Extended Partnership

Return

multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate

Spoke TS3 – Communities' resilience to risks: social, economic, legal and cultural dimensions

WP 7.2 – Innovative tools to evaluate risk mitigation effectiveness

T 7.2.3 – Tools for inclusive/participative decision making

Deliverable 7.2.3

An MCA procedure for evaluating the effectiveness of risk reduction strategies in multi-hazard environments

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1. Introduction to WP 7.2

In the context of the RETURN (multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate) project, the WP 7.2 "Innovative tools to evaluate risk mitigation effectiveness of the Spoke TS3 - Communities' resilience to risks: social, economic, legal and cultural dimensions", aims to establish national guidelines for evaluating the effectiveness of intervention alternatives in natural risk management.

The overall objective of WP7.2 "Innovative tools to evaluate risk mitigation effectiveness", is: "defining national guidelines for the evaluation of the effectiveness of alternatives of intervention in natural risks management, by considering in detail MCA tools".

The most relevant organizations involved in the decision-making process for natural risk management are civil protection, local authorities, and policy makers. Their fundamental role is to ensure the maintenance of the prosperity, security, and identity of communities before, during, and after the occurrence of natural hazard events. Yet, actions for improving the climate resilience of communities are not usually designed from a multi-disciplinary perspective, with an integration of the physical, economic, social, environmental, and cultural dimensions of the problem. Furthermore, to the extent of our knowledge, current practices are typically oriented towards a single risk approach with the different natural risks being addressed by different governmental agencies, each with specific priorities and preferences. For this reason, there is a need for the development of a risk-informed decision support system capable of evaluating, in a consistent and coherent way, the full range of natural hazard impacts on the natural and built environment, as well as the effect of multi-purposes intervention alternatives, through a multi-risk perspective.

To achieve this goal, we selected Multi-Criteria Analysis (MCA), among the several existing methodologies (e.g., cost-benefit analysis, cost-effectiveness analysis, life cycle assessment), as a supporting tool for the selection of effective strategies for natural risk management and climate change adaptation. This is because this type of analysis can enable decision-makers to integrate the multiple and often conflicting objectives of the various stakeholders involved in natural risk management into a structured framework, thus enhancing the effectiveness of group decisions in complex problems.

The work was divided into four main steps:

- Task 7.2.1: State of art on MCA applied to natural risk management
- Task 7.2.2: Problem definition
- Task 7.2.3: Tools for inclusive/participative decision making
- Task 7.2.4: *Pilot cases*

The work presented in this Deliverable correspond to Task 7.2.3 "Tools for inclusive/participative decision making" (see GANTT chart below).

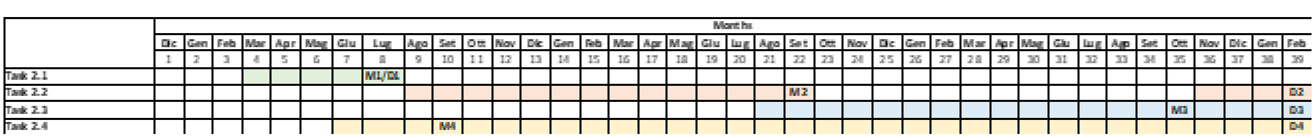

Figure 1 GANTT Chart of WP2

In Task 7.2.1, a flowchart to prioritize risk reduction strategies through MCA was developed. This process involved breaking down the problem into smaller parts: identifying intervention alternatives, recognizing stakeholders' objectives, defining evaluation attributes, selecting the appropriate MCA tool, and performing sensitivity analysis.

Task 7.2.2 focused on steps (i) and (iii) of the MCA flowchart, evaluating intervention alternatives for risk reduction in multi-hazard environments. Alternatives were characterized as an "Abacus of Measures," linking each with its potential risk changes for floods, landslides, drought, earthquakes, and volcanic activity, with the possibility to extend to other hazards. Additionally, a "Hazards-Impacts matrix" was developed to evaluate direct and indirect impacts on exposed elements due to hazard events, enabling the estimation of multi-risk reduction for specific alternatives.

Task 7.2.3 integrated the work of previous task through (i) defining additional evaluation criteria to fully comply with stakeholders' objectives, (ii) framing the MCA process by properly including all evaluation criteria and stakeholders' preferences, and (iii) supporting decision-makers with operational tools to assess the uncertainty and reliability of results.

2. Task 7.2.3: An MCA procedure for evaluating the effectiveness of risk reduction strategies in multi-hazard environments

This chapter introduces the rationale behind task 7.2.3, presenting the problem it poses itself to solve and its objectives. If further introduces to the task design and methodologies adopted in order to reach the results presented below.

2.1 Problem statement and task objectives

The tools developed in Task 2.2 provide a robust foundation for evaluating the risk reduction potential of mitigation measures within a multi-hazard context, forming the core of the Multi-Criteria Analysis (MCA) under development in WP 7.2.

However, in the current context of climate change and constrained resources, these tools can only address part of the complex challenge at hand. Today, effective risk mitigation requires the adoption of integrated strategies that simultaneously reduce risks across multiple hazards while promoting economic, social, and environmental sustainability. As a result, decision-making processes in risk management must extend beyond the evaluation of direct impacts on risk levels. They must also consider the broader range of benefits and trade-offs that proposed measures may bring to the affected communities, with the final aim of identifying win-win solutions.

The first objective of task 7.2.3 was then to comprehensively identify all the factors that should be influencing the selection of mitigating measures, beyond risk-reduction capabilities, and to characterize them in order to be properly included in the MCA evaluation process.

The second objective of the task was to integrate the identified evaluation criteria into the MCA procedure, which will serve as a decision-support tool for selecting appropriate mitigation measures. This requires identifying the MCA technique most suited to the problem at hand and defining methods to incorporate stakeholders' preferences and value judgments regarding how each evaluation criterion should influence the final decision.

Stakeholder participation is essential to ensure the acceptability of proposed measures and to anticipate and properly manage potential conflicts among different sectors of society. However, incorporating stakeholders' perspectives can increase the overall uncertainty that already affects the MCA process (mainly due to modelling choices and knowledge/data limitations) especially when stakeholders are numerous, diverse, and involved in complex or unresolved conflicts.

For this reason, the third objective of Task 7.2.3 is to conduct and systematize a comprehensive assessment of the uncertainties affecting the various components of the MCA, in order to evaluate the reliability of the results.

2.4 Task design and methodology

Task 7.2.3 was developed between October 2024 and November 2025, under the leadership of Politecnico di Milano and Eurac Research, and with the collaboration of all researchers involved into the Work Package 2. The task was initiated with a kick-off workshop hosted by Eurac Research in Bolzano on 28-29 October 2024. The results of the workshop (See Annex 1: Kick-off Workshop Report) set the basis to defining the work phases of the task, defining the allocation of expertise and resources, expected outputs and task design.

The research team was therefore divided in subgroups each actively engaging with one of the following phases that emerged from the workshop, according to task objectives:

1. definition of the “win-win attributes” to complete the process of evaluating mitigation measures;
2. definition of the procedural steps towards evaluating mitigation measures (by integrating evaluation attributes and stakeholder preferences);
3. identification of uncertainties within the procedural steps defined in Phase 2, and guidelines for addressing them.

All work groups have consulted with each other during various phases of the activity (see Table 1) to ensure that their outputs were mutually supportive. The results produced by Task 7.2.3 were applied and tested in Task 7.2.4 throughout the different phases of the activity (See dedicated deliverable).

Table 1 Timeline of the different phases of Task 7.2.3 in relation to Task 7.2.4

	2025			2026										
	October	November	December	January	February	March	April	May	June	July	August	September	October	November
Phase 1: win-win attributes														
Phase 2: procedural steps														
Phase 3: uncertainties														
PoC (presented in DV 7.2.4)														

Each one of the three phases introduced above is addressed and explored in detail in the following chapters (See Chapter 3, Chapter 4 and Chapter 5).

3. Evaluation criteria for mitigating measures

The initial stage of Task 7.2.3 entailed a thorough analysis of factors that should be influencing the selection of mitigating measures. This included evaluating the criteria for their applicability, assessing potential secondary impacts, and considering the broader consequences of implementation on real-world systems, while taking into account the involvement of multiple stakeholders and layers of government decision-making. We recognize that mitigating measures are often designed with the primary goal of addressing specific hazards; however, their effects frequently extend beyond simply reducing risk. To help decision makers gain a clearer understanding of how to evaluate a measure beyond its immediate purpose, we propose a tool that breaks down the various implications associated with implementing each measure.

This work led to the identification of additional considerations for evaluating disaster risk mitigation measures, ensuring that all relevant variables and impacts beyond risk reduction are addressed. For example, implementing an infrastructural measure to reduce flood risk in peri-urban areas may have unintended environmental or social effects. A careful analysis of benefits and drawbacks is necessary to determine whether the measure adequately compensates for any potential negative outcomes. It is also important in order to provide clear guidance for decision makers and MCA users to facilitate the consideration of all implications beyond primary risk mitigation goals.

Launched during the kick-off workshop, this activity systematically examined the potential implications of each measure identified in the abacus (see Deliverable 7.2.2). The team collaboratively brainstormed possible effects from multiple perspectives, considering impacts beyond the immediate objectives of each measure. Potential side effects, such as those related to environmental factors, local finances, cultural assets, and societal issues, were identified and further developed through group discussions that drew on the diverse expertise of the participating researchers. Additionally, the process led to the emergence of other evaluating criteria that should be taken into account while evaluating a measure. All resulting evaluating criteria are presented below, together with the process that led to their delineation and categorization as such.

Evaluation criteria for mitigating measures have been categorized into two principal types: (a) intrinsic qualifying characteristics of the measure, and (b) secondary impacts on other domains. These typologies were established as the process highlighted essential considerations that must be addressed when determining the appropriateness of implementing a mitigating measure. The first type comprehends all characteristics that relate to the implementability and reliability of the measure under assessment (See Figure 2). The second type includes all possible side impacts that the implementation of a mitigating measure could have on other domains. These effects may be direct or indirect, and can be favourable or unfavourable, offering supplementary benefits that provide multifunctionality, or potentially diminishing other values in exchange for reduced hazard risks (See Figure 2).

The figure below summarizes the evaluating criteria that emerged at this phase:

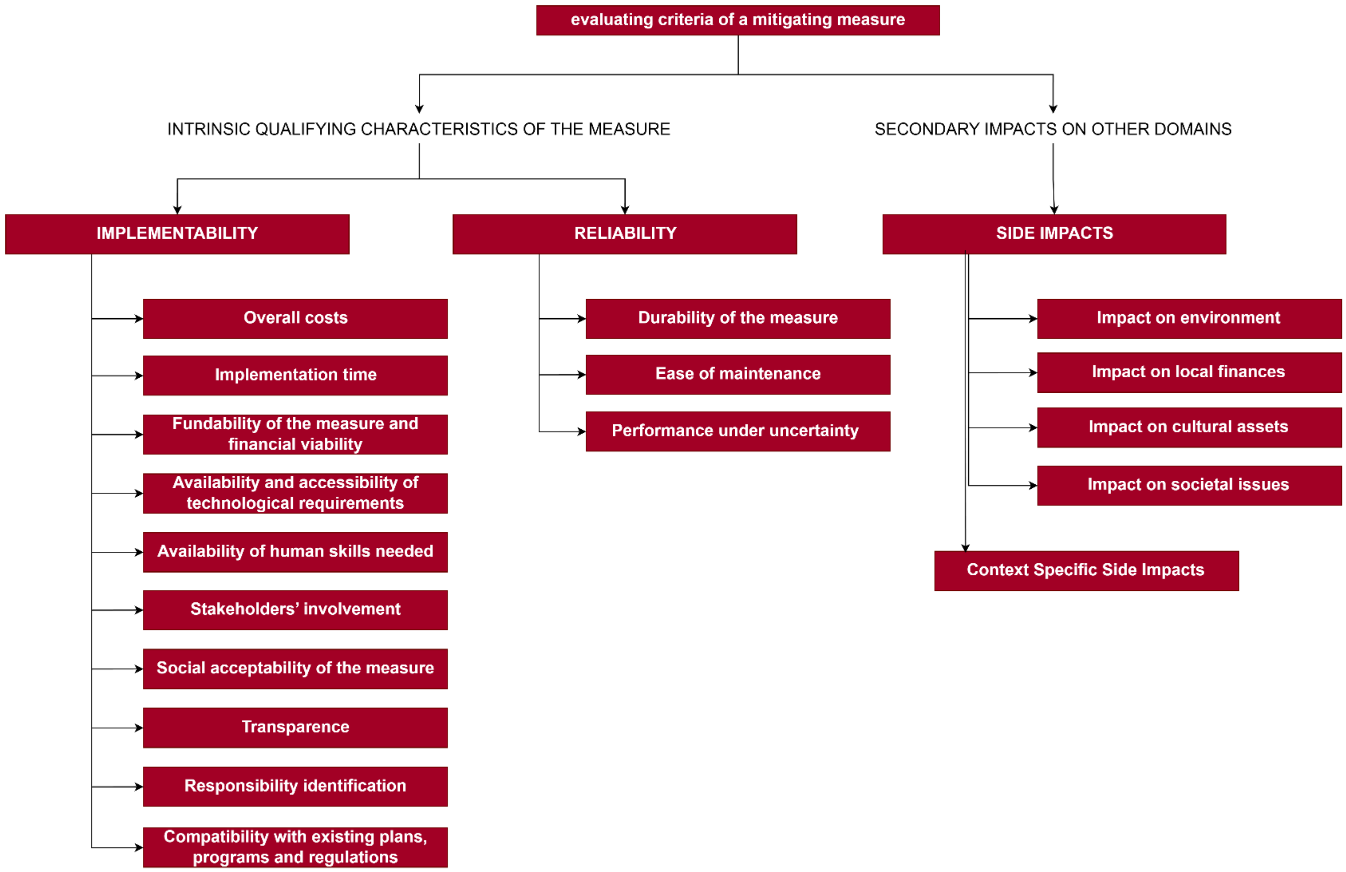

Figure 2 Overview of the evaluating criteria for mitigating measures.

