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Integrated Assessment of Natural Hazards and Climate Change Adaptation:
I. The KULTURisk Methodological Framework

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Abstract
A conceptual framework integrating different disciplines has been developed to comprehensively evaluate the benefits of risk prevention. Three main innovations are proposed with regards to the state of the art: (1) to include the social capacities of reducing risk, (2) to go beyond the estimation of direct tangible costs, and (3) to provide an operational solution to assess risks, impacts and the benefits of plausible risk reduction measures. The traditional risk metric in the physical sciences is the expected damage (direct tangible costs), which is defined as a function of hazard, vulnerability (physical) and exposure. The last element, exposure, provides the information to convert results into monetary terms. In the development of the KULTURisk Framework (KR-FWK), we considered several different pre-existing proposals, and we designed a new one as a conceptual model and also a flow-chart for the elaboration of information. The proposed KR-FWK is thus expected to provide: 1) an operational basis for multidisciplinary integration; 2) a flexible reference to deal with heterogeneous case studies and potentially various types of hazards; and 3) a means to support the assessment of alternative risk prevention measures including consideration of social and cultural dimensions. The project case studies of the process are expected to provide a quite diversified set of situations, allowing to consolidate the framework itself and to develop ad hoc tailored solutions for most common implementation cases.

Keywords
Natural disasters, Integrated Risk Assessment, Climate change adaptation

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Q51, Q54, D81

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1 Introduction

Several legal documents including the European Flood Directive (2007/60/EC) call for the development of "flood risk maps showing the potential adverse consequence" of floods with different return times. Those maps, together with the results of other analyses and in particular economic valuations, are then used as planning instruments to support decisions. The need thus emerges for methods and tools to assess the adverse consequences of the flood risk in an integrated, comprehensive, and coherent manner. Such effort is in essence multidisciplinary, including contributions ranging from hydrology, and environmental sciences to economic and social sciences. However, when discussing about natural disasters, the notions of vulnerability and risk and the approaches for their assessment have found different and often contrasting solutions by various schools of thought in the recent years. Therefore, a straightforward solution for disciplinary integration does not exist and conceptual discrepancies and terminological inconsistencies emerging from the various research communities have to be solved preliminarily (Thomalla et al., 2006; Mercer, 2010; Renaud and Perez, 2010). This is not an unusual situation, which makes it difficult to collaborate within an interdisciplinary environment, and thus limits the number of available operational solutions to cope with societal needs and by law obligations of competent authorities.

The definition of risk itself and its measurement are still open issues in the scientific literature. Many disciplines dealing with risk have different views about its definition and thus the components that have to be considered together with the process of its calculation.

Preliminary analyses conducted in preparation of the development of this paper brought to identify a series of evidences that were kept in the background during all the activities:

a) substantial discrepancies are evident in the risk literature, fragmented into many disciplinary streams;
b) at least two distinct research streams are of greatest interest for our work: Disaster Risk Reduction (DRR), and Climate Change Adaptation (CCA);
c) the ambition of trying to unify the terminologies in use is out of scope and KULTURisk does not have the role for having an adequate impact, at the international level, but can instead contribute significantly by providing communication interfaces and operational solutions;
d) moreover, definitions are evolving within each community;
e) risk assessment is usually focused on damages, i.e. direct tangible costs, but they are (also by law) only limited measures of risk; other direct, indirect, and intangible costs should be considered, whenever possible;

f) in general, social and non-physical aspects are crucial for a comprehensive assessment of the risk;

One well established approach for the calculation of risk in the physical/environmental (P/E) sciences within DRR research community refers risk to the expected damages (more precisely ‘direct tangible costs’), which are calculated as a function of hazard, P/E vulnerability, and exposure (Crichton, 1999):

$$R = f(H, V, E) \qquad [1]$$

The first element is characterized by probability distributions or referred to specific return times, and together with the second it is usually expressed as a dimensionless index, while the latter, exposure, provides the unit of measurement of risk, that is money.

