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Transboundary Storm Risk and
Impact Assessment in Alpine Regions

APPLICATION OF IMPACT CHAIN METHODOLOGY TO STORM SCENARIOS PORTFOLIO

Deliverable 4.2

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Main changes compared to previous version	Page(s)

Table of Contents

1 Introduction

The purpose of this document is to report on the application of the "impact chains" approach to the case of complex, intense hydrometeorological events considered in the TRANS-ALP project. In the next chapter an introductory description of the selected approach is provided. In the subsequent chapters for the three events already analysed within the deliverable D3.2 a set of impact chains related to specific risks are described and discussed. In the last chapter several concluding remarks are given.

2 The Impact Chains Methodology

The impact chains methodology was first designed and developed as an analytical tool to better understand, systemise, and prioritise the factors that drive vulnerability to climate change in a (possibly complex social) system under review. The original methodology can be split in two distinct but interrelated macro phases, namely: *conceptualization* and *aggregation*, that will be described in further details in the next sections.

2.1 Conceptualization

The first macro-phase focuses on the conceptualization of the impact chains structure, including the analysis of the underlying components, the definition of intermediate components and their relationships. The structure of the impact chain is based on the Vulnerability Sourcebook's understanding of vulnerability, as shown in Figure 1.

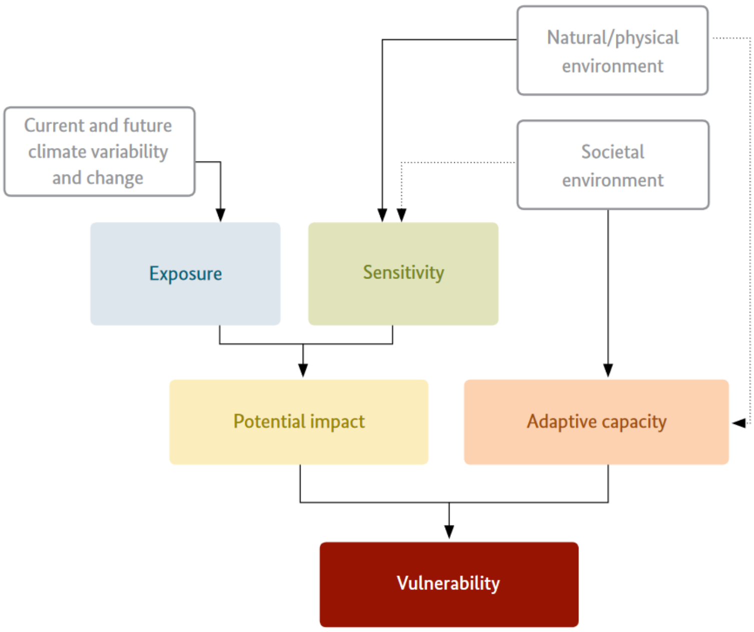


Figure 1 Structure of an Impact chain according to AR4 basic concepts (source: Vulnerability Sourcebook, 2014).

The Sourcebook's approach was based on the commonly applied concept of climate change vulnerability as proposed by the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). Meanwhile, the current IPCC-AR5 WII report (Field et al., 2014) introduced a new concept of "climate risk", which is closer to the disaster risk community than the AR4 concept. While it differed in terminology, the general idea was always to understand the underlying root-causes of potential negative climate impacts, including climatic, natural, physical and socio-economic factors. An updated formulation of impact chains more adherent to AR5 concepts has been thus proposed in the Risk´s Supplement to Vulnerability Sourcebook, in 2017, as shown in Figure 2.

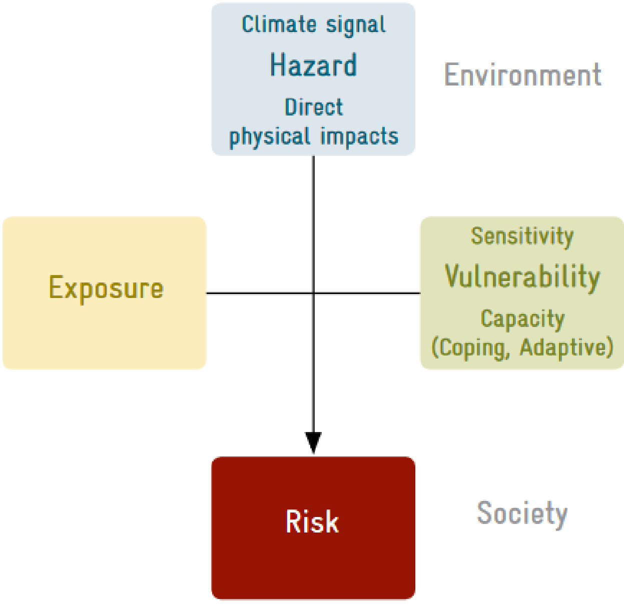


*Figure 2 Structure of an Impact chain according to **AR5** basic concepts (source: Vulnerability Sourcebook Risk Supplement, 2017)*

Throughout this document the latter version will be used, which follows a formulation of risk (see Figure 3) largely compatible with the one proposed by UNDRR in the 2015-2030 Sendai framework of disaster risk reduction (e.g., see the UNDRR´s terminology of DRR).

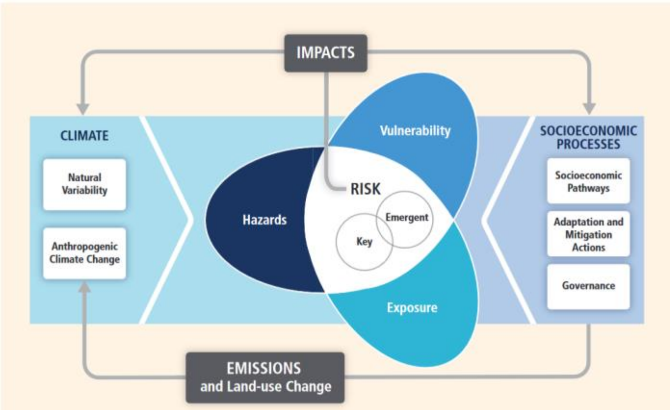


Figure 3 Representation of risk-related components in the AR5 framework (source: IPCC AR5)

The basic concepts underlying the impact chains methodology in the above-mentioned (mainly DRR) context are briefly recalled in the following:

- **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. *Annotations*: Hazards may be natural, anthropogenic or socio-natural in origin. Natural hazards are predominantly associated with natural processes and phenomena. Anthropogenic hazards, or human-induced hazards, are induced entirely or predominantly by human activities and choices. This term does not 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. Several hazards are socio-natural, in that they are associated with a combination of natural and anthropogenic factors, including environmental degradation and climate change. Hazards may be single, sequential or combined in their origin and effects. Each hazard is characterized by its location, intensity or magnitude, frequency and probability. Biological hazards are also defined by their infectiousness or toxicity, or other characteristics of the pathogen such as dose-response, incubation period, case fatality rate and estimation of the pathogen for transmission (UNDRR).

