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OUTPUT

IMPACT CHAINS – Towards a shared standard for complex risk conceptualization

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Massimiliano Pittore, Silvia Cocuccioni, Liz Olaya Calderon,
Federica Romagnoli, Sophie Rose Fruchter, Kathrin Renner,
Stefan Schneiderbauer, Marc Zebisch

Eurac Research
Center for Climate Change and Transformation
in collaboration with
Center for Global Mountain Safeguard Research
Viale Druso 1/Drususallee 1
39100 Bolzano/Bozen, Italy
T +39 0471 055700
climate.change@eurac.edu
www.eurac.edu

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Edited by: Silvia Cocuccioni, Massimiliano Pittore
Authors: Massimiliano Pittore, Silvia Cocuccioni, Liz Olaya Calderon, Federica Romagnoli, Sophie Rose Fruchter, Kathrin Renner, Stefan Schneiderbauer, Marc Zebisch
Scientific coordination: Massimiliano Pittore
Graphics: Eurac Research/Alessandra Stefanut

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Content

1 Executive summary

Impact Chains (IC) provide a methodology to elicit, conceptualize, represent, and share a body of knowledge about process- and event-related risks within a given geographical and temporal scope. They are increasingly considered as a key tool in the most recent frameworks for climate and disaster risk assessments, but this leads in turn to an increasing need for a more systematic approach in the use of this powerful approach. **In this document we aim therefore to provide all necessary information and guidance to allow for the development of more structured and consistent Impact Chains as actionable knowledge tool to be leveraged in the framework of comprehensive risk management.**

The guidelines within this document are aimed at a heterogeneous group including risk practitioners with different domain expertise and background, interested in using Impact Chains to analyse complex environmental situations to devise better risk mitigation and climate adaptation actions and strategies. There is no specific technical and scientific requirement to use these guidelines, but a good comprehension of the basics of risk analysis is certainly important. In the first chapter several useful references are provided.

This document is organized into six main chapters. Chapter 2 introduces the concept of Impact Chains, their role in climate and disaster risk assessment, and the need for a more standardized methodology. Chapter 3 describes the main structure and components of Impact Chains, including factors, connections, and their attributes. Chapter 4 provides guidance on the development of Impact Chains, from scoping and knowledge collection to their implementation using web-based platforms. Chapter 5 focuses on quality assessment and validation. Chapter 6 explains how to read, navigate, and interpret Impact Chains. Finally, Chapter 7 presents the main conclusions, limitations, and future perspectives of the methodology.

NOTE: This guideline is intended as a ´living document´, as the document will be periodically edited, updated and re-published to reflect the most up-to-date Impact Chain methodology. We refer the interested readers to the [EURAC Impact Chains web page] for further information, material and tools.

2 Introduction to Impact Chains

2.1 Introduction to the concept of risk

A concise introduction to risk is needed for a proper understanding of Impact Chains. The term *risk* refers to the potential for adverse consequences of a hazard (possibly climate-related), or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure", following the definition of IPCC (IPCC, 2022). This definition is also consistent with the one proposed by UNISDR in 2009, where risk is defined as "the combination of the probability of an event and its negative consequences", and with the standard ISO/FDIS 31000:2009 (ISO/IEC, 2018). According to UNISDR the word "risk" has two distinctive connotations: in popular usage the emphasis is usually placed on the concept of chance or possibility, such as in "the risk of an accident"; whereas in technical settings the emphasis is usually placed on the consequences, in terms of "potential losses" for some particular cause, place and period" (UNISDR, 2009). Further information is provided, e.g., in (Aven & Renn, 2009; Aven & Thekdi, 2021). Further ISO-standard definitions are available (ISO/IEC, 2019, 2021).

Besides the conceptual definition, risk is commonly understood as resulting from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (possibly climate-related) hazard and the likelihood of its occurrence (IPCC, 2022). For a more in-depth discussion on climate risk, see Zebisch et al. (2023). A graphical depiction of this representation, which is commonly used in Disaster Risk Reduction and based on the IPCC AR5 risk propeller, is shown in Figure 1.

Figure 1 Classical representation of risk in terms of hazard, exposure and vulnerability. The figure is rotated 90° with respect to the IPCC AR5 original.

2.2 What are Impact Chains

Impact Chains (ICs) are an analytical tool that helps to better understand, systemise and prioritise the factors that drive impact-related risks in a specific system of concern and serve as a backbone for an operational climate risk assessment (Zebisch et al., 2017). Impact Chains are conceptual models that describe risk-related impacts as cause–effect relationships within a socio-ecological system, focusing on identifying and describing important linkages between the different components of risks (see Figure 2). The concept was first co-developed by Eurac Research for studies on climate vulnerability in the Alps, and then proposed in collaboration with the German Institute for International Cooperation (GIZ) as part of a methodological framework to assess vulnerability to climate change (Fritzsche et al., 2014; Schneiderbauer et al., 2013; Zebisch et al., 2017). The IC method is also partially covered in the International Organization for Standardization 14091 standard (ISO/IEC, 2021), which provides step-by-step guidelines for climate-related vulnerability assessment.

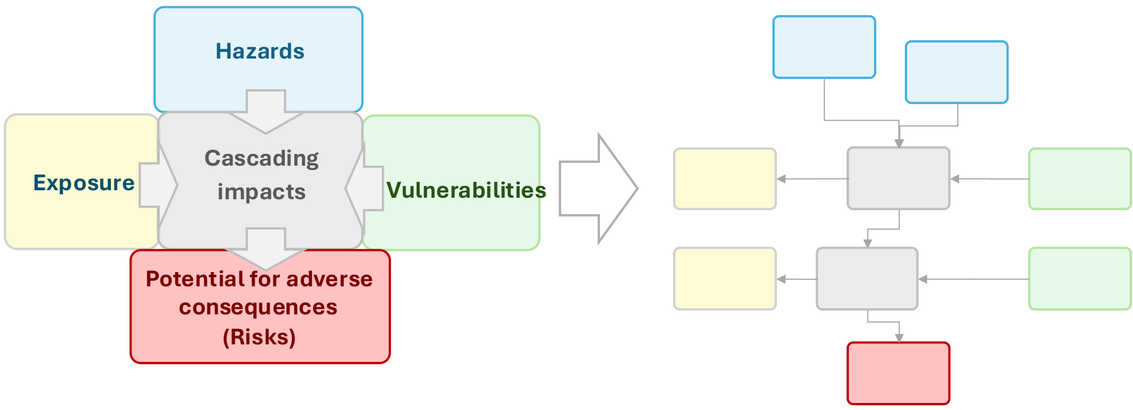

Figure 2 Impact Chains provide a more structured description of risk, also including explicitly the role of impacts.

ICs innovatively provide a conceptual description of risk that is consistent with the most recent interpretation (e.g., by the IPCC) as well as the more historical DRR perspective. Additionally, they explicitly include and highlight the role of **impacts** in this conceptual representation (as shown in Figure 2). In fact, impacts are described by the IPCC as

> "*The consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes and in general can be adverse or beneficial*." (IPCC, 2022).

When impacts are adverse, they can be associated with risks. Each adverse impact affects one or more elements of exposure and is influenced by one or more vulnerability factors, thus serving as a natural linking element to the concept of risk.

In recent years, the proposed approach has gained significant attention within the international community of climate risk scientists and practitioners (Menk et al., 2022) due to a combination of useful and appealing features, including:

- A clear and intuitive conceptual and visual representation of the main drivers of risk (hazard, exposure, vulnerability) and their relationships, including aspects related to cascading risks.
- The explicit reference to impacts as key observable components of risk, and their (possibly causal) interrelation.

- A strong focus on vulnerability as a paramount risk driver, which is often underrated due to its inherent complexity.
- The potential for the explicit consideration of mitigation and adaptation measures.
- The ability to integrate quantitative, semi-quantitative, qualitative and narrative approaches.

2.3 What Impact Chains are not

It´s important to highlight that Impact Chains are naturally constrained by their definition. Despite the flexibility of the approach, if they are used outside their natural boundaries misinterpretations might arise. In particular, Impact Chains:

- **Do not represent a <u>specific</u> event or a set of environmental conditions**. They can instead represent *the risk related to an event* or environmental conditions. A certain degree of abstraction or generalisation is paramount to ensure that risk is correctly addressed.

- **Are not causal networks and <u>do not represent</u> <u>only</u> causal relationships**. In fact, some of the connections (e.g., between hazards and impacts, or among impacts) might be of causal nature, but other types of relationships hold as well (e.g., the link between vulnerability factors and impacts does not describe a causal relationship). Furthermore, ascertaining causality is often challenging and require comprehensive empirical evidence or custom-tailored statistical verification (Pearl & Mackenzie, 2018; Reichenbach et al., 1991; Runge et al., 2019).

- **Are not meant to represent <u>loops and feedback</u> cycles**. In contrast with more physical-inspired representation of dynamics systems, Impact Chains are only describing linear relationships. Complex dynamics related to, e.g., circular causality (Roos, 2024) should be described at a more abstract level.

- **Do not include elements <u>of generic type</u>**. Only a specific set of risk driving factors and connections/relationships are used to describe Impact Chains (see Chapter 3). ***IC should not be used as "generic" conceptual models, rather as conceptual representations of risk.***

2.4 Role and application of Impact Chains for climate and disaster risk assessment

The assessment of risks is fundamental to better-planning adaptation strategies and measures. In the context of Climate Change Adaptation, Impact Chains have been proposed and widely used (Fritzsche et al., 2014; Zebisch et al., 2023). More recently, Impact Chains have been used also in the framework of disaster risk reduction (Cocuccioni, Romagnoli, et al., 2024; Olaya Calderon et al., 2026). In both applicational frameworks the main purpose is to:

- **co-develop a common knowledge** and understanding between experts and stakeholders of key risks, their underlying drivers and interactions for the specific context and specific risks,

- **structure the description and analysis of key risks** and their risk drivers for the current situation and potential future situations making use of the best quantitative and qualitative knowledge and evidence available,

- **identify key vulnerabilities**, gaps in risk management and entry points for risk mitigation and adaptation planning.

These applications are useful in the wider context of **comprehensive risk management** (UNDRR, 2022), where climate and disaster risks are jointly considered to improve risk reduction and climate change adaptation in a more organic and holistic perspective.

Impact Chains can, therefore, be used to represent key risks related to climate-related slow-onset processes like increase in temperature and aridity, as well as to rapid-onset, climate-related hazards such as extreme heatwaves and non-climate related hazards such as earthquakes or technological accidents, as shown in Figure 3.