This framework is straightforward and widely adopted, but it finds its limitations mainly in the narrow consideration of the complexity of the various dimensions of risk and in particular of the social ones. In order to fit within the formula reported above, all the risk dimensions have to be extremely simplified and aggregated in order to produce two dimensionless indices of hazard and vulnerability. This can be quite challenging when the attention is driven to the social dimensions of vulnerability as in Cutter (1996), where it is distinct from biophysical vulnerability, but later aggregated into a single notion of “place vulnerability”.

While the DRR community drives more emphasis on the concept of risk, other research streams and in particular the one focused on climate change adaptation (CCA), under the auspices of the Intergovernmental Panel on Climate Change (IPCC), were more focused on the assessment of vulnerability. In the DRR studies, vulnerability is indeed considered, but it is mainly regarded as an input for the quantification of risk. Instead, CCA research considers vulnerability as an output deriving from social conditions and processes, and in particular by the combination of the status of the adaptive capacity of the social-ecological system and the potential impacts deriving in turn from the combination of local sensitivity and the exposure to a specific hazard (Klein, 2004; IPCC-AR4 2007).

As a consequence, while DRR focuses on the knowledge of hazard by means of risk analysis, CCA is focused more on the importance of understanding the behaviour of and the consequences for the - local - communities involved by means of vulnerability assessment.

The two main research streams have been increasingly integrated since the climate change dimension has gained ever-greater attention in the consideration of natural disasters, while climate variability and extreme events have been brought to the core of both climate change science and the political agenda. The process of integration between DRR and CCA on one hand and between physical / environmental and social sciences on the other hand is still in progress. Effects are clearly visible when considering the sequence of IPCC publications in recent years. In the framework adopted by the IPCC-AR4 (2007), briefly described above, the concept of risk is missing, while potential impacts (of climate change) were included and vulnerability resulted as an output. Recently, with the publication of IPCC-SREX (2012), a substantial move from the CCA community towards the concepts and definitions consolidated in the DRR could be observed. Disaster risk is explicitly included in the conceptual framework (see Figure 1), but the causal chain of relations between climatic events and the concepts of vulnerability and exposure is not clearly defined, thus limiting the possibility to derive uncontroversial operational assessment methods.

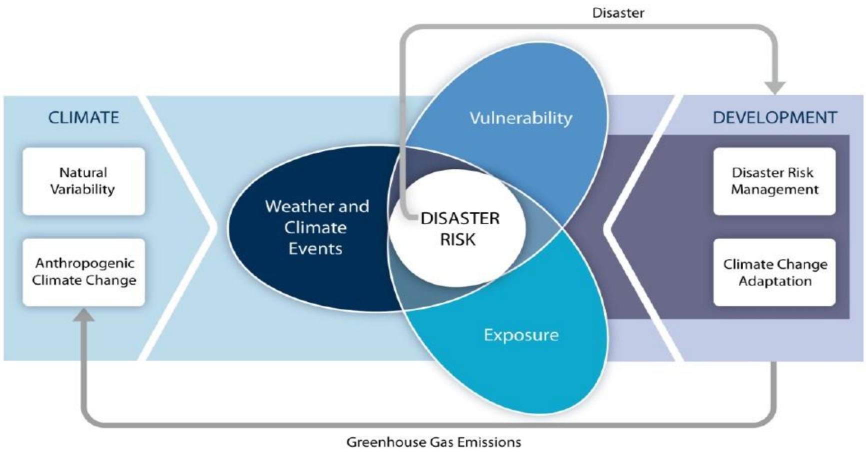

Figure 1: Managing the risk of extreme events and disasters to advance climate change adaptation, from IPCC- SREX (2012).

Many authors and research projects have provided their own view on the subject matter. Worth to be mentioned here is the approach for Probabilistic Risk Assessment proposed by the CAPRA Platform[1] (Cardona et al., 2010) as an operational combination of multiple disciplinary models and cost benefit analysis for decision support. An alternative and rather complex conceptual framework can be found in the MOVE Project[2] (2010) in which risk is determined by the interactions between the environmental dimension in terms of hazards and the society with its specific features in terms of susceptibility, fragility, resilience, etc. A more mechanistic approach based on system dynamics and the notion of socio-ecosystem modelling can be found in Turner et al. (2003), with focus on the analysis of vulnerability in relation again to the notions of resilience, exposure, sensitivity, etc., but without explicit consideration of risk.