- **Exposure**. Describes the extent to which sensitive assets and systems are exposed to hazardous conditions (that is, conditions that can potentially generate impacts). **Exposed elements** are physical, socio-economic or intangible assets or systems that are susceptible to be impacted (and potentially damaged) by one or more hazardous conditions and hence can incur a loss.

- **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). Vulnerability can be also described in terms of two different type of factors, namely sensitivity and coping capacity:

    - **Sensitivity**. Sensitivity determines the degree to which a system is adversely or beneficially affected by a given climate change exposure. Sensitivity is typically shaped by natural and/or physical attributes of the system including topography, the capacity of different soil types to resist erosion, land cover type. But it also refers to human activities which affect the physical constitution of a system, such as tillage systems, water management, resource depletion and population pressure. As most systems have been adapted to the current climate (e.g. construction of dams and dikes, irrigation systems), sensitivity already includes historic and recent adaptation. Societal factors such as population density should only be regarded as sensitivities if they contribute directly to a specific climate (change) impact.

    - **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).

- **Potential Impacts**. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts. Climate change impacts can form a chain from more direct / physical impacts (e.g., erosion) to indirect impacts (e.g., reduction in yield, loss of income) which stretches from the biophysical sphere to the societal sphere. In many developing countries, direct dependency on natural resources means that the link between biophysical impacts of climate change and human activities and well-being is particularly strong (see Figure 2).

- **Stressors (conditioning factors)**. Events and trends, often not climate-related, that have an important effect on the system exposed and can increase vulnerability to climate-related risk. Conditioning factors refer to environmental conditions that can exacerbate the impacts and increase the risk by, e.g., increasing the sensitivity of the exposed assets, or by affecting negatively the copying capacity of the affected communities.

- **Risk**. The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk = (Probability of Events or Trends) × Consequences. Risk results from the interaction of vulnerability, exposure, and hazard (see Figure 3). In this report, the term risk is used primarily to refer to the risks of climate-change impacts.

The impact chains contribute to foster a comprehensive understanding of vulnerability (i.e., a vulnerability hypothesis) shared by various stakeholders and can help in the identification of suitable adaptation activities.

In developing impact chains, expert knowledge and a sound understanding of the system at the heart of the vulnerability assessment are indispensable. In the vulnerability sourcebook the following breakdown of steps was proposed:

- Prepare the process within the project team with the help of external experts where necessary (review of known impacts and cause-and-effect relationships).

- Use participatory methods such as workshops involving key institutions and experts as well as representatives of affected sectors or communities to broaden knowledge, create a common concept and encourage ownership (brainstorming on additional impacts, prioritisation of impacts, drafting impact chains).

- Finalise the process within the project team with the help of external experts where necessary (fine-tuning and finalisation of impact chains).

Building an impact chain is, in fact, an iterative process, and new aspects can arise throughout.

2.2 AGGREGATION

Once the conceptualization of impact chains for the selected case is done, the original methodology foresees a second phase, where the most relevant exposure and vulnerability components are (where possible) described in terms of geospatial distributions and suitably aggregated (in Figure 4 an example is provided) into a composite indicator that conveys a spatialized information on potential risk hotspots.

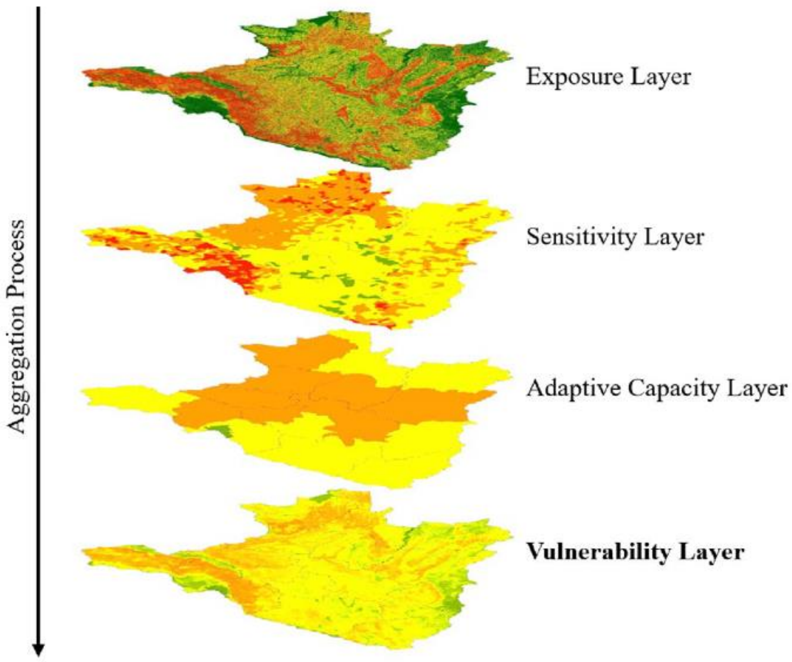


Figure 4 Structure of semiquantitative aggregation process (Zebisch et al., 2021)

This macro-phase can be further split into several steps, briefly described in the following.

1.1.1 IDENTIFYING AND SELECTING INDICATORS

For each impact chain component (hazard, exposure, vulnerability), one or more factors are defined in the conceptualization phase. Each factor describes a specific aspect of the component which is relevant in the analysed context. For instance, in the hazard component the specific factor “heavy precipitation” or “strong wind” can be explicitly addressed. In terms of exposure, the factors usually describe the specific exposed assets (including, e.g., the population). In terms of vulnerability, the possible factors depend on whether sensitivity or coping capacity are addressed. For each factor, a suitable indicator can be defined. The indicators have the function to describe quantitatively and possibly in geospatial terms the related factors. Table 1 provides several examples of factors and related possible indicators.

Table 1 Examples of factors and indicators

Risk component	Factor	Possible indicator
hazard	Heavy precipitation	Gridded cumulated daily precipitation (in mm)
exposure	Residential buildings	Built-up area (% of land)
Vulnerability (sensitivity)	Land-use prone to erosion	% of land-cover class with high erosion risk

1.1.2 Normalization

In the normalization step each indicator is mapped into a common unitless representation, typically described by real values in the range [0,1], or in terms of ordinal values (e.g., in terms of a 1 to 5 Likert scale). The resulting normalised values should describe the criticalness of the related indicator values, so that, e.g., the value '0' may indicate a somehow optimal state with respect to the contribution to risk (e.g., cumulated precipitation less than 1mm can be mapped to '0' hazard value, while higher precipitations would be associated to higher potential risk). Different mathematical operations can be employed in the process depending on the characteristics and distribution of the indicator values and the considerations of criticality.