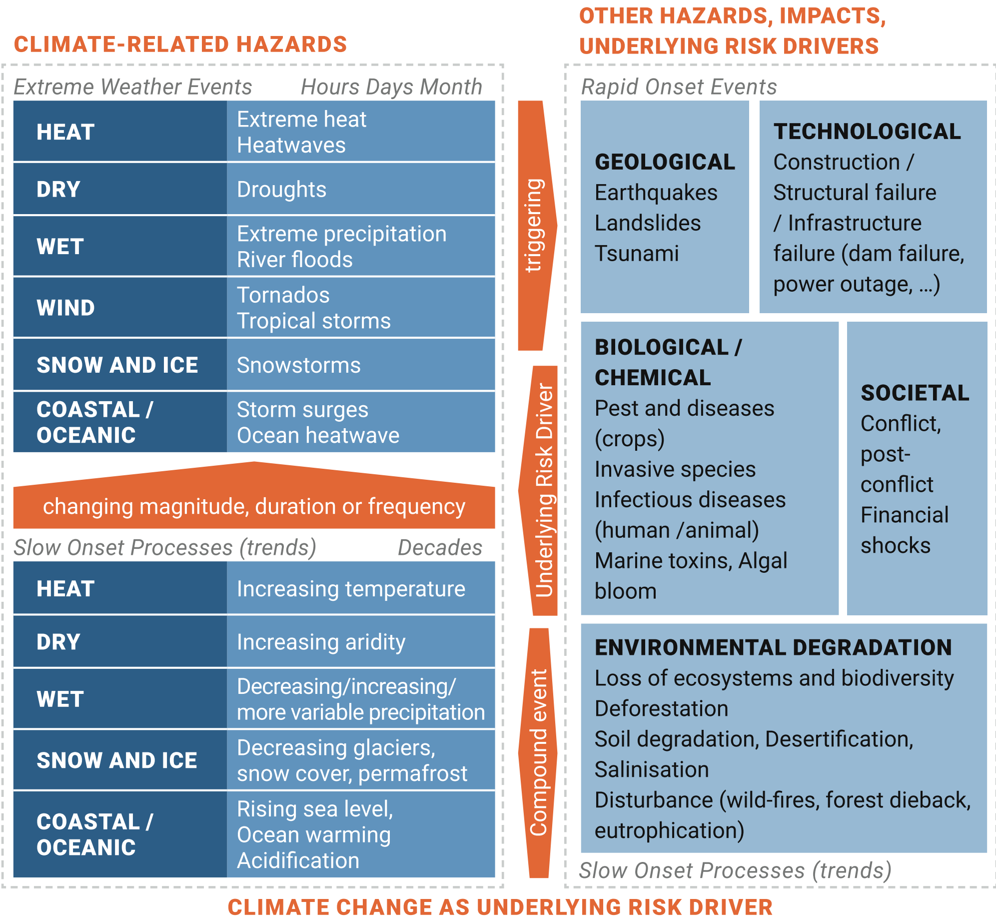

Figure 3 Key hazards and their relationship that could be considered within a comprehensive risk management approach, from (UNDRR, 2022).

Impact Chains can therefore be used to represent risks related to trends and processes as well as complex risks arising from single- and multi-hazard events, including cascading and compounding phenomena (e.g., as in the case of large storms entailing extreme precipitation triggering both landslides and floods in mountainous environments) (Cocuccioni, Romagnoli, et al., 2024).

Further information can be found in Chapter 6.

2.4.1 Impact Chains within an ecosystem of graphical conceptual models

Impact Chains can be considered graphical conceptual models since they provide a precise, meaningful description that can be visualised in different ways for different stakeholders. Graphical models provide a convenient approach for domain experts to convey information and knowledge about complex situations in an intuitive and interpretable way, although with some limitations. However, as mentioned in Section 2.3, Impact Chains should not be confused with other graphical approaches used in the context of risk analysis.

Causal diagrams, for instance, consist of a set of nodes which may or may not be interlinked by arrows. Arrows between nodes denote causal relationships with the arrow pointing from the cause to the effect. Different types of causal diagrams have been proposed to study cause-effect relationships; amongst others, we will briefly review *Bayesian networks* and *causal loop diagrams*.

Bayesian networks are probabilistic graphical models that represent a set of variables and their conditional dependencies via a directed acyclic graph. Bayesian networks can be used, for instance, to consider an event that occurred and predict the likelihood that any one of several possible known causes was the contributing factor, and they have been widely used, e.g., in the context of environmental risk assessment (Kaikkonen et al., 2021). Although Impact Chains cannot be considered Bayesian networks, some of the elements representing impacts (see Section 3.13.1) could be described by suitable variables and analysed within a Bayesian network approach, with their mutual connections (see Section 3.2) representing the related possible causal connections.

Causal loop diagrams visualise how different variables in a system are causally interrelated. Causal feedback loops in the diagrams are particularly important features since they help identify non-obvious vicious and virtuous circles. Causal loop diagrams are used within the *system dynamics* approach to understanding the nonlinear behaviour of complex systems over time using stocks, flows, internal feedback loops, table functions and time delays. As in the case of Bayesian networks, causal loop diagrams might be used to integrate the Impact Chain description to describe in a more quantitative way the interplay among the variables describing some of the factors in the Impact Chain.

2.5 Towards a standardization of the Impact Chains methodology

Despite the widespread adoption of the Impact Chain (IC) methodology in climate risk assessments, its implementation still lacks a sufficient degree of standardisation. Impact Chains are often developed independently for specific applications, resulting in fragmented approaches, heterogeneous representations, and limited comparability across assessments. While the participatory and context specific nature of IC development is one of the methodology's main strengths, the repeated need to develop chains from scratch can be resource intensive and may hinder the systematic accumulation and reuse of knowledge. In practice, many ICs remain stored as static images, embedded in reports or presentation slides, or are only partially documented and eventually lost after the completion of a project. The absence of structured repositories or searchable libraries limits the possibility to consult, compare, update, or reuse existing ICs across sectors and geographical contexts, as well as to monitor how risks, vulnerabilities, and adaptation efforts evolve over time. In addition, ICs are frequently limited to visual representations, with little integration of structured information, metadata, or attributes associated with factors and connections. This further constrains interoperability across tools and platforms and makes it difficult to systematically interpret and track the evolution of risk knowledge over time.

To address these challenges, there is a growing need to move towards a more standardised and interoperable representation of ICs. This includes clearly defining the different IC components, both in terms of factors and causal connections, and establishing methodological constraints to ensure logical consistency and transparency in their development. Standardisation does not aim to reduce the flexibility or participatory nature of the methodology, but rather to improve traceability, comparability, accessibility, and reusability across applications and scales. In this context, the adoption of interoperable tools, structured data models, metadata conventions, and common formatting standards can support a more systematic documentation of ICs and facilitate their integration into broader risk assessment workflows, databases, and digital platforms.

3 Main structure and components of Impact Chains

Each Impact Chain can be seen as a visual model in the form of a graph, composed of two main types of components: factors and connections (among these factors). The following sections will explain those components.

3.1 Factors

The *factors* are the main building blocks of the ICs, representing the main drivers of risk. They are usually depicted as boxes in the visual representation of Impact Chains. These factors can be one of the following types: Hazard, Impact, Vulnerability, Exposure, Adaptation/Risk mitigation measures, Key Risk, and Underlying Risk Drivers.

3.1.1 Factor types

The main pre-defined factors are listed in the following table. Where possible, a standard classification scheme (taxonomy) should be used to describe the specific factor types to improve consistency and shareability.

Table 1 List of pre-defined types of factors in Impact Chains

Factor type	Description	Standard reference
Hazard (including climatic drivers)	Climatic influence, climatic or non-climatic event or trend that may constitute a hazard to the exposed assets and systems and result in an impact and possibly a risk (with damage or loss).	E.g., Understanding Risk. Extensive classification: UNDRR (2021); Climate related hazard indices for Europe (Crespi et al., 2020)
Impact	Effect or consequence caused by a hazard or another impact. Within the Impact Chain, Impacts relate to adverse (negative) consequences that can be considered as potential materializations of risks.	Climate Risk Sourcebook (Zebisch et al., 2023)
Exposure	The (presence of) people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2021) (see also Box A below).	No standard reference, see IPCC (2022), UNDRR, Prevention web or Climate Risk Sourcebook (Zebisch et al., 2023)
Vulnerability	Vulnerability refers to the predisposition/propensity of exposed elements such as human beings, their livelihoods, and assets to be adversely affected by a natural hazard. This element contributes to and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and/or	e.g., INFORM, MOVE Framework (Birkmann et al., 2013) (both for risk assessment but incl. classification of vulnerability components)

	lack of capacity to prevent, prepare, respond, cope and/or adapt (IPCC, 2021) (see Box B below).	
Adaptation / risk mitigation measure	Measure to decrease the negative consequences of an impact by addressing one or more vulnerabilities or impacting mechanisms.	e.g. IPCC WGII AR5 Categories of adaptation options (page 845) (Field et al., 2014)
Risk (Key Risk)	Combined impacts, exposure elements and vulnerabilities that describe potential risks highly relevant in the scope of the Impact Chain.	Climate Risk Sourcebook (Zebisch et al., 2023)
Underlying Risk Drivers	It refers to the (non-climatic) risk drivers that may significantly alter the socio-economic or environmental situations and possibly amplify the negative consequences of impacts by acting on their determinants (e.g. vulnerability or exposure) but cannot be mitigated or controlled within the scope of the Impact Chain.	PAR, Climate Risk Sourcebook (Zebisch et al., 2023) and Forin (Oliver-Smith, et al., 2016)

Each factor should be objectively defined and possibly measured/assessed/estimated independently of the other factors. If possible, provide a reference to a standard or a commonly agreed-upon definition.

BOX A. Understanding exposure in risk analysis

Exposure is a fundamental concept that delineates the scope of the Impact Chain. It encompasses the presence and distribution of elements exposed to hazardous events, including individuals, infrastructure, economic activities, and ecosystems (UNDRR). Within the Impact Chain, exposure is the factor that receives the impacts' action and indicates **what is at risk.**

To effectively analyse exposure, it is helpful to explore interconnected nested categories through a systemic risk approach. A system is defined as a set of (partly) interconnected elements with clear boundaries (Hochrainer-Stigler et al., 2023). Therefore, the first step in analysing exposure is to delineate both the boundaries and elements within the system under analysis.