In general, it is clear from the analysis of the literature that there is no practical solution for integrating and synthesizing the main references without facing the need to decide among contrasting definitions. Moreover, it should be noticed that often the proposed frameworks

[1] See http://www.ecapra.org/.
[2] See http://www.move-fp7.eu/.

provide only a pictorial representation of relationships among different concepts without providing any identification of causal or functional relationships, which are instead the basis for any attempt to develop operational algorithms for risk assessment. Even in the cases in which some sort of index is proposed (e.g. a vulnerability index), the procedure for the management of information are often rather naive, with a prevalence of additive procedures applied to dimensionless indicators, without the adequate consideration of fundamental issues, such as normalisation effects, internal compensation, weighting, independence of variables, etc.

Furthermore, risk assessment is usually focused on the valuation of the potential consequences, but very often these are limited to the expected damages in terms of direct and tangible expected costs. Yet very little attention is given to indirect and intangible costs, which are proven to be a quite relevant component of the potential consequences of a natural disaster (Cochrane 2004, Okuyama and Sahin 2009). Given the interconnectivity of the economy at multiple scales, it is very important to evaluate the indirect risks of flood damages outside of the disaster area to achieve a comprehensive risk assessment. Similarly, the intangible damage to human health is a major component of any risk assessment that often is described very briefly and in a very coarse manner.

Given the current status of theoretical analyses and operational solutions briefly introduced above, the KULTURisk Project[3], an EU funded research aimed at developing a culture of risk prevention by evaluating the benefits of different risk prevention initiatives, has approached the development of a novel methodology focused on different types of water-related catastrophes, such as inundations, urban flash floods, and rainfall triggered debris flows[4].

A methodological framework and an operational approach named Socio-Economic Regional Risk Assessment (SERRA), developed upon the well-established Regional Risk Assessment methodology (RRA; Landis 2005) have been developed during the first half of the 3-year project, to be implemented in a series of European project case studies and elsewhere. The main purpose is to provide an innovative approach for natural disaster assessments and climate change adaptation by developing upon pre-existing RRA[5] approaches and by: (i) including consideration of the social capacities of reducing risk, and (ii) defining an economic measure of risk that goes beyond the direct tangible costs.

According to those purposes, the KULTURisk Framework was designed to provide: (i) an operational basis for multidisciplinary integration; (ii) a flexible reference to deal with heterogeneous case studies and potentially various types of hazards; and (iii) means to support the

[3]KULTURisk: Knowledge-based approach to develop a cULTUre of Risk prevention. FP7-ENV-2010 Project 265280 (http://www.kulturisk.eu/)

[4] The present paper is the result of author’s elaborations on the contents of Project Deliverable 1.6.

[5] For details about the KULTURisk approach to RRA, see Project deliverables 1.2 and 1.7 at http://www.kulturisk.eu/results/wp1.

assessment of alternative risk reduction measures including consideration of social and cultural dimensions.
The main focus of the social dimension of risk is on the role of 'Adaptive' and 'Coping' capacities of societies, which can prepare them for a better response to natural disasters as they face and adapt to climate related risks and the unknowns of climate change. The economic dimension is dealt with the estimation and monetization of a 'Total Cost Matrix' (TCM), made by the combination of the estimated direct and indirect and tangible and intangible costs.
As a whole, SERRA is thus designed to combine the notion of physical and environmental risk together with social vulnerability and economical value factors to help policy/decision makers to perform a meticulous cost-benefit analysis (CBA) of different scenarios of risk mitigation at an aggregated or disaggregated spatial level. The framework and the methodology were not designed upon CBA as the only possible solution given that our specific aim was to provide operational solutions for supporting decisions with focus on climate change adaptation. Alternative methods, such as cost-effectiveness or multi-criteria analyses are also considered and solutions for implementation are provided in the following sections.
In Section 1, we show the conceptual discrepancies and terminological inconsistencies emerging from the various research communities dealing with risk and vulnerability, and examine some of the main existing frameworks, which have inspired our work. Two main innovations are proposed with regard to the state of the art of disaster risk assessments: (1) to define a measure of risk that goes beyond the direct tangible costs, and (2) to include the social capacities of reducing risk. Both these elements of novelty are treated in Section 2, where we present and describe the KULTURisk Framework. In Section 3 and 4, we introduce the approaches proposed for economic valuation and for the assessment of the social dimension. In Section 5, we describe operational solutions of the framework, whereas in Section 6, we provide two examples of application contexts, which stay at the extremes of the range of possibilities emerging from treating risk in a spatially disaggregated or aggregated way and as a discrete or continuous relationship with the varying levels of hazard. The choice between aggregated or disaggregated risk assessments mainly depends on the availability of data. In Section 7, we discuss the uncertainty of disaster risk estimation. Finally, we conclude by providing some final remarks.

