure, vulnerability, hazard or capacity can change the level of risk, and therefore the scale and impacts of any disaster. These variations can be both positive (allowing us to reduce disaster risk) or negative (increasing disaster risk).

Variations are influenced by a number of risk drivers across physical, environmental, social, economic, and cultural factors (see disaster risk drivers in the glossary). Understanding trends in vulnerability and exposure are therefore important aspects of risk assessment (Cardona et al., 2012). Stress factors, such as climate change, conflict, or a pandemic can change exposure and vulnerability through impacts on the number of people in poverty or suffering from food and water insecurity, changing disease patterns and general health levels, and where people live (migration patterns). Disaster risk should account for both impacts and the responses (e.g. for instance adverse health outcomes in populations that migrate because of climate, Reisinger et al., 2020).

Hazard, exposure, and vulnerability are terms characterizing the risk equation. Changes in each of them lead to changes in risk but they also influence each other, meaning that they are not independent (Duncan et al., 2016; Gill et al., 2021). Understanding the interrelationships across hazards, exposure and vulnerability is therefore essential to understanding multi-hazard risk and multi-risk. Here we provide descriptions and examples of how hazard, exposure and vulnerability are be interrelated.

Changes in exposure and/or vulnerability can influence hazard and multi-hazard events

Both the exposure and vulnerability components of the risk equation can change over time, either increasing or decreasing due to complex, multi-scale processes (risk drivers). These changes can contribute to the triggering and/or amplification (or reduction) of multi-hazard events. For example,

- urban expansion in a hazard prone region increases exposure to these hazards, with associated changes to drainage exacerbating rain triggered flooding.
- conflict increases vulnerability and may reduce capacity to maintain infrastructure, with blocked non-maintained drainage channels exacerbating rain triggered landslides.
- development decisions may result in new and amplified anthropogenic processes. Different development trajectories, therefore, have differential impacts on exposure and vulnerability, with consequential impacts on the generation of hazard.

Progression through multi-hazard events can change exposure and/or vulnerability

A multi-hazard event may involve two or more consecutive hazards in close succession, with changes to exposure and vulnerability between these (de Ruiter et al., 2020). 'Consecutive disasters' refers to two or more disasters that occur in succession with direct impacts (tangible and intangible) overlapping spatially, before recovery from the previous event is complete (de Ruiter et al., 2020). In this context, the way in which one hazard can affect another hazard is manifested through changes in exposure and vulnerability, i.e., the first hazard may change exposure and/or vulnerability to the impacts of any successive hazards. For example,

- an earthquake may result in many people losing their homes and other public shelters destroyed. Following this disaster, pressures on society, infrastructure and coping capacity are likely to be increased. The vulnerability of people and their systems/assets to further hazards (e.g., extreme cold, a tropical storm, disease outbreaks) will could increase. The occurrence of the earthquake hazard changed vulnerability by limiting the capacity of the system to react to new hazards.
- volcanic unrest or an eruption can result in the evacuation of people. While this reduces their exposure to the ongoing volcanic eruption, it may increase their exposure to other hazards affecting the latter.

Disaster risk, through the multi-risk lens, is therefore more complex than presented in **Figure 4**. Individual concepts are dynamic, as are interrelationships existent between these. The term *risk dynamics* is used to encompass this complexity, including interrelationships between and evolution through time of hazard, exposure, and vulnerability, and underlying risk drivers. Bringing together several of the examples above, to illustrate complexity: changes in land use in response to a natural hazard could trigger another hazard or amplify vulnerability to a future hazard event. These responses are not uniform or discrete. There is the potential for one interrelationship to feedback into another, causing large uncertainties in the potential impacts of hazard events, leading to indirect and emergent risks.

Risk assessment approaches must therefore consider these interrelationships and evolutions in risk dynamics, and feedback between risk drivers, across sectors, scales, and regions. The assessment of these dynamics forms the basis of forward-looking multi-hazard, multi-risk assessment approaches that consider the evolution of hazard, exposure and vulnerability under a changing environment and different development trajectories.

Coming back to **Figure 4**, the discussion above informs an alternative visualisation of disaster risk that illustrates the dynamic nature of each term and the existence of relationships between these. Different representations of risk, capturing some of this complexity, are included in **Figure 5**, from Gill et al. (2021) and **Figure 6**, from Simpson et al. (2021).

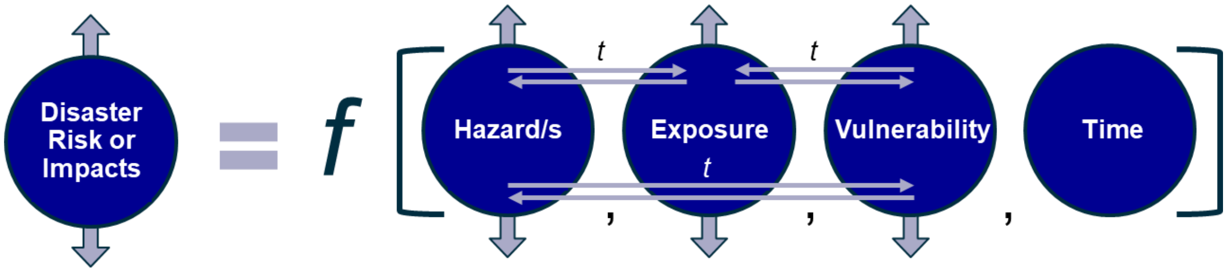

Figure 5 Dynamic Risk. A representation of risk that builds on Figure 4, shown as a function f [ ] of hazard, exposure, vulnerability, and time, where terms are not simply multiplied and interrelationships between them are recognised. Source: Gill et al. (2021) CC BY 4.0.

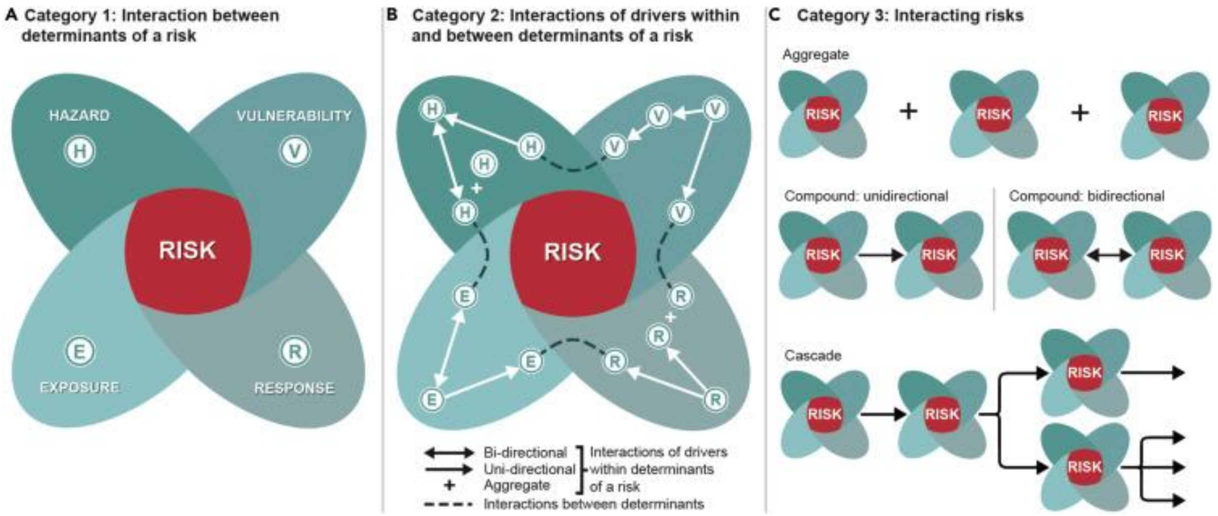

Figure 6 Three categories of increasingly complex climate change risk. Source: Simpson et al. (2021) CC BY 4.0.

(A) Category 1: interactions among single drivers (small circles) for each determinant of a risk, namely hazard, vulnerability, exposure, and response to climate change. (B) Category 2: interactions of multiple drivers (e.g., compounding vulnerabilities of education and income) within each determinant of risk, as well as among the determinants of a risk. (C) Category 3: interacting risks. Across categories 2 and 3, compounding and cascading interactions, together with aggregations, generate increasing complexity for risk assessment. The authors use "determinant" to refer to hazard, vulnerability, exposure, and response, within which the term "driver" refers to individual components, such as heavy precipitation (a driver within the hazard determinant) or access to shelter (a driver within the vulnerability determinant), that interact to affect the overall risk (e.g., flood mortality).

Within MYRIAD-EU, these dynamic feedbacks will be identified and quantified under WP4 and WP5, to better understand how hazard interrelationships can influence the overall risk to specific sectors. These data will then be used to support forward-looking risk modelling approaches that include risk dynamics in their quantification of risk.

In the glossary (table 3), we present definitions for multi-hazard risk and multi-risk using the short version definitions of Zschau et al. (2017; see Figure 7).

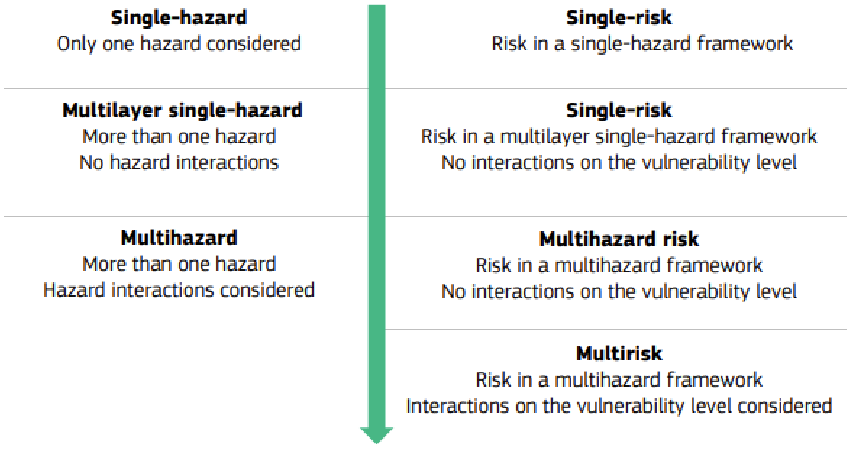

Figure 7 Source: Zschau (2017) © European Union, 2017

Whilst helpful to explain the evolution from single to multi-hazard risk and from multi-hazard risk to multi-risk when described in detail, the proposed terminology is not easily distinguishable, and it may require further refinement and use until it is fully established. We also acknowledge that within the literature there are definitions of multi-hazard risk and multi-risk that can differ. By way of example, figure 8 visualises complex risk terms (many without an IPCC definition) used within climate change:

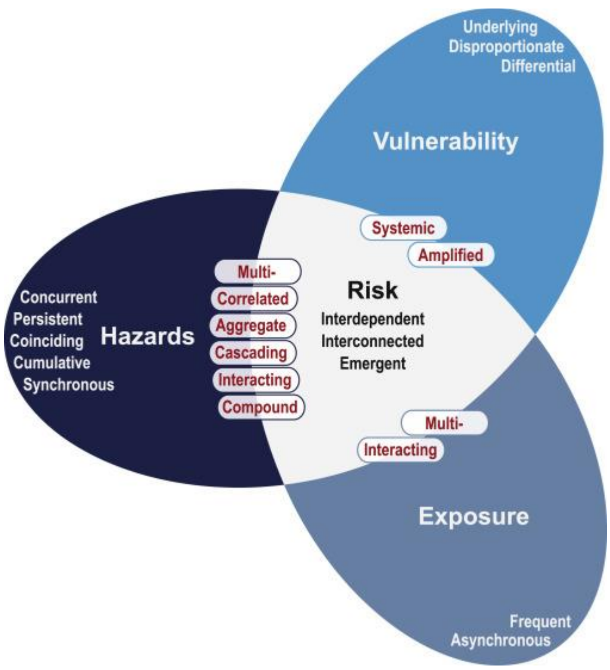

Figure 8 The diverse complexity of climate change risk terminology. Source: Simpson et al. (2021) CC BY 4.0

Some definitions related to the term multi-hazard risk refer to 'multi-exposure' and 'multi-vulnerability' (e.g. Arrighi et al., 2022). 'Multi-vulnerability' might consider different exposed elements or different susceptibilities of the same element according to different types of hazards (Arrighi et al., 2022). During the first General Assembly, we shared the following two definitions of multi-vulnerability presented in Gallina et al. (2016):

(1) a variety of exposed sensitive targets (e.g. population, infrastructure, cultural heritage, etc.) with possible different vulnerability degree against the various hazards.

(2) time-dependent vulnerabilities, in which the vulnerability of a specific class of exposed elements may change with time as consequence of different factors (e.g. the occurrence of other hazardous events).

Sources: Carpignano et al., 2009; Garcia-Aristizabal and Marzocchi, 2012a; Garcia-Aristizabal and Marzocchi, 2012b; Arrighi et al. 2022)

During the stock-take of terminology, there was some agreement with the above definitions, with the comment that the phrasing could be improved, for instance 'exposed' should not be in a definition of vulnerability (see Appendix 2).

There appears to be limited application of the term 'multi-vulnerability' in established glossaries and feedback from the GA was that this term need not be included in our glossary of terms. However, part of the objective of the handbook is to present the current status of terminology, which is why 'multi-vulnerability' appears in the glossary (table 3). Within the literature and existing glossaries, we found fewer examples of prefixing 'exposure' with 'multi-'. As section 2.3 has evidenced, there is a tendency towards the concept of risk dynamics, including dynamic exposure and vulnerability, as the preferred terminology to describe these influences and interrelationships with multi-risk. We will explore this further in section 5, where we review the utility prefix of the term 'multi-'.

In the final part of section 3, we provide expanded definitions and descriptions of the related concepts of direct and indirect loss and risk.

3.4 Direct and Indirect Loss and Risk

Natural hazards affect a wide range of systems described in sustainability research as part of the 'five capitals' framework (natural, social, human, manufactured and economic, McLellan et al., 2012). The common practice in risk assessments is to divide risk impacts into economic and non-economic losses associated with direct and indirect risk, respectively. Economic losses can be understood as the loss of resources, goods and services that are commonly traded in markets and market prices can be used to value them. Non-economic losses can be understood as the remainder of items that are not economic items; that is to say that non-economic items are those that are not commonly traded in markets (see Table 3). The absence of a market price is one of the main reasons why assessing non-economic losses is challenging. However, their effect on human welfare is no less important (UNFCCC, 2013).

Many losses are difficult to quantify. For instance, the destruction of culturally significant sites by a natural hazard is a direct loss although quantifying the value of such loss may arguably be difficult. The replacement or real market value of the site and its buildings does not consider the social and cultural meaning, or the services provided by the site to its community. These more difficult to value assets are sometimes known as 'intangible losses'. As a consequence, disaster loss databases rarely account for psychological (post-traumatic stress), cultural, and environmental (contamination of drinking water, saltwater intrusion, etc.) impacts (PreventionWeb, n.d., *d*). A full consideration of all direct, indirect, and intangible losses would produce much higher loss estimates than the more easily quantified and commonly seen records of direct loss (GFDRR, 2014).

There are three major global agreements which guide priorities for disaster and climate risks impacts to different extents: The Sendai Framework for Action (Sendai), the Sustainable Development Goals (SDGs), and the Paris Agreement on Climate Action (Climate Action), all agreed in 2015 (see Figure 9). Common standards are still being developed to ensure synergy among these frameworks and efforts are being made to harmonise their implementation despite different priorities and ambitions for action on L&D from different stakeholders.