1.1.3 Weighting and Aggregation

Once the indicators for the most relevant factors are defined and properly normalised, in order to have an overall proximal evaluation of risk they have to be aggregated. A possible approach to risk-oriented aggregation is based on a weighted sum of the indicators related to the hazard, exposure, and vulnerability components, described in Equation 1.

$$\text{Risk} = \frac{(\text{Hazard} * w_H) + (\text{Vulnerability} * w_V) + (\text{Exposure} * w_E)}{w_H + w_V + w_E}$$

Equation 1 Weighted aggregation of risk-related indicators

The weights have the double-fold purpose of ensuring a proper normalization of the aggregated values, and can be used to highlight some components with respect to others.

2.3 The TRANS-ALP Approach

The Impact chains methodology has been developed to describe the structuring of cause – effect relationships between drivers and/or inhibitors affecting the vulnerability of a system. Impact chains allow for a visualization of interrelations and feedbacks, help to identify the key impacts, on which level they occur and allow visualising which climate signals may lead to them. They further help to clarify and/or validate the objectives and the scope of the vulnerability assessment and are a useful tool to involve stakeholders. Although the original concept has been developed for applications related to climate risks (i.e., risks related to climate change), it can be efficiently applied also in the case of extreme events, where there is not necessarily a clear connection to climate change (although there is a high chance that climate change is a driving factor underlying the perceived trend of extreme hydromet events either in terms of frequency or intensity). In the case of TRANS-ALP the original methodology has been slightly adapted, as detailed in the next section.

2.4 The methodology

In order to apply the Impact Chains approach in the operational context of the TRANS-ALP project, higher priority has been given to the conceptualization macro-phase. In fact, the aggregation phase has been deemed less suitable to describe a complex multi-hazard / multi-risk event, due to potential oversimplification of the relationships between hazard, exposure, and vulnerability. On the other side, a structured conceptualization of the different impact pathways linking different hazards to risks can be advantageous to support a more comprehensive understanding of such extreme events and their multiple impacts on socio-ecological systems. The following steps are proposed.

2.4.1 Risk analysis – definition of main target risks

A first scoping analysis is conducted, analysing the available information on the considered event (or classes of event). A set of target risks are selected as a driving element for the development of the impact chains. The criteria to select the target risk include for instance the relevance of the consequences related to risk in absolute (e.g., the related economic loss) or relative (with respect to the other risks) terms.

2.4.2 Definition of main components and factors

An iterative evaluation of the main factors for each risk component is then carried out, in order to highlight relevant elements that are expected to play a role in the impacting mechanism, or to act as powerful influencing factors. In particular, exposure and vulnerability elements are analysed and linked to the other components.

2.4.3 Intermediate Impacts description and referencing

The actual impact chains representation is generated, placing the individual components in a visual format that describes (causal) links with the other factors and highlighting the impact pathways according to their type (e.g., direct link between hazard factors and physical impacts).

For each impact pathway (that is, the path linking intermediate impacts, linking hazard to impacts and linking impacts to risks) a textual description is provided in order to complement the visual depiction of impact chains with a narrative providing details on the rationale behind the link and including information on the level of confidence of the link itself, its source and a possible referencing to existing ancillary information or data. The referencing is useful to provide a clear explanation of the amount of empirical evidence motivating that particular link, hence improving soundness of the procedure and better dissemination and further analysis of the results.

2.4.4 Iterative updating

The above procedure can be carried out completely off-line, basing on desktop studies and other available information sources, or in a more participatory environment, consulting domain experts or local stakeholders. A more comprehensive approach could include an iterative assessment, where a preliminary definition of the impact chains would be followed by further refinements based on external ancillary documentation or interaction with experts.

In the following section an exemplification of the above-described methodology to two selected extreme events is provided and discussed.

3 APPLICATION TO SELECTED EXTREME METEOROLOGICAL EVENTS

To exemplify the application of the Impact Chains methodology, one of the three events addressed in the TRANS-ALP deliverable D3.2 (Guidelines for harmonised, cross-border collection of geocoded storm damage and impact data) is considered, namely:

- **Storm Vaia/Adrian:** depression/low from 28th to 30th October 2018

For this event several documents, reports and geospatial information have been collected in the regions Alto-Adige/South Tyrol, Veneto and in East Tyrol, mainly related to the observed impacts. The hazard factors related to these events have been also documented in the TRANS-ALP deliverable *D2.2 Hazard Set - Historical* (among other events). Information on exposure and vulnerability factors have been derived from the analysis of available information.

3.1 STORM VAIA / ADRIAN

3.1.1 TARGET RISKS

Following a preliminary analysis of the impact data, two main target risks have been selected: target risk 1: "*Injuries and loss of lives and properties*" and target risk 2: "*Loss of ecosystem services*". The former is of particular concern for the civil protection authorities, while the latter is more relevant from the socio-economic perspective.

3.1.2 IMPACT CHAINS

Based on the available impact information and data, the impact chains related to target risk 1 has been developed as shown in Figure 5. The factors related to the different components (hazard, exposure, vulnerability and impacts) are grouped together and color-coded accordingly, while causal links have been explicitly indicated only for intermediate impacts. Links related to exposure and vulnerability are not indicated but related information is provided in the narrative description of the impacts themselves. In grey a few external drivers (i.e., conditioning factors) have been indicated as well. We can note that in the case of VAIA and similar events, at least two hazards are compounded (heavy rains and strong wind) and their contributions to the different impacts are often entangled, also including cascading effects.