This analysis can be extended to a "system of systems" model, where individual elements within a larger system can themselves function as a system (Hochrainer-Stigler et al., 2023). For instance, cities, regions, or entire nations are complex systems comprising many subsystems. These subsystems, such as the healthcare and agriculture systems, experience impacts differently based on factors including geographic location, functional dependencies, and socioeconomic characteristics.

Finally, at the most granular level, exposure refers to specific assets—both tangible and intangible—that are directly impacted by hazards. This includes buildings, individuals, infrastructure components, and natural resources. Figure 4 represents a simplified example.

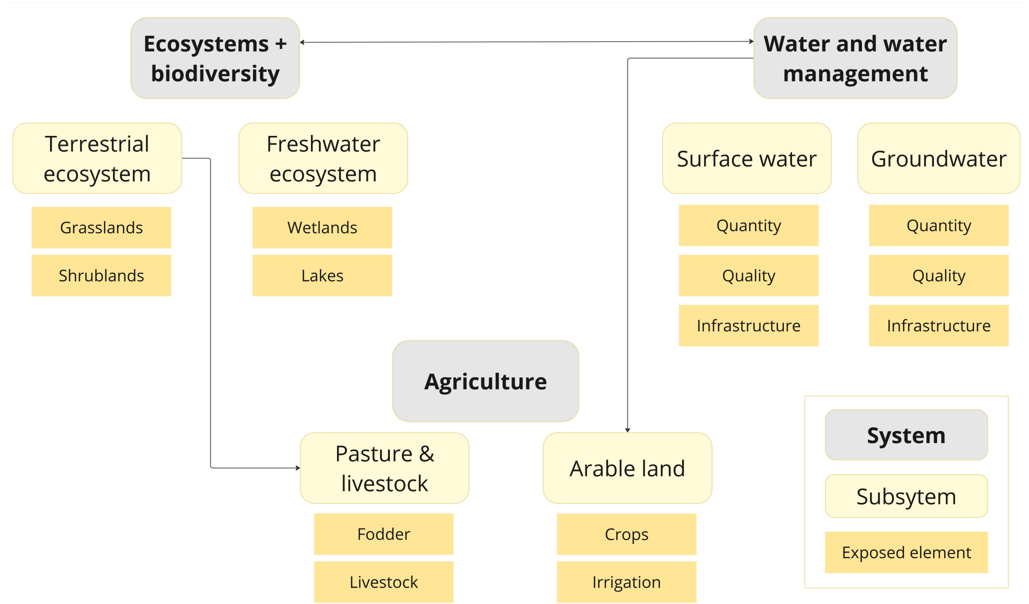

Figure 4. Example representing systems, subsystems, and exposed elements and their relationships (adapted from Zebisch et al. 2023)

Box B. Vulnerability Operational Framework

This box aims to explain how to operationalise the vulnerability framework in Figure 5. The following steps are recommended to achieve this.

- **Assign the vulnerability factors to their corresponding dimensions**: link each identified vulnerability factor to its corresponding vulnerability dimension. The proposed framework, based on Birkman et al. (2013) (MOVE framework), identifies five different dimensions of vulnerability: economic, physical, environmental, socio-cultural, and institutional.
- **Ensure coverage of all different dimensions**: A comprehensive risk analysis should ideally cover all dimensions for a more thorough evaluation.
- **Analyse Underlying Risk Drivers**: For each vulnerability factor, examine the underlying risk drivers connected to it. A vulnerability factor may link to multiple risk drivers, and vice versa.

NOTE: A forensic analysis of a disaster event can help identify the connections between vulnerability factors and risk drivers (Cocuccioni, Olaya Calderon, et al., 2024; Olaya Calderon et al., 2026).

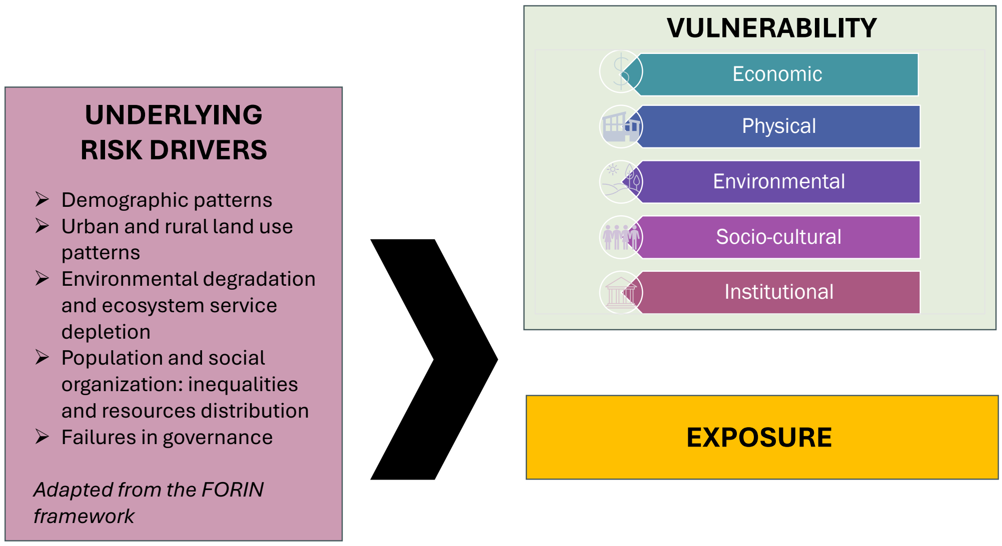

Figure 5. Vulnerability framework showing the dimensions of vulnerability as well as the underlying risk drivers which can be connected to the vulnerability factors

3.1.2 Factor attributes

Each Impact Chain consists of several factors. For each factor, several attributes should be defined and populated with information. The following table lists the main attributes (Table 2).

Table 2: Features of a factor in an Impact Chain

Factor Attribute	Description	Examples
Type	Type of the factor. It must be one of the types listed in Table 1.	*Hazard, vulnerability, exposure, risk.*
Label	Synthetic description/title of the factor for visual depiction.	*Increase in extreme rainfall events*
Description	Extended description of the factor providing all necessary information to understand its role and significance in the IC scope.	*Increase in extreme rainfall events: The intensity and frequency of extreme precipitation and associated flooding are projected to increase. Rising temperatures lead to enhanced evaporation from surface water bodies and increased evapotranspiration, which contributes to a more vigorous water cycle.*
Source	Source of the information/knowledge on the factor, including possibly the authoring institution/author who proposed the factor.	*Factsheets, reports, journal articles, expert opinion*
References	References to the information sources used to justify, validate and possibly monitor the factor.	*(IPCC, 2022); (USAID, 2018)*
Confidence	Evaluated using a qualitative method based on evidence, reflecting the IPCC's approach to evaluating the validity of factor. There are three proposed categories of confidence: – **Low**: This refers to limited evidence, ranging from having no data supporting the element to only newspaper articles supporting it. – **Medium**: This refers to moderate evidence, which includes news reports, stakeholder input, expert opinions, and combinations of these sources. – **High**: This refers to robust evidence, which includes data from official entities, scientific articles, books, and multiple credible sources.	*Buildings damaged (impact) by a hurricane (hazard) are influenced by various factors, including the intensity of the storm, construction quality, and geographical location. The mechanism by which hurricanes cause damage to buildings has been extensively studied, revealing that the extent of damage depends on these and other variables. Given that multiple reliable sources support this impact, confidence is **high.***

3.2 Connections

Each connection represents a relationship between two factors in the Impact Chain. Therefore, each factor within the Impact Chain can influence one or more other factors and vice versa (except for those factors at the beginning of the chain). All connections are directed, indicating a specific direction of the relationships they imply.

3.2.1 Connection types

The possible connections/relationship types are defined in the following table.

Table 3: List of possible connection types

Connection type	Description	Type of factors the connection can be linked to	Example
"Leads to"	Indicates a relationship where one factor contributes to another (often indicating a causal relationship).	Hazard to Hazard Hazard to Impact Impact to Impact	An increase in average temperature (*hazard*) ***leads to*** the melting of glaciers (*impact*).
"Affects"	Indicates a generic relationship where one factor is supposed to alter (in intensity or geographic extent) the second one in some way (not necessarily based on a causal link).	Vulnerability to Impact/risk.	Lack of land ownership (*vulnerability*) ***affects*** the disruption of agricultural livelihoods in a flood (*impact*).
"Impacts on"	Indicates mainly a relationship between an impact and an exposed asset.	Impact to Exposure.	An increase in power outages (*impact*) ***impacts*** industries (*exposure*).
"Mitigates"	Indicates a relationship that aims to reduce vulnerability or impacts.	Adaptation/Risk mitigation measure to Vulnerability and Impact.	An improved irrigation technique (*adaptation measure*) ***mitigates*** the decrease in crop yield (*impact*) during droughts.

Further connection types could be defined in future releases.

3.2.2 Connections constraints

Connection constraints specify how factors interact within Impact Chains to ensure consistency. The relationships between the Impact Chain factors follow specific connection types and constraints, described by Table 4. The second column denotes the factor at which the connection starts, and the second row denotes the factor to which the connection is directed. The content of the cell specifies the type of connection (i.e., relationship) between the two factors. For example, type factor "impact" can be connected with other factors of type "impact" through the relationship "Leads to" and to factors of type "Exposure" through the connection "Impacts on". The blank cells indicate that no connection is allowed between the factors involved.

Table 4: Connection constraints in an Impact Chain

Interacts with

Initial factor	Hazard	Impacts	Exposure	Vulnerabi-lity	Adaptatio/ Risk mitigation measure	Underlying risk driver	Risk (Key Risk)
Hazard	*Leads to*	*Leads to*					
Impact		*Leads to*	*Impacts on*				*Leads to*
Vulnerability		*Affects*		*Affects*			
Adaptation/ Risk mitigation measure		*Mitigates*		*Mitigates*			
Underlying risk driver			*Affects*	*Affects*		*Affects*	
Risk (Key Risk)							

Hazards act as initiating factors in the Impact Chain. They can lead both to other hazards or direct impacts. For instance, torrential rain may trigger landslides, which can damage infrastructure.

Impacts emerge from multiple sources: they can result directly from hazards, cascade from other impacts, be worsened by vulnerabilities, or be mitigated by adaptation measures. These impacts can cascade into further impacts through the system and impact exposed elements.

Vulnerabilities directly affect the severity of impacts. For example, a location with limited healthcare infrastructure will experience more severe consequences when its medical system is overwhelmed during a crisis.

Adaptation and risk reduction measures can be strategically implemented to address both vulnerabilities and impacts. An example would be specialised insurance products designed to protect against agricultural losses during extreme weather events.