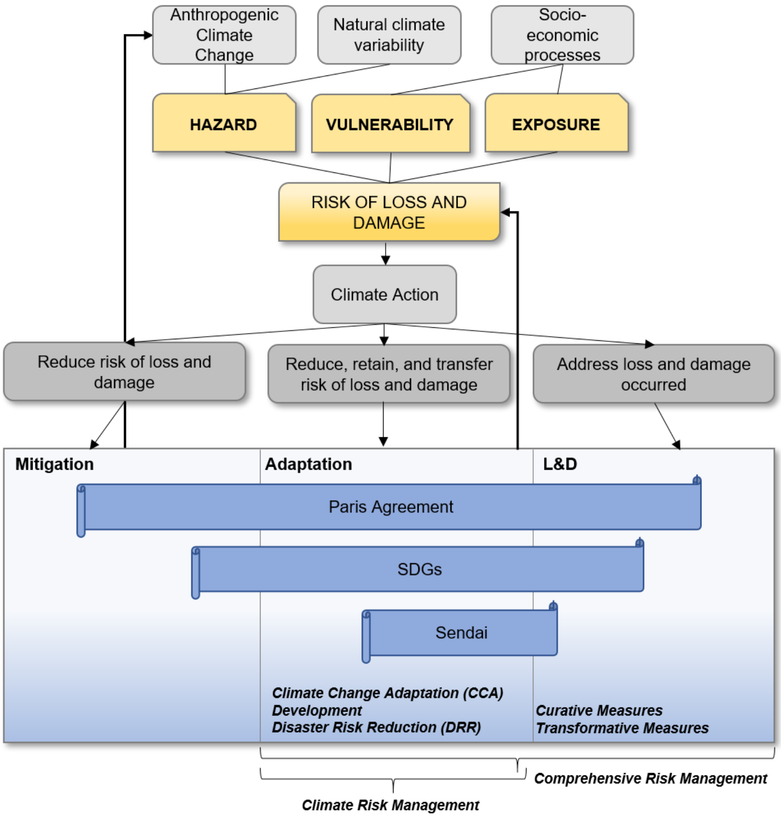

Figure 9 Overview of the relationship between risk of loss and damage and the three key global agreements: Sendai, SDGs, and Climate Action (modified after van den Homberg and McQuistan (2019) CC BY 4.0)

In an analysis of the three key global agreements and their corresponding regional, national and local counterparts, van den Homberg and McQuistan (2019) illustrate their remit in relation to risk mitigation, adaptation, and L&D. In a broader context, these three pillars can be seen as costs associated with a certain hazard, with the latter being losses that are likely to occur despite adaptation and mitigation efforts. The authors note that Sendai, being a framework tailored towards DRR, has indicators on losses and damages and includes paragraphs on relocation of settlements but does not go into attribution of impact data to climate change. On the other hand, the SDGs encompass development in many dimensions and have synergies with all three dimensions of risk mitigation, adaptation, and L&D.

Addressing climate and disaster risk through inclusive and participatory mechanisms has been the work of a growing number of projects, initiatives and studies at the interface between the Paris Agreement, Warsaw Mechanism and Sendai Framework. The Warsaw International Mechanism for Loss and Damage (The Warsaw Mechanism or WIM) was established in 2013 to address loss and damage associated with impacts of climate change, including extreme events and slow onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change. Under this umbrella, UNFCC's technical paper on non-economic losses and damages (2013) identifies four broad categories of valuation technique: economic valuation, multicriteria decision analysis (MCDA), composite risk indices and qualitative/semi-quantitative methods. All of them have been used in a climate change context. Another way to describe the extent of the indirect losses brought about by disasters is in terms of life years lost, a metric developed for the Global Assessment Report on Disaster Risk Reduction 2015 (UNDRR, 2015b). Rather than using only the four dimensions of fatalities, injuries, dislocations (displacement) and the financial damage that they wreak, life years lost is a way to describe the time required to produce economic development and social progress. It provides a way of measuring setbacks to social and economic development across countries and regions (Doan and Noy, 2022 – see also UNDRR, 2022).

Taking a specific example, work by a panel of experts on a European project on the Costs of Natural Hazards (CONHAZ) has extended the standard classification by considering business interruptions as a separate category to direct and indirect costs and also by explicitly including risk mitigation costs as a major category (Green et al., 2011; Meyer et al., 2013). We summarise the different cost categories, including business interruptions in Figure 10. Direct damage costs are the most visible or easily recognisable components. These costs relate to the physical damage to buildings, road and other infrastructure and also to the destruction of commodities and other assets. Direct damages are commonly estimated as a function of a single parameter (e.g. depth of inundation) and in some cases as a function of multiple parameters. Both types of models, using single or multiple parameters to estimate damages, have been subject to criticism.

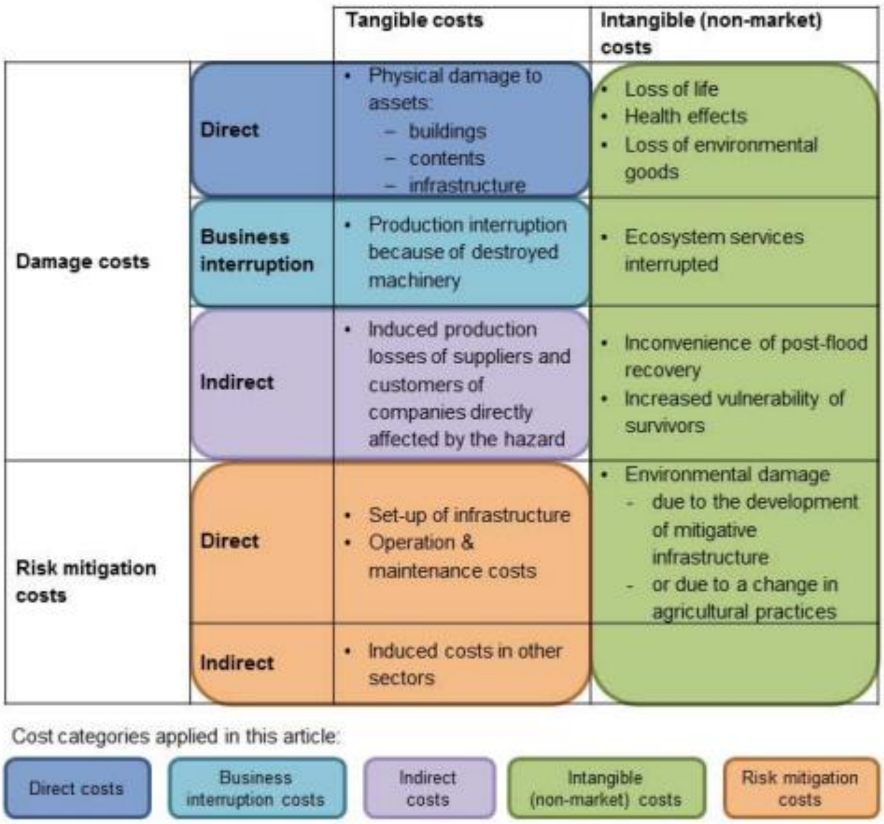

Figure 10 Cost categorisation applied in this article with examples. Source: Meyer et al. (2013), CC BY 3.0

Business interruption costs occur in areas directly affected by the hazard when people are not able to undertake their business activities because of accessibility problems or damages to the workplace (Meyer et al., 2013). They can be similar to 'direct damages' if they result from direct impact on production infrastructure; but can also be categorised as 'indirect damages' when they result from the interruption of economic activity. Business disruption costs include losses in business income and employee wages.

Indirect costs do not directly result from the physical hazard damages. They are consequences of direct damages and business interruptions. These costs can occur inside or outside the disaster area but typically involve a time lag and can span over a longer period. They stem from the disruption of public service, transport and supply activities affecting downstream or upstream clients of the companies directly affected by the hazard. The implementation of mitigation strategies (e.g. structural works) generates costs that can also be classified as direct and indirect.

Direct costs are the expenditure on research, design, construction and maintenance of mitigation infrastructure (Meyer et al., 2013). Indirect costs relate to the externality effects on other sectors of the economy that result from mitigation expenses (e.g. through competition for resources or labour). Meyer et al.'s (2013) definition of direct and indirect risks for floods, holds for all disasters. (BNHCRC, 2017).

4 Multi-Hazard, Multi-Risk Indicators

4.1 Using Indicators in Disaster Risk Management

While recognising sectoral and disciplinary differences in the definition and use of indicators, in the context of disaster risk management, they are typically used to (i) translate the state of a concept or phenomenon (either quantitatively or qualitatively), and/or (ii) track a phenomenon over time and space (Ivčević et al., 2019). These characteristics are embedded into the definition of 'indicator' that we use within MYRIAD-EU, introduced in **Section 3**.

> *"Indicators are observable and measurable characteristics that can be used to simplify information to help understand the state of a concept or phenomenon, and/or to monitor it over time to show changes or progress towards achieving a specific change."*

Adapted from Ivčević et al. (2019) and Scotland's International Development Alliance (Unknown),

Brecht et al. (2013) succinctly describe the benefits of using indicators in the context of disaster risk management as allowing the aggregation of information and summary of knowledge from a wide range of disciplines to enable accessible use of information, comparison of risk levels spatially (for example, between cities or countries), and comparisons over time (documenting progress towards resilience and identification of long-term, persistent risk where interventions need to be prioritised.

To represent a feature of a region, such as disaster risk, multiple indicators can be brought together, and weighting added as appropriate, to give a scaled composite variable (or index). This approach helps to translate the state of a concept (i.e., disaster risk) in a given region, and allows the comparison of risk across different geographic regions. There are many occurrences in the literature of this type of use, with selected examples including:

- The *Urban Disaster Risk Index (UDRi)* uses indicators to capture both the direct physical damage of buildings and infrastructure and social fragility / risk drivers that aggravate the physical effects of natural hazards (Khazai et al., 2015). The approach was developed by Carreño (2006) and Carreño et al. (2007a), based on work by Omar Dario Cardona (Cardona, 2001; Cardona and Hurtado, 2002; Barbat and Cardona, 2003; IDEA, 2005).
- The *Disaster Risk Index* combines hazard-specific risk models (for cyclones, droughts, earthquakes and floods), to allow a classification of countries based on fatalities. The *Disaster Risk Index* is computed by considering both the absolute (killed per year) and relative (killed per year as percentage of the total country population) multiple risk figures. Eight *Disaster Risk Index* classes exist (0–7), giving an overview of risk (due to natural hazards) at a specific time, and allowing comparison between countries (Peduzzi *et al.,* 2009).
- The INFORM Risk Index is a composite indicator that identifies countries at risk of humanitarian crises and disaster that would overwhelm national response capacity. It balances hazards & exposure on one side and vulnerability and lack of coping capacity on the other, adopting the following risk equation: Risk = Hazard&Exposure 1/3 × Vulnerability 1/3 × Lack of coping capacity 1/3. These 'dimensions' are sub-divided into categories and components of risk (54 core indicators). The authors acknowledge that interactions amongst the dimensions are not considered in the index (Marin-Ferrier et al., 2017).
- The *Global Urban Risk Index* focuses on cities in the Global South. This work included the development of four single hazard risk indices (earthquakes, cyclones, floods, and

landslides), with these brought together into a multi-layer single hazard index. Absolute risk values are converted into index values (1–10), to allow comparison of risk between locations (Brecht et al., 2013).

Such approaches give a picture of risk at a specific time, and by doing them repeatedly over time one can monitor changes. Other approaches, often referred to as 'scorecard approaches', use indicators that help measure progress towards a desired future state (e.g., strengthened resilience to natural hazards), and help guide disaster risk management actions. Examples of this use of indicators include:

- The *Disaster Resilience Index (DRI)*, a monitoring and evaluation tool for benchmarking and measuring progress (or lack of) on the mainstreaming of risk reduction and resilience approaches in a city's development policies and processes (Khazai and Bendimerad, 2011).
- The *City Resilience Index*, developed by Arup with support from the Rockefeller Foundation, includes 52 indicators, assessed based on responses to 156 questions. Qualitative and quantitative data are combined, and indicators aggregated in relation to 12 goals that cities should strive towards to achieve resilience. Assessing the *City Resilience Index* enables governments to understand and measure their performance, thus providing a means of understanding what further actions could strengthen resilience (Arup, 2018).
- The *Risk Management Index (RMI)* provides a quantitative measure of risk management based on predefined qualitative targets/benchmarks that risk management efforts should strive to achieve (Carreño et al., 2007b). The RMI is the average of four composite indicators, relating to public policies of risk identification, risk reduction, disaster management, and governance and financial protection. Each of these four indexes are a composite of six indicators, and collectively they help to characterise risk management performance (Carreño et al., 2007b).
- The *UNDRR Disaster Resilience Scorecard for Cities* is an assessment that focuses on targets and indicators within the Sendai Framework for Disaster Risk Reduction: 2015-2030. This scorecard allows stakeholders to monitor and review progress and challenges in the implementation of the Sendai Framework and is based on UNDRR's Ten Essentials for Making Cities Resilient (UNDRR, 2017a; UNDRR, 2017b).

> *UNDRR's Ten Essentials for Making Cities Resilient: (1) Organise for disaster resilience. (2) Identify, understand, and use current and future risk scenarios. (3) Strengthen financial capability for resilience. (4) Pursue resilient urban development and design. (5) Safeguard natural buffers to enhance the protective functions offered by natural capital. (6) Strengthen institutional capacity for resilience. (7) Understand and strengthen societal capacity for resilience. (8) Increase infrastructure resilience. (9) Ensure effective disaster response. (10) Expedite recovery and build back better.*

UNDRR, https://mcr2030.undrr.org/ten-essentials-making-cities-resilient

An initial review of literature on multi-hazard and multi-risk indicators (described in **Section 2**) suggests that scaled, composite variables predominantly focus on individual hazards or multiple single hazards (treated as discrete independent events). For example, the Disaster Risk Index focuses on cyclones, droughts, earthquakes, and floods (Peduzzi et al., 2009) and the Global Urban Risk Index on earthquakes, cyclones, floods, and landslides (Brecht et al., 2013). Hotspots developed three risk indexes (focused on mortality, economic loss, and economic loss as a proportion of GDP), and considered six hazards: floods, cyclones, drought, earthquakes, landslides, and volcanoes (Dilley, 2005).

Indicators selected and used in scorecard approaches can relate to multi-hazard and multi-risk contexts. For example, an indicator within the Disaster Resilience Index is the effectiveness of institutional arrangements, characterised (in part) by organisational structures that define roles and responsibilities. While not explicitly mentioning multi-hazard, multi-risk management – this could be looked at through the lens of multi-hazard (multiple hazards AND their interrelationships, as defined in **Section 3**). Effective multi-hazard, multi-risk management requires clarity around the roles and responsibilities of organisations, including preparing for and responding to events where multiple hazards occur simultaneously or consecutively. Another example, from the Disaster Resilience Index is the indicator focused on hazard, vulnerability, and risk assessment, characterised (in part) by awareness of hazards. While this implicitly suggests awareness of multiple hazards is needed, it could easily be extended to expect awareness of hazards and their interrelationships.

In the examples above (and many others) existing indicators and indicator sets could be used to drive forward progress towards multi-hazard, multi-risk management. This would be supported by an expansion of the narratives/descriptions putting indicators into context, to ensure these are viewed through a multi-hazard, multi-risk lens as standard practice. For example, the UNDRR Disaster Resilience Scorecard for Cities reminds those completing the scorecard to consider how multiple hazards might combine and suggests that cities may also attempt to estimate the impact of multiple consecutive smaller hazards, or combinations of hazards (a hurricane and accompanying storm surge, for example) (UNDRR, 2017a). Indicators explicitly focused on improving aspects of multi-hazard, multi-risk management may also be required, and these are typically missing from existing sets of indicators. Addressing these gaps would help monitor progress towards the mainstreaming of multi-hazard risk management, as advocated for in the Sendai Framework (e.g., "disaster risk reduction practices need to be multi-hazard… to be efficient and effective" (UNDRR, 2015, Paragraph 7). As part of the work of task 1.1, we have generated an initial draft of multi-hazard, multi-risk indicators that could be used to support implementation of the MYRIAD-EU project (see **Section 6**).