3.1 Intrinsic qualifying characteristics of the measure

The typology of evaluation criteria, encompassing the intrinsic qualifying characteristics of a mitigating measure, has been further refined by the research team. The framework for assessment is structured as follows:

- **Attribute:** The principal dimension or characteristic used to evaluate the performance or effectiveness of the mitigating measure.
- **Sub-attribute:** A secondary or component element of an attribute, applied when the attribute is multidimensional and its full significance emerges only through the aggregation of its constituent parts.
- **Description:** A concise definition specifying the conceptual meaning and scope of the attribute or sub-attribute.
- **Indicator:** A measurable variable or set of variables that quantitatively or qualitatively express the state, performance, or behaviour of the attribute or sub-attribute.
- **Unit of Measure:** The standardized unit or qualitative scale used to express the indicator's value.

- **Model:** The analytical or computational framework through which the indicator is interpreted, and the attribute is assigned meaning (e.g., empirical model, simulation, or theoretical construct).
- **Input Data:** The specific datasets, parameters, or empirical observations required for calculating or estimating the indicator.
- **Reference:** The bibliographic or documentary sources that justify the methodological choices or provide data, parameters, or theoretical foundations for the assessment.
- **Comments:** Additional notes highlighting methodological assumptions, data limitations, or considerations relevant to the interpretation of results.
- **Aggregation Criteria for Attribute:** The procedure or rule by which sub-attributes are combined to produce a single representative value or judgment for the corresponding attribute (e.g., weighted averaging, normalization, or multi-criteria integration).

Both evaluating criteria linked to the **implementability** and **reliability** of a measure are further explained below.

3.1.1 Implementability

This category encompasses the fundamental enabling conditions that determine whether a mitigating measure can be effectively implemented, operated, and sustained over time. It examines the economic, financial, technical, institutional, and social factors that influence feasibility, focusing on the practical requirements and contextual constraints within which the measure must function.

The analysis considers not only the direct and indirect costs of implementation but also the availability of financial resources, technological readiness, human capacities, and institutional coordination mechanisms necessary for success. Furthermore, it assesses stakeholder involvement, social acceptance, and the alignment of the measure with existing regulatory and planning frameworks, recognizing that these aspects are essential for long-term viability and public legitimacy.

Identified attributes and sub-attributes are the following:

- **[attribute] Overall Costs:** Refers to the total economic burden associated with the implementation, operation, and maintenance of the measure, considering both direct and indirect expenditures.
    - **[sub-attribute] Implementation Costs:** Encompasses all expenditures required for the realization of the measure, including design, materials, construction or installation, commissioning, and acquisition of necessary technologies and expertise. Both direct and indirect costs should be included.
    - **[sub-attribute] Maintenance Costs:** Covers the recurring expenditure required to ensure the continued operation and effectiveness of the measure, including routine maintenance, repairs, replacements, and system upgrades.

- **[attribute] Implementation Timeframe:** Assesses the temporal dimension of the measure's implementation and operationalization, accounting for both construction and functional effectiveness phases.
    - **[sub-attribute] Implementation Duration:** Refers to the total time required to complete the implementation process, from project commissioning to full deployment.
    - **[sub-attribute] Time to Full Effectiveness:** Represents the period required for the measure to achieve its intended level of performance or impact, recognizing that implementation costs are typically concentrated in the early project phases while benefits accrue progressively over time.
- **[attribute] Fundability and Financial Viability:** Evaluates the overall capacity of a mitigation measure to be implemented from a financial perspective, considering both short-term funding readiness and medium-term financing feasibility. The concept is further divided into sub-attributes focusing on the short-term availability of funds and the potential of the measure to attract funds from different sources in the medium to long-term.
    - **[sub-attribute] Fundability (Short-Term Availability):** Assesses the immediate availability and accessibility of financial resources required for the implementation of the measure. This includes: secured public budgets (municipal, regional, national), confirmed grants or appropriations, readiness to draw down funds (procurement plans, cash-flow authorizations), coverage of operation and maintenance (O&M) costs (B. Love, 2007; P. E. D. Love et al., 2016; Volden, 2019).
    - **[sub-attribute] Bankability (Medium-Term Financing Feasibility):** Examines the measure's potential to attract financing from public, private, or blended sources, based on financial viability metrics (FIRR/EIRR, NPV, payback period), market/funder interest (EOIs, term sheets, eligibility for funding calls), instrument fit and concessionality (alignment with OECD DAC principles), risk allocation quality (construction, demand, O&M risks), co-financing leverage and fiscal affordability (Chua, 2018; Muellner, 2017; Rasheed et al., 2022).
- **[attribute] Availability of Technological Requirements:** Evaluates whether the technologies, equipment, or infrastructure necessary for implementing and maintaining the measure are accessible, reliable, and compatible with local technical capacities.
- **[attribute] Availability of Human Skills:** Assesses whether the technical and managerial competencies required for planning, implementing, and operating the measure are available locally or can be feasibly developed through training or recruitment.
- **[attribute] Stakeholder Involvement:** Examines the degree and quality of engagement of key stakeholders throughout the measure's lifecycle. This includes assessing the number, diversity, and influence of involved actors, as well as the manageability of their interactions and contributions to the implementation process.

- **[attribute] Social Acceptability:** Evaluates public and stakeholder support for the measure and the potential for conflict during planning or implementation.
    - **[sub-attribute] Public Acceptance / Vertical Conflict:** Assesses the likelihood of opposition or resistance from the general public, communities, or affected groups during planning or implementation.
    - **[sub-attribute] Stakeholder Agreement / Horizontal Conflict:** Evaluates the potential for disagreements, coordination issues, or conflicts among stakeholder groups involved in or affected by the measure.
- **[attribute] Transparency and Communication:** Assesses the clarity, openness, and adequacy of communication processes related to the measure's planning, implementation, and monitoring. It examines the existence, accessibility, and effectiveness of communication strategies and public information mechanisms, ensuring that stakeholders are well informed and can participate meaningfully.
- **[attribute] Responsibility Identification:** Evaluates clarity of institutional roles and coordination among responsible entities.
    - **[sub-attribute] Clarity of Responsibility Assignment:** Assesses whether all actions have clearly assigned responsible actors.
    - **[sub-attribute] Coordination among Responsible Actors:** Examines coordination and consistency among responsible entities, identifying overlaps or conflicts.
- **[attribute] Compatibility with Existing Plans, Programs, and Regulations:** Evaluates the degree to which the measure aligns with, complements, or potentially conflicts with existing policy, planning, and regulatory frameworks. It examines the consistency of the measure with current strategic plans, sectoral policies, and legal instruments (e.g., environmental management, land use, infrastructure development). This includes identifying synergies, overlaps, or conflicts with existing frameworks and assessing potential regulatory implications.

3.1.2 Reliability

The **reliability** of a measure refers to its capacity to perform effectively and sustainably over the long term. This encompasses its **durability**, **maintainability**, and **flexibility** in the face of evolving environmental, technical, and socio-economic conditions. Reliability also considers the measure's **adaptability** and **reversibility**, particularly in the context of decommissioning or project closure.

- **[attribute] Durability of the measure:** Refers to the expected operational lifespan of the measure, particularly relevant for structural interventions. It considers material resistance to degradation, exposure to environmental stressors, and the anticipated frequency and complexity of maintenance activities needed to preserve functionality over time.

- **[attribute] Ease of maintenance:** Evaluates the practicality and technical feasibility of carrying out regular and extraordinary maintenance operations. This attribute depends on the design characteristics of the measure, accessibility of components, availability of required tools or expertise, and the frequency, duration, and cost of maintenance interventions (ISPRA, 2016).
- **[attribute] Performance under uncertainty (composite attribute):** A composite attribute combining **adaptability**, **reversibility**, and **no-regret capacity** to assess the overall flexibility and robustness of the measure under uncertain future conditions. Uncertainty may arise from climate change and climate variability, environmental changes, technological developments, or socio-economic transformations. These sub-attributes become particularly relevant when assessing risk mitigation measures aimed at addressing climate-related hazards, such as floods, heatwaves or landslides. Although knowledge on climate change expected scenarios and their associated impacts is increasing, there is growing evidence that improved knowledge does not necessarily lead to narrower climate projection, and uncertainty is not going to disappear. Thus, probabilities cannot be reliably assigned to characterize future conditions and these attributes become particularly important for identifying effective measures, reducing the waste of economic resources and enhancing the sustainability of selected coping strategies (Hallegatte, 2009).
    - **[sub-attribute] Adaptability of the measure:** Assesses the capacity of the measure to adjust to changing environmental, climatic, or societal conditions without incurring excessive costs or operational disruptions. A highly adaptable measure can be modified, upgraded, or scaled as scenarios evolve, while a rigid measure may entail significant additional costs or reduced effectiveness (Hallegatte, 2009; ISPRA, 2016).
    - **[sub-attribute] Reversibility of the measure:** Evaluates the potential to dismantle, deactivate, or decommission the measure at reasonable cost and with minimal environmental or social impact (Baills et al., 2020). This includes the presence of design features enabling reversibility and adequate plans for closure, disposal, or site restoration, particularly for temporary or time-limited measures. On the contrary, irreversible measures generate significant over-costs if abandoned or simply cannot be abandoned. Reversibility is particularly relevant when decision-makers are dealing with highly uncertain environmental and socio-economic conditions, which may lead to a waste of economic resources and to maladaptation to the effects of climate change (Hallegatte, 2009).
    - **[sub-attribute] No-regret capacity:** Refers to the extent to which the measure produces benefits across a wide range of possible future conditions, including those without significant climate change impacts. The United Kingdom Climate Impacts Programme (Willows and Connell, 2003) defines no-regret adaptation options (or measures) as: "*options (or measures) that would be justified under all plausible future scenarios, including the absence of human-induced climate change*". De Bruin et al (2009) analyse no-regret options when presenting criteria to assess climate change adaptation measures, and define no-regret measures as those whose non-climate related benefits, such as improved air quality, exceed the costs of implementation: hence they will be beneficial irrespective of future climate change taking place. Thus, a no-regret measure performs effectively under current

conditions and remains advantageous regardless of the projected future scenarios, minimizing the risk of maladaptation or resource inefficiency. A measure that is not rated as "no regret" will generate significant additional costs if applied in climatic conditions that differ from those for which it was designed (Baills et al., 2020).

3.2 Secondary impacts on other domains

This section investigates the impacts of the measure beyond its mitigating purpose. It provides a detailed definition of the types of side impacts that must be considered when assessing the appropriateness of a mitigating measure. To ensure that indirect or secondary effects are not overlooked, the framework distinguishes among different spheres of impact, each encompassing a set of specific (direct) impacts that reflect the immediate consequences of a structural or non-structural measure within that sphere. In addition, the framework introduces the concept of cascading consequences, which represent the systemic or cross-sectoral effects that arise from direct impacts, enabling decision-makers to identify and account for less obvious or long-term implications of each measure.

Many of the evaluation criteria listed in the previous two characteristics are also linked to the evaluation criteria listed below, highlighting the interconnectedness of these factors. It is important to recognize that all impacts, whether direct, indirect, or cascading, can be either positive or negative depending on the context in which the measure is applied. Therefore, a comprehensive assessment must account for the full spectrum of potential outcomes, ensuring that both beneficial and adverse effects are considered.

The structure for evaluating impacts is organized as follows:

- **Sphere of Impact:** The broad domain or category affected by the measure (divided into environmental, financial, cultural, social).
- **Attribute:** A key aspect within the sphere of impact that could be impacted by the measure.
- **Sub-attribute:** A component or dimension of an attribute, applied when the attribute comprises multiple interrelated factors that must be evaluated jointly to capture its full significance.
- **Description:** A concise statement defining the meaning, scope, and relevance of the attribute or sub-attribute within the assessment framework.
- **Indicator:** A quantitative or qualitative variable used to measure or represent the magnitude, direction, or quality of the impact associated with the attribute or sub-attribute.
- **Unit of Measure:** The standard measurement unit or evaluative scale used to express the indicator's value.
- **Model:** The analytical, statistical, or conceptual framework employed to interpret the indicator and quantify or qualify the associated impact.
- **Input Data:** The empirical, observational, or modeled datasets required to compute or estimate the indicator.

- **Reference:** The relevant literature, methodological guidelines, or empirical sources supporting the choice of indicators, models, or data.
- **Comments:** Supplementary notes highlighting uncertainties, data limitations, methodological assumptions, or interpretive considerations relevant to the assessment.
- **Cascading Impacts:** The secondary or systemic consequences resulting from direct or indirect impacts of the measure, typically extending across multiple spheres of impact or over longer temporal scales.
- **Aggregation Criteria for Single Attribute:** The method or rule used to synthesize multiple sub-attributes into a composite value or judgment for a given attribute (e.g., normalization, weighting, or scoring).
- **Aggregation Criteria for Whole Sphere:** The overarching procedure for integrating the evaluated attributes within a sphere into a comprehensive representation of its overall impact, supporting comparative analysis and prioritization across spheres.

For what concerns economic impacts, a distinction is made between economic impacts within specific spheres and identified as cascading consequences (e.g. impacts on agriculture within environmental sphere, or inequality impacts as a consequence in societal issues), and macro-economy. Macroeconomics approach looks into these sectoral impacts from a systemic point of view. It examines economy-wide phenomena such as inflation, price levels, rate of economic growth, national income, gross domestic product (GDP), and changes in unemployment. Macroeconomists develop models to explain the relationships between these factors and use these models to aid in constructing and evaluating economic, monetary, and fiscal policy. While this guideline to evaluate the side impacts of a measure does not provide models of evaluation of macroeconomic variables, it still provides insights into the potential impact that a measure could have at a broader level.

These spheres of impact and specific impacts have been identified taking into account both structural and non-structural measures.

3.2.1 Environment

The sphere of impact on "environment" evaluates how a measure can have significant impacts on the surrounding environment, with cascading consequences on societal wellbeing as the relationship between people and environment changes, with consequences on safety and economy.

- **[attribute] Impact on soil:** Evaluates how a mitigation measure affects soil structure, fertility, erosion, and contamination levels. Negative effects could include soil degradation or compaction; positive ones might include improved drainage or erosion prevention (Hamidov et al., 2018).
- **[attribute] Impact on noise:** Considers noise or acoustic disturbances in urban, rural, and protected areas (Sordello et al., 2019) that can result from the measure's implementation (e.g., construction noise, operational sound emissions).