Underlying risk drivers, such as population growth or land use change, influence vulnerability and exposure by increasing or exacerbating these factors. However, they represent systemic drivers that cannot be directly addressed or mitigated within the scope of the Impact Chain.

Exposure factors represent the elements at risk, such as individuals, systems, or assets, that might be adversely affected by impacts. Within the Impact Chain, exposure factors are connected only to impacts, as they are the recipients of these consequences.

Further connection constraints could be defined in future releases.

3.2.3 Connections attributes

Each connection in an Impact Chain should be characterised by the attributes listed in Table 5.

Table 5: Attributes of a connection in an Impact Chain

Connection Attribute	Description	Example
Type	Type of the connection. It must be one of the types listed in Table 4.	*Leads to*
Description	Extended description of the connection, providing all necessary information to understand the role and significance of the element in the IC scope	*High temperatures reduce feed intake and growth rates, increase livestock mortality, and result in economic losses.*
Source	Source of the connection, if already standard or authoring institution/author	*Factsheet, journal article*
References	References to the information sources used to justify, validate and possibly monitor the connection.	*(USAID, 2018); (Tapasco et al., 2019)*
Confidence	Evaluated using a qualitative method based on evidence, reflecting the IPCC's approach to evaluating the validity of elements. There are three proposed categories of confidence: – **Low**: This refers to limited evidence, ranging from having no data supporting the element to only newspaper articles supporting it. – **Medium**: This refers to moderate evidence, which includes news reports, stakeholder input, expert opinions, and combinations of these sources. – **High:** This refers to robust evidence, which includes data from official entities, scientific articles, books, and multiple credible sources.	*High*
Time lag	Refers to the time lapse between the incidence of the source factor and the subsequent factor (see Box C).	*Minutes to hours*

Box C. Time Lag in Impact Chain Connections

Refers to the time lapse between the incidence of the source factor and the subsequent factor. We proposed the following classification for this feature:

Classification	Example
Minutes to Hours	An Earthquake (hazard) can trigger (leads to) a landslide
Hours to Days	Prolonged rainfall leading to flooding
Days to Weeks	Dengue infection leading to health deterioration
Weeks to Months	Reduced irrigation (during a drought) leading to crop loss
Months to Years	Unsustainable agricultural practices leading to soil erosion

NOTE: Time lag applies mainly to the interactions from hazard to hazard, hazard to impact and impact to impact.

4 How to develop Impact Chains

4.1 Scoping

Each IC is developed -and must be interpreted- within a given purpose and within a specific geographical and temporal framework, which together describe the “scope” of the IC. This outlines the limit of validity of the underlying assumptions and the individual IC components. The scope of the Impact Chain should be clearly stated and documented as part of its metadata to facilitate transparent interpretation, interoperability, and future reuse in accordance with the FAIR principles (Findable, Accessible, Interoperable, and Reusable). The main information describing the scope includes:

- **Operational framework**. This includes the main purpose of the IC (e.g., to identify climate risks in the context of a regional climate change adaptation plan, or to stress-test a civil protection plan), the implementation details (expert workshop, desktop analysis, machine-generated, etc.) and the specific sectors addressed (e.g., urban environments, energy, ecosystems).
- **Geographical context**. Specify the geographical region where the IC is expected to be valid. This is particularly important for connection elements, which might arise from location-specific assumptions or observations. The description of the geographical context can be relatively loose (e.g., Italian Alps) or more specific in the case of local assessments.
- **Administrative context** If the risk assessment is addressing a specific administrative context, e.g. a specific municipality or region, which applies often in the case of risk governance applications, this should be clearly specified. This information also provides indirect information on the ownership of the identified risks.
- **Temporal scope**. Describe the period of the elicitation process. Specify the temporal validity of the underlying assumptions. If the Impact Chain relates to a specific past event, categorise it as “Past” or “Scenario” and define the timeframe. If it addresses more generic risks, categorise it as “Present Time“, “Near Future“, “Distant Future“ or provide a specific timeframe (e.g., 2042. This is particularly crucial under non-stationary conditions. For example, it is important to specify the time frame in cases where climatological baselines such as 1981–2010 are used to describe hazards in the past or the future (e.g., 2040-2070), since this constrains the boundary assumptions.

- **Exposed systems and subsystems**. Further to the indications of the addressed sectors, it is very useful to indicate the specific systems and subsystems which are exposed to impacts and susceptible to damage (i.e., elements of type "exposure", see Box A in Chapter 3). According to the operational framework of the IC, exposure can focus on the entire system (e.g., "energy sector"), or on one or more subsystems (e.g., "Energy providers" and "power distribution grid"). This information significantly influences the analysis and ultimately shapes the final Impact Chain.

4.2 Knowledge collection for building Impact Chains

In this section, we provide some indicative guidelines on how to gather knowledge on risk-related components to then define Impact Chain factors and their connections. Defining these aspects is a critical step in Impact Chain development and needs to rely on a clearly defined and structured approach. The knowledge collection process serves as a foundation for identifying which factors compose the Impact Chain, their interrelations, and ensuring thematic quality and consistency. Therefore, the structure of this process must be aligned with the final objective of the conceptual model: to represent risks and their interconnected consequences in relation to specific events or environmental conditions. Hence, the knowledge underpinning the Impact Chain needs to be general enough to remain independent from the local context or the manifestation of a specific risk chain. To achieve this, we recommend including a general descriptive statement for each element, supported by scientific literature, along with an informative explanation of how a given factor is observed in a specific case study.

From the operational point of view, knowledge collection can be structured around two main approaches: participatory and desk-based research. These two data collection methods are usually employed in a complementary manner through an iterative process, where data collected from stakeholders and experts' consultations are supported by desk-based research.
In case of time constraints, we recommend starting knowledge collection with desktop-based research, which can subsequently be enriched by data collected through interviews and workshops.

Independent of the methodology used, a critical aspect is that the information collected must be aligned with the scope of the Impact Chain identified during the scoping phase (see Section 4.1). These two preconditions would enable to meet the following critical objectives:

a) Identify key context-specific risk elements and related interconnections composing a specific risk
b) Obtain a list of further data and information sources
c) Support the factors identified with verified sources

The aim of the data collection process is to organize available knowledge in a structured manner and identify the most relevant risks and associated factors affecting the systems and subsystems defined during the scoping phase. To facilitate the systematic collection of information and support the development of the Impact Chain, a table such as the one presented below can be completed during the analysis.

The process can start from the exposed elements identified during the scoping phase, recording the hazards that may affect them as well as the corresponding impacts. Direct impacts refer to the immediate consequences of a hazard on a selected exposed element. Indirect impacts refer to secondary or cascading effects that propagate through the system and affect other exposed elements, potentially belonging to different subsystems. The table also supports the identification of vulnerabilities and their underlying risk drivers. The collected information provides a structured basis for the subsequent development of the Impact Chain and can serve as a reference and quality check when translating the collected knowledge into the graphical representation at a later stage.

Table 6 Table to be filled in to support knowledge collection. For the definition of the different factors please refer to Table 1.

Hazards	Exposed elements	Direct Impacts	Indirect Impacts	Vulnerabilities	Underlying risk drivers
Increasing frequency /intensity of heatwaves	Population	Heat stress, heat related illnesses, increased mortality	*Reduced labour productivity, increased healthcare demand (impacts on Health and Health system)*	*Lack of cooling infrastructure and heat shelters*	*Social inequalities*
…	….	…	…	…	…

To support knowledge collection, whether through desk-based research, participatory methods, or a combination of both, Figure 6 illustrates a generic workflow for identifying hazards, impacts, vulnerabilities, and adaptation or risk mitigation measures. The sequence of steps should not be interpreted as prescriptive, as information can be collected and refined reiteratively depending on the objectives of the analysis and the availability of knowledge sources.

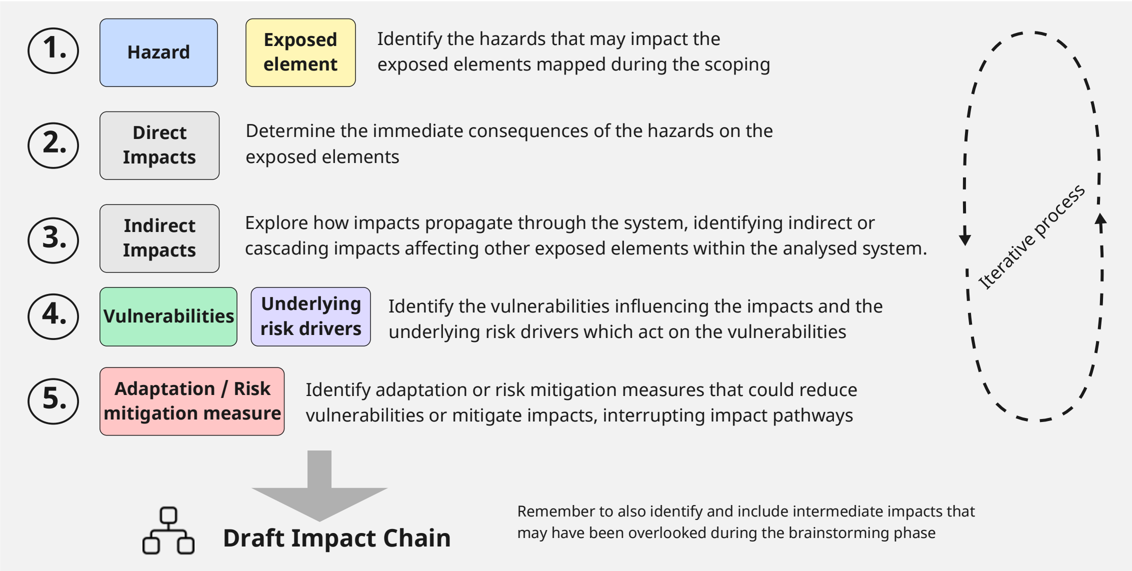

Figure 6 Suggested workflow for the brainstorming and mapping of factors within an Impact Chain.

4.2.1 Desk-based approach

Knowledge collection through desk-based research is based on the systematic review and analysis of available evidence sources. Information is collected through the analysis of different types of documents, such as scientific articles but also grey literature, technical reports, newspaper articles, blogs, etc, to identify the most relevant risk factors (i.e. hazards, impacts, exposure, vulnerabilities) and related interconnections. Existing Impact Chains with a comparable scope may also be consulted and adapted to support the elicitation process, thereby promoting the reuse of existing knowledge and reducing duplication of effort. In such cases, the original sources and any modifications should be clearly documented.