4.2 Draft Multi-Risk Indicators

Given the opportunity identified in **Section 4.1**, and based on our definitions of multi-hazard, multi-risk, and disaster risk management in **Section 3**, we propose the following (non-exhaustive) list of indicators or themes to be embedded into or considered for the development of indicators:

Group 1: Multi-Risk Characterisation

1. Awareness and characterisation of multiple relevant hazards, and their potential interrelated effects.
2. Awareness of potential multi-hazard risk scenarios, including those that are high likelihood and those that are high impact.
3. *(For high likelihood or high impact multi-hazard scenarios)* Awareness of how progression through these multi-hazard risk scenarios will affect vulnerability and exposure.
4. Awareness of the risk dynamics, changes and interactions between its components (hazards, exposure, vulnerability, capacity/response) and the feedback between risk drivers, across sectors and regions

Group 2: Effectiveness of Governance for Multi-Risk Disaster Management

1. Existence of a policy/legislative framework that supports the assessment of multiple hazards and their interrelated effects.
2. Existence of a policy/legislative framework that supports a 'multi-hazard' approach to the management of risk (i.e., by setting out roles and responsibilities for disaster risk reduction and response, and financial mechanisms for disaster risk management).
3. Existence of a policy/legislative framework that facilitates interaction between different agencies/institutions involved in disaster risk management.

4. Evidence of formal and/or informal communication mechanisms across agencies and institutes, both vertically (from national to local) and horizontally (between those with different mandates).

Group 3: Multi-Risk Preparedness

1. Integration of the 'multi-hazard' and 'multi-risk' concepts in planning (e.g., infrastructure, urban environments, land-use).
2. Preparedness of sectors to multi-hazard and multi-risk events, including impacts cascading through sectors.
3. Coping capacity at local and national levels to prepare for and respond to different types of multi-hazard and multi-risk events (e.g., two hazards occurring simultaneously, or consecutively; a complex multi-hazard event whereby a primary hazard triggers multiple secondary hazards; cascading hazards leading to asynergies in disaster risk mitigation measures)
4. Existence of public funding for partnership building and research aligned to multi-risk ambitions.

Alongside our road map for the implementation and continuation of task 1.1 activities within the project, in **Section 6**, we propose three general ways in which the draft indicators for multi-hazard, multi-risk assessment and management could be developed, tested and used in the MYRIAD-EU project.

5 Overview of Other Terminology and Concepts used in MYRIAD-EU

While **Section 3** sets out terminology relevant to the field of multi-hazard, multi-risk disaster management, resilience, and adaptation commonly defined by groups outside of the MYRIAD-EU project but also proposed by the Consortium, there is additional terminology where clarity and (internal) consensus can support interdisciplinary, multi-sectoral working. This section therefore focuses on terminology relating to the task descriptions, methods, and outputs of MYRIAD-EU work packages. The inclusion of terms specific to methods (generally accepted within disciplines) here and not in section 3, is owing to their generic application to research rather than specifically or exclusively to disaster risk, resilience and adaptation.

Table 4: Terminology and associated definitions (project structure)

Term	Definition	Source	Additional Notes
(Knowledge) Co-production (for Sustainability Research)	An iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future.	Norström et al. (2020)	
Cross-Sectoral Dependencies	Relationships (either correlated or otherwise) between two or more sectors of the economy	WP5 (MYRIAD-EU)	See also: *Sector*, *Sectoral Representative* May also be termed: *Intersectoral Interactions*

Term	Definition	Source	Additional Notes
(MYRIAD-EU) Dashboard	Web-based platform to help risk managers, decision-makers, and researchers navigate the MYRIAD-EU framework. The dashboard will provide access to all the products and services of MYRIAD-EU, as well as links to key methods and tools from previous and ongoing external projects.		
Decision Makers	Decision-makers influence a system (e.g., local authority, company) by means of policies that could change either the behaviour of the system or its physical elements. In a system that consists of various sub-systems, many decision-makers can play a role. Policies are used as a collective term for any legal, technological, or behavioural measures that a system could take.	WP6 (MYRIAD-EU)	
Empirical Evidence	Data that is observable and experimental (i.e. gathered from actual experience rather than theory or belief).	Adapted from Merriam-Webster (n.d.); Njoku (2017)	An example in application to WP4: quantitative and qualitative data of actual, current, or past events/states.
Evidence Base	Empirical evidence and other research findings that increase our understanding and support future policy making.	Carabine (2015)	
Event Loss Tables	Simulated losses which are stored for each simulated event and location, along with the associated occurrence frequencies (probabilities) in tables.	WP5 (MYRIAD-EU)	
Framework	Set of beliefs, ideas or rules that is used as a basis for making judgements, decisions	Oxford Dictionary (n.d.)	Note that the literature review associated with WP1, Task 1.2 identified many different uses of the term 'framework' in the literature.
Function	An expression, rule, or law that defines a relationship between one variable (the independent variable) and another variable (the dependent variable). A function can be used to describe quantitative and qualitative relationships.	Adapted from Britannica (2021)	

Term	Definition	Source	Additional Notes
Geocoding	Transforming location information contained in exposure data (buildings number, street, city, state, and postal) into coordinates (e.g., latitude and longitude) that risk modelling software can process.	WP5 (MYRIAD-EU)	
Graphical Models	Models representing the probabilistic relationships among a set of variables. Nodes in the graph correspond to variables, and the absence of edges corresponds to conditional independence.	Heckerman (2001)	
Grey Literature	Information that is not produced by commercial publishers (e.g., research reports, working papers, podcasts, blogs, theses, policy documents).	WP1 (MYRIAD-EU)	
Guidance protocols	A structured explanation that provides a clear and easy to understand way for different users how to navigate through the framework and dashboard.	WP2 (MYRIAD-EU)	
Helpdesk	MYRIAD-EU's laboratory approach is designed to ensure co-development with stakeholders and to bridge the divide between science and practice. The helpdesk aims to facilitate this two-way knowledge sharing and iterative feedback between Pilot Studies and the scientific work packages (WP4-6), throughout their duration.	WP4 (MYRIAD-EU)	
Impact (of Research)	The demonstrable contribution that excellent work (including research) makes to society and the economy, and its benefits to individuals, organisations, or nations.	ESRC (n.d.)	See also: *Disaster Impact*
Intangible (Disaster) Costs	Captures direct and indirect damages that cannot be easily priced such as death and injury, impacts on health and wellbeing, and community connectedness. Intangible costs include the opportunity cost of expending resources: that is, the value of the next best alternative use of the resource that is foregone. For instance, if time is spent in hospital due to injury caused by a disaster, the opportunity cost could include lost leisure time or lost wages from not working.	WP5 (MYRIAD-EU)	See also: *Economic loss*, *Direct and Indirect economic loss* (***Table 3***)

Term	Definition	Source	Additional Notes
Interdisciplinary	Interdisciplinary studies address specific real-world problems, bringing people and ideas together from different disciplines to collectively frame a problem, agree on a methodological approach, and analyse data in an integrated manner.	Adapted from Hammer and Söderqvist (2001) and Stock and Burton (2011), and references therein	
Macroeconomic Models	An analytical tool designed to replicate the operation of the global or individual country's economy. It examines the dynamics of important economic indicators like output, inflation, and unemployment.	Saltenyte (2019)	
Method	A systematic procedure or process for achieving specific objectives.	WP1 (MYRIAD-EU)	
Model	A physical, mathematical or conceptual representation of a system, phenomenon or process.	WP1 (MYRIAD-EU)	
Multi-Sector Setting	Any analysis that involves one or more economic sectors.	WP5 (MYRIAD-EU)	See also: *Sector*
Multivariate Methods	Methods used to analyse the joint behaviour of more than one random variable.	WP5 (MYRIAD-EU)	
Narrative	Often used by social scientists to characterise peoples' views, understandings or perspectives.	WP6 (MYRIAD-EU)	
Non-linearity	A situation where the relationship between an independent variable and a dependent variable is not predictable from a straight line. Changes in the output do not change in direct proportion to changes in any of the inputs.	Hayes (2021)	
Pilot Study	A preliminary study where proposed research can be implemented, tested, and evaluated to prove its viability.	WP3 (MYRIAD-EU)	
Platform	An online software architecture that hosts applications, services and/or other resources used to meet specific objectives	Based on Martens (2016)	
(Cross-Sectoral) Risks	Risks which propagate between two or more sectors.	WP5 (MYRIAD-EU)	See also: *Disaster Risk* *(Table 3)*
Sector	Services and products that emerge from the interdependent dynamics of the underlying systems-of-systems that shape resources, demands, and impacts from global to local scales.	Reed et al. (2022)	See also: *Cross-Sectoral Dependencies*, *Sectoral Representative*
Sectoral Representative	An individual or organisation with specific and demonstrable knowledge, experience, and expertise in an area of specialisation within a given sector.	WP3 (MYRIAD-EU)	

Term	Definition	Source	Additional Notes
Sensitivity Analysis	With respect to quantitative analysis, this assesses how changing assumptions alters the outcomes. For example, one chooses different values for specific parameters and reruns a given model to assess the impact of these changes on model output.	Allwood et al. (2014)	
Stakeholder	Persons, organisations, networks or groups with an interest or concern in a topic of interest or in the process and outcomes of a project, research, or policy endeavour.	Adapted from UNDRR (2016)	
Statistical Dependencies	The mathematical relationship between data.	WP5 (MYRIAD-EU)	See also: *Multi-hazard*, *(Triggering) Relationship*, *(Compound) Relationships*
Stochastic Model	A model using statistical concepts, such as probability distribution and randomness. Stochastic models are based on a set of random variables, where the projections and calculations are repeated to achieve a probability distribution. The models can be repeated thousands of times, with a new set of random variables each time.	WMO (1992)	
Stock-taking	Surveying and appraising a certain situation or condition at a given moment.	WP3 (MYRIAD-EU)	See also: ***Section 4.4.4***
Storylines	A physically self-consistent unfolding of past events, or of plausible future events or pathways. As no a priori probability of the storyline is assessed, it is not a prediction. Emphasis is placed instead on understanding the driving factors involved and the plausibility of those factors (or of changes in those factors).	Shepherd et al. (2018)	See also: *Scenario*
Tool	A resource or technique designed to carry out a particular function to solve a particular problem.	WP1 (MYRIAD-EU)	
Upscaling	The upgrade and improvement of research output in terms of scale, quality, or resolution.	WP3 (MYRIAD-EU)	
User	In general terms, a user is an individual, organisation or community who employs or uses a product, model, or service.	WP3 (MYRIAD-EU)	

The following sections provide expanded definitions and descriptions of key terms and concepts within the MYRIAD-EU project activities and management.

5.1 Multi-Risk Pilot Study Stocktaking (Work Package 3)

In general terms, stock-taking refers to the activity of surveying and appraising a certain situation or condition at a given moment. Within MYRIAD-EU (WP3), this term refers to the initial comprehensive collection of available up-to-date relevant information and data that describe the current risk profile of each Pilot Study region. In detail, this stock-taking is focused on gathering the following information:

- Existing hazards, exposures, and vulnerabilities as well as any interrelationships existing between these.
- Existing or planned policies and adaptation measures.
- Previous and ongoing research projects relating to the objectives of MYRIAD-EU.
- Methods, models, and tools used by local experts and stakeholders.
- Data and indicators that are needed as inputs to methods and tools used in MYRIAD-EU.

The stock-taking integrates literature searches, consultations with local experts, and feedback from Pilot Stakeholder Groups and Pilot Core User Groups (see Section 5.6).

The results are used to define what the problems (or risk management challenges) are in each Pilot Study and the set of MYRIAD-EU methods and tools that could address those problems. Examples of possible risk management challenges may include the decision on how to reduce the risk caused by multiple hazards to a specific economic sector, a lack of data to characterise the vulnerability of a certain geographical area, a policy gap that may hamper the implementation of a disaster risk reduction measure, or the low effectiveness of an adaptation measure already in place.

Stock-taking is to be carried out in Task 3.3 (months 7-24) of MYRIAD-EU.

5.2 Multi-Risk Pilot Study Stocktaking Event Sets (Work Package 5)

"Stochastic" means being or having a random variable. A stochastic model (see table 3) can estimate probability distributions of potential outcomes by allowing for random variation in one or more inputs over time. The random variation is usually based on fluctuations observed in historical data for a selected period using standard time-series techniques. Distributions of potential outcomes are derived from a large number of simulations (stochastic projections) which reflect the random variation in the input(s) (SSA, n.d.).

In a single-hazard stochastic event set, empirical or mechanical or analytical datasets can be used to produce the stochastic event set where different hazard events are produced based on sampling of distributions or using established physical, mathematical, or conceptual models. Each event within an event set is given a hazard footprint, size metrics (e.g., earthquake magnitude, discharge etc.), temporal information, and return period/probability of occurrence. A stochastic event set can be built for a current year analysis or for past or future scenarios. Within work package 5, Task 5.1, these types of stochastic event sets will be produced for hazards across Europe.

There are two approaches to extend this to multi- hazards, examining:

1. A set of multiple single-hazard stochastic event sets, such as two independent single hazard stochastic event sets are combined via a temporal component (such as synthetic year, time of year, month, day and time).
2. A set of interconnected, dependent stochastic event sets, where the two or more hazards are interconnected via relationships (correlated, triggered, etc. – see coinciding events definition). Here, the stochastic event sets include not only the information above but are also built-in tandem via copulas or other regressions, presented with the relevant additional information.

The move to multi-risk stochastic event sets involves the combination of exposure and vulnerability with the above hazard event sets to create damage, loss, or other metrics per event. This is further developed for certain case studies.

5.3 Time- Dependent Intensity-Damage Functions for Specific (Combinations of) Hazards (Work Package 4)

The concept of intensity-damage functions is about comparing the magnitudes of hazards with corresponding damage caused. Thereby, the magnitude can be inferred from, for example, temperature (for heat waves), soil moisture (for droughts), discharge (for floods), or respective return periods of the peaks in these time series (Orth et al 2022). Damage caused can be measured by any impact-related metric (Schewe et al. 2019, e.g., hospitalizations, crop yield reductions, or property damage). Using data from several independent events we can infer intensity-damage relationships that are a reflection of the vulnerability of a system/region and can, for example, indicate thresholds of event magnitude above which the expected damage strongly increases. These relationships can be altered by preceding hazards (e.g. in the previous year) of the same or different type which affect the vulnerability of a system/region and hence its preparedness for subsequent hazards.

5.4 Dynamic Adaptive Policy Pathways (DAPP) Approach (Work Package 6)

Developed by Deltares and TU Delft, this approach aims to support the development of an adaptive plan that can deal with changing future conditions.

> *"DAPP policy analysis begins with the identification of objectives, constraints, and uncertainties that are relevant for decision-making. The uncertainties are then used to generate an ensemble of plausible futures. These futures are compared with the objectives to see if problems arise or if opportunities occur. This determines if and when an adaptation tipping point may occur and thus when policy actions are needed."*

Dynamic Adaptive Policy Pathways, https://www.deltares.nl/en/adaptive-pathways/

DAPP helps focus on important planning questions: which actions to prioritise? which to postpone? are there low-regret situations? DAPP can be applied on various levels of assessment, enabling a systematic analysis of alternatives to reduce risk and prepare for the future:

1. *Initial qualitative pathways* – construction of narratives for problem framing and stakeholder knowledge co-development
2. *Quantitative design of pathways* - expert judgment-based identification of promising combinations of measures to reduce risk
3. *Full assessment of pathways* - detailed system development analysis based on computer-models to identify flexible and promising pathways.

These levels of analysis can be applied in a phased approach. Thus, the resources and aspired level of confidence required for certain (long-term) risk management strategies can be increased iteratively.

Through 1 to 3, above, the term 'pathways' describes a sequence of policy actions or investments over time to achieve a set of pre-specified objectives under a variety of plausible scenarios representing the uncertain changing socioeconomic/climatic conditions. The exploration of adaptation pathways is key to adaptive planning.

Actions are identified based on an assessment of vulnerabilities and opportunities. The performance of each 'action' and 'pathway' is assessed considering the defined objectives to determine its adaptation tipping point (the point in which it can no longer meet its pre-defined objectives). Promising actions are used as the basic building blocks for the assembly of potential adaptation pathways (a sequence of actions), that can be presented in an adaptation pathways map (**Figure 11**). Visualised in the form of a metro map, an adaptation pathways map provides insight into policy options, the sequencing of actions over time, potential lock-ins, and path dependencies.