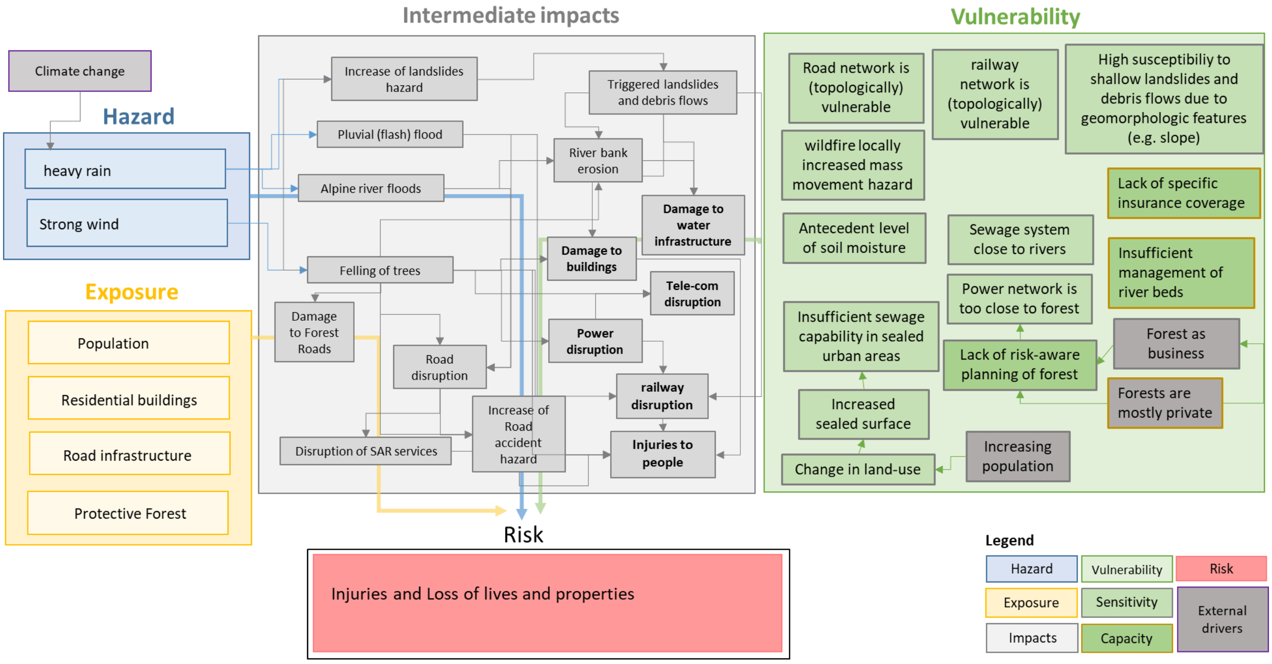


Figure 5 Event Storm "VAIA" - Impact chains related to target risk: "Injuries and loss of lives and properties"

A second set of Impact Chains, shown in Figure 6, has been derived considering as target risk the loss of ecosystem services, that particularly in the case of VAIA was a very significant consequence of the event.

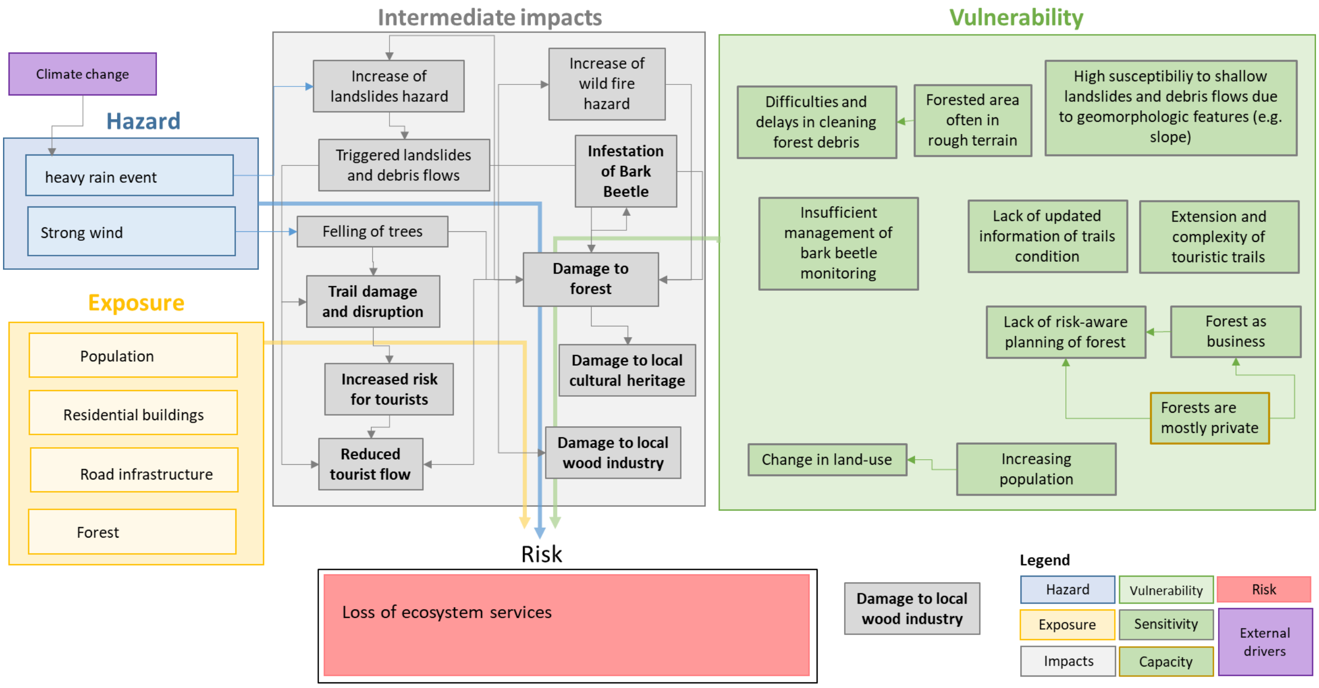


Figure 6 Impact chains, target risk: "Loss of ecosystem services"

3.1.3 Exposure

The main factors of the exposure component that have been selected include:

- **Population**. People can be affected directly by physical impact with the hazard factors, or indirectly due to disruption in lifelines and critical services (e.g., SAR teams, firefighters). Areas with higher population density can potentially be more exposed to natural hazards.

- **Residential buildings**. Host the population and can be affected by several phenomena either directly by physical impact, or indirectly by disruption of the utilities.

- **Road infrastructure**. Roads (and related structures such as bridges and tunnels) can be directly affected and damaged by hazards (e.g., floods or landslides) or indirectly by interruption due to, e.g., windthrows and rock falls. Roads represent both a physical asset and an infrastructure that is functional to several services (e.g., public transportation).

- **Forested area**. Forests are a very important asset in mountainous regions. They represent a valuable ecosystem service, either by their protective function, their intrinsic commercial value and their critical role as intangible socio-cultural role. Forests can be damaged and incur a loss, and can contribute directly and directly to other impacts.

3.1.4 Impacts

The different impacts can be further subdivided into *first*-, *second*- and *third-level* impacts. First-level impacts, depicted in Figure 7, represent the impacts most closely related to the hazard factors, and in most cases can be themselves considered as hazards (e.g., pluvial floods as direct consequence of heavy rains). We can note that there might be further first-level impacts not explicitly considered in the impact chains. For instance, the link between heavy rains, soil moisture and floods hazard represent a causal link that does not necessarily act on the same temporal horizon of the other factors but can be for instance antecedent to the considered event and relevant on longer term (e.g., rain in the days preceding the event might increase the floods hazard by saturating the soil). On a longer time-frame, complex feedback loops can be found among first-level impacts that even link together different hazard factors. For instance, as highlighted in Figure 7, the windthrow due to strong wind can affect the susceptibility to shallow landslides in the months following the event. Second-level impacts, depicted in Figure 8, represent intermediate impacts that have typically both incoming and outcoming links and describe (usually not exhaustively) chained processes leading to final impacts.