The objective is not to conduct a comprehensive literature review for every component of the Impact Chain, but rather to identify and justify the inclusion of relevant factors and connections through supporting evidence. Evidence may take different forms. Some sources provide context specific evidence, and demonstrate that a given factor or causal relationship exists within the system under investigation. For example, a local newspaper article may document how an extreme rainfall event caused flooding and subsequent damage to road infrastructure. Other sources provide more general evidence on risk mechanisms and causal relationships, regardless of the specific context. For example, a scientific publication may describe the relationship between intense rainfall and landslide occurrence. Both types of evidence are valuable and can contribute to building a robust and transparent Impact Chain.

4.2.2 Participatory approach

A participatory approach is typically chosen when the goal is to engage stakeholders in identifying the most relevant risks for a specific area and determining the critical factors that contribute to those risks. Participatory activities can be used either as the primary source of knowledge collection or as a complementary exercise to refine and contextualize information obtained through desk-based research.

The participatory approach is usually structured as a collaborative workshop which, through a series of guided steps, supports participants in identifying the main climate related risks affecting a given area and the factors contributing to them. The workshop ultimately leads to the visualization of interconnections among risk factors in a preliminary Impact Chain.

The Impact Chain workshop has three main points of strength that provide added value to the data collection:

a) The engagement of local stakeholders and experts gives a clear representation of the most relevant risks at the local level and also identifies which are the most relevant risk factors in a given context.

b) By combining domain experts with representatives from the local community, this method ensures a systemic understanding of the stakes and consequences associated with a particular risk across various stakeholder groups and sectors (e.g., institutional sectors, business, citizens, etc.). Additionally, the involvement of local experts enables a deeper exploration of data availability and the relevance of specific scenarios when considering future risks.

c) The workshop creates an opportunity to examine existing vulnerabilities and underlying risk drivers that exacerbate certain climate-related impacts or consequences of specific hazards. This information is often challenging to obtain through desk-based research, as academic literature tends to focus more on hazards and impacts. Nonetheless, understanding these vulnerabilities and risk drivers is crucial for identifying feasible and effective adaptation options.

The information collected during participatory activities should be documented through a narrative description of the identified factors and their interconnections. Where possible, this description should also be supported by quantitative or qualitative data, such as biophysical indicators, spatial information, or socio-economic data.

Participatory data collection can be structured as an iterative process. After the identification of relevant factors and connections, the preliminary Impact Chain may be resubmitted to local stakeholders or experts for further discussion and validation.

4.2.3 Combining participatory and desk-based approaches

Desk based and participatory approaches should not be considered as alternative methodologies, but rather as complementary sources of knowledge that can be combined throughout the Impact Chain development process. While desk-based research provides evidence-based information on hazards, impacts, vulnerabilities, and causal relationships, participatory activities contribute context specific knowledge, local expertise, and insights that may not be documented in the available literature. The combination of both approaches therefore supports the identification of risk factors and connections that are both scientifically grounded and locally relevant.

The integration of both approaches also strengthens the validation and refinement of the collected information. When stakeholder consultation serves as the primary source of knowledge, desk-based research can be used to corroborate identified factors and connections through supporting evidence. Conversely, when the analysis is primarily based on literature and existing documentation, stakeholder engagement can help assess the relevance, completeness, and plausibility of the resulting Impact Chain within the local context. By combining local knowledge with documentary evidence, the analysis can achieve both local specificity and broader applicability, contributing to the transparency, traceability, credibility, and reusability of the final Impact Chain.

Although both approaches can be applied independently, their strengths and limitations should be carefully considered when designing the knowledge collection process. The choice of methodology will depend on the objectives of the assessment, the availability of resources, the characteristics of the study area, and the level of stakeholder engagement required. In many cases, combining desk based and participatory approaches provides the most comprehensive understanding of the risk system by leveraging the advantages of both methodologies while mitigating their respective limitations. Table 7 summarizes the main strengths and weaknesses associated with each approach.

Table 7 Short summary of pros and cons of the two selected methodologies

Knowledge collection methodology	Pros	Cons
Desk based	– Systematic literature analysis approach – Justify risk elements with empirical or scientific evidence – Combines local data with global trends	– May lack local context – Can be time-consuming – May overlook specific vulnerabilities
Participatory	– Engages local stakeholders and experts – Provides clear representation of local risks – Examines existing vulnerabilities and risk drivers	– Requires coordination and planning – May introduce diverse biases – Needs validation with scientific data

4.3 Building Impact Chains Using web-based platforms

This section provides guidance on utilising existing technical solutions to facilitate the implementation, documentation, and sharing of Impact Chains.

4.3.1 Using KUMU to build and explore Impact Chains

Currently, KUMU (https://KUMU.io, proprietary, commercial) is one of the most advanced web-based solutions available for developing, documenting, and sharing Impact Chains in a structured environment. KUMU allows users to assign predefined types to factors and connections, which can be associated with specific colours, icons, and visual settings to create a consistent representation of the Impact Chain.

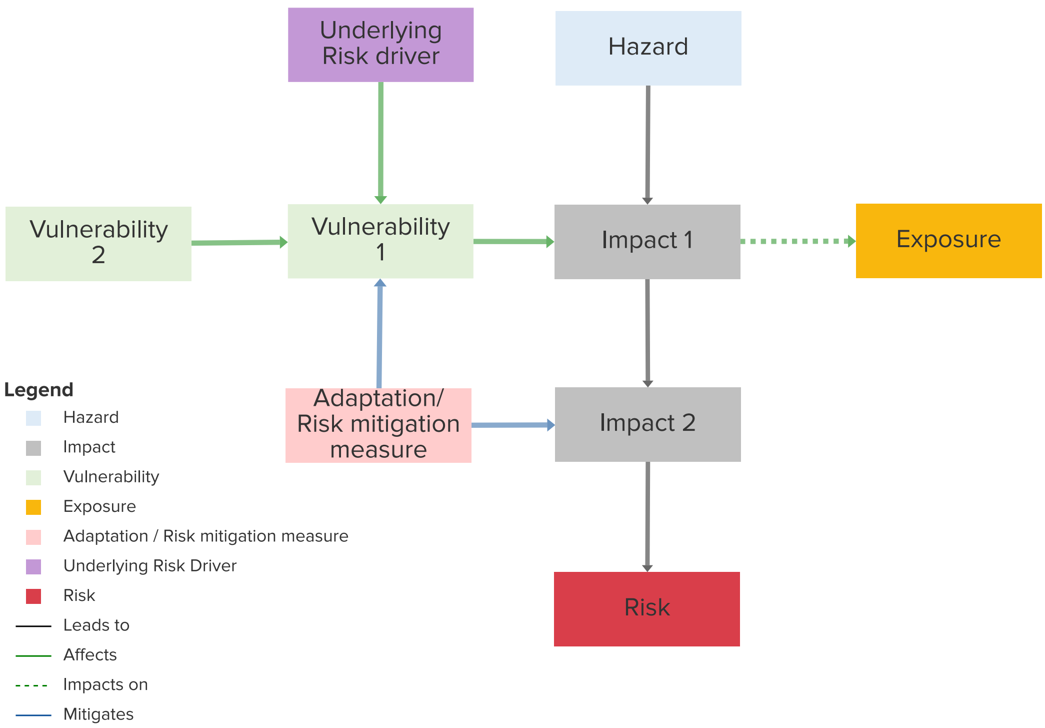

Figure 7 Template of an Impact Chain developed in KUMU. Each factor and connection is assigned to a predefined type and associated visual settings.

Beyond the graphical representation, KUMU enables the storage of metadata associated with each factor and connection (Figure 8). These metadata include all the attributes described in Chapter 3, such as type, description, confidence level, references, and additional notes. Information can be viewed and edited directly through the interface by selecting the corresponding factor or connection.

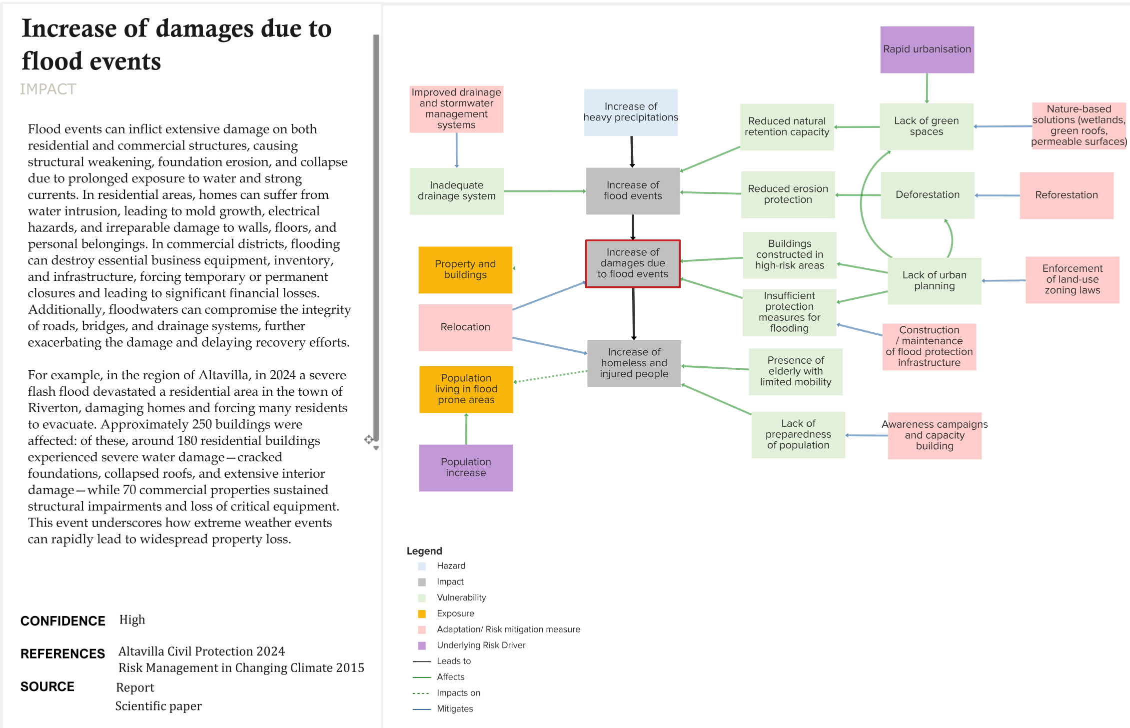

Figure 8 An Impact Chain factor displayed in KUMU together with its associated metadata. The complete Impact Chain can be viewed at this link.