The exploration of adaptation pathways is one of the main ingredients of an adaptive plan that specifies both immediate actions if we are to be prepared for the near future and the required actions to keep options open to adapt in the future. A monitoring system collects information to get early warning signals (triggers) for implementation of actions or for reassessment of the plan.

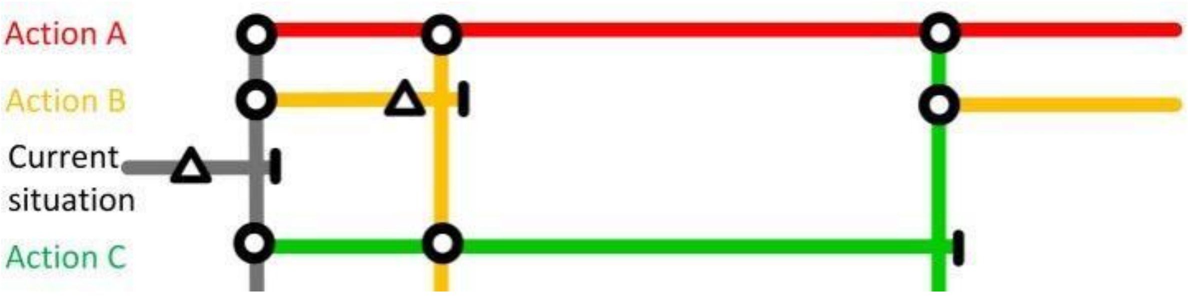

Figure 11: Example of an Adaptation Pathways Map. Source: adapted from Haasnoot et al. (2019) CC BY 4.0

A scorecard can be used to present the costs and (co)-benefits of each of the adaptation pathways. Subsequently one or more preferred pathways can be selected as input for an adaptive plan. The aim of this plan is to stay on the preferred pathway as long as possible. For this purpose, contingency actions are specified and a trigger for each contingency action is specified and monitored.

DAPP has been applied in a wide field of decision-making processes, including flood risk management, drought management, and coastal planning.

More information: see Deltares (n.d.) https://www.deltares.nl/en/adaptive-pathways/

5.5 Collaborative systems analysis approach for forward-looking DRM pathways (Work Package 2, 6)

An approach for systems analysis and stakeholder engagement that allows decision-makers and policy-makers to accurately describe their decision-making context. This includes system characteristics, objectives and constraints in the current situation, and potential constraints in future situations.

5.6 Stakeholders and Sectors in MYRIAD-EU

5.6.1 Pilot Stakeholder Group

The Pilot Stakeholder Group forms part of the stakeholder network associated with each Pilot study in the MYRIAD-EU project. This group is composed of approximately 10 to 15 organisations per Pilot Study and its membership is established between Pilot Study Leads and Sectoral Representatives.

Examples of stakeholders in this group are local, regional, and national level governmental decision-makers in governmental agencies involved in disaster risk management/climate adaptation, private sector companies, non-governmental organisations, and civil society organisations.

The Pilot Stakeholder Group's role is to provide input on the Pilot Study-specific opportunities, challenges and required solutions, as well as feedback on the results and recommendations for future disaster risk management pathways. This will be achieved through their involvement in the Pilot Study Workshops.

Pilot Study Stakeholder Groups will be established in each Pilot Region between months 7 and 9 of the project, as part of the Stakeholder dialogue (Work Package 3, Task 3.2).

5.6.2 Pilot Core User Group

The Pilot Study Core User Group forms part of the stakeholder network associated with each Pilot Study in the MYRIAD-EU project. This group is composed of approximately 3 to 5 core organisations per Pilot Study and its membership is established between Pilot Study Leads and Sectoral Representatives. Examples of core users are local, regional, and national level governmental decision-makers in governmental agencies involved in disaster risk management/climate adaptation and private sector companies.

The Pilot Study Core User Group is a sub-group of the Pilot Study Stakeholder Group (see **Section 5.6.1** and **Figure 12**) with additional roles and responsibilities at the project level compared with the Pilot Study Stakeholder Group. These include testing of MYRIAD-EU products and services and giving input and feedback to the scientific Work Packages in the MYRIAD-EU project on how to tailor them to their needs. This, together with a wider involvement in the project, will be achieved through several activities, listed below:

- Interviews/focus groups to inform activities in Work Packages focused on diagnosis and development of a prototype framework
- Participation in Pilot Study Workshops and Focus Groups
- Testing of MYRIAD-EU products and services in close collaboration with Pilot Study teams

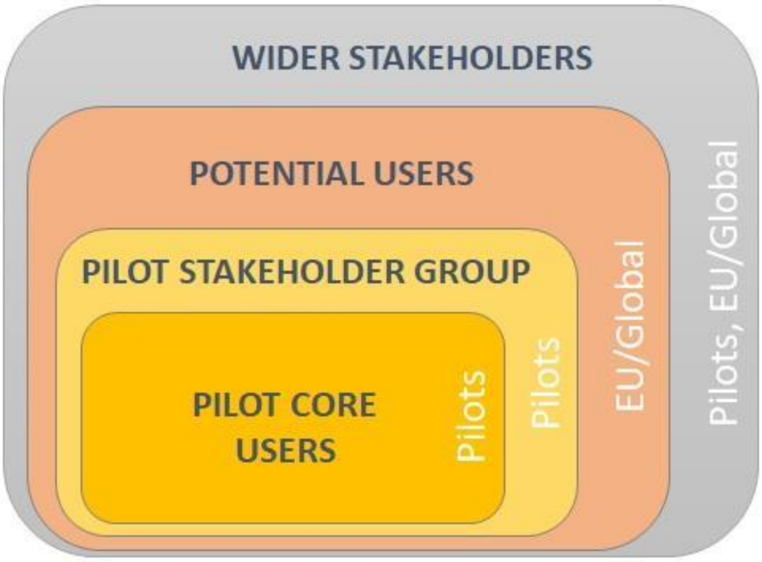

Figure 12: MYRIAD-EU Stakeholder groups (note the Pilot vs wider geographic focus of each group)

Pilot Study Core User Groups will be established in each Pilot Region between months 7 and 9 of the project, as part of the Stakeholder dialogue (Task 3.2).

5.6.3 MYRIAD-EU Sectoral Representatives

The MYRIAD-EU consortium includes representatives of six sectors (ecosystems, energy, finance, food and agriculture, infrastructure, tourism), with each of these characterised in Table 5.

Table 5: Descriptions of MYRIAD-EU Sectors

Sector	Description
Ecosystems and Forestry	The ecosystems and forestry sector is part of the wider environmental sector which consists of stakeholders aiming at protecting the environment and managing natural resources. *This sector includes a wide range of subsectors* including sustainable agriculture and fisheries, renewable energy, blue - green infrastructures, grey-green infrastructure, water, development, humanitarian and peace sector, recreational services, tourism, urban planning, trade, extracting industries. The ecosystems and forestry sector look at the sustainable management of natural resources and landscape restoration practices that will ensure healthy and resilient ecosystems that will sustain human activities and human well-being. Assessing the condition of different ecosystems, understanding what could cause its decline and how this would affect their services is essential to effective management, decision-making and policy design. Such an understanding helps target actions for conservation or restoration and more broadly sustainable use For instance, acting as the water sources, sinks and regulators, the "health" of wetlands affects the quantity and quality of water available for our use in every landscape. In other words, wetlands control our water security – widely regarded as the key natural resource challenge facing humanity. *Key European environmental legislations and policies* are: Biodiversity Strategy 2030, EU Nature Restoration Law and Climate package (Climate adaptation strategy, NDC, Climate law, Fit for 55). *Key partners to collaborate with*: governments, private sector, civil society organisations, engineering and marine contracting sectors; peacebuilders, civil protection and financial institutions. *This sector is represented in MYRIAD-EU by Wetlands International European Association, which brings together ten European NGO members from six European countries, working together to raise awareness about the status, trends and values of wetland ecosystems and their importance for the attainment of environmental and climate European policy goals. As a members-based organisation, our working model connects three knowledge levels: European, national and on the ground creating a virtuous cycle of information flow between the Secretariat of the Association and its members that combines bottom-up and top-down approaches and facilitates the collection of examples of best practices and lessons learned that are used to inform policy processes and decision makers.*

Sector	Description
Energy	The energy sector, following the traditional supply chain, consists of *fuel suppliers* for the electricity, heat and transport sector, *electricity and heat producers*, *network operators* and *energy retailers*. Main developments of the electricity and gas sector in the EU over the last decades are the unbundling of networks and the liberalisation and integration of markets. Still, networks and markets are highly regulated, by governmental agencies, i.e., regulators, both at European and national level. The energy sector in Europe is undergoing a radical transition towards carbon neutrality, following national commitments to comply to the Paris climate agreement and latest 55% EU emission reduction targets for 2030. This includes a variety of measures, such as large-scale deployment of renewable generation, expansion of network infrastructures, decarbonizing the energy demand, and reforming markets. Measures on the demand-side by end-users include electrification of industrial processes (either directly by replacing gas boilers by E-boilers, or indirectly, via converting power to hydrogen or other chemicals), improved energy efficiency (e.g., re-use of waste heat), or by CO2 capture (use) and storage. Also, for the transport sector both direct electrification (EV) and indirect electrification (green fuels for heavy transport) are ongoing developments. Another development is the growth of decentralized generation and demand-response, with many new parties becoming active on the market, including industrial suppliers of power (CHP) or waste heat, and domestic prosumers (e.g., smart EV charging via aggregators). These developments will increase dependencies between the sectors and increase the share of electricity in the energy mix. Also, this will increase the complexity of the energy system and its operation, as the supply will largely depend on weather resources, requiring sufficient storage potential and active participation of end-users to maintain cost-efficiency and security of supply. Planning the offshore and onshore generation and transmission infrastructure takes many years and requires participation of project developers, governments, NGOs and local communities, in order to consider impacts on other land/sea users, local communities and ecology. In particular, offshore ecological impacts are not well-known beforehand and require extensive studies. Infrastructure developments also have high capital costs, and therefore projects are mostly reserved for large investors. Over the last years, wind and solar PV costs have shown a dramatic decrease, largely removing the need for subsidies. Still technology suppliers, as well as project developers and contractors, are challenged to further reduce costs, to keep the total costs, including system integration costs, manageable, while future energy market prices become more uncertain. *This sector is represented in MYRIAD-EU by the Dutch applied research organization TNO's unit energy transition. The unit Energy Transition within TNO helps accelerate the energy transition together with knowledge institutions, companies and the government so that in 2050 the Netherlands will have an energy regime free of CO2 emissions.*

Sector	Description
Finance	The finance sector covers a wide range of industries that have an interest in multi-hazards and multi-risks. The main sector that will be focussed on in this project is the reinsurance sector. Primary insurers, who provide insurance to individuals and businesses, insure themselves against both single catastrophic events (e.g. widespread flooding, large windstorms) but also against all losses they may incur over the year. This is provided by reinsurers, who take on the risk from the primary insurers. Europe has one of the largest insurance markets with insurance penetration, the proportion of properties/business/individuals having insurance, being some of the highest in the world. Thus, the risk to Europe of un-prepared insurance sector is high. The insurance industry is also interested in the risks that go beyond the direct impacts of a natural hazard – business interruption and the post-event financial implications. This is another area which multi-hazards and multi-perils will be extremely important to consider. *This sector is represented in MYRIAD-EU by Aon, which represents multiple aspects of the finance sector. Aon's Reinsurance solutions provides risk transfer, claims advocacy and capital management solutions to help re/insurers reduce volatility and build more resilient businesses, governments and communities. Aon's Commercial Risk Solutions provides clients with the clarity and confidence they need to pursue their ambition by solving their risk needs. Through the identification, measurement and management of risk exposure – we help clients to protect and grow their businesses.*
Food and Agriculture	The food and agriculture (or agri-food) sector include several sub-sectors, differentiated according to the place they occupy in the chain of the sector: • Producers: This can be further divided into multiple sub-sectors (often done at a national level) including (but not limited to) viticulture, horticulture, livestock, horticulture, crops under cover (greenhouses), fish farms, and hydroponics. Each of these sub-sectors has the independence to be considered a sub-sector in itself but can be broadly grouped as 'production systems'. • Transport. Produce often needs to be transported from producers to retailers and consumers. This is generally using maritime and land-based transportation networks. Air travel may be used for high-value products. • Distribution and retailing. The distribution and retail of produce is another sub-sector, including drivers, retailers, and department stores. While the public tends to think that the agri-food sector is limited to farmers, the above demonstrates the wide scope of the sector and its multiple sub-sectors. The Common Agricultural Policy is the main tool managing the agri-food sector in the EU, and accounts for approximately 40% of the total EU budget. The sector is important and strategic within the EU; however it is vulnerable. The risks to the sector are environmental (climate change, increased periods of drought, extreme events), political (distribution of production, origin of exports, communication routes, international relations), and social (changes in dietary patterns, culinary preferences), among others. For example, because of the war in Ukraine, cereal production must be reviewed and boosted in other areas that were previously not cereal-growing areas. The international market also exerts great pressure on the sector, so that the development of China has a negative impact on exports from Europe. For more information, see the European Commission's 'Monitoring EU agri-food trade' report[2]. *This sector is represented in MYRIAD-EU by CICYTEX, a Research centre in Extremadura, focused on agri-food research and involved in several agri-food networks like the European Regions for Innovation in Agriculture, Food and Forestry (Eriaff).*

[2] https://ec.europa.eu/info/food-farming-fisheries/trade/trade-and-international-policy-analysis/monitoring-eu-agri-food-trade-previous-editions_en

Sector	Description
Infrastructure and Transport	Transport is the lifeblood of modern society and fundamental to the economy. According to the European Commission's data[3] , as of 2021, the transport sector: • Employs 14.6 million people. • Contributes € 906 billion to the economy of the EU (approximately 7.5% of its total value) • Includes 1.8 million companies (with 99.7% of these being Small and Medium Sized Enterprises (SMEs). The main transport modes are air, road, rail, maritime and inland waterways. Air transport is a key contributor to the European economy, with more than 100 scheduled airlines, a network of over 400 airports, and 60 air navigation service providers. The sector directly employs between 1.4-2 million people and directly contributes more than €110 billion to the European GDP[4]. Road transport is essential to the economy in terms of its contribution to GDP. The sector employs almost 5 million people in the EU[5]. In 2020, road freight transport accounted for 77.4 % of the total inland freight transport[6]. The railway sector overall accounts for more than 1 million direct and 1.2 million indirect jobs in the EU[7]. In 2020, rail freight transport accounted for 16.8 % of the total inland freight transport. Maritime transport remains the backbone supporting international trade and globalisation with over 80 % of world merchandise trade by volume being carried by sea. For the EU maritime transport and all related shipping services are essential to help European companies compete globally[8]. The EU's inland waterway network is about 41,000 kilometres of inland waterways. About 150 billion tonne-kilometres of cargo are transported yearly, carried by about 15,000 cargo vessels, while some 3,000 day-trip passenger vessels and 430 cruise vessels (>12 passengers) are in operation[9]. *This sector is represented in MYRIAD-EU by FEHRL, the association of highway research organisations in Europe. Formed in 1989 as the Forum of European National Highway Research Laboratories, FEHRL provides a structure for the coordination of road and transport infrastructure research. Comprising members from thirty European nations and international affiliates from USA, and Israel, FEHRL's aim is to encourage collaborative research and knowledge transfer as well as to provide relevant knowledge and advice to governments, the European Commission, the road industry and road users on related technologies and policies.*

[3] https://ec.europa.eu/info/sites/default/files/swd-annual-single-market-report-2021_en.pdf
[4] https://transport.ec.europa.eu/transport-modes/air/internal-market_en
[5] https://transport.ec.europa.eu/transport-modes/road/social-provisions_en
[6] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Freight_transport_statistics_-_modal_split
[7] https://ec.europa.eu/growth/sectors/mechanical-engineering/rail-supply-industry_fr
[8] https://transport.ec.europa.eu/transport-modes/maritime/international-cooperation-and-coordination_en
[9] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0324&rid=4

Sector	Description
Tourism	Tourism is a vast ecosystem comprising: • Accommodation and food service activities • Creative, art and entertainment, museums, sports, amusement and recreation activities • Transport • Travel agencies and tour operators According to the European Commission's data10, as of 2021, the Tourism sector: • Employs 20.3 million people. • Contributes € 850 billion to the economy of the EU (approximately 7% of its total value) • Includes 3.2 million companies (with 99% of these being Small and Medium Sized Enterprises (SMEs), and 90% classed as micro-enterprises). In the EU, service providers in tourism destinations (e.g., hospitality venues, tourism attractions) are, in their majority, controlled by small local owners. Some are franchisees of a few multinational companies providing branding, marketing, management, and selling services. SMEs represent 99.9% of the Tourism sector's companies. They generate 63.66% of its value added and employ 83.63% of its workers. The proportion of micro and small companies is particularly high in hospitality (hotels, bars, restaurants), with many owners operating independently or under franchise from large groups. It is also true but to a lesser extent for travel agencies and some transport operators (e.g., coach companies). *This sector is represented in MYRIAD-EU by HOTREC, an umbrella organisation for hotels, restaurants, cafés and similar establishments in Europe. They bring together 46 national associations representing the hospitality sector, in 36 countries across Europe.*

5.7 Summary

As the project continues, a number of terms will undoubtedly emerge that require a mutual understanding to be agreed across the multi- and interdisciplinary MYRIAD-EU consortium. In our final section below, we make recommendations for how to ensure that the outputs of task 1.1 are dynamic across the remainder of the project.