- **[attribute] Impact on pollution:** Measures the extent to which the mitigation action increases or reduces pollution in natural ecosystems such as air, water, and soil.
    - **[sub-attribute] Impact on air quality:** Evaluates emissions of pollutants (e.g., particulate matter, nitrogen oxides, VOCs, CO_2) and how these influence ambient air quality; requires comprehensive assessment of all pollutants (Huang et al., 2025).
    - **[sub-attribute] Impact on water:** Examines potential contamination or improvement of surface and groundwater quality, including runoff, chemical discharge, or sedimentation changes (Enríquez-de-Salamanca et al., 2017).
    - **[sub-attribute] Impact on soil:** Focuses on localized contamination or remediation effects on soil composition, nutrients, and biological activity.
- **[attribute] Impact on GHG:** Assesses the measure's effect on greenhouse gas emissions or sequestration capacity, influencing the area's carbon footprint (Mayer, 2025).
- **[attribute] Impact on biome and biodiversity:** Evaluates consequences on flora and fauna diversity across ecosystems (marine, riverine, and forest). Includes potential habitat loss, species migration, or positive restoration impacts.

3.2.2 Local finances

The sphere of impact on "local finances" addresses the direct and indirect effects of mitigation measures on local financial systems, focusing on how these measures influence resource allocation, fiscal stability, and economic efficiency.

- **[attribute] Release of Financial Resources:** Mitigation measures reduce emergency and contingency planning costs, enabling the reallocation of financial resources to other sectors, programmes or public policies (Federal Emergency Management Agency (FEMA), 2018; Rose & Liao, 2005).
- **[attribute] Impact on Public Finances (Public Debt Sustainability):** Mitigation measures influence the sustainability of local public debt by reducing disaster-related expenditure or, conversely, increasing debt through upfront investments (Barro, 1979; Ghesquiere & Mahul, 2010; Organisation for Economic Co-operation and Development (OECD), 2013).
- **[attribute] Impact on Opportunity Costs:** Evaluates the economic efficiency of mitigation measures compared to alternative uses of public funds (trade-offs), based on avoided losses and upfront costs (Bellaver et al., 2025; ISPRA, 2013; Mechler, 2016; Mechler et al., 2010).
- **[attribute] Capital Utility (CU):** Mitigation measures can alter property and asset values by reducing perceived or actual risk, affecting municipal revenue streams (e.g., areas no longer classified as high-risk may experience property appreciation) (Bellaver et al., 2025; Bin & Landry, 2013).

3.2.3 Cultural Assets

The sphere of impact on “cultural assets” sees how measures can have significant impacts on tangible and intangible heritage, cultural landscapes , and local identity (Jones & Pappas, 2023), influencing tourism, craftsmanship, community continuity, and wellbeing (Pereira et al., 2020).

- **[attribute] Changes on cultural landscape:** Examines how mitigation alters the visual, functional, or symbolic characteristics of landscapes that embody cultural meaning (e.g., rural terraces, historical urban areas).
    - **[sub-attribute] Cultural Landscape Land Cover Change:** Cultural landscapes are “living landscapes shaped by human activity”, and their loss can result in significant impacts on community resilience (Shirvani Dastgerdi & Kheyroddin, 2023). This sub-attribute evaluates potential alterations in land cover or land use patterns (e.g., transformation of agricultural terraces, grazing areas, or historical land-use mosaics) resulting from the measure.
    - **[sub-attribute] Continuity of Traditional Practices:** Traditional measures evolve over time and constant interaction between local communities and their living environment, and are result of centuries of trial-and-error (Ghani, 2020). This sub-attribute assesses whether the measure supports or erodes traditional cultural activities (e.g., transhumance, local festivals, seasonal rituals) that shape the landscape’s identity.
    - **[sub-attribute] Market Value of Local Products:** Measures how the intervention influences the economic and symbolic value of traditional products (e.g., crafts, crops, artisanal goods) tied to the cultural landscape and community livelihood.
- **[attribute] Intangible heritage:** Considers potential effects on traditions, languages, practices, and social customs that define community identity and continuity. Consistent transmission of intangible heritage has been widely recognized as crucial for community resilience (e.g. Kitamura, 2021; Pomeroy & Tapuke, 2016). It evaluates the quality of cultural expressions and ceremonies, assessing whether local festivals, ceremonies, and other cultural events are supported, transformed, or hindered by the measure (e.g., through access, participation, or funding changes).
- **[attribute] Impact on physical cultural heritage:** Evaluates effects on monuments, archaeological sites, historic buildings, and artifacts that may face risk from mitigation activities or benefit from protective measures. It measures the potential physical and economic impacts (positive or negative) of the measure on cultural heritage sites (such as preservation, restoration, or damage risk) and their contribution to local value chains.

3.2.4 Societal Issues

The sphere of impact on societal issues sees how mitigation measures (both structural and non-structural) can alter societal dynamics, affecting relationships, equity, trust, and civic safety through changes in governance and public interaction.

- **[attribute] Impacts on community cohesion:** Looks at how a measure influences community relationships, solidarity, and sense of belonging. Indirect effects can be observed through shifts in participation rates or social networks (*Global Social Progress Index*, n.d.; IndiKit, n.d.-b). E.g. relocation of people can influence social capital of a given community and of a given area, influencing connection between community members but also individual well-being (Abu et al., 2024; Hikichi et al., 2017).

- **[attribute] Impact on trust between institution and community:** Trust is intended as person's belief that another person or institution will act consistently with their expectations of positive behaviour" (OECD, 2017b). Mitigation processes can strengthen or weaken this trust depending on responsiveness of institutions, inclusiveness, transparency, and outcomes. The way in which mitigation measures are selected and implemented can influence citizens' perceptions of institutional performance, as well as their risk perceptions and the acceptability of risk communication (Ataç-Studt, 2025; Hanna et al., 2021). Indicators for analysis have been identified in the Good Governance indicators kit (IndiKit, n.d.-a)

- **[attribute] Impact on illegal activities (e.g., corruption):** Uses corruption rate or related metrics as proxies to assess whether measures increase transparency or create new opportunities for illicit behaviour. Post-event reconstruction, especially large-scale interventions, could unintentionally create conditions for infiltration of organized crimes. The increased presence of organized crime could have negative repercussion on social capital as well as in trust dynamics between citizenship and institutions (Alexander, 2017; Ha, 2023; Zafar et al., 2023). It's evaluated upon investigating the number of structural mitigation measures that have been halted due to proceedings for mafia infiltration or corruption.

- **[attribute] Impacts on social equity and justice:** Evaluates how measures affect distribution of benefits and burdens among social groups, especially vulnerable populations, through indicators of deprivation, inclusion, or accessibility. This variable summarizes the aspects mentioned in the previous attributes, placing the attention of how mitigation process can alter social dynamics among groups. Considering how a mitigation measure impacts social equity and justice, aligns with the call from the latest IPCC reports (IPCC, AR6 WGII) that stress the importance of placing equity and justice as central when evaluating mitigation and adaptation processes (Intergovernmental Panel On Climate Change (Ipcc), 2023; Juhola et al., 2022; Mach & Siders, 2021). It's evaluated based on the effect on equity and trust.

3.3 Context Specific

Some side impacts may only be applicable in certain areas. These attributes are context-specific and may be particularly relevant for individual case studies. When deemed pertinent and applicable, they can be considered as additional factors that enhance or streamline the decision-making process for a specific measure.

3.3.1 Existing infrastructure and built environment

The sphere of impact on existing infrastructure and built environment addresses how a measure could directly or indirectly produce positive impacts on pre-existing infrastructure and the built environment by reinforcing, complementing, or relieving stress on existing systems.

- **[attribute] Positive or Negative Externalities on Existing Infrastructure:** Identifies whether the mitigation measure generates beneficial or negative spillover effects on critical infrastructure or other mitigation interventions in the area.
    - **[sub-attribute] Synergies with Critical Infrastructure:** Evaluates how the measure supports, protects, or enhances the performance and resilience of critical systems (e.g., utilities, transport, communication networks).
    - **[sub-attribute] Compatibility with Other Mitigation Measures:** Assesses the degree to which the intervention aligns or integrates with pre-existing or planned mitigation strategies, ensuring consistency and efficiency in resource use.

3.3.2 Human health

The sphere of impact on human health focuses on the direct impacts (positive or negative) that a mitigation measure can have on human health. These impacts are direct consequences of the measure's implementation and independent from effects captured under environmental, societal, or cultural categories.

- **[attribute] Direct Health Impacts:** Examines measurable consequences of the measure on individual and public health.
    - **[sub-attribute] Physical Health Effects:** Evaluates impacts such as changes in exposure to pollutants, noise, or physical hazards that may affect respiratory, cardiovascular, or general physical well-being.
    - **[sub-attribute] Mental and Psychological Wellbeing:** Considers changes in perceived safety, stress, and quality of life resulting from implementation (e.g., improved safety infrastructure reducing anxiety).
    - **[sub-attribute] Public Health Service Demand:** Assesses shifts in healthcare needs (positive or negative) linked to the measure's outcomes (e.g., reduced injury rates or increased need for specialized monitoring).

3.3.3 Social issues (context specific)

The sphere of impact on social aspects sees how a mitigation measure can influence demographic dynamics and population trends. By identifying which trends are critical for the area (e.g., depopulation, overpopulation, aging population), it is possible to forecast whether and how a measure affects those dynamics, positively or negatively (Hudson et al., 2022).

- **[attribute] Impacts on Demographic Dynamics:** Measures how the intervention influences population distribution, migration, or structure.
    - **[sub-attribute] Population Retention and Attraction:** Evaluates whether the measure supports the stabilization of population levels or encourages migration to or from the area.
    - **[sub-attribute] Age Structure and Workforce Balance:** Assesses effects on age composition (e.g., young population retention, aging trends) and related economic and social implications.
    - **[sub-attribute] Urban-Rural Population Distribution:** Looks at how the measure impacts settlement patterns, such as concentration or dispersion of population across urban and rural zones.

3.3.4 Local capacities

The sphere of impact on local capacities evaluates whether the implementation of a mitigation measure may lead to significant changes in local skills, institutional capacity, and community readiness required for its implementation and long-term management.

- **[attribute] Education and Territorial Awareness:** Examines how the measure enhances understanding of local territory, risk awareness, and preparedness through education and outreach. It's evaluated through the number of educational programs or workshops implemented about the local context (including those related to intangible heritage) and impacted by the measure. It helps assessing the integration and transmission of territorial knowledge that enables informed decision-making and stewardship.
- **[attribute] Upskilling and Competence Improvement:** Focuses on the measure's contribution to developing or improving local professional and technical skills needed for implementation and maintenance. It's evaluated by assessing the number of competency-based trainings (including those related to intangible heritage) potentially impacted by the measure, and it measures the creation or enhancement of skill-building initiatives (training programs, workshops, certifications).
- **[attribute] Digital Literacy:** Evaluates how the measure supports digital readiness, use of digital tools, and access to data systems for managing or monitoring the intervention. It assesses improvements in local ability to use digital platforms for communication, coordination, or decision support, based on the number of individuals trained in digital tools and platforms.

3.3.5 Financial systems (context specific)

The sphere of impact on financial system (context specific) comprehends those indicators that apply primarily at higher administrative or economic scales (e.g., regional or municipal), to be assessed case-by-case based on the area's economic dimension (GDP, surface, population, or reach).

- **[attribute] Impact on Credit Rating:** Evaluates how the measure affects regional or municipal creditworthiness through perceived financial stability, fiscal sustainability, or risk mitigation outcomes. Upon assessing the change in regional/municipal credit score, it measures shifts in the assessed credit rating post-implementation, reflecting improved or diminished fiscal resilience.

- **[attribute] Impact on Insurance Resilience and Financial Stability:** Considers how the measure modifies exposure to risk for insurers and policyholders, potentially reducing premiums or improving coverage conditions. It examines whether risk reduction allows for greater insurance coverage or lower premiums across the affected area.
- **[attribute] Impact on Business Resilience and Economic Continuity:** Evaluates the measure's influence on local and regional economic systems' ability to maintain continuity during and after adverse events. It assesses the capacity of businesses to sustain activity or recover quickly following disruptions, due to benefits from the mitigation measure.

4. Procedural steps for technical evaluation of a measure

The objective of this activity was to structure the MCA procedure for the evaluation of risk mitigation (or reduction) alternatives, by detailing all its procedural steps, starting from the objectives and corresponding evaluation attributes identified in Task 7.2 and in the first part of Task 7.3 (see Chapter 3).

This required:

- defining at which step of the procedure each attribute should be considered
- defining how the different evaluation attributes should be combined or integrated, identifying the most appropriate MCA techniques to be implemented
- defining when and how stakeholders' values and preferences should be incorporated

Given the nature of the problem (i.e., comparing alternative intervention measures to select the most appropriate one), we adopted a classical MCA approach (Keeney et al., 1979). In this framework, each alternative that is not discarded during a preliminary screening phase (discarding criteria were defined within the procedure) is assigned a score representing its overall performance across all relevant attributes, thereby producing a complete ranking of alternatives.

To compute the overall score of each alternative, attributes/indicators are first homogenized through utility functions and then combined using weights defined through participatory processes involving all relevant stakeholders.

Considering that the evaluated measures primarily aim to reduce risk in multi-hazard contexts, we chose to separate the assessment of risk-related attributes/indicators from that of co-benefits attributes/indicators. These two assessments are carried out in parallel but independently, following the same methodology This decision allows to explicitly evaluate the performance of each measure against the dual objectives of risk reduction and sustainability. This also has the advantage to break down a complex process in two simpler and more manageable iterations. The two evaluations are finally merged into one score that reflects stakeholders' preferences regarding the two objectives.

Moreover, veto values were assigned to certain indicators linked to the intrinsic characteristics of the measures, as meeting these requirements is essential for ensuring their feasibility.

The next section provides a detailed description of all procedural steps.

4.1 Flowchart of procedural steps

MCA is meaningful only when at least two alternative projects are available. If "doing nothing" (the so-called zero alternative) is a viable option, it must be included as one of the alternatives. The designed MCA procedure consists of four main steps, summarized in Figure 9.