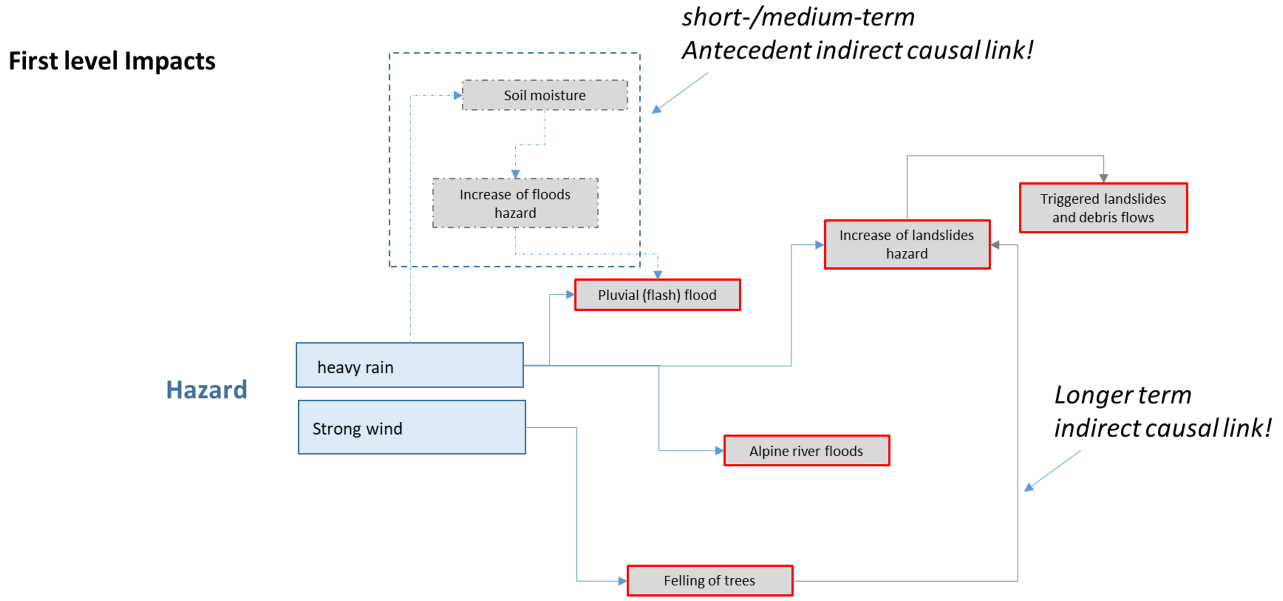


Figure 7 First-level impacts

Third-level impacts, depicted in Figure 9, represent the impacts most directly connected to the target risks. The final link is not explicitly shown, and can be either direct (e.g., injuries to people, or damage to water infrastructure) or indirect (e.g., the disruption of telecommunication).