6 Concluding Remarks

The aim of the handbook was to (i) acknowledge the differences and promote consistency in understanding across subsequent Work Packages in the MYRIAD-EU project (and their outputs), (ii) improve the accessibility of our work to a broad array of stakeholders in the community. Our ambition is that this work strengthens consensus across the hazard and risk community through a common understanding of multi-hazard, multi-risk terminology and concepts. We looked to make use of and build on an extensive body of work, particularly internationally recognised glossaries (**section 2**), which embody years of literature review and consultations. As an addition to the existing literature, D1.2 focused upon indicators for multi-risk management, and in this final section we set out options for their development, testing, and use through the MYRIAD-EU project.

This work concludes at a key time for disaster risk management. The 2022 Global Platform for Disaster Risk Reduction was held on 23-28 May with a reported increase in multi-hazard and multi-sectoral approaches and synergy with climate change adaptation (co-Chair Summary). We conclude

[10] https://ec.europa.eu/info/sites/default/files/swd-annual-single-market-report-2021_en.pdf

the handbook with some key observations and recommendations for embedding the work undertaken in D1.2 not only within the MYRIAD-EU project, but also within the wider disaster risk management community.

6.1 Selection of Key Observations and Recommendations

Terminology and definitions matter

The project comprises a multi-and interdisciplinary team, with different disciplinary backgrounds, experiences and expertise. Establishing a common understanding is central to successful interdisciplinary research and practice.

Terminology is an important contribution to the design, implementation and monitoring of disaster risk reduction and risk-informed investments at all levels – local, national, regional and global (Murray et al., 2022). Through the adoption of intergovernmental glossaries, such as the UNDRR/ISC Hazard Definition and Classification Review, countries can report progress against intergovernmental targets, including the Sendai Framework for Disaster Risk Reduction 2015-2030, the Paris Agreement on climate change and the Sustainable Development Goals of Agenda 2030, all of which require a multi-risk management approach. In the co-chair's summary of the 2022 Global Platform, it was emphasised that

> 'countries need to be able to better assess the risk associated with cascading, compounding hazards and complex crises, by making data more readily available to implement long-term strategies. Assessment of biological, environmental and technological hazards, including those related to frontier risks, should be strengthened in line with a multi-hazard approach to disaster risk management' (UNDRR, 2022).

Adopting internationally recognised terminology, as emphasised in the glossaries presented in D1.2, is therefore important for impact of the MYRIAD-EU project. As discussed in section 2, the MYRIAD-EU consortium has and will continue to make use of the established glossaries throughout the project. As a consortium, we also have the opportunity to provide our reflections and feedback on the application of these glossaries in the context of the project. For instance, what was apparent from the literature review (see section 2.1.2) is that despite well-established definitions, many publications defined words afresh, with intergovernmental glossaries being referenced arguably less than might have been expected. While this might be a natural development in an emerging field of science, some challenges may arise, for example, in relation to the application of standards and guidance protocols in practice and policy.

When is it helpful to include the 'multi-' as a prefix?

A number of established disaster risk terms were initially suggested for inclusion in D1.2 with the multi- prefix assigned to them. The WP1 discussed at length the use of the 'multi' prefix. The work of WP1 overall, and including task 1.1, proposes that the part of the 'paradigm shift' needed to successfully address complex questions and challenges facing an increasingly interconnected world that MYRIAD-EU seeks to catalyse is through inherently seeing vulnerability, exposure and risk (etc.) through the lens of multiple, interrelated hazards and dynamic exposure and vulnerability, without the requirement to create concepts like 'multi-vulnerability'. We recommend a constant reflection on this proposition throughout the project.

Evolution of terminology

Much of the work in D1.2 presents disaster risk terminology, particularly that related to multi-risk, as it exists. Section 2.2 and 2.3 presented an evolution of these terms. It is possible that over the course of the project, terms without internationally agreed definitions will continue to evolve. Within MYRIAD-EU, definitions are likely to emerge and be created through the project. Through the pilot studies and subsequent work packages, there is an opportunity to develop narratives and case studies to contextualise the terminology. It is therefore a key recommendation of WP1 that the handbook becomes a living, dynamic document. A searchable version of this glossary will therefore exist on the MYRIAD-EU Dashboard (Task 2.3) and can be updated as needed to ensure it remains useful within and beyond the project. We suggest that it is the responsibility of all members of the consortium to share and discuss terminology challenges and opportunities for reaching common ground throughout the project. We recommend that this is supported in part through the role of the Interdisciplinary Champion and through the monitoring of the co-development approach. We also recommend, where possible, that consortium members should strive to translate the glossary into the different MYRIAD-EU languages (Spanish, French, Norwegian, Romanian, German, Italian, Dutch).

Application of indicators to the MYRIAD-EU project

Existing indicators and indicator sets could be used to drive progress towards multi-hazard, multi-risk management. These could align with existing indicators, such as the Sendai Framework indicators. Moreover, a systemic, integrated perspective of disaster risk management and adaptation could also support this future work. This requires indicators to be viewed through a multi-hazard, multi-risk lens as standard practice. In section 5.2, we propose a roadmap for the development, testing and application of indicators in the MYRIAD-EU.

6.2 Roadmap for Testing Draft Multi-Hazards, Multi-Risk Indicators

Here, we present a roadmap for testing draft multi-hazard, multi-risk indicators in disaster risk management. There is an opportunity that these indicators could be developed and tested in MYRIAD-EU, therefore we use specific examples related to the project in the roadmap below. We suggest three broad approaches:

Generalisable Multi-Hazard, Multi-Risk Indicators.

- Establishing indicators that characterise effective 'multi-hazard, multi-risk disaster management' (taking forward the preliminary work in Section 4.2).
- Determine what data we can use to assess each indicator.
- Explore these indicators through, for example, the diverse Pilot Studies in the MYRIAD-EU project, including analysis of what data we can use to assess these.
- Publish a set of multi-hazard, multi-risk indicators that are generic enough that they can be used to strengthen different, existing (and new) sets of risk management indicators.

Characterise and Compare Multi-Hazard Risk.

- Determine a set of indicators, to give a scaled composite variable (or index) that characterise levels of 'multi-risk'.
- Calculate this index for the Pilot Study regions to give a baseline level of risk. As work progresses through MYRIAD-EU, this index can be used to assess how risk is changing (and in what direction).
- By adopting categories of risk the composite index could be broken down into manageable components to aid in the monitoring of how risk is changing and how components of risk are interrelated (for instance the occurrence of the pandemic infection resulting in mass quarantine reducing air population in urban centres, Venter et al. 2021).

Monitoring Project Impact, including Knowledge Co-production.

- Establishing '*performance indicators*' aligned to the stated, intended impact of MYRIAD-EU to '*catalyse a paradigm shift in risk science*' (and outcomes contributing to this impact, as set out in the proposal document[11]).
- Determine what data we can use to assess each indicator.
- Implement data collection at multiple scales (Pilot Studies and project-wide) to allow the *Impact Unit* of the MYRIAD-EU management structure to monitor and evaluate progress towards impact.
- Lastly, establish and monitor the progress of the knowledge co-production process using a set of principles and tools to ensure ongoing learning and sustainability of the research throughout and beyond the lifetime of the project.

These three suggestions are not intended to be exhaustive but aim to encourage dialogue across the consortium as to how to use indicators and advance this work in the continuing work packages. We intend to publish a paper on the findings from this work, integrated with subsequent WP1 tasks, in due course.

[11] Example outcomes include enabling 'diverse decision makers to develop forward-looking disaster risk management pathways that assess trade-offs and synergies of various strategies across sectors, hazards, and scales, recognising interrelated effects and the cascading effects of multi-hazard risk' (MYRIAD-EU proposal; see Ward et al. 2022).

7 References

Allwood J.M., V. Bosetti, N.K. Dubash, L. Gómez-Echeverri, and C. von Stechow, (2014). Glossary. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Arrighi, C., Tanganelli, M., Cristofaro, M. T., Cardinali, V., Marra, A., Castelli, F., & De Stefano, M. (2022). Multi-risk assessment in a historical city. Natural Hazards, 1-32, https://doi.org/10.1007/s11069-021-05125-6.

Arup (2018). City Resilience Index. Available at: https://www.cityresilienceindex.org/#/ (last accessed 5 April 2022).

Aven, T. (2019). The science of risk analysis: Foundation and practice, Routledge, 330 pp, ISBN 9780367139223.

Barbat, A., H. & Cardona, O., D. (2003). Vulnerability and disaster risk indices from engineering perspective and holistic approach to consider hard and soft variables at urban level. Information and indicators program for disaster risk management. Universidad Nacional de Colombia, Manizales, Colombia, 19.

Beh, E.H.Y., Zheng, F., Dandy, G.C., Maier, H.R., & Kapelan, Z. (2017). Robust optimization of water infrastructure planning under deep uncertainty using metamodels, Environmental Modelling & Software, 93, 92 – 105, https://doi.org/10.1016/j.envsoft.2017.03.013.

BNHCRC (2017). Economics of Natural Hazards. Annual project report 2016-2017. Available at: https://www.bnhcrc.com.au/sites/default/files/managed/downloads/pa05_pannell_with_eu_annualreport_2016-2017-mpr_approved.pdf (last accessed 30 May 2022).

Brecht H, Deichmann U, & Wang H.G. (2013). A global urban risk index. World Bank Policy Research Working Paper (6506).

Britannica (2021). Function. Available at: https://www.britannica.com/science/function-mathematics (last accessed 5 April 2022).

Brundtland, G. H. (1987). Our common future—Call for action. Environmental Conservation, 14(4), 291-294.

Carabine, E. (2015). Revitalising evidence-based policy for the Sendai Framework for Disaster Risk Reduction 2015-2030: lessons from existing international science partnerships. PLoS currents, 7. DOI: 10.1371/currents.dis.aaab45b2b4106307ae2168a485e03b8a

Cardona Arboleda, O. D. (2001). Estimación holística del riesgo sísmico utilizando sistemas dinámicos complejos. Ph.D Thesis. Universitat Politècnica de Catalunya.

Cardona O.D. & Hurtado J.E. (2000). Holistic Seismic Risk Estimation of a Metropolitan Center. Proceedings of the 12th World Conference of Earthquake Engineering, Auckland, New Zealand.

Cardona, O.D., Van Aalst, M.K., Birkmann, J., Fordham, M., Mc Gregor, G., Rosa, P., Pulwarty, R.S., Schipper, E.L.F., Sinh, B.T., Décamps, H. & Keim, M. (2012). Determinants of risk: exposure and vulnerability. In Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the intergovernmental panel on climate change, 65-108. Cambridge University Press.

Carreño Tibaduiza, M. L. (2006). Técnicas innovadoras para la evaluación del riesgo sísmico y su gestión en centros urbanos: Acciones ex ante y ex post. Ph.D Thesis. Universitat Politècnica de Catalunya.

Carreño, M. L., Cardona, O. D., & Barbat, A. H. (2007a). Urban seismic risk evaluation: a holistic approach. Natural Hazards, 40(1), 137-172, https://doi.org/10.1007/s11069-006-0008-8.

Carreño, M. L., Cardona, O. D., & Barbat, A. H. (2007b). A disaster risk management performance index. Natural hazards, 41(1), 1-20, https://doi.org/10.1007/s11069-006-9008-y.

Carter, T.R., La Rovere, E.L., Jones, R.N., Leemans, R., Mearns, L.O., Nakicenovic, N., Pittock, A.B., Semenov, S.M., Skea, J., Gromov, S. & Jordan, A.J. (2001). Developing and applying scenarios. Climate change, 200, pp.145-190.

CBD (2009). Ecosystem Based Adaptation. Available at: https://www.cbd.int/article/biodiversityagainstclimatechange-1 (last accessed 16 March 2022).

Ciurean, R., Gill, J.C., Reeves, H., O'Grady, S.K., Donald, K., & Aldridge, T. (2018). Review of multi-hazards research and risk assessments, British Geological Survey Engineering Geology & Infrastructure Programme. Open Report OR/18/057, 109 pp. Available at: http://nora.nerc.ac.uk/id/eprint/524399/ (last accessed 16 March 2022).

IPCC, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp.

De Pippo, T., Donadio, C., Pennetta, M., Petrosino, C., Terlizzi, F., & Valente, A. (2008). Coastal hazard assessment and mapping in Northern Campania, Italy. Geomorphology, 97(3-4), 451-466, https://doi.org/10.1016/j.geomorph.2007.08.015.

De Ruiter, M.C., Couasnon, A., van den Homberg, M.J., Daniell, J.E., Gill, J.C., & Ward, P.J. (2020). Why we can no longer ignore consecutive disasters. Earth's future, 8(3), e2019EF001425, https://doi.org/10.1029/2019EF001425.

De Ruiter, M. C., de Bruijn, J. A., Englhardt, J., Daniell, J. E., de Moel, H., & Ward, P. J. (2021). The asynergies of structural disaster risk reduction measures: Comparing floods and earthquakes. Earth's Future, 9(1), e2020EF001531. https://doi.org/10.1029/2020EF001531

Delmonaco, G., Margottini, C., & Spizzichino, D. (2006) 2006. ARMONIA methodology for multi-risk assessment and the harmonisation of different natural risk maps. Deliverable 3.1.1. European Commission.

Deltares (n.d.). Dynamic Adaptive Policy Pathways: supporting decision making under uncertainty using Adaptation Tipping Points and Adaptation Pathways in policy analysis. Available at: https://www.deltares.nl/en/adaptive-pathways/ (last accessed 16 March 2022).

Dilley, M. (2005). Natural disaster hotspots: a global risk analysis (Vol. 5). World Bank Publications.

Doan, N. & I. Noy (2022). A Global Measure of the Impact of COVID-19 in 2020 in Comparison to the Average Annual Cost of all Other Disasters (2000-2019). GAR2022 Contributing Paper. Geneva: United Nations Office for Disaster Risk Reduction. www.undrr.org/GAR2022

Duncan, M., Edwards, S., Kilburn, C., Twigg, J., & Crowley, K. (2016). An interrelated hazards approach to anticipating evolving risk. Global Facility for Disaster Reduction and Recovery. In: GFDRR (Ed.), The Making of a Riskier Future: How Our Decisions Are Shaping Future Disaster Risk. Global Facility for Disaster Reduction and Recovery, Washington, USA, 114–121. Available online: https://www.gfdrr.org/sites/default/files/publication/Riskier%20Future.pdf (last accessed 4 August 2022)

ESRC (n.d.) Defining Impact. Available at: https://www.ukri.org/councils/esrc/impact-toolkit-for-economic-and-social-sciences/defining-impact/ (last accessed 23 February 2022).