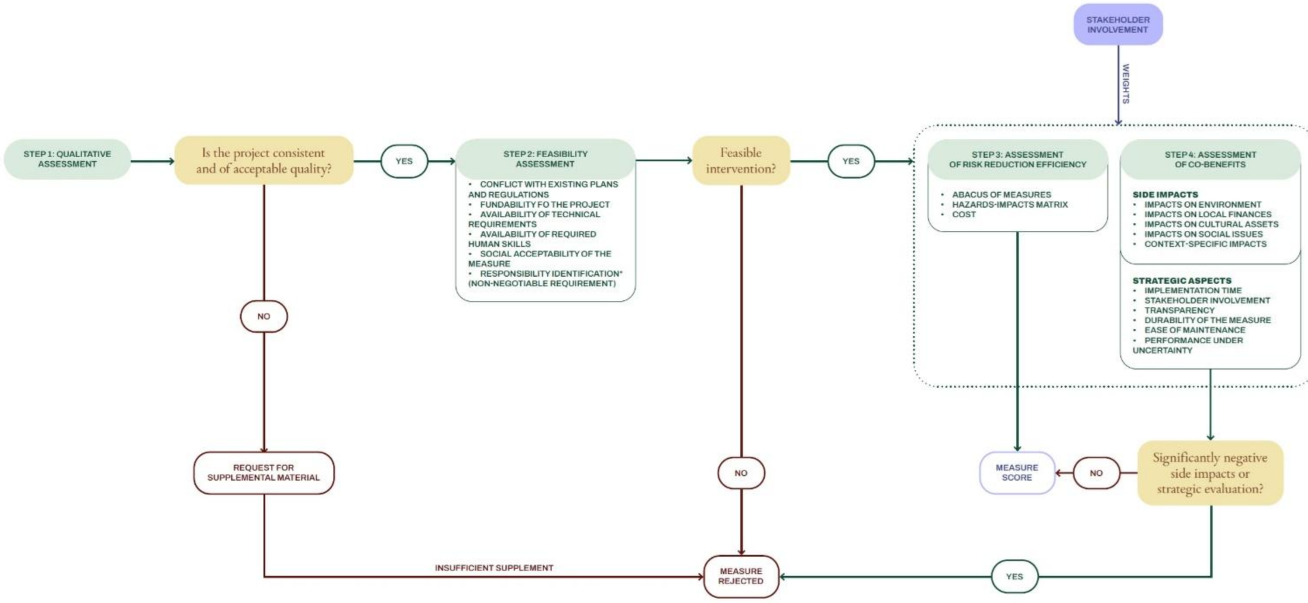

Figure 3 Procedural steps for decision making concerning the implementation of a measure

The four steps aim at facilitating the evaluation of a measure, inviting decision makers to systematically unpack the decision-making problem and investigate the several characteristics and implications of a measure for risk mitigating purposes, and the other meaningful factors like economic, social and environmental sustainability.

Step 1 of the evaluation procedure consists in verifying whether the project meets the minimum requirements of technical quality and provides the necessary documentation, as well as whether it aligns with the institutional goals of natural risk management. This preliminary screening excludes proposals that are either incomplete or misaligned with strategic risk mitigation objectives.

At the end of Step 1, two possible outcomes are foreseen:

- Admitted: the project is complete and clearly aligned with risk mitigation goals; it proceeds to Step 2;
- Integration required: the project shows gaps or lacks clarification; its evaluation is suspended until additional information is provided. If, even after integration, the project remains of poor quality or fails to meet risk-mitigation objectives, it is rejected and excluded from further evaluation.

Step 2 aims to assess the feasibility of the measure, highlighting the essential preconditions required to proceed with its evaluation and potential implementation. This phase ensures that the measure satisfies all feasibility requirements, identified among the intrinsic attributes of the measures described in Chapter 3, and corresponding to the following indicator values:

- alignment and consistency with existing plans and regulations
- availability of funding
- availability or credible acquisition of technical requirements and human skills

- social acceptability of the measure
- clear identification of responsibilities for implementation and management

Failure to meet any of these necessary preconditions results in the rejection of the project.

Once the feasibility of the study has been confirmed, the evaluation proceeds with parallel Step 3 and Step 4.

Step 3 consists of evaluating the risk-reduction efficiency of the measure. This assessment is carried out using the *Abacus of Measures* and the *Hazards–Impacts Matrix* developed in Task 2.2. Specifically:

- The Abacus of Measures identifies the temporal and spatial scales of the risk analysis, as well as the co-existing hazards in the study area that may be affected by the measure and therefore must be included in the analysis.
- The Hazards–Impacts Matrix enables the evaluation of the measure's risk-reduction (or risk-increase) potential across the different risk dimensions (individual well-being, built environment, public services, business activities, environmental systems, communities, and financial systems) for the different considered hazards (e.g., flood, earthquake, drought, landslide, volcano).

Once the risk-related attributes that are affected by the implementation of a measure have been identified and their related indicators estimated, utility functions must be defined for each indicator to convert the quantitative or qualitative values of each indicator into a utility value ranging conventionally from 0 to 100, where 0 is the minimum and 100 the maximum utility (satisfaction) among the indicator values. It is important to note that the utility functions must be calibrated by considering the full range of variability of each indicator across the entire set of alternatives. Utility functions allow to transform the Hazards-Impacts matrix, where each row corresponds to an indicator with its measurement units, into a more homogeneous utilities matrix, where each row has values ranging from 0 to 100. However, the values of one row are not yet directly comparable to the values of a different row. To aggregate the utilities of each alternative for the different indicators and obtain its risk reduction score, it is necessary to weight the relative importance of each indicator with respect to the others. The risk reduction score of each alternative, representing its risk reduction capability, is then computed through a weighted sum of its utilities. The weights to be used are identified via participatory processes involving all relevant stakeholders.

In **Step 4**, the side-impact attributes (i.e. co-benefit on environment, local finances, cultural assets, social assets, and context specific impacts) and the strategic attributes not evaluated so far (i.e. related to the implementation timeframe, stakeholder involvement, transparency and communication, durability of the measure, ease of maintenance, and performance under uncertainty) of each measure are assessed in order to obtain its side-impacts score and its strategic score. It is important to note that side-impact attributes and strategic attributes receive distinct scores to highlight their relative contribution to the overall performance of the measure.

The procedure followed to obtain these two scores is the same as in the previous step, going through utility functions and weights defined through participatory processes involving all relevant stakeholders.

Measures characterized by significantly negative side impacts or strategic evaluations are rejected.

For all admissible measures, the overall score is obtained by the weighted sum of the risk-reduction, side-impacts, and strategic scores, with weights defined again through a participated process.

How to design the participatory process for weights definition – empirical evidence gained during the project

Stakeholders include all actors who have an interest in any aspect of project implementation—decision-makers, funders, beneficiaries, and those who may be negatively affected by the project, from multiple perspectives beyond the economic one. They span governmental, community, private, and scientific sectors.

To obtain a meaningful consensus on stakeholders' preferences, all relevant stakeholder groups must be included in the participatory process. The larger and more diverse the stakeholder participation, the more significant and representative the results.

Working with real problems and real data facilitates stakeholders' reasoning and supports the definition of more informed and consistent preferences.

Asking stakeholders to assign weights directly is often challenging when evaluation criteria are numerous. This task can be simplified by: (i) grouping criteria into homogeneous categories (e.g. es business activities, individual wellbeing…) and assigning relative weights within each category, followed by weighting the categories themselves; (ii) asking stakeholders to rank criteria by preference (from most to least important), then converting rankings into weights using established algorithms.

Stakeholder participation can be organized in different ways. In-person meetings generally foster deeper engagement and more meaningful comparison among participants, but they require more effort in terms of time, logistics, and staffing. To facilitate in-person activities, stakeholders may be divided into multiple groups (each possibly including at least one representative of each stakeholder type), which then need to compare and reconcile their results in a subsequent step. The number of people in each group must be limited to 4 to 6 to give all participants the opportunity to talk. To prevent single individuals from dominating the process, a neutral facilitator should be present in each group.

Deliverable 7.4 includes the full description of how participatory processes were conducted within WP7.2

5. Identifying uncertainties in the MCA

The notion of uncertainty is crucial to a variety of fields, to the point that it is not easy to find a univocal definition. Our aim in approaching the topic of uncertainty for the developed MCA has been finding a framework that fitted with its general purposes. Uncertainty is a pervasive feature of life, which means that we need to deal with it in order to construct a reliable and effective MCA.

To do that, we started from an intuitive and all-compassing notion of uncertainty. The following questions guided the identification of existing objects of uncertainty:

- What do we ignore?
- On what do we have doubts?
- Where do we disagree?
- Where do we not have a univocal, reliable, robust, well-established position?
- What may be inaccurate, imprecise, incorrect?
- What might change depending on perspectives or on future scenarios?

The basic idea underlying this set of questions, then, is that uncertainty is that state where there may be reasonable doubts about the correct value of something, although these doubts may be rooted in a variety of things - ignorance, disagreement, or an unpredictable future.

Consequently, a crucial aspect of uncertainty is that it is variable concept: uncertainty comes in different degrees of severity and in different types, it can concern different objects, and it can have larger or smaller impacts on the overall model or decision. Once again, the centrality of uncertainty to many fields is such that there is no unique way of organizing this variety in a single typology – the correct framework is the one that best suits the purposes of the task at hand.

For this reason, our approach to uncertainty has been informed by two motivating principles behind the MCA methodology:

1. The *ratio* that justifies the use of MCA is that decision-making can be improved by decomposing the overall evaluation in evaluations of separate and often conflicting criteria. Similarly, our approach to uncertainty should also try to decompose its complexity into more manageable components.
2. The *ethics* that informs MCA is that decision-making processes should be transparent, so that all the relevant considerations and choices are made explicit. Similarly, the importance of a framework to deal with uncertainty lies in it being a tool to make uncertainty explicit throughout the decision-making process.

Starting from these considerations, we adopted a participatory approach to think about all possible uncertainties that may impact on the MCA, keeping the umbrella notion of uncertainty introduced above so as to avoid disciplinary biases that would have limited the scope of our considerations. A two-days workshop in Bolzano worked as an interdisciplinary brainstorming practice on the role of uncertainty in our MCA.

During this workshop, we adopted the "World Café" participatory methodology to reflect on which ingredients of the MCA it is possible to have reasonable doubts – and therefore where we can find uncertainty in the MCA process. Participants were divided into three groups and invited to rotate between three tables, where they would stay for 20 minutes to discuss the possible uncertainties in the main components of the MCA: the abacus of alternatives, the hazard-impacts matrix, and the win-win attributes (one component per table). To help participants think through the variety of possible uncertainties, a tentative typology was provided, which divided uncertainty according to its nature (whether it was epistemic – aleatory – normative) and to its object (whether the uncertainty concerned an element which was exogenous or endogenous to the model). More specifically:

1. **Epistemic** uncertainty: Uncertainty due to lack of data or understanding.
2. **Aleatory** uncertainty: Uncertainty due to the intrinsic variability and randomness of the phenomenon of interest.
3. **Normative** uncertainty: Uncertainty due to doubts about evaluative (e.g. ethical, moral, aesthetic) judgements and priorities.
4. **Exogenous** uncertainty: Uncertainty about the accuracy of external inputs (e.g. data, variables, parameters).
5. **Endogenous** uncertainty: Uncertainty about the adequacy of the model, theory, or the interpretations used in the construction of the analysis.

Participants were also invited to reflect on *whose* uncertainty we were talking about – namely, whether the uncertain agent in each instance was the decision-maker, the analyst, the scientists, or the stakeholders.

The brainstorming provided the material for reflections that led to a significant modification of the categories presented in Bolzano, with the aim of trying to define a typology that managed to capture within the variability of uncertainty those distinctions that actually matter to the MCA developed. In a subsequent meeting, held in Savona on 07-08/07/2025, the exogenous/endogenous distinction was eliminated, as it did not prove to be particularly fruitful for our context, and the other three types were expanded with the following two:

4. **Strategic** uncertainty: Uncertainty due to the fact that the correct value of the object of the uncertainty depends on other, possibly future, decisions.
5. **Vagueness**: Uncertainty due to the ambiguity of its object, which is open to multiple interpretations.

A literature review across multiple disciplines was conducted to identify the tools that were best suited to represent these types of uncertainty and to be integrated in the MCA workflow. These included probabilities, risk measure, fuzzy sets, grey numbers, scenarios, and sensitivity analysis.

However, this direction, while potentially interesting for the construction of a theoretical landscape of representational tools for uncertainty, was at odds with the principle of transparency that moves MCA. MCA is first and foremost a tool to support decision-makers in making a decision that is informed of the trade-offs required by the different considerations, perspectives, and goals that are relevant to the problem at hand. This implies that decision-makers must be able to understand and to handle the information provided by the MCA, as well as having enough time of resources to dedicate to it. A framework to treat uncertainty that adds complexity and uses tools the mechanism of which is not accessible to the untrained decision-maker makes the MCA, and consequently the whole decision, opaque. MCA must be manageable by decision-makers, and so must be the relative uncertainty framework.

The research was therefore steered in a different direction. In the spirit of putting the decision-maker in the position to make a decision in the most well-informed way possible, it is important that MCA include information about the limitations behind the results it provides. To do that, we have developed a framework that guides the discussion of all the uncertainties involved in the generation of the ranking yielded by the MCA as its final result.

This framework comprises three separate elements. Each of them addresses three sources of potential reasonable doubts about the reliability of the result: modelling choices made by the analyst in the construction of the MCA tools; models and data used to generate the values of the different criteria; and weights assigned by the stakeholders to represent their evaluative priorities with respect to the different impacts and win-win attributes. The ranking obtained in a MCA is the result of the structure of the analysis, the models and data employed, and the weights assigned by the stakeholders, and it will therefore be as reliable as these elements are. We will see each one of them in turn.

5.1 Modelling choices

The first possible reason to doubt the reliability of the ranking obtained is the fact that it is the result of a series of choices on the side of the analyst, which may be more or less robust. Thus, we developed a tree to guide the explicit discussion of these choices, addressing whether there were relevant alternatives, whether the choice was sufficiently supported, and whether there are reasons to expect it to have significant impacts on the ranking produced by the MCA, possibly suggesting the necessity of a sensitivity analysis. For each modelling and methodological choice made in the construction of the MCA, the analyst should go through the tree to justify the choice and provide all the relevant elements to the decision-maker to evaluate the robustness of the process and therefore of the result. The tree is provided in Figure 4.

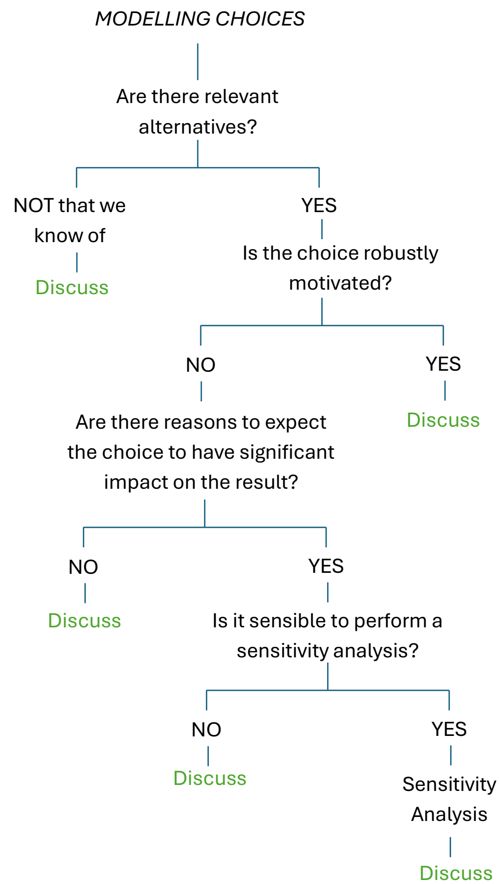

Figure 4 The first element of the framework: A tree to discuss modelling choices.