2 Methodological framework for integrated risk assessment

A long process of collaboration and recursive exchange of intermediate drafts within the KULTURisk consortium brought us to a comprehensive glossary of the adopted terminologies, reported in Table 1. The main sources of references are the IPCC-SREX (2012) and UNISDR Hyogo Framework (2009). The final choice of definitions is the responsibility of the authors of this work, which was based on the following main criteria:

1. internal consistency within the conceptual framework;
2. consistency with the main references of the DRR and CCA literatures, having identified the Hyogo Framework and and the IPCC SREX Report as the main ones;
3. minimizing the changes compared to the consolidated approaches adopted within the consortium.

Therefore, the KULTURisk framework implemented in SERRA has the ambition to offer an effective interface and a common ground for teams working across diverse disciplines, with the common aim of supporting decisions for risk mitigation actions.
Before entering into the details of the KULTURisk Framework, it is important to consider the decision-making context in which the framework should be utilized. In order to implement a decision-making process in the field of risk management and assessment of mitigation measures, a cycle of decision-making steps can be identified, as proposed by UKCIP (2003). We distinguish eight steps that we explain in the following paragraph (Figure 2).

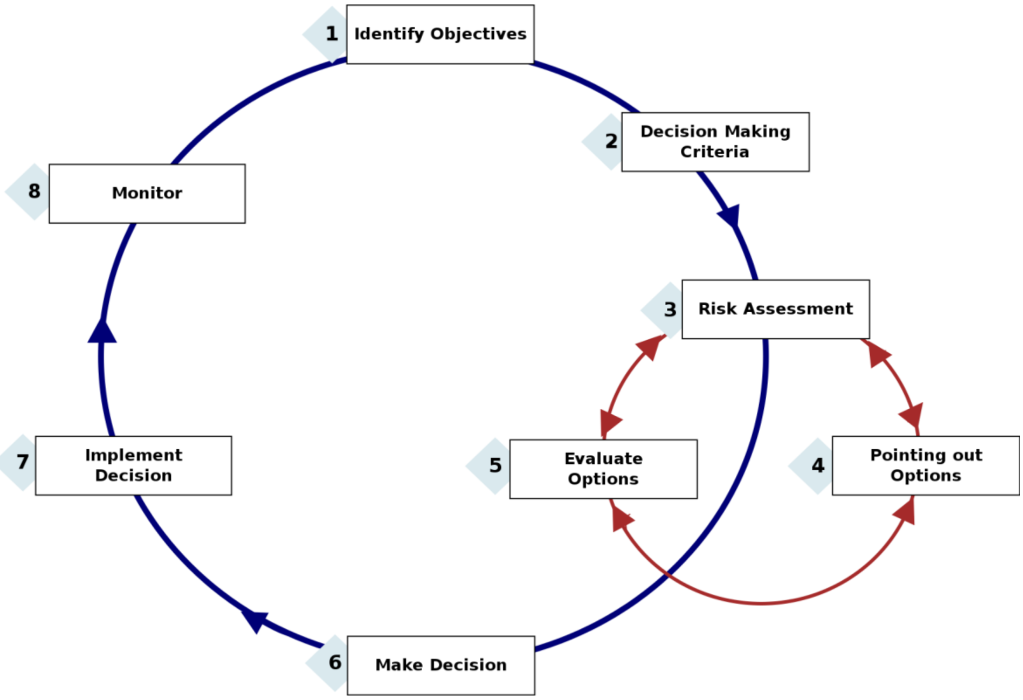

Figure 2: Cyclic Decision-Making Flowchart for CCA, source: UKCIP(2003), redrawn.