Estrella, M. and & Saalismaa, N. (2013). Ecosystem-based DRR: An overview. In: The Role of Ecosystems in Disaster Risk Reduction. Geneva: United Nations University Press, pp. 26-47.

European Commission Joint Research Centre (2021). eNatech: Natural hazard-triggered technological accidents database. Available at: https://enatech.jrc.ec.europa.eu/ (last accessed 23 February 2022).

Fitzgibbons, L. (2022). Feedback loop. Available at: https://www.techtarget.com/searchitchannel/definition/feedback-loop#:~:text=A%20feedback%20loop%20is%20the,a%20minimum%20of%20four%20stages. (last accessed 30 May 2022)

French, A., Mechler, R., Arestegui, M., MacClune, K. & Cisneros, A. (2020). Root causes of recurrent catastrophe: The political ecology of El Niño-related disasters in Peru. International Journal of Disaster Risk Reduction, 47, 101539, https://doi.org/10.1016/j.ijdrr.2020.101539.

Gallina, V., Torresan, S., Critto, A., Sperotto, A., Glade, T., & Marcomini, A. (2016). A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment. Journal of environmental management, 168, pp. 123-132, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2015.11.011.

Garcia-Aristizabal, A., Marzocchi, W. (n.d.) Review of Existing Procedures for Multi-Hazard Assessment, Deliverable 3.1. MATRIX (New Methodologies for Multi-Hazard and Multi-Risk Assessment Methods for Europe) Project (Contract n 265138).

Garcia-Aristizabal, A., Marzocchi, W. (2012a) Dictionary of the Terminology Adopted. Deliverable 3.2. MATRIX project (Contract n 265138).

Garcia-Aristizabal, A., Marzocchi, W. (2012b) Bayesian Multi-risk Model: Demonstration for Test City Researchers. Deliverable 2.13. CLUVA project (Contract n 265137) http://www.cluva.eu/deliverables/CLUVA_D2.13.pdf.

Gill, J.C., Hussain, E., & Malamud, B.D. (2021). Workshop Report: Multi-Hazard Risk Scenarios for Tomorrow's Cities. Available at: https://www.tomorrowscities.org/workshop-report-multi-hazard-risk-scenarios-tomorrows-cities (last accessed 23 February 2022).

Gill, J. C., & Malamud, B. D. (2014). Reviewing and visualizing the interactions of natural hazards. Reviews of Geophysics, 52(4), 680-722. https://doi.org/10.1002/2013RG000445

GFDRR (Global Facility for Disaster Reduction and Recovery) 2014 Understanding Risk in an Evolving World: Emerging Best Practices in Natural Disaster Risk Assessment.

Gold, D. F., Reed, P. M., Gorelick, D. E., & Characklis, G. W. (2022). Power and Pathways: Exploring Robustness, Cooperative Stability, and Power Relationships in Regional Infrastructure Investment and Water Supply Management Portfolio Pathways. Earth's Future, 10(2), e2021EF002472. https://doi.org/10.1029/2021EF002472

Government Office for Science. (2012). Foresight Reducing Risks of Future Disasters: Priorities for Decision Makers, Final Project Report. Government Office for Science, London, UK.

Green, C., Viavattene, C. & Thompson, P. (2011). Guidance for assessing flood losses. Available at: https://www.preventionweb.net/publication/guidance-assessing-flood-losses (last accessed 30 May 2022).

Greiving, S. (2006). Integrated risk assessment of multi-hazards: a new methodology. In: Schmidt-Thome, P (ed) Natural and Technological Hazards and Risks Affecting the Spatial Development of European Regions, Geological Survey of Finland, 42, pp 75–81.

Haasnoot, M., Warren, A., & Kwakkel, J. H. (2019). Dynamic adaptive policy pathways (DAPP). In Decision making under deep uncertainty (pp. 71-92). Springer

Hammer, M., & Söderqvist, T. (2001). Enhancing transdisciplinary dialogue in curricula development. Ecological economics, 38(1), 1-5. https://doi.org/10.1016/S0921-8009(01)00168-9.

Hayes, A. (2021). Nonlinearity. Available at: https://www.investopedia.com/terms/n/nonlinearity.asp (last accessed 23 February 2022).

Heckerman, D. (2001). Bayesian Graphical Models and Networks. In Smelser N.J. and Baltes P.B. (Eds.) International Encyclopedia of the Social & Behavioral Sciences, 1048-1052.

Herring, D. (2020) What is an "extreme event"? Is there evidence that global warming has caused or contributed to any particular extreme event? Climate Q&A, Climate.Gov, NOAA, (last accessed 29 May 2022). Available at: https://www.climate.gov/news-features/climate-qa/what-extreme-event-there-evidence-global-warming-has-caused-or-contributed#:~:text=An%20extreme%20event%20is%20a,the%20range%20of%20historical%20measurements

Hewitt, K., & Burton, I. (1971). Hazardousness of a place: a regional ecology of damaging events. University of Toronto, Department of Geography.

IAEA (2007). IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection. IAEA, Vienna.

IAEA SSG-3. (2010). Development and application of Level 1 probabilistic safety assessment for nuclear power plants, International Atomic Energy Agency, Vienna, 2010, 215 pp, IAEA safety standards series, ISBN 978–92–0–114509–3.

IDEA (2005). System of indicators for disaster risk management: Main technical report. IDB/IDEA Programme of Indicators for Disaster Risk Management. Manizales–Washington: Instituto de Estudios Ambientales Universidad Nacional de Colombia/Inter-American Development Bank.

IPCC (2007). Appendix I - Glossary. In IPCC (2007) AR4 Climate Change 2007: Impacts, Adaptation, and Vulnerability. Available at: https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf (last accessed 16 March 2022).

IPCC (2014). Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-AnnexII_FINAL.pdf (last accessed 16 March 2022).

IPCC (2018). Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 541-562, doi:10.1017/9781009157940.008. Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_AnnexI.pdf (last accessed 29 July 2022).

IPCC (2022). Annex II: Glossary [Möller, V, J.B.R. Matthews, R. van Diemen, C. Méndez, S. Semenov, J.S. Fuglestvedt, A. Reisinger (eds.)]. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Available at: https://www.ipcc.ch/report/ar6/wg2/ (last accessed 16 March 2022).

IUCN (2021) Nature-Based Solutions. Available at: https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions (last accessed 16 March 2022).

Ivčević, A., Mazurek, H., Siame, L., Moussa, A. B., & Bellier, O. (2019). Indicators in risk management: Are they a user-friendly interface between natural hazards and societal responses? Challenges and opportunities after UN Sendai conference in 2015. International Journal of Disaster Risk Reduction, 41, 101301. https://doi.org/10.1016/j.ijdrr.2019.101301.

Kappes, M. S., Keiler, M., von Elverfeldt, K., & Glade, T. (2012). Challenges of analyzing multi-hazard risk: a review. Natural hazards, 64(2), 1925-1958. https://doi.org/10.1007/s11069-012-0294-2.

Keating, A., Venkateswaran, K., Szoenyi, M., MacClune, K., & Mechler, R. (2016). From event analysis to global lessons: disaster forensics for building resilience. Natural Hazards and Earth System Sciences, 16(7), 1603-1616. https://doi.org/10.5194/nhess-16-1603-2016

Khazai, B., & Bendimerad, F. (2011). Resiliency Indicators for Mainstreaming Disaster Risk Reduction-Handbook for Evaluation of Indicators. Earthquake and Megacities Initiative.

Khazai, B., Bendimerad, F., Cardona, O. D., Carreño, M. L., Barbat, A. H., & Burton, C. G. (2015). A guide to measuring urban risk resilience: Principles, tools and practice of urban indicators. Earthquakes and Megacities Initiative (EMI), The Philippines.

Kreibich, H., Di Baldassarre, G., Vorogushyn, S., Aerts, J.C., Apel, H., Aronica, G.T., Arnbjerg-Nielsen, K., Bouwer, L. M., Bubeck, P., Caloiero, T., Chinh, D. T., Cortès, M., Gain, A. K., Giampá, V., Kuhlicke, C, Kundzewicz, Z. W., Llasat, M.C., Mård, J., Matczak, P., Mazzoleni, M., Molinari, D., Dung, N. V., Petrucci, O., Schröter, K., Slager, K., Thieken, A. H., Ward., P. J., & Merz., B. (2017). Adaptation to flood risk: Results of international paired flood event studies. Earth's Future, 5(10), 953-965.

Marchau, V.A.W.J., Walker, W.E., Bloemen, P.J.T.M., & Popper, S.W. (2019). Introduction. In: Marchau, V., Walker, W., Bloemen, P., Popper, S. (eds) Decision Making under Deep Uncertainty. Springer, Cham., https://doi.org/10.1007/978-3-030-05252-2_1.

Marin-Ferrer, M., Vernaccini, L., & Poljansek, K. (2017). Index for Risk Management INFORM Concept and Methodology Report. European Commission: Luxembourg. EUR 28655 EN, doi:10.2760/094023.

Martens, B. (2016) An Economic Policy Perspective on Online Platforms. Institute for Prospective Technological Studies Digital Economy Working Paper 2016/05. JRC101501. Available at: https://joint-research-centre.ec.europa.eu/system/files/2016-05/JRC101501.pdf (last accessed 31 May 2022).

Marzocchi, W., Mastellone, M., Di Ruocco, A., Novelli, P., Romeo, E. and Gasparini, P. (2009). Principles of multi-risk assessment. Interaction Amongst Natural and Man-induced Risks. European Commission. Available at: http://publications.europa.eu/resource/cellar/22eb788f-5d0a-496a-92d4-4759b0b57fde.0001.03/DOC_2 (last accessed 31 May 2022).

Mastrandrea, M.D., Field, C.B., Stocker, T.F., Edenhofer, O., Ebi, K.L., Frame, D.J., Held, H., Kriegler, E., Mach, K.J., Matschoss, P.R. & Plattner, G.K. (2010). Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, 6 pp.

Masys (2016). Disaster forensics. Advanced Sciences and Technologies for Security Applications Series. Switzerland: Springer International Publishing.

McClean, S.I. (2003). Data Mining and Knowledge Discovery. In Meyers R.A. (Eds.) Encyclopedia of Physical Science and Technology (Third Edition), 229-246. DOI:10.3390/challe3020153

McLellan, B., Zhang, Q., Farzaneh, H., Utama, N.A., & Ishihara, K.N. (2012). Resilience, sustainability and risk management: A focus on energy. Challenges, 3(2), 153-182.

Merriam Webster (n.d.). Empirical. Available at: https://www.merriam-webster.com/dictionary/empirical (last accessed 31 May 2022)

Merz, B., Kuhlicke, C., Kunz, M., Pittore, M., Babeyko, A., Bresch, D.N., Domeisen, D., Freser, F., et al. (2020) Impact Forecasting to Support Emergency Management of Natural Hazards, Reviews of Geophysics, 58 (4), e2020RG00070, https://doi.org/10.1029/2020RG000704.

Meyer, V., Becker, N., Markantonis, V., Schwarze, R., van den Bergh, J. C. J. M., Bouwer, L. M., Bubeck, P., Ciavola, P., Genovese, E., Green, C., Hallegatte, S., Kreibich, H., Lequeux, Q., Logar, I., Papyrakis, E., Pfurtscheller, C., Poussin, J., Przyluski, V., Thieken, A. H., & Viavattene, C. (2013). Review article: Assessing the costs of natural hazards – state of the art and knowledge gaps, Natural Hazards and Earth System Sciences, 13, 1351–1373, https://doi.org/10.5194/nhess-13-1351-2013.

Murray, V., Abrahams, J., Abdallah, C., Ahmed, K.: Angeles, L., Benouar, D., Brenes Torres, A., Chang Hun, C., Cox, S., Douris, J., Fagan, L., Fra Paleo, U., Han, Q., Handmer, J., Hodson, S., Khim, W., Mayner, L., Moody, N., Moraes, L. L., Osvaldo, Nagy, M., Norris, J., Peduzzi, P., Perwaiz, A., Peters, K., Radisch, J., Reichstein, M., Schneider, J., Smith, A., Souch, C., Stevance A.S., Triyanti, A., Weir, M., & Wright, N. (2021). Hazard Information Profiles: Supplement to UNDRR-ISC Hazard Definition & Classification Review: Technical Report: Geneva, Switzerland, United Nations Office for Disaster Risk Reduction; Paris, France, International Science Council. doi: 10.24948/2021.05.

Murray, V., Abrahams, J., Ahmed, K., Davies, P., Douris, J., Golding, B., Handmer, J., Selby, S., Stevance, A., Duerto Valero, S., Weir, M. (2022). Policy Brief: Using UNDRR/ISC Hazard Information Profiles to Manage Risk and implement the Sendai Framework for Disaster Risk Reduction. International Science Council, Paris, France. Available at: https://council.science/publications/policy-brief-hazards-informations-profiles-drr/ (last accessed 31 May 2022).

Nanda, A., Beesley, L., Locatelli, L., Gersonius, B., Hipsey, M., Ghadouani, A. (2018) Adaptation tipping points of a wetland under drying climate, Water, 10 (2), 234 – 254, https://doi.org/10.3390/w10020234.

Nature (n.d.) Statistical Methods. Available at: https://www.nature.com/subjects/statistical-methods (last accessed 10 April 2022).

Njoku E.T. (2017) Empirical Research. In: Leeming D. (eds) Encyclopaedia of Psychology and Religion. Springer, Berlin, Heidelberg, https://doi.org/10.1007/978-3-642-27771-9_200051-1.

Norström, A.V., Cvitanovic, C., Löf, M.F., West, S., Wyborn, C., Balvanera, P., Bednarek, A.T., et al. (2020). Principles for knowledge co-production in sustainability research, Nature Sustainability, 3, 182- 190, doi.org/10.1038/s41893-019-0448-2.

OECD (2012). Disaster Risk Assessment and Risk Financing A G20/OECD Methodological Framework. Available at: https://www.preventionweb.net/publication/g20/oecd-methodological-framework-disaster-risk-assessment-and-risk-financing (last accessed 10 April 2022).

Oppenheimer, M., M. Campos, R.Warren, J. Birkmann, G. Luber, B. O'Neill, and K. Takahashi, 2014: Emergent risks and key vulnerabilities. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039-1099.

Oxford Dictionary Online (n.d.) https://www.oxfordlearnersdictionaries.com/definition/american_english/framework (last accessed 30 May 2022).

PEDRR (2010) Glossary. Available at: https://pedrr.org/glossary/ (last accessed 23 February 2022).

Peduzzi, P., Dao, H., Herold, C., & Mouton, F. (2009). Assessing global exposure and vulnerability towards natural hazards: The Disaster Risk Index. Natural hazards and earth system sciences, 9(4), 1149-1159.

Perles Roselló, M.J., & Cantarero Prados, F. (2010). Problems and Challenges in the Analysis of Multiple Hazard in the Territory. Methodological Proposals for the Development of Multi-Hazard Mapping. Boletín de la Asociación de Geógrafos Españoles, 52, 245-271.

Pescaroli, G., & Alexander, D. (2015). A definition of cascading disasters and cascading effects: Going beyond the "toppling dominos" metaphor. Planet@ risk, 3(1), 58-67.

PreventionWeb (n.d., *a*). Environmental degradation. Available at: https://www.preventionweb.net/understanding-disaster-risk/risk-drivers/enviromental-degradation (last accessed 31 May 2022).

PreventionWeb (n.d., *b*). Deterministic and probabilistic risk. Available at: https://www.preventionweb.net/understanding-disaster-risk/key-concepts/deterministic-probablistic-risk (last accessed 23 February 2022).