The visual representation is dynamically linked to an underlying tabular structure that stores all factors, connections, and attributes (Figure 9). This repository can be edited directly within KUMU, imported from external spreadsheets, synchronized with Google Sheets, and exported in Microsoft Excel (.xlsx) format.

Filter...

	Label	Type	Description	Confidence	References
1	Awareness campaigns and capacity building	Adaptation/ Risk mitigation measure	Awareness campaigns and capacity building focus on increasing the k	Medium	Climate-ADAPT I Smith 2025
2	Buildings constructed in high-risk areas	Vulnerability	**Vulnerability dimension**: physical Buildings constructed in high-risk	High	Urban Planning office 2018
3	Construction / maintenance of flood protection i	Adaptation/ Risk mitigation measure	The construction and maintenance of flood protection infrastructure in	Medium	Climate-ADAPT I Rossi 2025
4	Deforestation	Vulnerability	**Vulnerability dimension**: environmental Deforestation is the process	High	urban planning office 2020
5	Enforcement of land-use zoning laws	Adaptation/ Risk mitigation measure	The enforcement of land-use zoning laws involves implementing and e	Medium	Climate-ADAPT I Rossi 2025
6	Improved drainage and stormwater managemer	Adaptation/ Risk mitigation measure	Improved drainage and stormwater management systems are essentia	Medium	Climate-ADAPT
7	Inadequate drainage system	Vulnerability	**Vulnerability dimension**: physical An inadequate drainage system ty	High	WaterCompany 2022
8	Increase of damages due to flood events	Impact	Flood events can inflict extensive damage on both residential and com	High	Altavilla civil protection 2024 I Risk Management in a Changing Climat
9	Increase of flood events	Impact	A flood event occurs when water overflows onto normally dry land, sul	High	EEA 2016 I The Guardian 2021
10	Increase of heavy precipitations	Hazard	The increase in heavy precipitation refers to more intense and frequen	High	IPCC AR6 2023 I EEA 2023 I Altavilla civil protection 2024

Figure 9 Spreadsheet editor in KUMU. The same factor shown in Figure 8 is visible in row 8 of the table.

When creating a new Impact Chain in Kumu, we recommend selecting the System Mapping template from the available KUMU templates. To support the standardized development of Impact Chains, Eurac Research provides a predefined KUMU configuration file (JSON format) containing the recommended factor types, connection types, colour schemes, and layouts. The configuration can be loaded into a new map by importing the JSON file through drag and drop and saving the project settings. To preserve the predefined visual layout, we recommend always using the "Impact Chain" view.

Impact Chains can be developed either through the visual interface, by manually creating and connecting factors, or through the spreadsheet editor, by entering information in tabular form and automatically generating the corresponding visualization. The latter approach is particularly useful when importing existing datasets or collaboratively developing Impact Chains outside the platform.

KUMU also supports collaborative work by allowing multiple users to contribute to the same project. Although several users can access and edit a project, simultaneous editing of the same Impact Chain is currently not supported.

Finally, KUMU provides several functionalities for exploring complex Impact Chains, including filter and focus modes. While these tools facilitate navigation and analysis, the default visualizations are often less polished than figures produced using dedicated graphic design software. To improve readability, we recommend arranging hazards at the top of the diagram, followed by direct impacts and then indirect impacts. Exposure and vulnerability factors can be positioned alongside the impacts to which they are most closely related.

Box D. Main features of KUMU

- **Pros**: flexible, structured, allows for collaboration, can work with spreadsheets, allows for metadata to be stored for each factor and connection.
- **Cons**: steeper learning curve, requires some technical skills, visualization tends to be complex. Importing / exporting towards other formats somehow limited.
- **Suggestions**: KUMU can be used efficiently to collect and structure a variety of knowledge and information, as a base for further discussion / consultation, and to initialize / update structured data management (e.g., using Excel).
- **Supporting materials**:
  - KUMU tutorial (Link)
  - Json file to start building Impact Chains (Link to download)
  - Example Impact Chain on KUMU (Link)

Getting started:

- Download the Json
- Create a free KUMU account and login
- Create a new KUMU project
- Select the *Systems* template and *Get started*
- Drag the Json on the new KUMU map and *Save changes*
- Add new factors and connections clicking on the green "+".

4.3.2 Using Draw.io to build and visualise Impact Chains

While KUMU is particularly suited for mapping complex systems and storing the knowledge and metadata associated with Impact Chains, it may result in visualizations that are difficult to interpret, especially when communicating with non-technical audiences. In such cases, simplified graphical representations can be useful to support stakeholder consultations, brainstorming activities, presentations, reports, and other communication purposes. Several tools can be used to create such visual representations, including Draw.io (https://app.diagrams.net/, free online software), MIRO (https://miro.com, proprietary commercial software), CANVA (https://www.canva.com/, proprietary commercial software), and Microsoft PowerPoint. These tools provide flexible environments for diagramming, visual communication, and collaborative work.

Among them, Draw.io offers a particularly useful balance between flexibility and ease of use. Compared to KUMU, it provides greater control over graphical aspects such as fonts, colours, shapes, connectors, and layout design. It also supports layers, which can be used to organize different categories of Impact Chain factors and selectively display or hide them to improve readability. In addition, Draw.io facilitates sharing and version management through integration with platforms such as Google Drive and GitHub.

Draw.io also allows users to associate metadata with individual factors and connections. However, unlike KUMU, these metadata are not managed through an underlying structured repository or spreadsheet that can be easily queried, filtered, exported, or reused independently of the graphical representation. As a result, Draw.io is better suited for visualisation and communication purposes than for the systematic documentation and management of Impact Chain knowledge.
For this reason, we recommend using such tools to primarily to develop simplified and visually appealing representations of Impact Chains, while maintaining a parallel version in a structured environment such as KUMU to ensure the preservation, documentation, and sharing of metadata, supporting evidence, and other associated information.

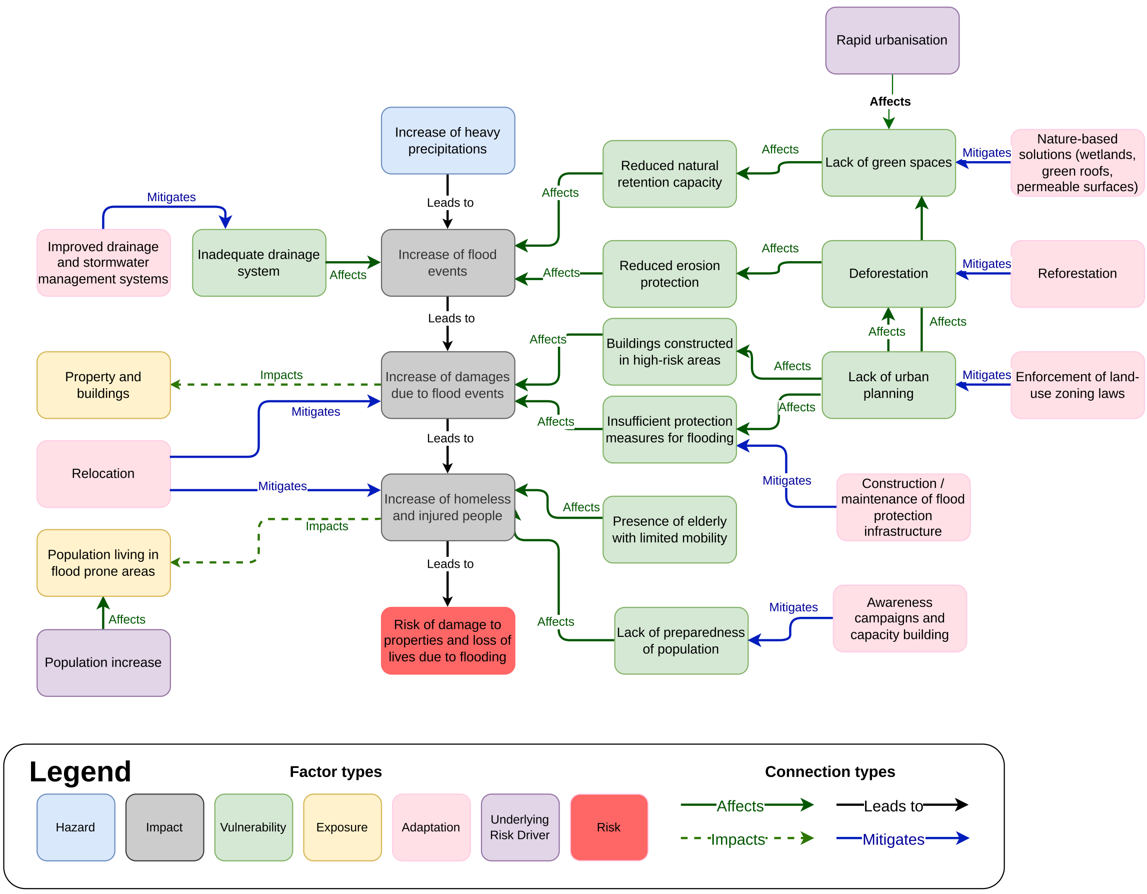

Figure 10 Example of the previously shown Impact Chain, now realized with Draw.io.

Box E. Main features of visualisation tools (e.g. Draw.io)

- **Pros**: efficient collaborative workspace, graphically appealing diagramming and mapping interface. Placing different factor types on different layers allows to filter and simplify the visualisation.
- **Cons**: cannot provide a systematic collection and visualization of content / knowledge associated to Impact Chains elements (as KUMU) which can be exported (e.g. in Microsoft Excel format).
- **Suggestions**: such tools can be used to support technical consultations, especially if carried out online. It can also be used to "convert" complex Impact Chains to simplified ones for communication and dissemination purposes.
- **Supporting materials**:
    - Draw.io file template to start building Impact Chains (Link to download)

4.4 Storing Knowledge Related to Impact Chains

A key objective when developing Impact Chains should be the systematic documentation and preservation of the knowledge associated with factors, connections, and supporting evidence. Impact Chains should not be treated solely as graphical representations, but as structured knowledge assets that can be consulted, updated, shared, and reused over time.

To support this objective, all factors and connections should be documented using a standardized set of metadata, such as descriptions, references, confidence levels, assumptions, and other relevant attributes. As described in Section 4.3.1, KUMU provides an effective environment for storing and managing this information through an integrated repository linked to the graphical representation of the Impact Chain. One of the formats in which this information can be exported is the Microsoft Excel spreadsheet. Spreadsheet based representations provide a simple and widely accessible way to store, exchange, and archive Impact Chain knowledge in a structured format. They also facilitate interoperability with other software tools, support data processing and analysis workflows, and provide a basis for future machine actionable applications. For researchers and practitioners working in the field of risk assessment and climate adaptation, spreadsheet-based formats can therefore significantly improve the shareability, transparency, and reusability of Impact Chains.