The first step is, obviously, stating our goal, which is developing a culture of water-related risk prevention by evaluating different risk reduction measures. In the second step, we need to identify the receptors with respect to which we would like to assess the risk and set forth the decision-making criteria. The decision-making criteria can be for instance reducing the damages equal to 20% from flood or landslides given a certain amount of budget or the ease and cost of implementation. In the third step, we assess risk with respect to identified receptors, hazard features, and vulnerability of the receptors. In the next step, we point out our options for reducing the risk. In the fifth step, we evaluate the merit of our options by applying them to several case studies. From this point on, one can identify other steps related to making decision and post decision-making actions. In this work we focus our attention on steps 2 to 5.

Herein, we first describe the comprehensive framework with reference to the glossary reported in Table 1. Initially the KULTURisk Framework was developed around three main subsections identified as three main areas of expertise within the consortium, which are described in the following: (1) the regional risk assessment, (2) the valuation of potential consequences, and (3) the social capacities/vulnerabilities. After a long process of interactions leading to a sequence of framework drafts, the solution was found in developing a comprehensive framework upon the consolidated formalization of risk being a function of *hazard, exposure, and vulnerability*. Therefore, the final proposal complies with the most consolidated approach for risk assessment, while providing an original and innovative solution operational implementation. The main concepts, and thus information bases, are considered for the quantification of the three components and then implemented into algorithms for the assessment of the fourth, i.e. risk. Overall formula [1] holds in the various processes proposed in SERRA[6] (e.g. risk being necessarily null, when hazard is zero), even if not necessarily the algorithm was forced to produce two independent and dimensionless indexes (H and V) to be used in a multiplicative combination with one monetary index of exposure.

Table 1: The comparison between KULTURisk Framework and other frameworks terminologies.

	KULTURisk Framework	**IPCC-SREX 2012** **UNISDR Terminology 2009**
Adaptive Capacity	(IPCC-SREX, 2012)	**IPCC:** The combination of the strengths, attributes, and resources available to an individual, community, society, or organization (ex-ante hazard) that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities. **UNISDR:** N/A
Attenuation	Considers structural and explicit, manufactured barriers to the hazard, which may affect exposure.	N/A
Coping Capacity	(IPCC-SREX, 2012)	**IPCC:** The ability of people, organizations, and systems, using available skills, resources, and opportunities, to address, manage, and overcome (ex-post hazard) adverse conditions. **UNISDR:** The ability of people, organizations, and systems, using available skills and resources, to face and manage adverse conditions, emergencies, or disasters.
Direct Costs	The costs due to the damages provoked by the hazard and which occur during the physical event (Merz et al., 2010).	N/A
Exposure	(IPCC-SREX, 2012)	**IPCC:** The presence of people; livelihoods;

[6] See Note 2 of the same Working Papers Seiries.

		environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected. **UNISDR**: People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.
Hazard	(IPCC-SREX, 2012)	**IPCC**: The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources. **UNISDR:** A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.
Indirect Costs	Those induced by the hazard but occurring, in space or time, outside the physical event (Merz et al., 2010)	N/A
Intangible Costs:	Values lost due to a disaster, which cannot, or are difficult/controversial to, be monetized because they are non-market values (Merz et al., 2010).	N/A
Pathway	The geomorphological characteristics of the region under assessment, which affect the way hazards propagate and therefore exposure (e.g. digital elevation model). It includes natural barriers to the hazard.	N/A
Potential Consequences	Are expressed in the form of the total cost matrix.	N/A
Receptor	A physical entity, with a specified geographical extent, which is characterized by particular features (e.g. human beings, protected areas, cities, etc.).	N/A
Resilience	Not applied in our framework but can be interpreted as opposite to the definition of vulnerability.	**IPCC:** The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions. **UNISDR:** The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions
Risk	The combination of the probability of a certain hazard to occur and of its consequences.	**IPCC:** The likelihood over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery. **UNISDR:** The combination of the probability of an event and its negative consequences.
Risk perception / Awareness	The overall view of risk as perceived by a person or group including feeling, judgment, and culture (ARMONIA project, 2007).	**IPCC:** N/A **UNISDR:** The extent of common knowledge about disaster risks, the factors that lead to disasters and the actions that can be taken individually and collectively to reduce exposure and susceptibility to hazards, while increasing the adaptive capacity