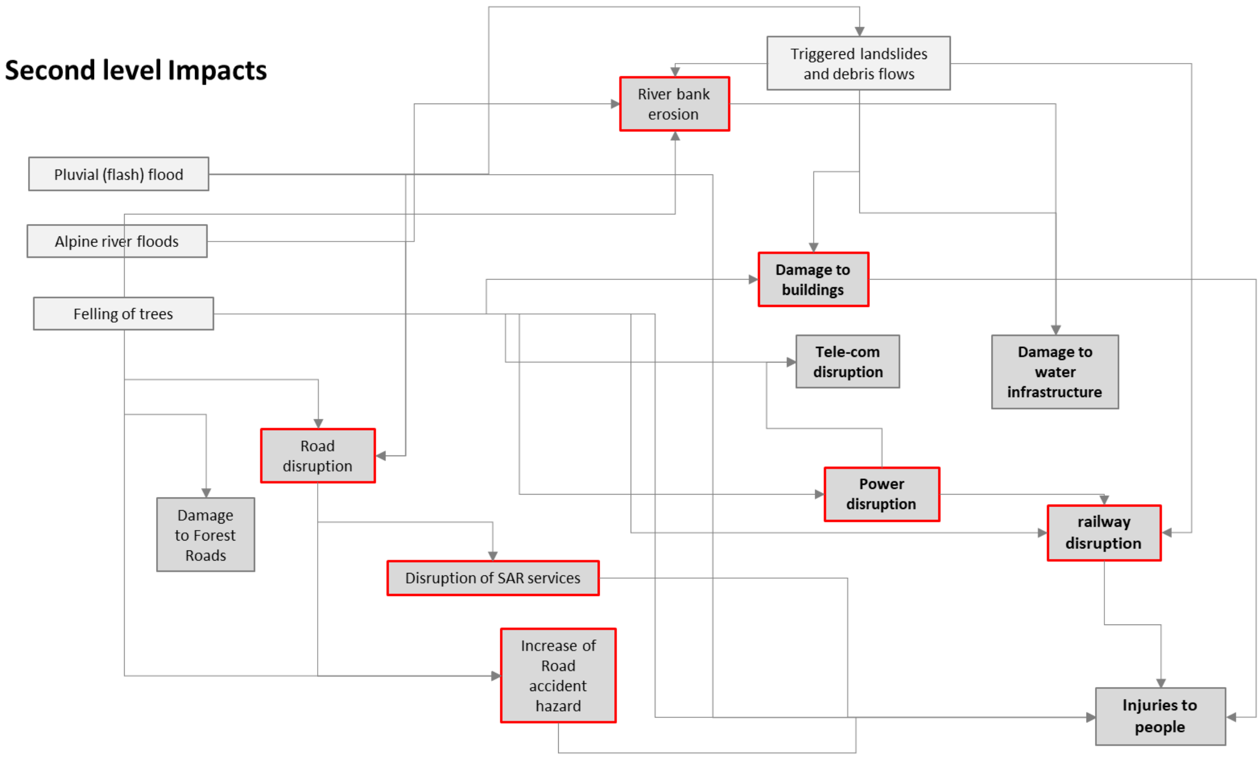


Figure 8 Second-level impacts

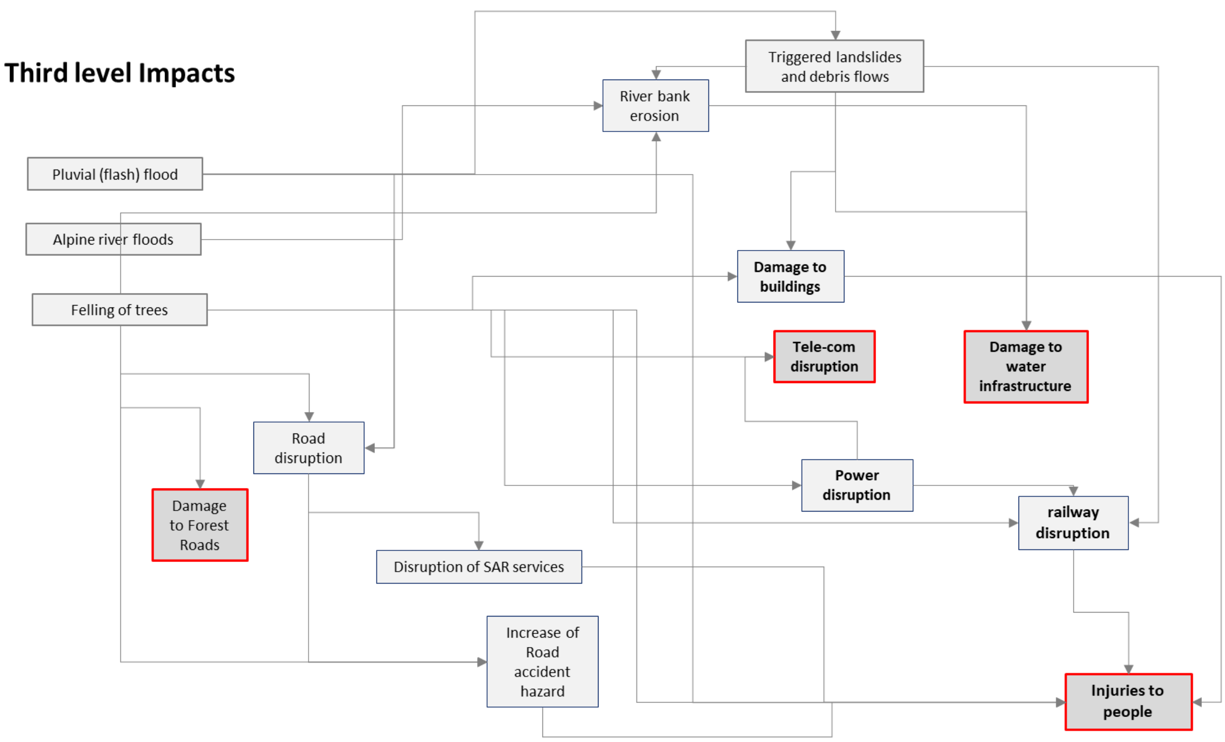
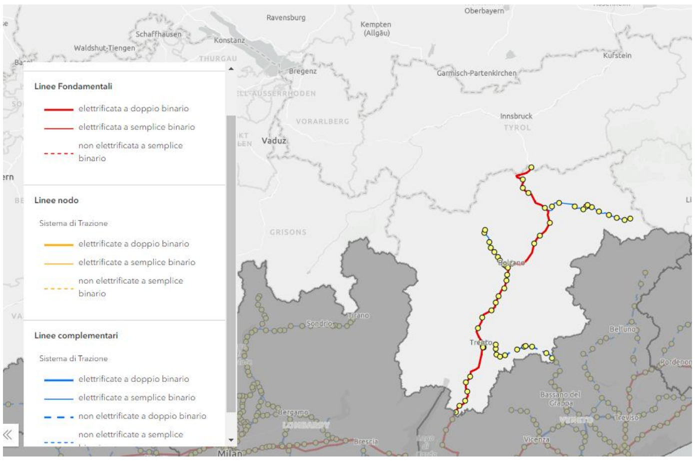


Figure 9 Third-level impacts

Further details on the specific impact pathways are provided in the Annex A.

3.1.5 Vulnerability

There is a number of vulnerability factors that play a role in influencing the impacts and possibly increasing the consequences of the considered hazard in events like the one considered in TRANS-ALP. Broadly, two type of factors can be addressed: *sensitivity* factors are intrinsic properties (e.g., of the exposed assets) that directly relate to their susceptibility to be damaged or otherwise adversely affected. These factors thus can directly increase the overall risk. For example, the topological vulnerability of railway and road networks in mountainous regions (e.g., related to the geographical constraints due to the shape of the valleys that decrease the redundancy of the network) are *sensitivity* factors (see Figure 10).



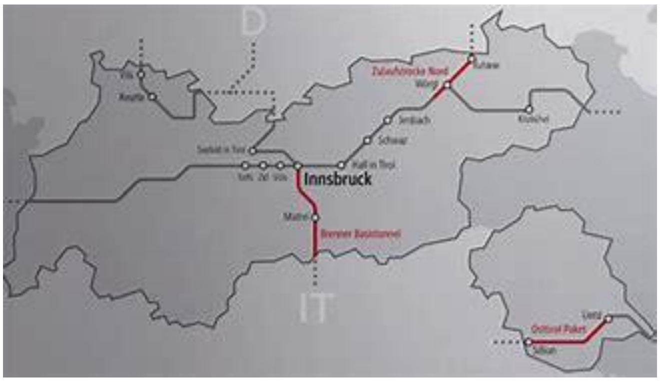


Figure 10 Left: Railway network in Trentino / Alto Adige and Veneto (source: Italian Railways), Right: railway network in Austria

Other sensitivity factors can, for instance, be related to the structural characteristics of residential building that make them more susceptible to damage from strong wind or landslides.
A different type of vulnerability is described as (lack of) *coping capacity*. This factor relates to structural weaknesses of the exposed communities that can amplify or worsen some of the considered impacts. For instance, insufficient management of forested areas can contribute to increase the risk by favouring conditions leading to larger windthrow, or lack of management of riverbeds can amplify the impacts related to floods. This categorization is useful to better structure the impact chains, and to foster a pragmatic discussion with experts and stakeholders, but of course is limited, as the complexity of vulnerability often exceeds such simplified schemes.

3.2 Conclusions

This document describes the application of the impact Chains methodology to the case of an extreme meteorological event in a cross border mountainous region. The impact chain methodology has been developed originally to describe complex impact pathways related to climate risks but can be efficiently applied to a different operational context oriented to DRR. In order to exemplify this methodology, a target event (storm VAIA) has been assessed, based on the information and data available on the related impacts and collected in the TRANS-ALP project. Based on this exemplification, a few main conclusions can be drawn:

1. Impact chains offer an efficient and intuitive method to conceptualize the complex interplay of factors that contribute to specific risks in the case of multi-hazard, multi-risk events (which is often the case for large-scale, cross-border storm events).

2. The approach, originally developed to analyse vulnerability in the case of climate risk, can be applied with almost no modification to the case of disaster analysis.

3. The main difference with the methodology originally proposed consists in the specific focus of the sole conceptualization phase. The aggregation phase (i.e., where indicators are associated to the considered factors, normalized and aggregated on a geospatial framework) has not yet been considered, since usually this phase only consider vulnerability and exposure factors, and may fall short in capturing the role of the different impacting mechanisms the vulnerability factors refer to.

4. Causal links between hazard and impacts and among intermediate impacts are relatively straightforward to be determined in most case, where there is sufficient availability of information collected by institutional and informal sources. While this is the case of the Storm Vaia, other relevant events have not been analysed with the same level of detail and thus their conceptualized would require more efforts and possibly the active participation of local domain experts.

5. All causal links explicitly appearing in the impact chains should be clearly described (e.g., in form of a table, as shown in the Annex A) complementing the graphical representation with a textual narrative part and other useful information, including for instance the underlying rationale (e.g., whether the specific causal link was based on expert evaluation, empirical evidence or literature source), the degree of confidence and any referencing to data and document substantiating the evidence of the link. This is paramount both to increase the sustainability and replicability of the approach and to favour an iterative refinement of the knowledge related to impact chains with potential further round of discussion with experts and stakeholder. A careful documentation also helps pointing out possible gaps in the related research (often in turn related to gaps in the underlying impact data collection).