We compiled a list of the choices made on our side during the construction of the MCA tool developed in this WP. These concerned the general MCA procedure and overall workflow, the aggregation of the various impacts and criteria, and the assessment of feasibility, of risk reduction efficiency, and of the possible co-benefits, following the procedural steps illustrated in figure 10. For each choice, we went through the tree, reaching different nodes depending on the status of that choice. The consequent discussion for each of the choices that we identified is provided below. Some of these choices or the node at which they land may depend on the specifics of the decision problem at hand; this has been signalled whenever appropriate.

5.1.1 Discussion of modelling choices: The general procedure

- Choice of MCA as the instrument to evaluate the relevant measure: Discussion: While there are relevant alternatives (e.g. CBA, CEA), the choice of MCA is robustly motivated because of the variety of considerations that are relevant for policy decisions and that are not well captured by other instruments. The choice is especially robust for the type of problems to which our evaluation instrument is expected to be applied, given the plurality of dimensions that are expected to be relevant.
- Division of relevant criteria in risk reduction, side impacts, procedural characteristics (some of which are context specific and only apply to some decisions): While the relevant criteria could have been

grouped differently, this choice is robustly motivated because it is based on relevant distinctions among the criteria. Furthermore, the way criteria are organised and grouped gives procedural facilitation but should not affect the final result.

- Procedural characteristics are divided between strategical aspects and feasibility bounds: While things could have been structured differently, this choice is robustly motivated because some of the procedural characteristics of the measure are better viewed as necessary requirements – whether it respects existing norms, for instance – while others may be seen as criteria that can count in favor of the measure, but are not necessary.
- Cost is counted in the assessment of risk reduction (i.e. along with the hazard-impacts matrix): Cost could have been included as a separate criterion besides the impact on risk reduction, i.e. among the side impacts of the measure, or as a feasibility bound. However, given the importance of the cost criterion, we decided to consider it together with what should be the main impact of the measures, i.e. risk reduction. It may have been legitimated to do otherwise, and in some cases a different choice may lead to a different ranking of the alternatives. Thus, if the resources available are sufficient and the stakes are significant, a sensitivity analysis is recommended.
- If side impacts are too negative, then the measure is rejected (regardless of the weight assigned to side impacts): Decision makers decide the value of the non-compensation thresholds, or they can decide not to set them. A sensitivity analysis is recommended whenever there are reasons to explore the effect of different non-compensation thresholds.
- Involvement of stakeholders only in the assignment of weights: While there may be reasons to recommend the inclusion of stakeholders in other parts of the procedure to increase participation, this would be quite taxing, making the procedure particularly heavy. A sensitivity analysis to check whether more involvement would change the result would likely not be sensible, as it would require the organization of a new event of stakeholder inclusion and the definition of alternatives for the steps on which we want to evaluate the impacts of stakeholder’s involvement, with potentially cascade effects on the whole procedure.
- Framework for the treatment of uncertainty.
  While there may be alternative approaches to treat uncertainty in MCA, the framework currently presented is robustly motivated by its adherence with the principles of MCA, in terms of simplicity, accessibility, transparency, and comprehensiveness in the face of complexity.

5.1.2 Discussion of modelling choices: The aggregation

General:

- Use of the classical MCA approach leading to a score for each measure representing its overall performance, hence allowing a complete ranking of the alternatives: Robustly motivated from the literature and expert judgement. Although not strictly needed, testing other approaches could be interesting but quite demanding, as it would alter the entire structure of the MCA.
- Selection of a methodology to elicit weights from stakeholders: The choice of the ranking elicitation method is motivated by its intuitive nature and the support it has in the literature as a tool for supporting problem interpretation by stakeholders.

Step 2 - feasibility:

- Selection of some characteristics as feasibility bounds: The selection was guided by the expert judgment of the researchers, informed by their experience in similar decision contexts. However, the choice of the characteristics can be context specific and change according to the needs of the individual project.
- No stakeholders involved in the aggregation of the feasibility bounds: This choice was motivated by the opinion that the characteristics selected as feasibility bounds were mostly technical issues, where the role of value judgements is limited or absent. Once their role as requirements that must be satisfied was determined, then there was no role for the stakeholders.
- Acceptability threshold set at one bound violated: Given that we see each of these characteristics as a necessary requirement for the feasibility of the measure, whenever one of them is not satisfied, then the measure must be rejected. The choice is therefore robustly motivated by the role that these bounds play.

Step 3 – risk-reduction:

- Structuring of the ingredients required to compute risk (according to the definition of risk adopted in the MCA methodology) in two instruments (abacus and matrix): This choice is motivated by the usefulness of this structure in taking into account the various measures and all their impacts on risk. While there may be alternative ways to structure the analysis, the result should be the same.
- Inclusion of three levels of scale (micro – meso – macro) in the abacus: This choice is motivated by the relevance that this distinction has for the decision, as the scale typically determines the actors involved in the implementation of the measure.
- Selection of the hazards included in the abacus: This choice is motivated by the relevance of the hazards for the Italian context and by the extent of the specific competence of the people involved in the construction of this tool.
- Selection of the risk attributes included in the matrix: The comprehensiveness of the risk attributes considered is one of the defining characteristics of this tool. It may be sensible to perform a sensitivity analysis considering only the typical and more easily quantifiable risk dimensions.
- Subdivision of the attributes in seven categories: While there may be alternative ways to group the risk attributes, there is no reason to believe that these may have a significant impact on the final ranking as risk attributes are weighted independently from their category
- Selection of indicators for each attribute: The selection of indicators for each attribute was robustly motivated by current literature and practice.
- Selection of models and datasets for each indicator: Given the preference for institutional datasets, the specific models and datasets selected were mostly the only relevant alternatives for a specific scale. If there are relevant alternatives in the decision context at stake, then a sensitivity analysis is recommended, as the use of different data and models may change the final ranking.
- Preference for institutional datasets rather than non-institutional (but potentially more up to date) datasets: Preference for institutional datasets, rather than non-institutional (but potentially more up to date) datasets is motivated by normative requirements related to public decisions. If more updated and reliable datasets are available for the specific decision at hand, then we would recommend using those instead.

Step 4 – strategic aspects and side-impacts:

- Selection of attributes: In identifying the relevant attributes for the evaluation of a risk reduction measure, we strived to be as comprehensive as possible through an inter-disciplinary brainstorming workshop. However, there may be alternative attributes that we did not consider, or alternative ways to structure the list. At this stage, it would probably not be sensible to do a sensitivity analysis: the tool we propose is very pioneering in this respect, and it would be hard to identify alternative attributes. If these are available for the decision problem at hand, then a sensitivity analysis may be both possible and sensible.
- Selection of indicators: The indicators adopted are the most adequate that we could think of or that were available in the literature. If there are known relevant alternatives, then it may be sensible to perform a sensitivity analysis (as always, on the proviso that the resources available allow that and that the stakes are sufficiently high to recommend it).
- Selection of models and datasets for each indicator: The models and datasets selected were the only alternatives that we knew of. A sensitivity analysis may be conducted in the presence of relevant alternatives.
- Preference for qualitative over quantitative indicators: This preference is motivated by the idea that quantitative indicators are appropriate to represent intrinsically quantitative attributes, but in the case of non-quantitative attributes they may become too complicated to handle in a way that would provide some meaningful representation.

5.1.3 Discussion of modelling choices: Models and data

The second element of the framework captures uncertainty at the level of the models and data employed. It is important to note that much of the potential uncertainty contained in these factors is, so to say, out of the analyst's control: the analyst can try to assess the reliability of the models and data employed, but they will hardly be in the position to reduce this uncertainty first hand, given that it is contained in models and data coming from different sources. The second element, therefore, represents the level of uncertainty due to the reliability of the models and data employed to obtain the value for each cell of the hazard-impacts matrix and for each attribute among the side-impacts, the strategic aspects, and the feasibility bounds.

In doing that, we decided to avoid quantitative representations of uncertainty, which may end up misrepresenting it. Objective, frequentist probabilities can only be applied when observable frequencies are available, while subjective, Bayesian probabilities may require the cumbersome elicitation and aggregation of expert judgements, and alternative quantification methods (e.g. fuzzy numbers) may be too opaque to the decision-maker for the purposes of an MCA. Instead, the tree we develop guides the assignment of qualitative levels of uncertainty to each cell or attribute, reflecting the reliability of the models and data underlying their value. Once again, the spirit is that of providing the decision-maker with as much transparent and accessible information as possible on all aspects that are relevant to the decision.

This second element comprises two trees, one for the assignment of levels of uncertainty to the cells of the hazard-impacts matrix (Figure 5) and one for the assignment of levels of uncertainty to non-risk-related attributes (Figure 6).

For both the hazard-impacts matrix and the non-risk-related attributes, information about the level of uncertainty is supplemented with an evaluation of the distance between the indicator used as proxy and the attribute that the indicator is supposed to represent. The closer the indicator is to the attribute it represents, the more reliable the value that the analysis attaches to that attribute. For example, while price is a very close indicator of the economic value of those goods and services that have a market, the level of expenditure in psychological support is only a partial indicator of the level of psychological distress caused by a hazardous event, as much of this distress may never be expressed in the request for psychological help. This proxy distance can be high, medium, or low, and its evaluation is left to the expert judgement of the analyst.

Hazard-impacts matrix

The level of risk for each hazard on each type of impact is obtained via either exposure or damage models. An exposure model assumes that the impact corresponds to all the resources exposed to the hazard, while a damage model adds to the exposure model information about the likelihood of damage based on either a vulnerability model (especially for impacts in built environment), statistical data for that hazard (especially for impacts on people), or qualitative models based on expert judgement (especially for environmental impacts). In the tree, the grey lines identify a disjunction, i.e. a fork where only one line must be followed, while the blue lines represent a conjunction, i.e. both lines need to be aggregated. For each decision problem, the analyst should assign a level of uncertainty to the elements used to determine risk for each type of impact under each hazard, depending on how reliable and established they are; then, these are aggregated into a unique level of uncertainty for the corresponding cell.

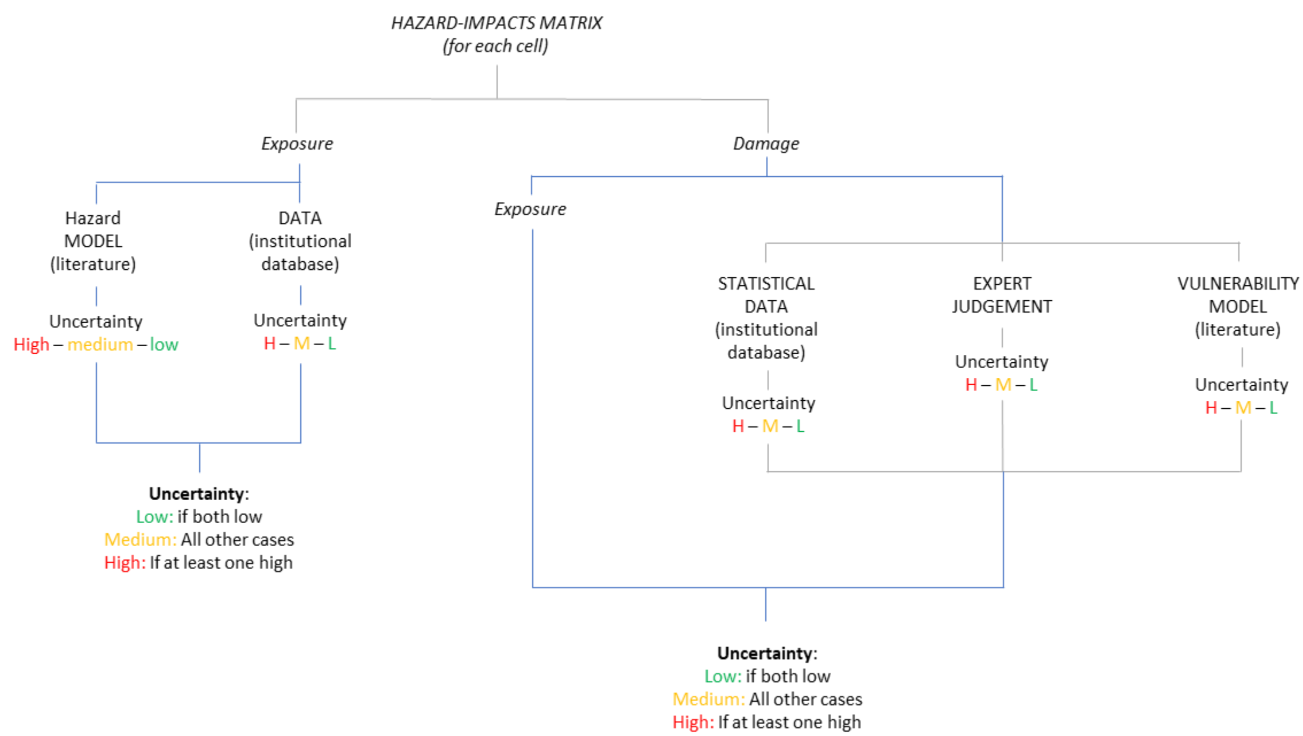

Figure 5 The tree for the assignment of levels of uncertainty to the cells of the hazard-impacts matrix.

Non-risk-related attributes

The mechanism for the assignment of levels of uncertainty to non-risk-related attributes (i.e. feasibility bounds, side impacts, and strategic aspects) is the same as the one used for the cells of the hazard-impacts matrix. The main difference is that the value of these attributes is not risk, and therefore the elements employed to calculate it are not exposure or damage models. Here, the value of the indicator for each attribute is determined by data taken from institutional databases or from the information provided in the project under evaluation, alongside a model that either comes from the literature or, when this is not available, is our proposal. The uncertainty of these two elements is evaluated separately on the basis of their reliability and robustness, and then the two evaluations are aggregated into a unique level of uncertainty for the whole attribute.