Susceptibility	Susceptibility brings in a physical/environmental assessment of the receptors, i.e. the likelihood that receptors could potentially be harmed by any hazard given their structural factors, typology of terrain and characteristics (in physical and non-monetary terms)	N/A
Tangible Costs	The costs, which can be easily specified in monetary terms because they refer to assets, which are traded in a market (Merz et al., 2010).	N/A
Value factor	The social, economical, and environmental value of the exposed receptors.	N/A
Vulnerability	Is consisted of susceptibility as the P/E component and adaptive & coping capacities as the social component.	**IPCC:** The propensity or predisposition to be adversely affected. **UNISDR:** The characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard.

In order to have an adequate concreteness in the identification of the KULTURisk Framework, we made a specific reference to flood risk, bearing in mind that subsequent project activities should assess the potentials for considering other risks.

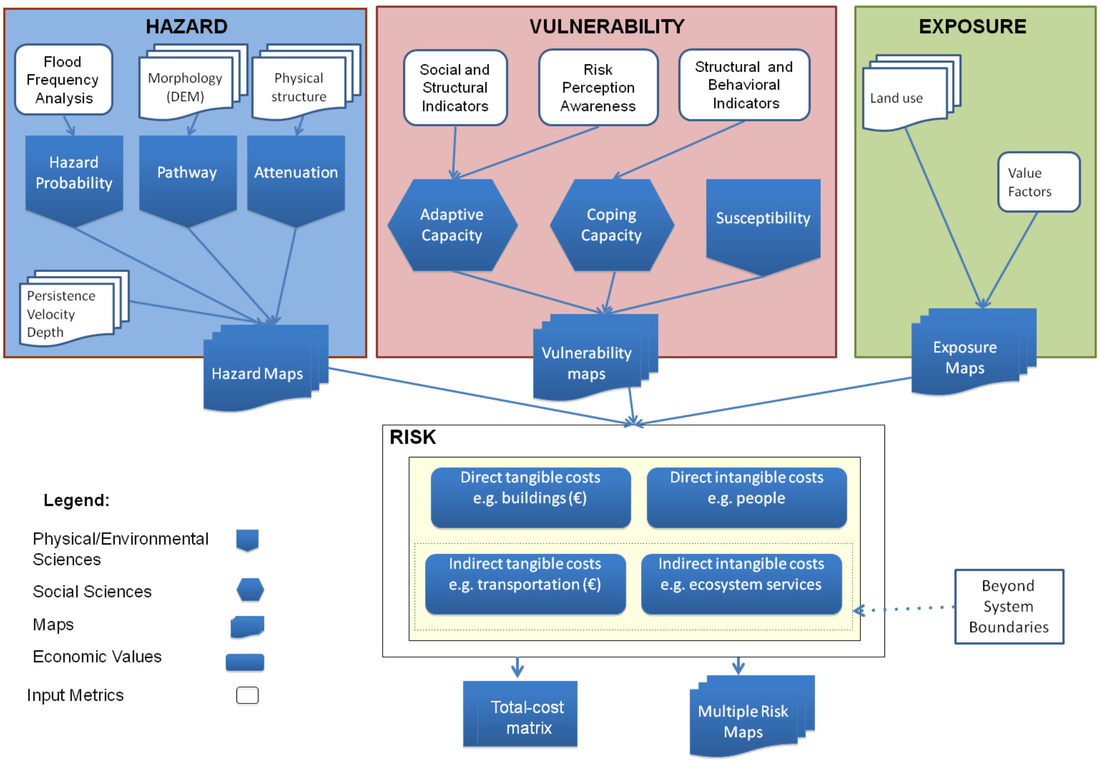

Figure 3: The KULTURisk Framework with the identification of the main sources of data for the quantification of nodes.