However, tabular formats alone are generally insufficient for exploring and communicating the complexity of risk systems. For this reason, structured repositories should ideally be complemented by tools that support the visualization and, where appropriate, graphical editing of Impact Chains.

An example of an online repository designed to store and share climate risk Impact Chains is presented in Box D.

BOX D. Example of an online Impact Chain knowledge base – the CRISP tool

CRISP (**C**limate **Ris**k **P**lanning and Managing Tool) is a freely available, quick and easy-to-use, interactive web-based tool for agricultural and rural development project planners (https://crisp.eurac.edu/).

CRISP allows users to visualise (as graphs or tables) and query 23 Impact Chains in the agricultural sector. It was developed to provide project managers and practitioners with access to existing knowledge structured in Impact Chains, thereby mainstreaming climate risk considerations into project design and implementation.

CRISP builds upon the method developed in the Climate Risk Sourcebook (Zebisch et al., 2023). This method has been reinterpreted within the framework of knowledge engineering and implemented using semantic technology. Semantic technologies enable the explicit representation of knowledge and its further processing within a machine-friendly environment. To this purpose, a simple applied ontology of Impact Chains has been implemented. The ontology includes Impact Chain factors (hazard, exposure, vulnerability, impact, and risk) and a basic set of relationships that account for the different ways these factors interact and contribute to risk. The structure defined by the ontology provides a simple means to structure the knowledge and information provided by different sources. Agricultural scientists reviewed scientific literature and stored the extracted information in a structured database to populate CRISP.

The CRISP knowledge base contains 23 Impact Chains composed of 367 distinct elements (19 hazard factors, 92 vulnerability factors, 108 impact factors and 140 Adaptation measures), 25 element types and 2668 connections. For each element and each connection there are Impact Chain specific descriptions and literature references.

5 Quality assessment and validation of Impact Chains

In the field of risk assessment, the necessity to assess and validate conceptual models stems from the inherent complexity and sensitivity of risk management frameworks. Ensuring completeness, thematic quality, and minimizing biases are critical aspects of validating conceptual models (e.g., Aven, 2016). Completeness entails incorporating all relevant factors and connections without oversimplifying the complexity of the risk landscape. Thematic quality addresses the coherence and relevance of the factors and connections represented within the Impact Chain model. Biases, which might arise from different sources of knowledge, must be meticulously managed. This chapter is divided into two sections: quality assessment and approaching validation.

5.1 Quality Assessment

Quality assessment in Impact Chains is related to three main aspects: completeness, thematic quality and potential bias, which are described below.

5.1.1 Completeness

One of the fundamental tasks in assessing the completeness of the Impact Chain is to ensure that all relevant factors and connections are comprehensively represented. This is no easy task and involves a thorough review of the model's scope to ensure it encompasses all significant variables and their interdependencies.

To achieve this, one must systematically identify and validate each element of the model, ensuring it contributes meaningfully to the overall understanding of the risk scenario. This process might involve cross-referencing with expert knowledge, empirical data, and relevant literature to confirm that no significant factor has been overlooked. It is crucial to achieve a balance where the complexity of the risk landscape is adequately captured without overwhelming the model with excessive detail that could obscure critical insights and allow for a more intuitive understanding by the Impact Chain end users. Additionally, it is recommended to consider all the dimensions suggested in the vulnerability framework (Box B, chapter 3) to ensure a more holistic assessment.

5.1.2 Thematic Quality

The thematic quality of an Impact Chain involves evaluating the coherence and relevance of the factors and connections within the model, as well as their informational content and uncertainty. This requires a thorough examination of the conceptual framework underpinning the Impact Chain, ensuring that it aligns with established scientific literature, knowledge, and empirical evidence. Regular updates and reviews based on the latest research findings and expert feedback are crucial.

Furthermore, thematic quality assessment should include an analysis of the internal consistency of the model. This involves verifying that the logical flow of cause-and-effect relationships (e.g., from hazard to impacts and across impacts) and the compliance with constraints on other connections is maintained throughout the Impact Chain. Discrepancies or logical gaps should be identified and addressed to prevent potential misinterpretations. Finally, it is important to document the rationale behind the inclusion and confidence rating of specific factors and connections. This transparency enables other researchers or stakeholders to understand the decision-making process and provides a basis for future refinement and validation efforts.

NOTE. The thematic quality of an Impact Chain can be further enhanced by employing a participatory approach that incorporates diverse viewpoints. Engaging a broad range of stakeholders ensures that the model captures the multifaceted nature of the risk landscape and reduces the chance of inadvertent oversights or biases.

5.1.3 Potential bias

Expert opinion is invaluable for its depth of insight and practical experience, although it may be subjective and influenced by individual perspectives. Participatory approaches, which involve a broader array of stakeholders, help in democratizing the knowledge base, yet they also risk incorporating diverse biases from varied viewpoints. Scientific literature provides a foundation of peer-reviewed, theoretically sound information; however, it may lag behind reality due to publication delays and may not always align with practical nuances. Empirical evidence, grounded in real-world data, provides robust, quantifiable insights, although the availability and quality of data may limit it.

According to the International Risk Governance Council (IRGC), involving a diverse group of stakeholders and experts in the validation process enhances the robustness and credibility of the models (IRGC, 2017). Combining these sources through a balanced, integrative approach ensures that risk models are comprehensive, thematically coherent, and minimally biased, thereby equipping decision-makers with precise and holistic insights.

5.2 Approaching validation

The validation of an Impact Chain is an iterative process aimed at assessing the plausibility, completeness, and relevance of the identified factors and connections. Depending on the objectives of the exercise and the stakeholders involved, validation can be approached through two complementary mechanisms: **technical consultation** and **communication and feedback**.

Technical consultation focuses on the detailed review, refinement, and expansion of an Impact Chain through direct engagement with subject matter experts and key stakeholders. This approach is particularly useful when validating specific factors, causal relationships, assumptions, or evidence supporting the Impact Chain. Technical consultations can be organized as individual interviews, focus groups, or dedicated workshops, either online or in person. Depending on the purpose of the consultation, participants may be invited to review the entire Impact Chain or only selected sections relevant to their expertise. The outcome of the process is a revised version of the Impact Chain that incorporates expert knowledge, corrections, and additional information.

Communication and feedback focuses on presenting the Impact Chain to a broader audience and collecting comments from stakeholders, practitioners, decision makers, and potential end users. The objective is not necessarily to perform a detailed technical review, but rather to assess whether the Impact Chain is understandable, relevant, and representative of the issues it seeks to describe. To facilitate communication, it may be useful to develop simplified or tailored visual representations of the Impact Chain that are easier to interpret than the full technical version.

Feedback can be collected through workshops, interviews, presentations, online consultations, surveys, or other engagement activities. Supporting materials should clearly describe the scope of the analysis, the underlying assumptions, the main results, and any identified uncertainties or knowledge gaps. Comments and suggestions should be documented in a structured manner and reviewed to determine whether modifications to the Impact Chain are required. The validation process should result in a documented record of the feedback received, the changes implemented, and the rationale for any revisions. Typical outputs include an updated version of the Impact Chain, and any supporting communication or consultation materials developed during the process.

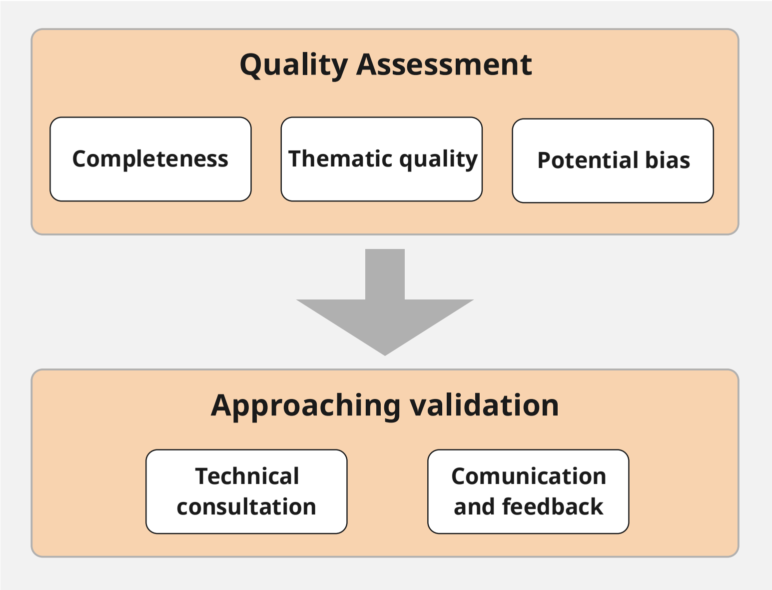

Figure 11. Workflow of quality assessment and approaching validation of the Impact Chains

6 How to read and interpret Impact Chains

This chapter aims to explain how to read and interpret Impact Chains in risk analysis. As explained in previous chapters, Impact Chains are valuable tools that help identify interdependencies, visualise cascading impacts, and highlight key risks. They provide a structured approach to understanding risk propagation from hazards and impacts across various systems.

The interpretation of an Impact Chain can be approached by adopting different navigation and analytical techniques (see Figure 12).