6. A clear and comprehensive description of impact pathways, considering multiple hazards the interplay of impacts on the exposed assets and system is an innovative way to expose and conceptualize the numerous factors contributing to risk in the case of complex, intense events and their strong interdisciplinary nature. The intuitive and standardized graphical representation in form of a graph allows experts with different background domain expertise to share knowledge and could highly improve the risk minimization and adaptation activities, especially in cross-border applications. Furthermore, the consideration of impacts acting on different spatial and temporal scales and multiple layers of exposure could highly improve the “attribution” of impacts to root causes therefore improving the understanding and assessment of the overall “reach” of intense events in terms of medium and long-term consequences, which are highly probable in case of natural systems (e.g., related to ecosystem services and environmental impacts).

7. The conceptualization of the vulnerability component is still very challenging, with respect to the hazard and exposure ones. On the one side, this is due to the lack of underlying damage and loss data that are critical to inform quantitative sensitivity models. On the other side, large part of vulnerability factors are related to lack of capacity or to potential weaknesses in the management of socio-ecological systems. A more comprehensive analysis of these factors requires a tighter and committed collaboration of experts and stakeholders, and a new set of methodological tools to systematically collect information and support a pragmatic discussion. While certainly the use of impact chains can be of great help to foster and drive such discussion in the different regions impacted by intense events, further research is needed to complement the impact chain methodology with other approaches to appraise and compare the institutional and operational capacities (and lack thereof) and the specific ways such potential weaknesses could contribute to overall risk, with the overarching objective of devising efficient risk minimization and adaptation options.

8. Considering the highly probable link between extreme events like the VAIA storm, and the ongoing processes fueled by climate change, a further integration of Climate Change Adaptation (CCA) and Disaster Risk Reduction (DRR) methodologies and approaches is definitively needed. The use of such tools as the Impact Chains can be regarded as a practical step in this direction.

Note: In the Annex A at the end of this document further details are provided on the impact chains related to target risk 1: ‘loss of lives and properties’ in the context of VAIA Storm.

3.3 References

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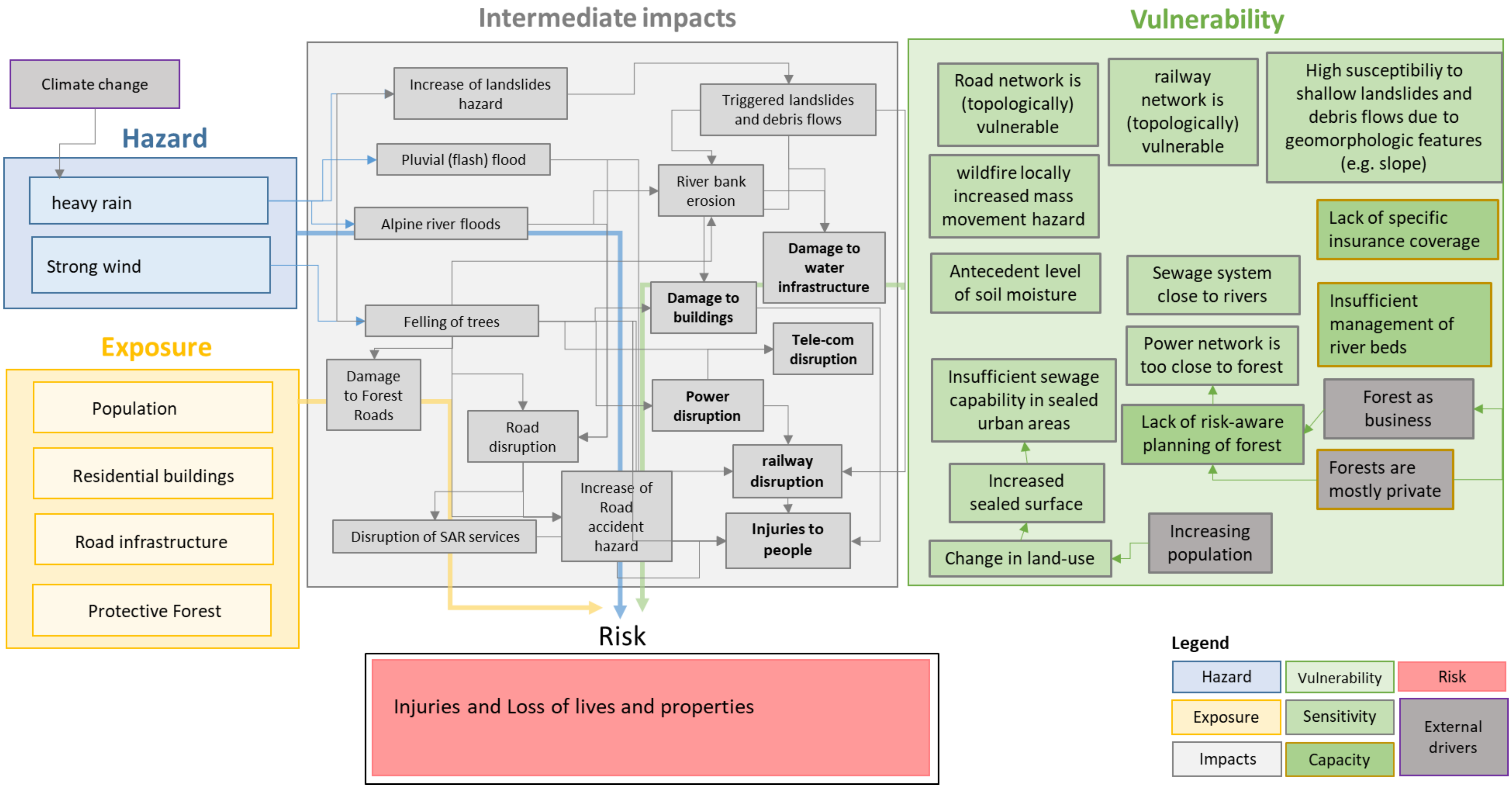
4 ANNEX A – IMPACT CHAINS