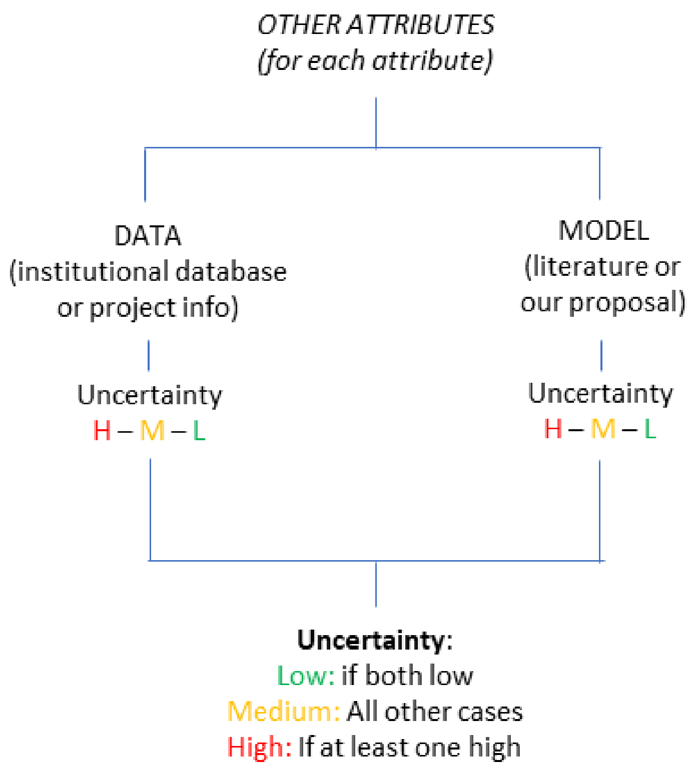

Figure 6 The tree for the assignment of levels of uncertainty to non-risk-related attributes.

Weights

The third element of the framework concerns the potential uncertainty about the weights assigned by the stakeholders, which are the final ingredient necessary to compose the MCA. Uncertainty over weights is normative: it is uncertainty about what is more important or what should be prioritized. Once we interpret it as doubt over the correct value to use, uncertainty over weights is best understood as disagreement among stakeholders. If there is no disagreement, then there is no doubt over the weights to use. If, on the other hand, there is at least some level of conflict between individual stakeholders and groups of stakeholders as to the right weights' assignment, then there may be doubts about which of the alternative assignments may be more adequate. Note that doubts about elicitation and aggregation methods are included in the discussion of modelling choices: here we are only concerned with uncertainty over the right set of weights to use.

This element comprises two tools. One is a tree to guide discussion and action in the face of uncertainty over weights (Figure 7); the other is a disagreement matrix that is needed to determine the value of a node of the tree (Figure 8).

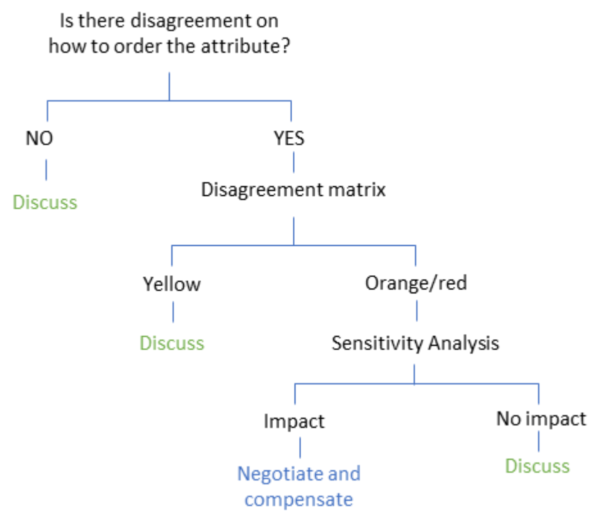

Figure 7 The tree to guide discussion over uncertainty about weights.

Distant alternatives Low disagreement	Close alternatives Low disagreement
Distant alternatives High disagreement	Distant alternatives High disagreement

Figure 8 Disagreement matrix.

When there are conflicting weights assignments, it may be sensible to perform a sensitivity analysis to check the robustness of the result to different sets of weights. However, the mere existence of disagreement may not be sufficient reason to require a sensitivity analysis. If the score assigned to the alternatives under evaluation using the weights aggregation method proposed in the procedure is such that the alternatives are very distant – i.e., if one alternative is significantly better than the other one – then there may be little need for a sensitivity analysis, as disagreement on weights should be very high for a change in the ranking to be expected. Thus, if the alternatives are distant and disagreement on weights is low, then a sensitivity analysis may be superfluous. This is what the disagreement matrix postulates. The level of disagreement may depend on whether there is only one group ranking the impacts or the attributes differently, or whether there is widespread discordance across groups; and on whether the disagreement concerns ranking impacts or attributes in different positions within the same class (high / medium / low priority) or in different classes, which would suggest higher disagreement and possibly a stronger impact on the final result. The evaluation of the level of disagreement is left to the judgement of the analyst performing the MCA.

If the sensitivity analysis shows that alternative weights assignments lead to rank reversal, then this is crucial information for the decision-maker, as it tells them that the implementation of a certain measure would go against the preferences of those stakeholders that prioritized impacts and attributes differently. Thus, the decision-maker should try to take this disagreement into account and to reduce it where possible, for instance by negotiating with the stakeholders that do not see their priorities reflected in the final ranking or by proposing compensating measures to meet their priorities in other ways.

6. Conclusion

This Deliverable marks a significant advancement in the development of participatory tools for evaluating risk mitigation strategies within multi-hazard environments. The work presented here was conducted under Task 7.2.3 of the RETURN project, and responds to the urgent need for integrated, multi-disciplinary approaches to natural risk management. The framework presented in this document is structured to ensure that decision-makers systematically consider both intrinsic characteristics of mitigation measures (implementability, reliability) and their secondary impacts across multiple domains (environment, finances, cultural assets, societal issues, and context-specific factors).

A central achievement of this present Deliverable is the operationalization of stakeholder engagement throughout the evaluation process. The methodology provides clear guidance for incorporating diverse stakeholder preferences and value judgments, ensuring that selected measures are both effective and socially acceptable. The procedural steps for assessment are outlined in Chapter 4, ranging from preliminary screening to feasibility assessment, risk-reduction efficiency, and side-impact evaluation. These steps aim to provide a clear, replicable roadmap for practitioners. The separation of risk-related and co-benefit assessments allows for a dual focus on both hazard reduction and sustainability, facilitating more balanced and informed decisions.

As a last point, the document provides guidance for identifying, categorizing, and addressing uncertainties inherent in risk mitigation decision-making. This includes epistemic, aleatory, normative, strategic, and vagueness-related uncertainties, with practical tools for qualitative assessment and sensitivity analysis. By making uncertainties explicit and manageable, the MCA process enhances the reliability and robustness of its recommendations.

To conclude, this present Deliverable 7.2.3 demonstrates that effective risk mitigation in multi-hazard contexts requires a holistic, participatory approach. The MCA framework developed here facilitates decision-makers to navigate complex trade-offs, anticipate unintended consequences, and pursue win-win solutions that align with the diverse objectives of affected communities and stakeholders. The application of the framework in pilot cases (to be detailed in Deliverable 7.2.4) validates its practical utility and adaptability to real-world scenarios, confirming its value as a decision-support tool for national guidelines in natural risk management.

The tools and methodologies outlined in this Deliverable lay potential to support a wide variety of stakeholders involved in the decision-making process for mitigating risk measures. This framework can become a valuable support tool for informed, transparent, and inclusive decision-making in alignment with efforts towards increasing community resilience and sustainability actions, serving particularly policy makers, practitioners, and civil protection agencies. In the field of research and innovation for community resilience, this Deliverable establishes a new standard for multi-risk management, serving as a replicable and adaptable model for future studies in order to address emerging challenges.

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Annex 1: Kick-off Workshop Report

Participants from WP2: Francesca Vigotti, Malvina Ongaro, Daniela Molinari, Gloria Padovan, Anna Rita Balingit, Paola Fontanella Pisa, Simona Muratori, Panagiotis Asaridis, Francesco Airoldi, Daria Ottonelli, Tommaso Bastiani, Alessandro Rubino, Federica Romagnoli, Luca Cetara, Alice Gallazzi

Day 1 Workshop: MCA evaluating criteria – what makes a good or a bad measure?

The overall objective of WP7.2 “Innovative tools to evaluate risk mitigation effectiveness”, is: “defining national guidelines for the evaluation of the effectiveness of alternatives of intervention in natural risks management, by considering in detail MCA tools”.

This work is divided in four main steps:

Task 7.2.1: ***State of art on MCA applied to natural risk management***

Task 7.2.2: ***Problem definition***

Task 7.2.3: ***Tools for inclusive/participative decision making***

Task 7.2.4: ***Pilot cases***

This workshop marks the start of Task 7.2.3 “Tools for inclusive/participative decision making” (see GANTT chart below).

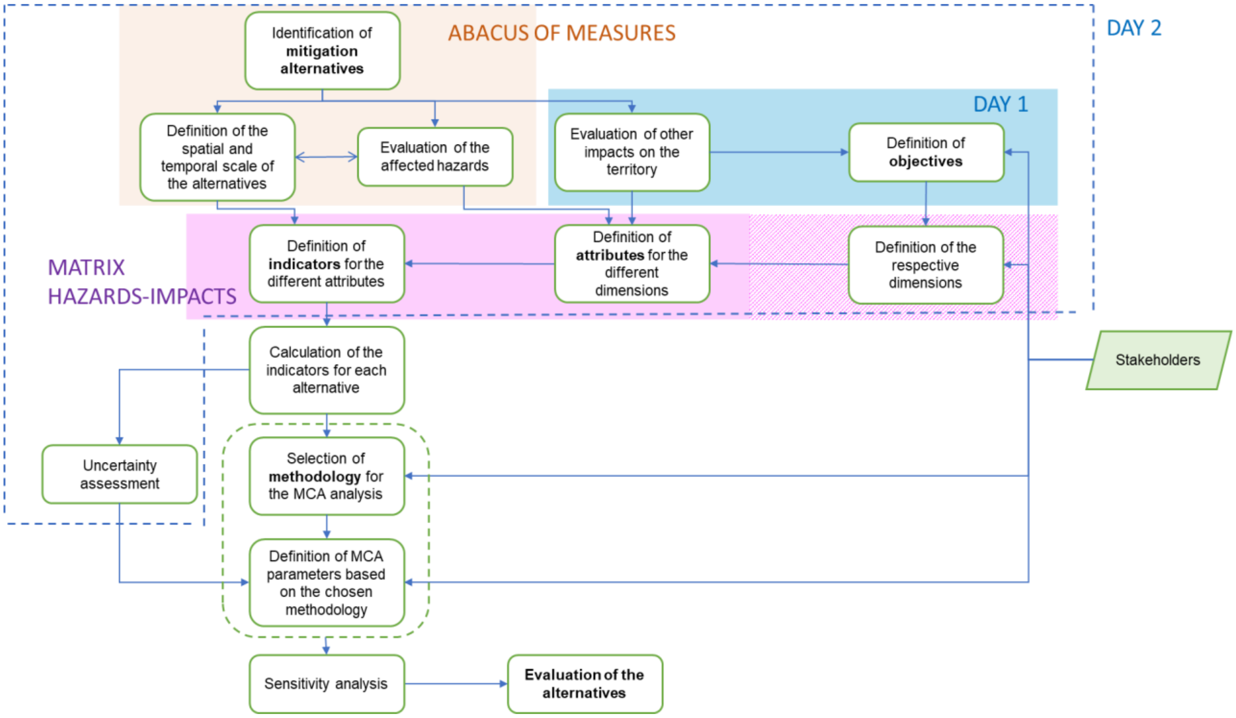
	Months																																						
	Dic	Gen	Feb	Mar	Apr	Mag	Giu	Lug	Ago	Set	Ott	Nov	Dic	Gen	Feb	Mar	Apr	Mag	Giu	Lug	Ago	Set	Ott	Nov	Dic	Gen	Feb	Mar	Apr	Mag	Giu	Lug	Ago	Set	Ott	Nov	Dic	Gen	Feb
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Task 2.1								M1/D1																															
Task 2.2																						M2																	D2
Task 2.3																																			M3				D3
Task 2.4										M4																													D4

The objective of this task is to explore, identify and evaluate (in terms of challenges and opportunities) the most appropriate technique(s) for conducting MCA in natural risk management.

The key questions guiding this process are the following:

- How are decisions made within the real system?
- Which stakeholders are involved and at which level of government decisions are taken?
- How can we deal with uncertainty and ignorance?

The workshop, distributed over two days, will cover the following elements of the process (see figure below)



Introduction to the Day 1 Workshop Activity

In this step we divide into three groups and each discuss in answer to the question "what makes a measure good or bad, besides its role towards disaster risk reduction? Starting from the example provided by Daniela Molinari (see figure below), each group went through identified measures from the abacus, and brainstormed about possible implications under different points of view and other spheres of impacts beyond the direct purpose of the measure under discussion.

Example 1: Levee (Flood)

- Reduction in expected deaths and injuries
- Reduction in expected damage to buildings
- Reduction in flooded sources of pollution
- Potential increase in damage to agriculture downstream
- Reduction in the number of exposed cultural events
- Reduction in business interruption duration
- .....
- ....

MATRIX HAZARDS-IMPACTS

- High cost
- Negative impact on ecosystems
- Negative impact on landscape
- Levee effect (reduction in risk awareness)
- Low adaptability to change in H,E,V
- Compliance with national risk strategy
- .....
- .....

WHAT ELSE?

Example 2: Renaturalisation

- Reduction in expected deaths and injuries
- Reduction in expected damage to buildings
- Reduction in flooded sources of pollution
- Reduction in the number of exposed cultural events
- Potential increase in damage to ecosystem
- Potential increase in damage to agriculture
- ....