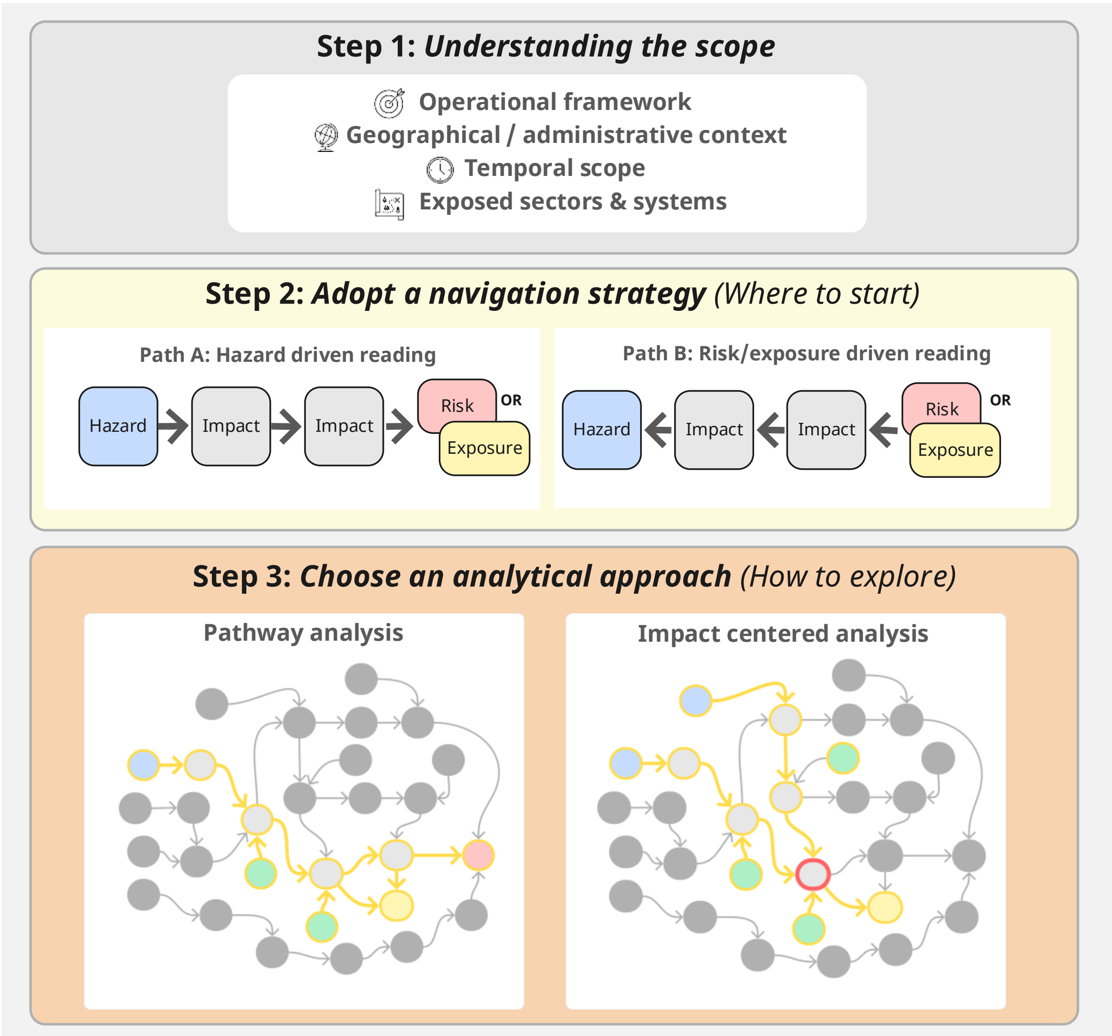

Figure 12. Suggested process for reading and interpreting an Impact Chain

Step 1: Understanding the scope

Before interpreting and exploring an Impact Chain in depth, it is important to understand its scope and intended purpose. The interpretation should start by reviewing the contextual information associated with the Impact Chain and answering questions such as:

- What is the main purpose of the Impact Chain (e.g. climate adaptation planning, disaster risk management)?
- Which sectors, systems, or exposed elements does it address?

- Which geographical area does the model cover?
- What type of hazards does it address?
- Which time period does the Impact Chain describe? (e.g. current conditions, near future)

Understanding the scope helps establish the boundaries of the analysis and prevents misinterpretation of the represented factors and relationships, ensuring that the interpretation aligns with the intended objectives.

Step 2: Adopt a navigation strategy

Impact Chains can be explored from two complementary perspectives. The first approach follows a path starting from the hazards, while the second starts from a specific risk or outcome. Below, each path is described.

Path A: Hazard driven reading - This approach starts from one or more hazards (at the start of the chain) and follows their consequences down through the system. Consider these guiding questions in order:

1. Which hazards are represented?
2. Do multiple hazards interact?
3. What are the impacts generated by these hazards?
4. Which exposed elements are affected?

This perspective is particularly useful for understanding how hazards propagate through a system and generate direct and indirect impacts across multiple exposed elements.

Path B: Risk/exposure driven reading - This approach starts from a specific risk or outcome (typically located at the end of the chain) and works backwards to identify the factors that contribute to it. Guiding questions include:

1. What risk is being analysed?
2. Which exposure elements are impacted?
3. Which factors, vulnerabilities, and preceding impacts contribute to its occurrence?
4. Which hazards ultimately trigger the chain of events leading to this risk?

This perspective is particularly useful for identifying the drivers of a specific risk or to analyse what may impact a specific exposed element. It can also be used to determine which factors along the chain can be targeted through adaptation or risk reduction measures.

Step 3: Choose an analytical approach

Once a navigation strategy has been selected, the Impact Chain can be explored more deeply using two complementary analytical approaches.

- **Pathway analysis**. Pathway analysis consists of following a sequence of connected factors to understand how impacts propagate through the system. The analysis can be conducted either forwards (hazard driven) or backwards (risk/exposure driven), depending on the selected navigation strategy. By tracing chains of cause and effect, this approach helps identify critical vulnerabilities and intervention points and analyse the temporal sequence of cascading effects. It can also support the understanding of how risks spread across sectors and systems. However, focusing on a single pathway has limitations, as it may overlook broader interconnections within the larger Impact Chain. The reader should expand their focus to include multiple pathways and interactions to capture these broader interconnections. Particular attention should be given to critical pathways, namely those representing the most plausible, or severe sequences of events within the Impact Chain. They can be determined by assessing the confidence levels of connections between factors, often supported by scenario analysis or probabilistic modelling. Exploring multiple pathways can also provide insights into whether different impacts occur simultaneously or sequentially, whether they exhibit specific spatial patterns, and how long different processes and consequences may persist over time. Pathway analysis is particularly useful for emergency managers, civil protection agencies, public administrations, and decision makers interested in understanding how risks evolve over time and across sectors and for identifying entry points where interventions can interrupt or reduce cascading effects.

***Example**. Consider a drought scenario affecting an agricultural system. A critical pathway may begin with prolonged precipitation deficits leading to reduced water availability. This, in turn, may reduce irrigation capacity, resulting in lower agricultural productivity and consequently reduced farm income and food insecurity. Over time, these impacts may contribute to land abandonment and changes in livelihoods and landscape management. By following this sequence of events, pathway analysis helps identify how impacts propagate through the system and where interventions may be most effective. For example, measures aimed at improving water storage or irrigation efficiency could reduce the likelihood or severity of impacts occurring further downstream in the pathway.*

- **Impact centred analysis.** Rather than following a single pathway, this approach focuses on a specific impact and explores its connections within the Impact Chain. This includes analysing which hazards, vulnerabilities, and upstream impacts contribute to its occurrence, as well as which adaptation or risk reduction options could prevent, reduce, or manage its consequences. By examining all relationships associated with a given impact, the reader can better understand its role within the broader risk system and identify the factors that most strongly influence its occurrence. Particular attention should be given to critical impacts, namely those that play a central role within the Impact Chain due to their centrality (number of connections), capacity to trigger cascading effects, or sensitivity to changes in other factors and conditions. Focusing on these impacts can help identify priority areas for risk reduction and adaptation. Impact centred analysis is particularly useful for sectoral experts, adaptation planners, policy makers, and practitioners interested in understanding the drivers, consequences, and management options associated with a specific impact.

  ***Example.** Consider the impact "Reduced agricultural productivity". Rather than following a single sequence of events, the analysis focuses on all factors connected to this impact. Upstream contributors may include drought and reduced water availability (as in the previous example) but also landslides and soil degradation caused by an increase in heavy precipitations, or pest outbreaks caused by increasing temperatures. Relevant vulnerabilities could include insufficient irrigation infrastructure, limited financial resources, dependence on a single crop type and lack of pest control mechanisms. Potential adaptation options could include improved irrigation efficiency, crop diversification, or the adoption of drought or pest resilient crop varieties. By examining all these relationships, the reader can better understand the role of this impact within the broader risk system and identify effective adaptation options to prevent or reduce such impact.*

The two analytical approaches are complementary and can be applied to the same Impact Chain depending on the objectives of the analysis. While pathway analysis follows chains of cause and effect across the system, impact centred analysis focuses on understanding a specific impact and its surrounding relationships. Similarly, hazard driven and risk driven reading define the starting point of the exploration within the Impact Chain. Once a starting point has been selected, the reader can investigate the system using pathway analysis, impact centred analysis, or a combination of both approaches.

Combining these navigation strategies and analytical approaches enables both a systemic and a targeted understanding of risk. This can support the identification of critical vulnerabilities, cascading effects, cross sectoral interactions, and opportunities for risk reduction and adaptation. Depending on the objectives of the analysis, readers may choose to focus on specific pathways, individual impacts, or alternate between different perspectives to gain a more comprehensive understanding of the system.

7 Conclusions and outlook

7.1 Conclusions

Understanding how natural hazards and their underlying processes lead to negative impacts and ultimately affect different socioecological systems is essential for comprehensive risk management. It is vital to understand and analyse these complex interactions to grasp the full scope of risk and its related determinants, such as exposure and vulnerability. In this context, Impact Chains have proven very useful to develop conceptual models of complex risks, and they are increasingly used by both researchers and risk practitioners.

In order to further harness the wealth of information and knowledge which is embedded in ICs and turn them into a more efficient research tool, we decided to develop this technical guideline, which will be subjected to regular updates following the evolution of the underlying research. We aim at developing Impact Chains into structured, consistent, replicable and sustainable knowledge management tools able to improve both Disaster Risk Reduction and Climate Change Adaptation applications and strive to grow further the heterogenous community of practice which is developing.

7.2 Current limitations and outlook

The methodologies for Impact Chain development and analysis in the context of risk identification are continuously evolving. By addressing current limitations and integrating new developments, the accuracy and applicability of these assessments will be enhanced, leading to better risk management strategies.

Although Impact Chains provide an intuitive representation of the determinants and drivers of risk, this very aspect also outlines one limitation of the approach. In fact, as the natural complexity of real processes and their tight interrelations are being captured by the Impact Chains, this complexity hinders an efficient exploration and comprehension of the resulting representation. A viable strategy to address this limitation entails the use of more structured knowledge and data representation, such as ontological models, which is currently being explored.

The use of ontologies, along with a more systematic application of the detailed specifications provided here, would also alleviate a further limitation of the Impact Chain framework, which is related to the inherent semantic complexity of the concept of risk, especially within cross-disciplinary applications.

A related limitation is the lack of software solutions to consistently create and visualize Impact Chains. Although in this document several optional solutions have been presented, they are suboptimal, and in the near future, the development of a custom-tailored Web-based interface is sought.

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