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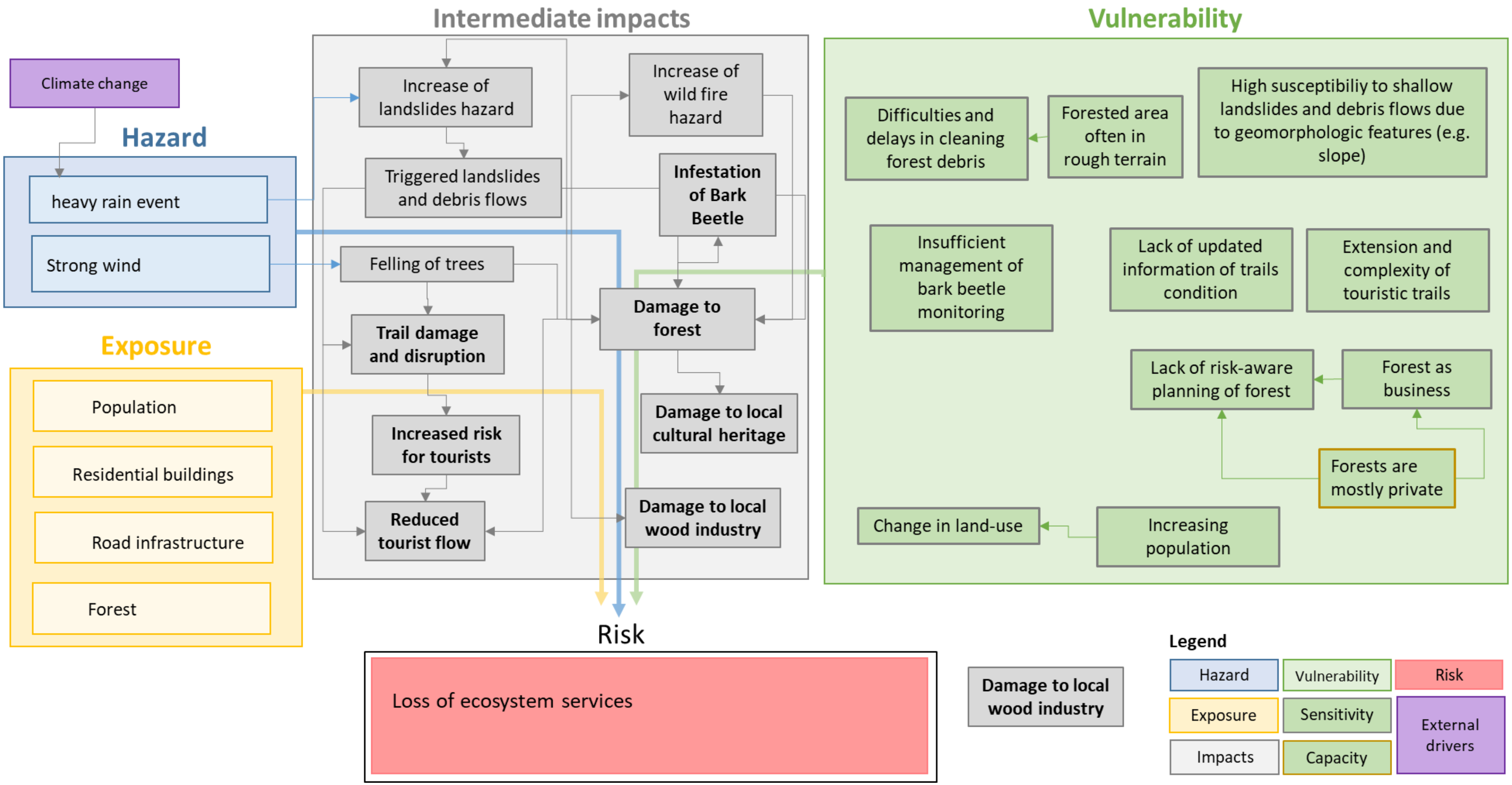
Depends on	Intermediate Impact	Exposed asset	Description	Link type	Source	Ref	Confidence	Research Gap
heavy rain	Increase of landslides hazard		heavy rains increase the susceptibility to different mass movements, especially shallow landslides and debris flows and increase unstability of slopes leading to rock-fall	Leads to	literature, expert		high	dnyamic susceptibility models are underway
Increase of landslides hazard	Triggered landslides and debris flows		due to high susceptibility and possibly depending on a series of thresholds, multiple events are triggered in a small time frame	leads to	literature, expert		high	This requires the transition from susceptibility to hazard, which is active research topic
River floods	River bank erosion		abrupt increase of river discharge and increased amount of sediments leads to sudden river bank erosion in correspondence to river turns. This erosion can happen abruptly and destroy areas adjacent to the river	Leads to	literature, expert, evidence		high	lack of data
River bank erosion	Damage to water infrastructure	water infrastructure	erosion of river banks can destroy water infrastructure buried close to the river	Leads to	evidence		high	lack of data
strong wind	Felling of trees (windthrow)	forest	Strong winds with gusts over a given threshold (e.g. 100k/h) can damage and often fell or uproot trees, also very old and big ones, over large areas.	Leads to	literature, expert, evidence		high	
Felling of trees (windthrow)	Damage to Forest Roads	road infrastruture	Forest roads can be damaged or interrupted by fallen and uprooted trees.	Leads to	evidence		high	lack of data
Felling of trees (windthrow)	Roads disruption	road infrastruture	Roads can be damaged or interrupted by fallen and uprooted trees.	Leads to	evidence		high	lack of data
Felling of trees (windthrow)	Power disruption	power infrastruture	Trees can fall over suspended high-voltage power lines leading to collapse of pylons and power outages	Leads to	evidence		high	lack of data
Power disruption	Railway disruption	railway infrastructure	power outage hinders functioning of railways infrastructure and trains	Leads to	literature, expert, evidence		high	
Felling of trees (windthrow)	increase of road accident hazard	people travelling	broken branches and entire felled trees can increase the hazard of roads accidents	Leads to	expert		low	more statistical analysis needed
Roads disruption	Disruption of SAR services		Blockage of roads can disrupt lifeline supports (e.g. ambulances) and other SAR services.	Leads to	expert		low	more statistical analysis needed
heavy rain	alpine river floods		heavy rains abruptly increase the discharge of alpine rivers leading to local floods	leads to	literature, expert, evidence		high	
heavy rain	Pluvial (flash) floods		heavy rains abruptly increase the water runoff, resulting in sudden floods, especially in urban areas characterized by sealed surfaces	leads to	literature, expert, evidence		high	
Triggered landslides and debris flows	Damage to buildings	residential and commercial buildings	mass movements can damage or even destroy buildings either by direct impact or by shear deformation of the soil	leads to	literature, expert, evidence		high	
Damage to buildings	Injuries to people	population	Damages to buildings can lead to injuries or fatalities, either due to debris falling or partial and total collapse	leads to	literature, expert, evidence		high	


Intermediate impacts
Vulnerability
Climate change
Hazard
heavy rain event
Strong wind
Exposure
Population
Residential buildings
Road infrastructure
Forest
Increase of landslides hazard
Triggered landslides and debris flows
Felling of trees
Trail damage and disruption
Increased risk for tourists
Reduced tourist flow
Increase of wild fire hazard
Infestation of Bark Beetle
Damage to forest
Damage to local cultural heritage
Damage to local wood industry
Difficulties and delays in cleaning forest debris
Forested area often in rough terrain
High susceptibiliy to shallow landslides and debris flows due to geomorphologic features (e.g. slope)
Insufficient management of bark beetle monitoring
Lack of updated information of trails condition
Extension and complexity of touristic trails
Lack of risk-aware planning of forest
Forest as business
Forests are mostly private
Change in land-use
Increasing population
Risk
Loss of ecosystem services
Damage to local wood industry
Legend
Hazard
Vulnerability
Risk
Exposure
Sensitivity
External drivers
Impacts
Capacity