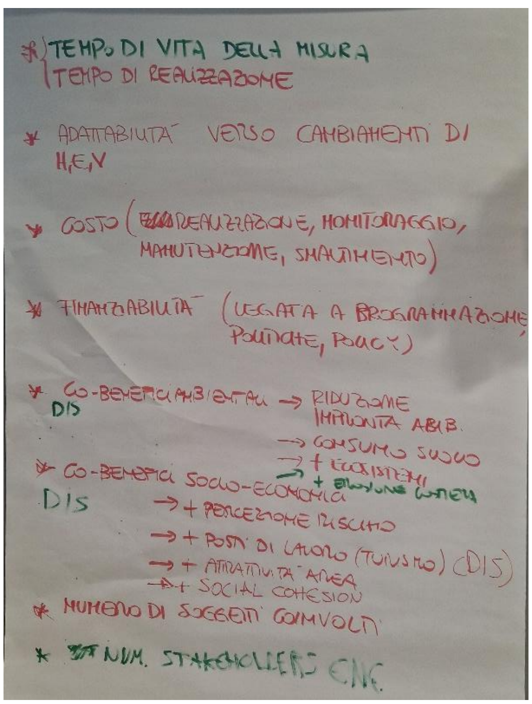
MATRIX HAZARDS-IMPACTS

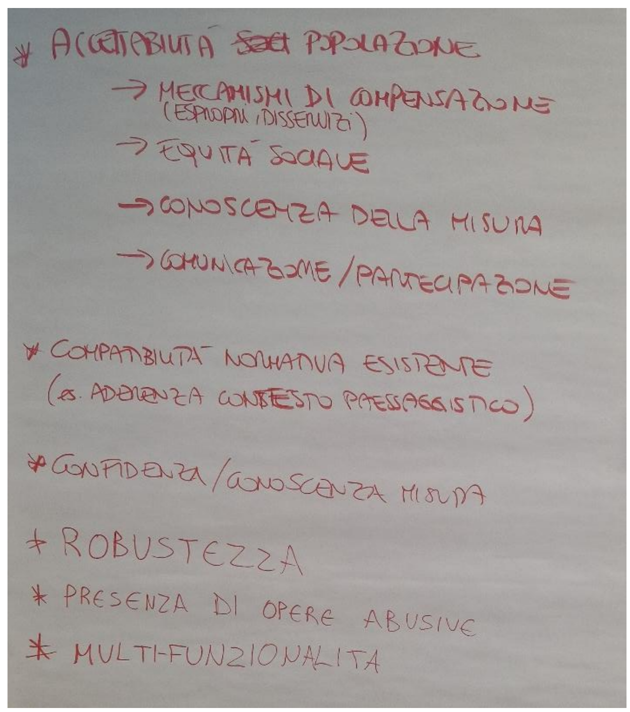
- Cost
- Ecosystems improvement
- Landscape improvement
- Great acceptability
- High adaptability to change in H, E, V
- Potential social conflicts
- .....

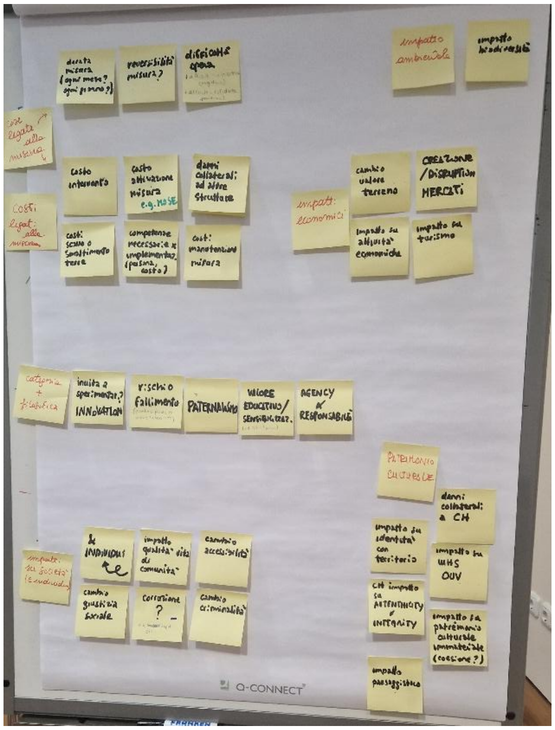
WHAT ELSE?

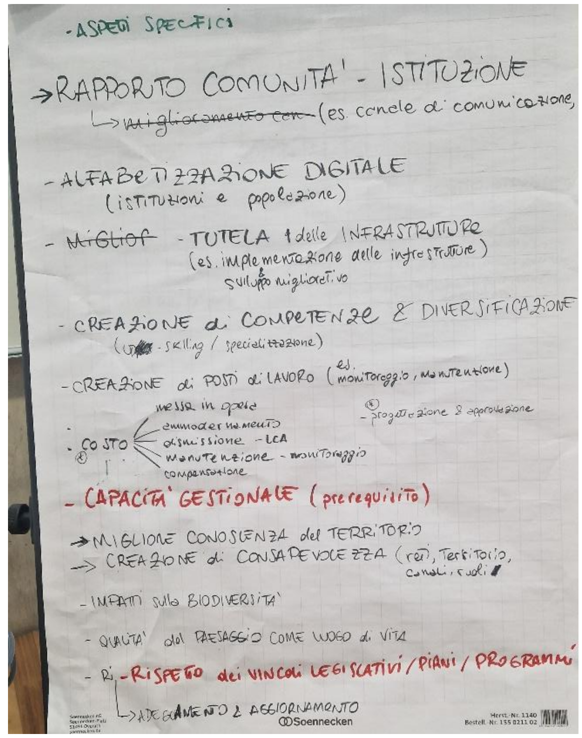
Brainstorming Session

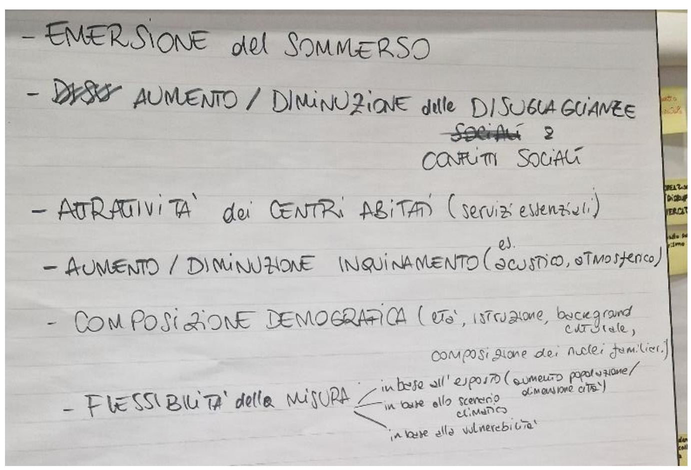
The brainstorming session led to the following results:











In addition, the online group produced the following considerations:

Good measures and evaluation criteria Co-benefits: we believe they are greater in medium and long-term measures; not very applicable in a state of emergency SOCIO-CULTURAL: Co-participation (co-design) and consensus (the measure should be known and accepted by all stakeholders); increased trust in institutions; sense of community and social cohesion SOCIO-CULTURAL: Avoiding 'displacement'; social cohesion SPATIAL AND ENVIRONMENTAL Plan updates (maintenance plan; civil protection plan) Ease of Implementation (non-structural) Flexibility and adaptability to changing contexts and climate change (monitor socio-economic context, climate change, measure effectiveness)

SPATIAL AND ENVIRONMENTAL, ECONOMIC Urban regeneration (mitigation-adaptation + improved quality of public space) --> heat bubble reduction, pollutant reduction
ENVIRONMENTAL: Greenhouse gas mitigation (greenhouse gas emission in the development of the intervention - structural measures - or CO_2 absorption in the case of nature base solutions)
ENVIRONMENTAL: Increased quality and availability of water resources
ENVIRONMENTAL: Improved biodiversity
SOCIO-CULTURAL: Educating, creating risk culture and educating to correct behaviour in case of prevention; Living and building competence (from soil consumption to conscious-sustainable use of resources)SPAZIALI E ENVIRONMENTAL, ECONOMIC Co-benefits resulting from the improved quality of places after the implementation of the measure (e.g. increased attractiveness and benefits for the tourism sector). Cost-benefits of the implementation spin-offs
ECONOMIC: increased agricultural or forestry production related to measures to disseminate flood-resistant agricultural practices or reforestation works
ECONOMIC: positive impact on public finance, releasing financial resources for other policies and sectors. Co-benefit generated by both taxes and good prevention that goes to reduce, if effective, public costs of emergency management and reconstruction (prevention)

Uncertainty and potential failure of success

ABACUS ALTERNATIVES

- Uncertainty with respect to the estimated cost of the measure related to the lack of data at the design stage but also to the evolution of the socio-economic context etc. (epistemic and aleatory)
- Uncertainty with respect to the availability of public economic resources, linked to both the evolution of the socio-economic context (e.g. war, covid) and the evolution of the political context

HAZARD-IMPACT MATRIX

- Uncertainty with respect to the effectiveness of the measure in relation to the expected evolution of the context: i) socio-economic; ii) environmental, related to climate change. Uncertainty that affects the actual effectiveness of the measure over time (epistemic and aleatory --> with data I can reduce it but even if I have a lot of data there is still uncertainty with respect to randomness in the evolution of society and climate change, see greenhouse gas emissions)
- Uncertainty with respect to the expected evolution of the context that influences the assessment of the actual impacts that could occur (epistemic and aleatory)
- Uncertainty with respect to the cataloguing approach (matrix) and the attributes/indicators I have chosen
- Uncertainty with respect to the reliability of the data with which to populate the identified indicators (epistemic)
- Uncertainty with respect to the stakeholder involvement methodology to weigh the relevance of the different attributes (normative) Uncertainty with respect to which stakeholders to involve (normative). Uncertainty with respect to the willingness of stakeholders to be involved (random but possibly also epistemic).

EVALUATION CRITERIA

- Acceptability of the measure by the community (also with respect to the ease of implementation of the measure) (Normative)
- Acceptability of the measure by the regulatory context and the local governance system (Normative - Endogenous/Exogenous?)
- Acceptability and implementation with respect to the uncertain evolution of the political context, in particular within the public administration (Uncertain)
- Uncertainty with respect to the adaptability/flexibility of the measure over time linked to the uncertainty of the evolution of the context (epistemic/aleatory)

- Uncertainty with respect to the effectiveness of the measure in its indirect effects. The measure may be effective in reducing risk but fail to bring about other expected effects (e.g. improving attractiveness of places and benefits in economic terms). (Epistemic and random uncertainty with respect to community and context reaction - psychological and emotional component).
- - Uncertainty with respect to the reliability of the data with which to populate the identified indicators (epistemic)

These results were further analysed and inserted into a MIRO board, leading to the following categorization.

Miro board on evaluating criteria:

The discussion led to the compilation of this MIRO board. The results of the MIRO board and discussion are reflected in the tables below:

Evaluation aspects_ Broad category	***Specific aspect***	***To which type of measure is it related the specific aspect*** ***(structural / non-structural / educational / etc.)***
Environmental aspects	• *Impacts on natural resource management* • *Implementation or boosting of NBS* • *Greenhouse gas uptake and mitigation* • *Impacts on biodiversity & biomes* • *Land consumption* • *Impacts on environmental aspects (air, water, soil, costal & forest areas)* • *Erosion* • *Pollution (air / noise / water / etc.)*	
Agricultural sector _ Economic co- benefits	• *Species resistance* • *increased agricultural or forestry production*	
Tourism sector_ economic co- benefits	• *Landscape improvements consequent to measure implementation*	
Public finance_ economic co- benefits	• *reducing public expenditure,* • *releasing financial resources for other policies and sectors* • *improving opportunity cost (?)*	
Economic aspects	• *cost (LCA, commissioning, compensation, implementation, maintenance, disposal)* • *Fundability*	
Social aspects	• *Impacts on community cohesion, increased community participation,* • *Increased trust between institution and community* • *Risk education and perception ****	

	• *Impacts on inequality & social conflict* • *Impacts on Social equity /justice* • *Education / territorial awareness* • *Employment sector (upskllling & creation of new jobs)*	
Institutional aspects	• *Ease of implementation, flexibility of the measure (climate change + adaptation to changing scenarios* • *Corruption* • *Compatibility with existing plans* • *Upskilling and improvement of competencies*	
Socio-institutional aspects	• *Social acceptability, adaptation to existing plans* • *Implications on citizens co- design, co- participation* • *citizen-institution relationship (i.e. trust in institutions) capacity building* • *Crime* • *Compensation mechanisms* • *Perception of risk* • *Skills enhancement* • *Communication* • *Consensus*	
Economic and institutional aspects	• *Regularisation of workforce / management aspects / urban planning aspects (amnesties, etc.)*	
Technological aspects	• *Digital literacy* • *Digital device modernisation ***	
Infrastrucutural aspects	• *Improvements / upgrading of infrastructures*	
Demography	• *Impacts on demographic dynamics*	
Urban planning aspects	• *Urban regeneration, air quality improvement, co-benefits given by the mitigation of multiple hazards* • *Attractiveness of settlements / areas* • *Impact on land use / land use zoning* • *Updates of city plans (maintenance plan; civil protection plan)* • *Impacts on the quality of landscape as living space*	
Cultural aspects	• *Collateral damage to cultural heritage* • *Impacts on transmission of intangible heritage* • *Perception of the territory*	
Wellbeing	• *Psycological wellbeing*	
"Philosophical aspects"	• *Paternalism* • *Risk management repsonsability*	

	• *Risk of failure*	
Political aspects	• *Election effect -> political showoff*	
Aspects directly linked with the measure	• *Adaptability to future change* • *Life time of the measure* • *Number of stakeholders involved* • *Acceptability of the measure* • *Disservices* • *Knoweldge of the detailed aspects of the measure* • *Robustness of the measure* • *Multifunctionality* • *Difficulty of implementation*	

Analysis

In the brainstorming session we identified 63 evaluation criteria that could influence the selection of risk reduction measures. We grouped the evaluation criteria in 18 categories, according to the belonging to a specific dimensions. Thirteen categories include elements strongly related social and community aspects such as social, institutional, economic, cultural, political and organizational aspects. Some evaluation criteria take are directly linked to specific aspects that characterize the measures implemented, for example (numbers of stakeholders involved, disservices that may create, adaptability to future changes). Beyond spillovers in social aspects, consequences at environmental level have been identified as crucial to be taken into consideration, as well as eventual improvements and positive spillover effects on technological and urban planning aspects.

To ease the analysis and the identification of general criteria to be consider during the decision-making process the 17 categories can be further grouped in further overarching categories.