PreventionWeb (n.d., *c*) Disaster Risk. Available at: https://www.preventionweb.net/understanding-disaster-risk/component-risk/disaster-risk (last accessed 23 February 2022).

PreventionWeb (n.d., *d*). Direct and Indirect Losses. Available at: https://www.preventionweb.net/understanding-disaster-risk/key-concepts/direct-indirect-losses (last accessed 23 February 2022).

Reed, P. M., Hadjimichael, A., Moss, R. H., Brelsford, C., Burleyson, C. D., Cohen, S., Dyreson, A., Gold, D. F., Gupdat, R. S., Keller, K., Konar, M., Monier, E., Morris, J., Srikrishnan, V., Voisin, N. And Yoon, J. 2022. Multisector Dynamics: Advancing the Science of Complex Adaptive Human-Earth Systems. Earth's Future, 10(3), p. 1-18.

Rene, O., Sungmin, O., Zscheischler, J., Mahecha, M.D. and Reichstein, M. (2022). Contrasting biophysical and societal impacts of hydro-meteorological extremes. Environ. Res. Lett. 17 014044, https://doi.org/10.1088/1748-9326/ac4139.

Reisinger, A., Howden, M., Vera, C., Garschagen, M., Hurlbert, M., Kreibiehl, S., Mach, K.J., et al. (2020). The concept of risk in the IPCC Sixth Assessment Report: a summary of cross-working group discussions. Intergovernmental Panel on Climate Change, p.15. Available online: https://www.ipcc.ch/event/guidance-note-concept-of-risk-in-the-6ar-cross-wg-discussions/ (last accessed 4 August 2022).

Saltenyte, U. (2019). What is a Macro Model? Available at https://www.euromonitor.com/article/what-is-a-macro-model (last accessed 30 May 2022).

Scotland's International Development Alliance (n.d.). Monitoring, Evaluation and Learning (MEL) Guide. Available at: https://www.intdevalliance.scot/application/files/5715/0211/8537/MEL_Support_Package_4th_June.pdf (last accessed 30 May 2022).

Schewe, J., Gosling, S.N., Reyer, C. et al. (2019). State-of-the-art global models underestimate impacts from climate extremes. Nat Commun 10, 1005, https://doi.org/10.1038/s41467-019-08745-6.

Shepherd, T.G., Boyd, E., Calel, R.A., Chapman, S.C., Dessai, S., Dima-West, I.M., Fowler, H.J., James, R., Maraun, D., Martius, O., & Senior, C.A. (2018). Storylines: an alternative approach to representing uncertainty in physical aspects of climate change. Climatic change, 151(3), pp.555-571, https://doi.org/10.1007/s10584-018-2317-9.

Simpson, N. P., Mach, K. J., Constable, A., Hess, J., Hogarth, R., Howden, M., Lawrence, J., Lempert, R. J., Muccione, V., Mackey, B., New, M. G., O'Neill, B., Otto, F., Pörtner, H.O., Reisinger, A., Roberts, D., Schmidt, D. N., Seneviratne, S., Strongin, S., … Trisos, C. H. (2021). A framework for complex climate change risk assessment. One Earth, 4(4), 489–501. https://doi.org/10.1016/j.oneear.2021.03.005

Society of Actuaries (2022) Probable Maximum Loss. Available at: https://actuarialtoolkit.soa.org/tool/glossary/probable-maximum-loss-pml (last accessed 23 February 2022).

SSA (n.d.). Stochastic projections. Available at: https://www.ssa.gov/oact/stochastic/index.html (last accessed 31 May 2022).

Stock, P. & Burton, R.J. (2011). Defining terms for integrated (multi-inter-trans-disciplinary) sustainability research. Sustainability, 3(8), pp.1090-1113, https://doi.org/10.3390/su3081090.

Sudmeier-Rieux, K. & Ash, N. (2009). Environmental guidance note for disaster risk reduction: healthy ecosystems for human security. IUCN.

Tarvainen, T., Jarva, J., & Greiving, S. (2006). Spatial pattern of hazards and hazard interactions in Europe. In: Schmidt-Thome, P (ed) Natural and Technological Hazards and Risks Affecting the Spatial Development of European Regions, 42, Geological Survey of Finland, pp 83–91.

Tilloy, A., Malamud, B., & Joly-Laugel, A. (2021). A Methodology for the Spatiotemporal Identification of Compound Hazards: Wind and Precipitation Extremes in Great Britain (1979–2019). Earth System Dynamics Discussions, 1-45, https://doi.org/10.5194/esd-13-993-2022.

Tilloy, A., Malamud, B.D., Winter, H., & Joly-Laugel, A. (2019). A review of quantification methodologies for multi-hazard interrelationships. Earth-Science Reviews, 196, 102881, https://doi.org/10.1016/j.earscirev.2019.102881.

Tuhkanen, H. (2020) Understanding trade-offs in post-disaster reconstruction. Available at: http://haznet.ca/understanding-trade-offs-post-disaster-reconstruction/ (last accessed 29 July 2022).

UN (2002). Johannesburg plan of implementation of the world summit on sustainable development. United Nations. Available at: http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/WSSD_PlanImpl.pdf (last accessed 30 May 2022).

UNCED (1992) AGENDA 21: the Rio declaration on environment and development. United Nations, New York. Available at: https://sustainabledevelopment.un.org/outcomedocuments/agenda21#:~:text=Agenda%2021%2C%20the%20Rio%20Declaration,3%20to%2014%20June%201992 (last accessed 4 August 2022).

UNDRR (2005) Hyogo framework for action 2005–2015: building the resilience of nations and communities to disasters. United Nations, New York. Available at: https://www.unisdr.org/2005/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf (last accessed 30 May 2005).

UNDRR (2015a). Sendai Framework for Disaster Risk Reduction 2015–30. UN Office for Disaster Risk Reduction. Available at: https://www.undrr.org/implementing-sendai-framework/what-sendai-framework (last accessed 23 February 2022).

UNDRR (2015b). Global Assessment Report. Available at: https://www.preventionweb.net/english/hyogo/gar/2015/en/home/ (last accessed 23 February 2022).

UNDRR (2016). Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction. Terminology available at: https://www.undrr.org/terminology (last accessed 23 February 2022).

UNDRR (2017a). Disaster Resilience Scorecard for Cities. Available at: https://mcr2030.undrr.org/sites/default/files/2021-08/UNDRR_Disaster%20resilience%20scorecard%20for%20cities_Detailed_English_Jan2021.pdf (last accessed 23 February 2022).

UNDRR (2017b). How To Make Cities More Resilient: A Handbook For Local Government Leaders. Available at: https://www.preventionweb.net/publication/how-make-cities-more-resilient-handbook-local-government-leaders-2017 (last accessed 23 February 2022).

UNDRR (2019). Global Assessment Report on Disaster Risk Reduction; United Nations Office for Disaster Risk Reduction (UNDRR): Geneva, Switzerland. Available online: https://gar.undrr.org/report-2019.html (last accessed 4 August 2022).

UNDRR (2022). Global Assessment Report on Disaster Risk Reduction 2022: Our World at Risk: Transforming Governance for a Resilient Future. Geneva. Available online: https://www.undrr.org/gar2022-our-world-risk#container-downloads (last accessed 4 August 2022).

UNDRR & ISC (2020). Hazard Definition and Classification Review: Technical Report. Geneva, Switzerland, United Nations Office for Disaster Risk Reduction; Paris, France, International Science Council. DOI: 10.24948/2021.05.

UNDRR 2022. Co-Chairs' Summary: Bali Agenda for Resilience. Available at: https://globalplatform.undrr.org/publication/co-chairs-summary-bali-agenda-resilience (last accessed 31 May 2022).

UNTERM Portal (2022) Early Warning. Available at: https://unterm.un.org/unterm/display/record/unhq/na?OriginalId=ae98e4ecfd75ab7385257a460059799e (last accessed 23 February 2022).

UNFCCC (2013). Non-economic losses in the context of the work programme on loss and damage. Technical paper. Available at: https://unfccc.int/documents/7954 (last accessed 2 August 2022).

UNFCCC (n.d). Non-economic losses. Available at: https://unfccc.int/wim-excom/areas-of-work/non-economic-losses (last accessed 3 August 2022).

Homberg, M.V.D., & McQuistan, C. (2019). Technology for climate justice: A reporting framework for loss and damage as part of key global agreements. In Loss and damage from climate change, in: Loss and Damage from Climate Change. Concepts, Methods and Policy Options. 2019, edited by: Mechler, R., Bouwer, L.M., Schinko, T., Linnerooth-Bayer, J., Climate Risk Management, Policy and Governance, 513-545. Available online: https://link.springer.com/book/10.1007/978-3-319-72026-5 (last accessed: 4 August 2022).

Van Westen, C. J., Kappes. M. S., Luna, B.Q., Frigerio, S., Glade, T. & Malet, J, P. (2014). Medium-scale multi-hazard risk assessment of gravitational processes, in: T. van Asch, J. Corominas, S. Greiving, J-P. Malet & S. Sterlacchini (eds.) Mountain risks: from prediction to management and governance, Springer, Netherlands, 201–231, doi:10.1007/978-94-007-6769-0_7.

Venter, Z. S., Aunan, K., Chowdhury, S., & Lelieveld, J. (2021). Air pollution declines during COVID-19 lockdowns mitigate the global health burden. Environmental research, 192, 110403, https://doi.org/10.1016/j.envres.2020.110403.

Wachinger, G., Renn, O., Begg, C., & Kuhlicke, C. (2013). The risk perception paradox—implications for governance and communication of natural hazards. Risk analysis, 33(6), 1049-1065, DOI: 10.1111/j.1539-6924.2012.01942.x.

Ward, P. J., Daniell, J., Duncan, M., Dunne, A., Hananel, C., Hochrainer-Stigler, S. et al. (2022). Invited perspectives: A research agenda towards disaster risk management pathways in multi-(hazard-) risk assessment. Natural Hazards and Earth System Sciences, 22(4), 1487-1497, https://doi.org/10.5194/nhess-22-1487-2022.

WHO (2020). Glossary of health emergency and disaster risk management terminology. Geneva. Licence: CC BY-NC-SA 3.0 IGO. Available at: https://www.who.int/publications/i/item/9789240003699 (last accessed 4 Aug 2022).

WMO (1992). International Meteorological Vocabulary - No. 182, World Meteorological Organization, Geneva, Switzerland, 2nd edition. ISBN 978-92-63-02182-3. Available at: https://library.wmo.int/?lvl=notice_display&id=220#.YuuoC3bMKUk (last accessed 4 Aug 2022).

Xu, L., Meng, X., & Xu, X. (2014). Natural hazard chain research in China: A review. Natural hazards, 70(2), 1631-1659, https://doi.org/10.1007/s11069-013-0881-x.

Zschau. (2017). Where are we with multihazards, multirisks assessment capacities?, in: Science for disaster risk management 2017: knowing better and losing less, edited by: Poljansek, K., Marin Ferrer, M., De Groeve, T., and Clark, I., European Union, Brussels, Belgium. Available at: https://drmkc.jrc.ec.europa.eu/knowledge/science-for-drm/science-for-disaster-risk-management-2017 (last accessed 31 May 2022).

Zscheischler, J., Westra, S., Van Den Hurk, B.J., Seneviratne, S.I., Ward, P.J., Pitman, A., AghaKouchak, A., Bresch, D.N., Leonard, M., Wahl, T. and Zhang, X., 2018. Future climate risk from compound events. Nature Climate Change, 8(6), 469-477, https://doi.org/10.1038/s41558-018-0156-3.

Zscheischler, J., Martius, O., Westra, S., Bevacqua, E., Raymond, C., Horton, R. M., van den Hurk, B., AghaKochak, A., Jézéquel, A., Mahecha, M.D., Maraun, D., Ramos, A.M., Ridder, N.N., Thiery, W. & Vignotto, E. (2020). A typology of compound weather and climate events. Nature reviews earth & environment, 1(7), 333-347, https://doi.org/10.1038/s43017-020-0060-z.

Zuccaro, G., & Leone, M. (2011). Volcanic crisis management and mitigation strategies: a multi-risk framework case study. Earthzine, 4, 402-405.

Appendix

Appendix A – Initial Data Curation

<table>
<tr><td colspan="4">MYRIAD_EU Work Package 1 - Diagnosis</td></tr>
<tr><td>Organisation:</td><td colspan="3"></td></tr>
<tr><td colspan="4">Task 1.1: Review and development of multi-hazard, multi-risk concepts, definitions, and indicators</td></tr>
<tr><td>TERM
Relating to multi-hazard, multi-risk management, that you think should be included in a handbook of definitions.</td><td colspan="2">DEFINITION
What existing definition for this term (if any) do you use? You can leave this blank if you don’t have a preferred definition.</td><td>REFERENCE
If this definition comes from a published source, please include or link to the reference here.</td></tr>
<tr><td colspan="4">General Terminology
(although not specific to multi-hazards, they are terms where a uniform, consistent use would be helpful)</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="4">Multi-Hazard Terminology</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="4">Sectoral Descriptions</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="4">PLEASE SHARE LINKS TO ANY GLOSSARIES OR PUBLISHED DEFINITIONS THAT MAY INFORM THIS WORK:</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Task 1.2: Review of methods, models and tools for multi-hazard, multi-risk management</td></tr>
<tr><td colspan="4">What search criteria would you find useful to have access to on a wiki-style online platform of multi-hazard, multi-risk methods, models, and tools?</td></tr>
<tr><td>SEARCH CRITERIA</td><td colspan="3">DESCRIPTION (AS NEEDED)
Help us understand what you mean by this criteria, and why it is important to you</td></tr>
<tr><td></td><td colspan="3"></td></tr>
<tr><td></td><td colspan="3"></td></tr>
<tr><td colspan="4">Task 1.3: Review of policies, policy-making processes, and governance for multi-hazard, multi-risk management</td></tr>
<tr><td colspan="4">Are you aware of any existing policies relating to multi-hazard risk management at diverse scales (e.g., local, national, EU-scales)?</td></tr>
<tr><td>POLICY</td><td>SCALE (e.g., local, national, EU)</td><td colspan="2">LINK</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
</table>

Appendix B – Feedback on the definitions presented at the First General Assembly (1 October 2021)

Multi-hazard

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.

Source: UNDRR, 2017

Feedback:

- not necessarily faced by countries. It can be faced by regions or specific locations
- not only “major” hazards are relevant. (2) one hazard can occur over a period of time
- not necessarily “major”
- Interaction/inter relation between hazards should be emphasised more

– **Multi-risk/multi-hazard risk**

It is related to multiple risks such as economic, ecological, social, etc. It determines the whole risk from several hazards, taking into account possible hazards and vulnerability interactions entailing both a multi-hazard and multi-vulnerability perspective.

Source: Carpignano, A., Golia, E., Di Mauro, C., Bouchon, S., Nordvik, J.-P., 2009. A methodological approach for the definition of multi-risk maps at regional level: first application. J. Risk Res. 12 (3e4), 513e534. http://dx.doi.org/10.1080/13669870903050269. Garcia-Aristizabal, A., Marzocchi, W., 2012b. Bayesian Multi-risk Model: Demonstration for Test City Researchers. Deliverable 2.13. CLUVA project (Contract n265137).

It refers to the risk arising from multiple hazards.

Source: Kappes, M.S., Keiler, M., von Elverfeldt, K., Glade, T., 2012a. Challenges of analyzing multi-hazard risk: a review. Nat. Hazards 64 (2), 1925e1958. http://dx.doi.org/10.1007/s11069-012-0294-2.

Feedback

- agree broadly but difficult phrasing
- It is used in finance too. So I suggest adding the similar definition from finance for reference.

– **Multi-vulnerability**

It refers to:

(1) a variety of exposed sensitive targets (e.g. population, infrastructure, cultural heritage, etc.) with possible different vulnerability degree against the various hazards.

(2) time-dependent vulnerabilities, in which the vulnerability of a specific class of exposed elements may change with time as consequence of different factors (e.g. the occurrence of other hazardous events).