Overarching category	Specific categories
Impacts on community /citizens	Social aspects
	Cultural aspects
	Demography
	Socio-institutional aspects
	Wellbeing
Institutional and political dimension	Organizational aspects
	Economic aspects
	Economic co-benefits
	Political aspects
Impacts on the territory	Environmental aspects
	Urban planning aspects
	Infrastructural aspects
Impacts on technology	
Characteristics of the measure	Specific characteristics of the measure

	Value- related aspects linked to the measure

Day 2 Workshop: Uncertainties in the MCA

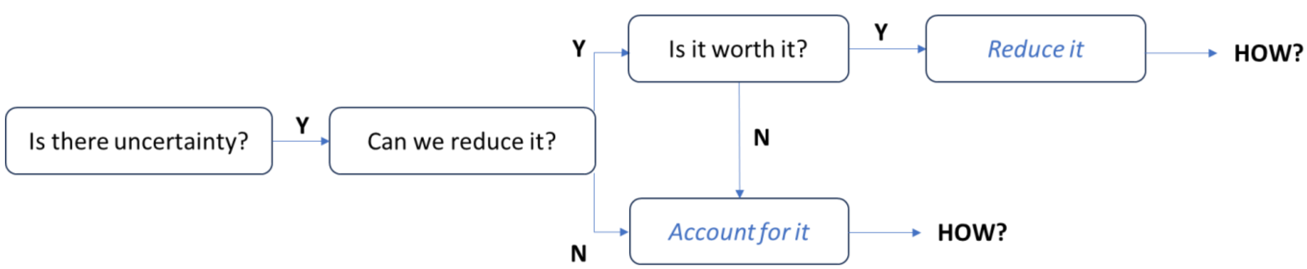
What do we mean by "uncertainty"?

We mean the following:

- *What do we ignore?*
- *On what do we have doubts?*
- *On what do we disagree?*
- *Where do we not have a univocal, reliable, robust, well-established position?*
- *What may be inaccurate, imprecise, incorrect?*
- *What might change depending on perspectives or on future scenarios?*

Uncertainty is a pervasive feature of life. It is problematic because it hinders our goal to move effectively in the environment. Yet, in the face of all this uncertainty we still need to *take action*.

We are not interested in a definition – rather, in **how to deal with it** to construct a reliable & effective MCA. The process towards understanding how to deal with uncertainty can be summarized with the figure below:



In order to do so, we need to break down uncertainties in order to understand the following characteristics:

1. **Object**
   What do we have doubts about?
2. **Type**
   What is the nature of these doubts?
3. **Severity**
   How deep are the doubts?
4. **Impact**
   How heavily does the result of the analysis depend on them?

During this workshop activity we adopted the World Café participatory workshop methodology and divided into three group addressing each one of the main elements of the work produced so far:

1. *Abacus of alternatives*

2. *Matrix Hazards-Impacts*
3. *Further Impacts*

Participants were invited to rotate and stay on each group for 20 minutes and answer the following questions:

- Which ingredients are necessary for the construction of each step?
- On which of these ingredients is it possible to have reasonable doubts?

Identified uncertainties were discussed within the frame of given typologies:

EPISTEMIC:

Due to lack of data or understanding

➢ A property of *belief*

ALEATORY:

Due to variability and randomness

➢ A property of *reality*

NORMATIVE:

Due to doubts about worth

➢ A property of *normative judgements*

EXOGENOUS:

Uncertainty about the accuracy of data – variables – parameters

➢ From external inputs

ENDOGENOUS:

Uncertainty about the adequacy of model – theory – interpretations

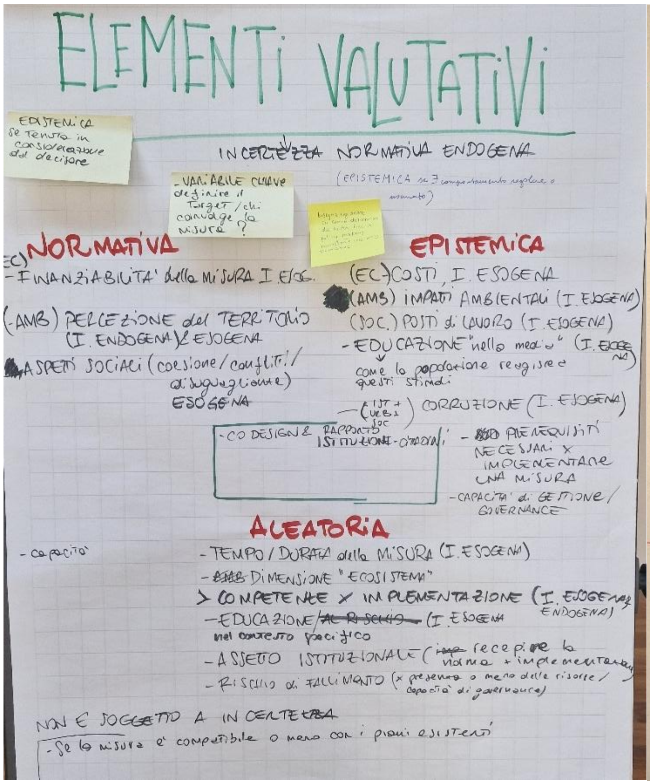
➢ From the analysis construction

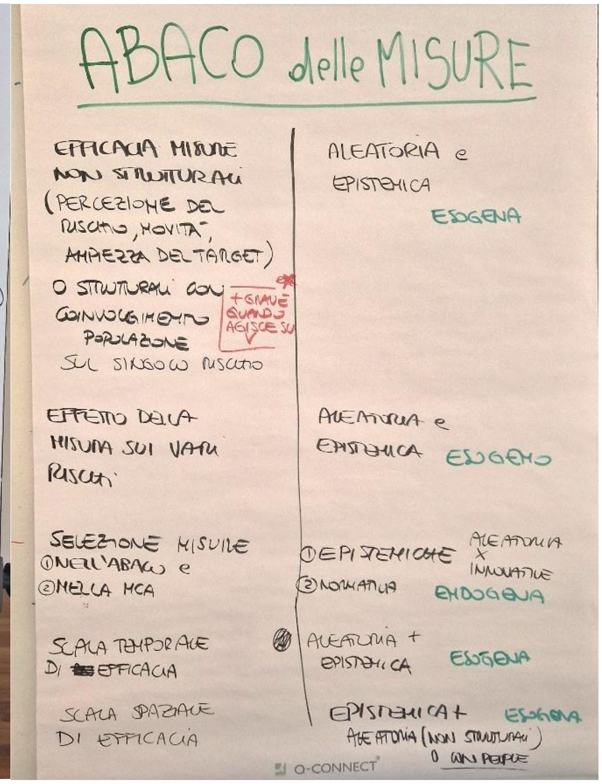
Here is an example of how the brainstorming session was supposed to be structured:

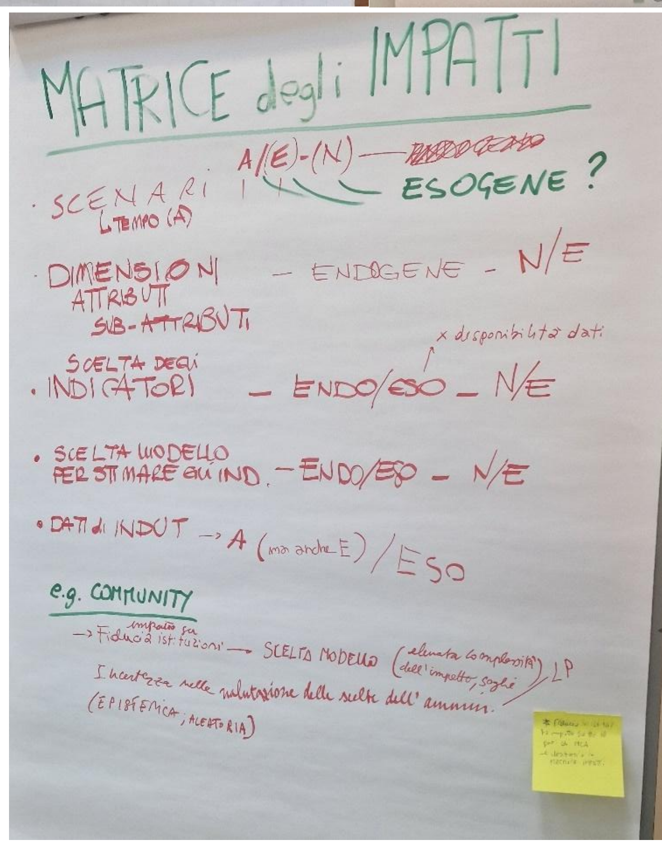
OBJECT	***DOUBT***	***TYPE***
Selection of measures	*Does it include all relevant alternatives?*	Normative / Endogenous
Measure A	*Is it feasible?*	Epistemic / Exogenous
Vulnerability curve	*Is it accurate?*	Epistemic / Exogenous
Choice of indicator *x* for attribute B	*Is it adequate?*	Epistemic / Endogenous
Classification of impacts	*Is it the most useful?*	Normative / Endogenous
Data for economic exposure	*Is it accurate?*	Epistemic / Exogenous
Seisimic hazard	*Will it happen?*	Aleatory / Exogenous

Brainstorming Session

The brainstorming session produced the following flipcharts:


ELEMENTI VALUTATIVI
INCERTEZZA NORMATIVA ENDOGENA
NORMATIVA
EPISTEMICA
ALEATORIA
NON È SOGGETTO A INCERTEZZA


ABACO delle MISURE
ALEATORIA e EPISTEMICA
ESOGENA
EFFETTO DELLA MISURA SUI VARI RISCHI
SELEZIONE MISURE
SCALA TEMPORALE DI EFFICACIA
SCALA SPAZIALE DI EFFICACIA


MATRICE degli IMPATTI
SCENARI
ESOGENE ?
DIMENSIONI
ATTRIBUTI
SUB-ATTRIBUTI
ENDOGENE - N/E
SCELTA DEGLI INDICATORI - ENDO/ESO - N/E
SCELTA MODELLO PER STIMARE GLI IND. - ENDO/ESO - N/E
DATI di INPUT → A (ma anche E) / ESO
e.g. COMMUNITY

Miro board on uncertainties

The discussion led to the compilation of this MIRO board. The results of the MIRO board and discussion are reflected in the tables below:

Abacus of measures

Uncertainty	**What does lead to uncertainty?**	**Type of uncertainty**	**Quality of uncertainty**
Effectiveness of measures: non structural measures (risk perception, novelty, type of target) Or structural with population engagement on a specific risk		Aleatory and Epistemic	Exogenous
Design of the measure / how I design the measure. Uncertainty about the possible alternatives of a given measure (uncertainty about the selection of alternatives to include)	What type of measure do I include? Effectiveness of effect		
Impacts of the measures on risks:	which are the risks considered and on which risks does the measure act on?	epistemic (I can collect data) & aleatory (what is in the abacus is based on the current condition which can change)	Exogenous
measure design phase selection of measures in relation to MCA impacts	at what stage do I design the measure (e.g. prevention, recovery)? When is it best to design it? for which specific context does the measure apply / best fit?	Epistemic & aleatory	
Identifying Measurement Effectiveness. Uncertainty prediction	When do I estimate the effectiveness of the measure?	Systemic & aleatory	
selection of measures	Identification of measures in the abacus (the measures identified in the abacus are not necessarily all those available) measures identified in MCA	Aleatory as it is not possible to know if there will be future innovation & epistemic Normative because the measures chosen are the most suitable for the context	Endogenous

time scale of effectiveness	how will the measure be maintained? What does influence the maintenance of the measure?	Epistemic & aleatory	Exogenous
Spatial scale		Epistemic & aleatory (for non structural measurs)	Exogenous

Matrix of Hazards & Impacts

Uncertainty	**What does lead to uncertainty?**	**Type of uncertainty**	**Quality of uncertainty**
Expected future context_ context could change both from environmental and climate point of view The measure may be effective in the short term but not in the long term		EPISTEMIC AND ALEATORY Epistemic if I improve my knowledge of the context Normative if I choose what I want (?) I can overcome epistemic uncertainty related to the context but not aleatory uncertainty	
availability of economic resources _ dependent on historical & political context	Uncertainty with respect to the expected evolution of the context affecting the assessment of the actual impacts that might occur		
Uncertainty of the political context and context sensitivity		Aleatory	
Which will be the impact of the measure?	Uncertainty affecting the actual effectiveness of the measure over time	Epistemic & aleatory	
construction of the matrix: how do I identify the criteria, what data do I have?	How reliable are the data I consider for the indicators? What can I estimate?	Epistemic & aleatory	Endogenous
identification of weights : which stkh do I identify and involve to identify the weights? how much do I estimate my involvement?			
willingness of stakeholders to be involved	I do not know how much stkh are willing to be involved	Aleatory (?)	

Future scenarios	how the scenario changes in the future available data	aleatory systemic if we focus on data collection normative because the choice of scenario is also given by a value scale	exogenous
choice of dimensions + attributes and sub attributes _ how we built the matrix structure		epistemic (if the willing is to grasp important aspects that have not been tested, there has been no feedback with reality as to whether the identified structure works or not) normative_ the scate of attributes depends on our values	Endogenous
choice of indicators	Available data choice of model to estimate indicators input data chosen to build the model	Normative and epistemic epistimic and normative Aleatory and Epistemic	Exogenous (as depends on data availability) & endogenous Exogenous Exogenous
impact: trust in institutions	how do i estimate the indicator ? how do i estimate the impact? starting conditions have a big influence on how I estimate the impact / more time variables	Epistemic & Aleatory	Exogen

Evaluation criteria

Characterized by endogeonoues uncertainty that can be wither epistemic or normative. The type of uncertainty strongly depends on the target / who is involved in the definition and design of the measure. According to the target (i.e. policy-makers, technicians, citizanes) the uncertainty related to evaluation criteria can change. What is not subject to uncertainty is if the measure is compatible with existing plans & institutional set up.

Uncertainty	**What does lead to uncertainty?**	**Type of uncertainty**	**Quality of uncertainty**

fundability	Depends on the context	Normative	Exogenous
perception of the territory		normative but also exogenous as it depends on data available	Endogenous & exogenous
Social- related evaluation criteria : social cohesion, minorities, relationship between institution and citizens involved in co-monitoring & co-planning	Depends on existing inequalities	Normative, epistemic and aleatory	Exogenous
Costs		Epistemic	Exogenous
Environmental impacts		Epistemic	Exogenous
Job creation		Epistemic	Exogenous
Education		epistemic - how the population reacts to educational stimuli (whether or not measures that are triggered on the educational side) - context-specific	Exogenous
Corruption		Epistemic	Exogenous
Time and duration of the measures- how long a measure is appropriate or not		Aleatory	Exogenous
Skills needed to implement the measure		Aleatory	Exogenous & Endogenous
Institutional set up	How the institutional set up influence the implementation	Aleatory	