Source: Carpignano, A., Golia, E., Di Mauro, C., Bouchon, S., Nordvik, J.-P., 2009. A methodological approach for the definition of multi-risk maps at regional level: first application. J. Risk Res. 12 (3e4), 513e534. http://dx.doi.org/10.1080/13669870903050269. Garcia-Aristizabal, A., Marzocchi, W., 2012b. Bayesian Multi-risk Model: Demonstration for Test City Researchers. Deliverable 2.13. CLUVA project (Contract n265137).

Feedback

- agrees
- agree but phrased in a difficult way
- “vulnerability” is a very specific term in finance
- “multi” is not accounted for
- do not like the word “exposed” to talk about vulnerability

Indicators

Observable and measurable characteristics that can be used to monitor and show changes or progress towards achieving a specific change.

Source: Adapted from Scotland’s International Development Alliance (accessed online at https://www.intdevalliance.scot/application/files/5715/0211/8537/MEL_Support_Package_4th_June.pdf)

– Feedback

- not all are measurable
- indicators don’t always need to be changes
- not all indicators are used to monitor change or progress towards a specific change. Indicators can indicate state of something independent of temporal dimension.

Systemic risk

Risk that is endogenous to, or embedded in, a system that is not itself considered to be a risk and is therefore not generally tracked or managed, but which is understood through systems analysis to have a latent or cumulative risk potential to negatively impact overall system performance when some characteristics of the system change.

Source: Global Assessment Report, 2019, Chapter 2, p.45 (accessed online at https://gar.undrr.org/sites/default/files/chapter/2019-06/chapter_2.pdf)

– Feedback

- elements are there but difficult to understand
- finance will have a different definition
- not only endogenous
- I cannot get to the end of the sentence
- Risk and system need to be explained separately first, and then their joint meaning
- The definition itself is too long. Shorter definitions would be welcome, no everyone understands. Replace word “endogenous”

Scenario

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.

Source: IPCC, 2018: Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

A scenario is a model-generated set of market projections based on alternative assumptions than those used in the baseline. Used to provide quantitative information on the impact of changes in assumptions on the outlook.

Source: OECD Agricultural Outlook: 2001-2006, OECD, 2001, Annex II – Glossary of Terms.

Feedback

- (2) is a very specific def. of scenarios (MR agreed)
- (2) mostly agree bar use of the word "model"
- I agree with 1 (not 2)

Adaptation pathways

A series of adaptation choices involving trade-offs between short-term and long-term goals and values. These are processes of deliberation to identify solutions that are meaningful to people in the context of their daily lives and to avoid potential maladaptation.

Source: IPCC, 2018: Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

Feedback

- agree
- agree with first sentence – but second sentence imposes a [unclear] "meaningful to people in context of daily life" which I don't understand
- The expression "trade-off" is also difficult to understand. Replace the word "maladaptation" by another one – this one seems to have negative impact
- Using maladaptation to explain adaptation is not optimal
- Step-by-step along a timescale
- Good definition. But always discussion of what is (difference between) "adaptation" and "disaster risk reduction/management". Maybe qualify this aspect.
- Define levels

Risk dynamics

[No definition sourced in existing glossaries]

Suggestions:

- Multiple risks can interact
- Should include time horizon – change of gravity; cascade – compound – risk
- They are not static
- MR: Multi-risk + feedback loops + interactions – spatiotemporal variability

Appendix C – Results of Padlet Exercise (12 November 2021)

An online workshop was coordinated with members of the MYRIAD-EU Consortium in November 2021, using Padlet (an online collaborative tool) to collect information on the questions below.

What (technical) glossaries do you use or refer to in your work?

Consider both internal and external glossaries. When a new person joins your organisation, where would they go to get information?

- UNDRR Terminology: https://www.undrr.org/terminology
- ReliefWeb Humanitarian Terms: https://reliefweb.int/taxonomy-descriptions
- Australian Disaster Resilience Glossary: https://knowledge.aidr.org.au/glossary/
- IPCC Risk Concepts and Terminology
- Partnership for Environment and Disaster Risk Reduction (PEDRR) Glossary: https://pedrr.org/glossary/
- UN Term: https://unterm.un.org/unterm/portal/welcome?
- ISO: https://www.iso.org/standard/44651.html
- ISO Guide 73:2009 Risk management — Vocabulary: https://www.iso.org/obp/ui/#iso:std:iso:guide:73:ed-1:v1:en
- IDRM Glossary of Disaster Risk Management Terminology: https://www.preventionweb.net/files/7662_IDRMGlossary.pdf
- Natural Hazard Partnership (NHP): http://www.naturalhazardspartnership.org.uk/science/glossary-of-terms/
- Lloyds London - Insurance Market Regulator - Glossary and Acronyms: https://www.lloyds.com/help/glossary-and-acronyms
- U.S. Energy Information Administration (EIA): https://www.eia.gov/tools/glossary/index.php?id=i
- Eurostat Energy Glossary: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Category:Energy_glossary
- International Electrotechnical Commission (IEC): https://www.electropedia.org/
- RADIX Glossary: https://www.radixonline.org/further-resources-glossary-of-disaster-reduction-terminology
-
- *How may we use indicators for multi-hazard risk management?*
- Measure resilience performance of locality/city, region, or sector
- Compare performance between locations to identify priorities, gaps, areas of action
- Information to feed data-based approaches
-
- *Have you any good examples of indicators (especially, but not exclusively for risk management)?*
- Examples of reports, papers, links to websites.
-
- Indicators for Sustainable Cities: https://ec.europa.eu/environment/integration/research/newsalert/pdf/indicators_for_sustainable_cities_IR12_en.pdf
- ETCCDI Climate Change Indices: http://etccdi.pacificclimate.org/list_27_indices.shtml
- INFORM Risk Index: https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk
- Indicators in Climate-ADAPT: https://climate-adapt.eea.europa.eu/knowledge/c-a-indicators
- Vulnerability Indicators for Natural Hazards: https://www.nature.com/articles/s41598-019-50257-2

- GIZ/IISD Repository of Adaptation Indicators: https://www.adaptationcommunity.net/download/me/me-guides-manuals-reports/giz2014-en-climate-adaptation-indicator-repository.pdf
- De Ruiter *et al. (2017)* A comparison of flood and earthquake vulnerability assessment indicators (Natural Hazards and Earth System Sciences: https://nhess.copernicus.org/articles/17/1231/2017/
- Indicators of Disaster Risk and Risk Management - IPCC
- IDB (2010) Indicators of Disaster Risk and Risk Management Program for Latin America and the Caribbean Summary Report: https://publications.iadb.org/en/publication/11611/indicators-disaster-risk-and-risk-management-program-latin-america-and-caribbean
- Cardona (2005) Indicators of Disaster Risk and Risk Management: Program for Latin America and the Caribbean: Summary Report: https://publications.iadb.org/handle/11319/4801
- Environmental Hazards Methodologies for Risk Assessment and Management (Chapter 2): https://www.iwapublishing.com/books/9781780407128/environmental-hazards-methodologies-risk-assessment-and-management
- Making Cities Resilient 2030 – Disaster Resilience Scorecard: https://mcr2030.undrr.org/disaster-resilience-scorecard-cities
- Finance Risk Indicators: The sector has a number of indicators that they relate to financial risk and loss. Their definitions can be correlated with definitions generated during this project.
- Risk management related to Cyber Threats in the Electricity Sector (from IEA 2021): https://iea.blob.core.windows.net/assets/0ddf8935-be23-4d5f-b798-3aad1f32432f/Enhancing_Cyber_Resilience_in_Electricity_Systems.pdf
- ClimInvest: https://www.cicero.oslo.no/en/climinvest
- Multi-Risk Indicators Approach for Urban Resilience Assessment: https://www.cedim.kit.edu/english/3330.php
- A multi-hazard regional level impact assessment for Europe combining indicators of climatic and non-climatic change: https://publications.jrc.ec.europa.eu/repository/handle/JRC82302
- Indicators Relating to Development of Building Codes for Schools, Hospitals: https://www.fema.gov/sites/default/files/2020-08/fema543_design_guide_complete.pdf

Appendix D – Reflections on Literature Review (Multi-Hazard, Multi-Risk Terminology and Definitions)

[Rough notes below, collated from the team, to be expanded in March 2022]

Emerging themes and gaps

In order to look into the emerging themes, we identify terms that are getting more in use in recent years. Moreover, we identify gaps by looking at the existing definitions of terms that are less commonly used. The review shows that terms with a 'multi' prefix are getting more common in recent years, indicating that the need to define these terms in literature. Out of the 38 terms with the 'multi' prefix, the majority of the definitions (25) are defined in the literature of the last three years. Specifically, the occurrence of the term multi-hazard has increased in recent years.

Other terms that appear to become more common in recent years (2017 onwards) include "compound (hazards/events)", "complexity", "complex system", "concurrent (hazards/events)", "consecutive v" and "systemic (hazards/events/risk)". This could mean that multi-(hazard)risk research is increasingly looking at 'the bigger picture'.

When looking at the definitions of the most defined terms (e.g. resilience, risk, vulnerability, exposure, hazard, multi-hazard, disaster, and sustainability), we identify a gap as most of these terms do not include descriptions of "systemic", "changes", "dynamics" and "temporal" in their definitions. Only the terms "resilience" and "multi-hazard" include aspects of temporal change and dynamics in their definitions.

Areas of contention

Finally, for multi-(hazard)risk related terms, we specifically looked at existing definitions and tried to identify areas of contention that emerge from the literature. Several terms have a high (>10) number of different definitions ("hazard" (20), "exposure" (20), "multi-hazard" (13), "resilience" (67), "risk" (59), "sustainability" (10), "vulnerability" (41). Some of those terms are known areas of contention. For example, there is a large body of literature discussing the different interpretations and definitions of the concept of "vulnerability" (e.g., Adger 2006) or that of "resilience" (e.g., Manyena 2006, Djalante and Thomalla 2010).

A closer look at the different definitions of "multi-hazard" shows that while there are small differences between definitions, they have in common that they all refer to the (threat of) the occurrence of more than one hazard. Some of these definitions explicitly include hazard interactions, account for varying spatial and/or temporal scales, or include the context in which multiple hazards take place. The definition proposed by the UNDRR (2017) appears to capture these different elements: "Multi-hazard means (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."

Interestingly, there are fewer different definitions for the concept of "multi-(hazard)risk" (namely, four). However, there does appear to be contention whether the definition of multi-(hazard)risk should merely focus on the risk of multiple hazards, or also include trickle down effects across different risk categories (e.g., economic, ecological, and social risk).

Another area of contention appears to exist around the concept of "compound (hazards/events/risk)". While there are not that many different definitions, the definitions that are used do differ. While some define "compound" as multiple events hitting a place at or around the same time, others define the concept as a combination of multiple drivers and/or hazards that contributes to societal or environmental risk (AghaKouchak et al., 2020; Leonard et al., 2014; Zscheischler et al., 2018).

General Reflections

- Surprised to see only 4 definitions related to 'multi-hazard'. The bulk of definitions were for other terms, like resilience, risk, hazard, vulnerability, catastrophe
- Surprised at the number of self-generated definitions for terms that have already been defined by reputable sources.
- Many terms, such as 'resilience', 'hazard', 'risk', 'disaster' and 'vulnerability' are boundary objects, since they are used by different communities of practice, albeit in different ways. These terms are therefore important for building and maintaining coherence across intersecting communities.
- Most studies consider flood/water management (9), for other sectors, papers are much scarcer: transport/infrastructure (3), earthquakes (3), biological hazards/COVID (3), forests/ecosystems (2), geo-resource management (1), snow (1), landslides (1).
- Terminology in a multi-hazard setting is much more diverse and less well streamlined. Some people talk about multi-hazard referring to only one hazard type, but most consider more than one hazard type.
- It seems that the terms "vulnerability' and 'resilience' usually have a really holistic definition, but just by using them, it is not clear to what extend this holistic definition is used in the papers. Often, they limit it to very few aspects of it.
- If more than one hazard was considered, mostly not more than two hazards were considered. And if more hazards were considered, it did not necessarily mean that they are also assumed to be dependent. Some frequently mentioned hazard combinations were: flooding – COVID, flooding – earthquakes, precipitation – drought, storm – precipitation.
- In line with the recognition that the temporal component are rather scarcely accounted for in the definitions, it seems that most studies focused more on compound events than cascading events. As such they might account for more elements-at-risk, but not really the full range of multi-sectoral dependencies.
- Most literature still comes from the individual hazard disciplines
- Some studies (mainly those combining one hazard with COVID) seem to have a strong local focus with some locally developed tools/frameworks rather than general frameworks
- Interesting comment from forestry paper (Bastit et al. 2021): they mention that ecological disciplines might be much more used to holistic thinking (in line with multi-hazards), while other disciplines struggle with this.
- Many articles (around a half or more) were not related to natural hazards but to other fields such as finance and computer science
- Often, definitions were not introduced by "we define" but by "is defined" or "means" or simply "is", so it was necessary to read the whole introduction section of the articles (or further) to find them – these definitions also cannot then be connected to the search terms
- Only 1 term with "multi" was found, i.e. "multi-risk assessment" in 2015, and 3 terms related to multi-hazard in 2016
- Most defined terms are risk, resilience, vulnerability, exposure
- More or less half of the definitions were referenced and half self-generated
- Many of the definitions that were found were from thesis/dissertations or reports.
- Surprised by the small number of definitions related to multi-hazard and multi-risk
- The definition of resilience appears in a large number of papers
- Interesting definitions related to the different types of interactions between hazards (concurrent, cascading, successive, compound…hazards)
- The analysis highlights interesting papers to take into account within the project
- Significant amount of the papers that came up were not related to natural hazards and completely irrelevant to the MYRIAD-EU research
- Often when "multi-hazard" was mentioned in a paper, it was mentioned only once and was part of a citation at the end of a paper.
- The most common type of multi-hazard that was defined is a "compound" hazard. Definitions of "compound" did vary.

- Majority of the papers focused on a single hazard or particular hazard group (e.g. climatological, geophysical, hydrological etc.)
- Not all the results could be used because there are some publications not relevant for the subject of the project or with definitions which are strictly related to the methodology (e.g. naming variables).
- the results are mostly published in journal articles from different areas, conference papers, books, reports and dissertation/thesis. Most of journal articles are from the environmental science and earth sciences, but there are also from other domains such as: technology, engineering, architecture, economics; management, and statistics.
  The conference volumes are in the areas of engineering, computing and technology information.
- The definitions are 51% referenced and 49% self-generated.
- The terms that have the highest number of definitions are related to the concept of resilience and the derived terms: climate resilience, comprehensive urban resilience, disaster resilience, infrastructure system resilience, multi hazard resilience, resilience improvement program, system resilience, resilience of a community's built environment, resilience-based design, total resilience. Function of the frequency on the 2nd place is the term vulnerability.
- The terms related to multi-hazard are not defined as often as we might have expected in 2017 (5% of definitions). There are new concepts generated in the literature: multi-risk governance, multi hazard resilience.

Appendix E – Terminology and Definitions (French and Spanish)

French / Français

UNDRR (2016) Rapport du groupe de travail intergouvernemental d'experts à composition non limitée chargé des indicateurs et de la terminologie relatifs à la réduction des risques de catastrophe. Available at: https://www.preventionweb.net/files/50683_oiewgreportfrench.pdf (last accessed 16 March 2022).

IPCC (2018) 5th Assessment Report Working Group II – Annex II Glossaire. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_WGII_glossary_FR.pdf (last accessed 16 March 2022).

Spanish / Español

UNDRR (2016) Informe del grupo de trabajo intergubernamental de expertos de composición abierta sobre los indicadores y la terminología relacionados con la reducción del riesgo de desastres. Available at: https://www.preventionweb.net/files/50683_oiewgreportspanish.pdf (last accessed 16 March 2022).

IPCC (2018) 5th Assessment Report Working Group II – Glosario. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_WGII_glossary_ES.pdf (last accessed 16 March 2022).