As shown in Figure 3, the proposed approach for integrated assessment consists of four pillars namely *hazard*, *vulnerability*, *exposure*, *and risk*, where the outcome of the first three affects the latter. In the case of a flood event, the **hazard** outcome is a map of intensity (expressed in terms of depth, persistence, or velocity) of the flood, provided by the hydrological analysis and modelling i.e. flood frequency analysis, geomorphological characteristics of the region under assessment (pathway), and manufactured barriers against the hazard (attenuation) elements of the assessed area. Considering different return times and measures of intensity, multiple hazard maps can be produced, following the specific requirements of the legislation. Additionally, multiple receptors have to be considered. For example, the Flood Directive identified four categories of receptors: people, economic activities, cultural goods, and the environment component (EC, 2007).

In the proposed framework, **Exposure** identifies the presence of people and assets and as much as possible the social, environmental, and economical value of them. **Vulnerability** is defined as another map resulting from the combination of P/E and social components. The P/E component is captured by the likelihood that receptors located in the area considered could potentially be harmed (*susceptibility* of receptors). The social one is the ex-ante preparedness of society given their risk perception of awareness to combat hazard and reduce its adverse impact or their ex-post skills to overcome the hazard damages and return to initial state (represented by *adaptive and coping capacities)*. A list of social indicators that can proxy adaptive and coping capacities is proposed in the following section. The above-described elements help us to calculate the expected damages related to the **risks** associated to different hazardous scenarios. We decompose risk into four components that together they make the **Total Cost Matrix (TCM)** of indirect/direct tangible/intangible costs. The direct costs are corresponding to all the tangible/intangible costs in the geographical location and during the hazardous event. All the costs outside the time frame or the geographical location of hazardous event are represented by indirect costs. The dashed line in risk component of Figure 3 is pointing to the above-mentioned distinction. Hazard, vulnerability, and exposure are foreseen as maps, therefore, they are spatially explicit, and they will be integrated in a GIS context. For instance in a grid cell of GIS maps of a certain size, we can explicitly show the expected depth of inundation and the presence of buildings and people and the likelihood of them to be damaged or harmed. In many cases, we expect that social data related to adaptive and coping capacities can be managed in a spatially distributed fashion. Typically by allocating census and other information to administrative sub-units, but we can imagine cases in which only aggregated information could be available and therefore, the assessment of risk mitigation measures could only be possible in a non-spatial aggregated manner. In those cases, the benefits expected from measures, deriving from the comparison of ex-post situation with the Baseline Scenario, could only be expressed as a lumped sum (in case of full monetization) or as a series of deltas describing the changes of the indicators considered. The adoption of monetary units for risk facilitates the aggregation of the values obtained whenever needed, for example to sum up costs referred to the various receptors.

3 The evaluation of benefits of risk reduction

Theevaluationofthepotentialbenefitsofanyriskpreventionmeasurerequirest hevaluationof avoided costs due to its implementation. Furthermore, the avoided damages must be confronted with the costs of the measure implementation itself. Thus, having identified a measure or set of measures of potential interest, the first step required is to define the cost of a hydrological disaster without any preventive measure (baseline scenario). A second step is to estimate the expected costs of the same hydrological disaster with the risk prevention measure in place (alternative scenario), including the cost of the prevention measure itself. The benefits are then the difference between the costs in the baseline and in the alternative scenarios. Nevertheless, what are the costs of a hydrological disaster? Traditional risk assessments have been primarily dealing with direct tangible costs in a very detailed fashion, however there exist a whole set of neglected costs that should be considered in view of providing a comprehensive quantification of risk. For this reason the concept of **Total Costs Matrix (TCM)** as shown in Figures 3 and 4 has been proposed.

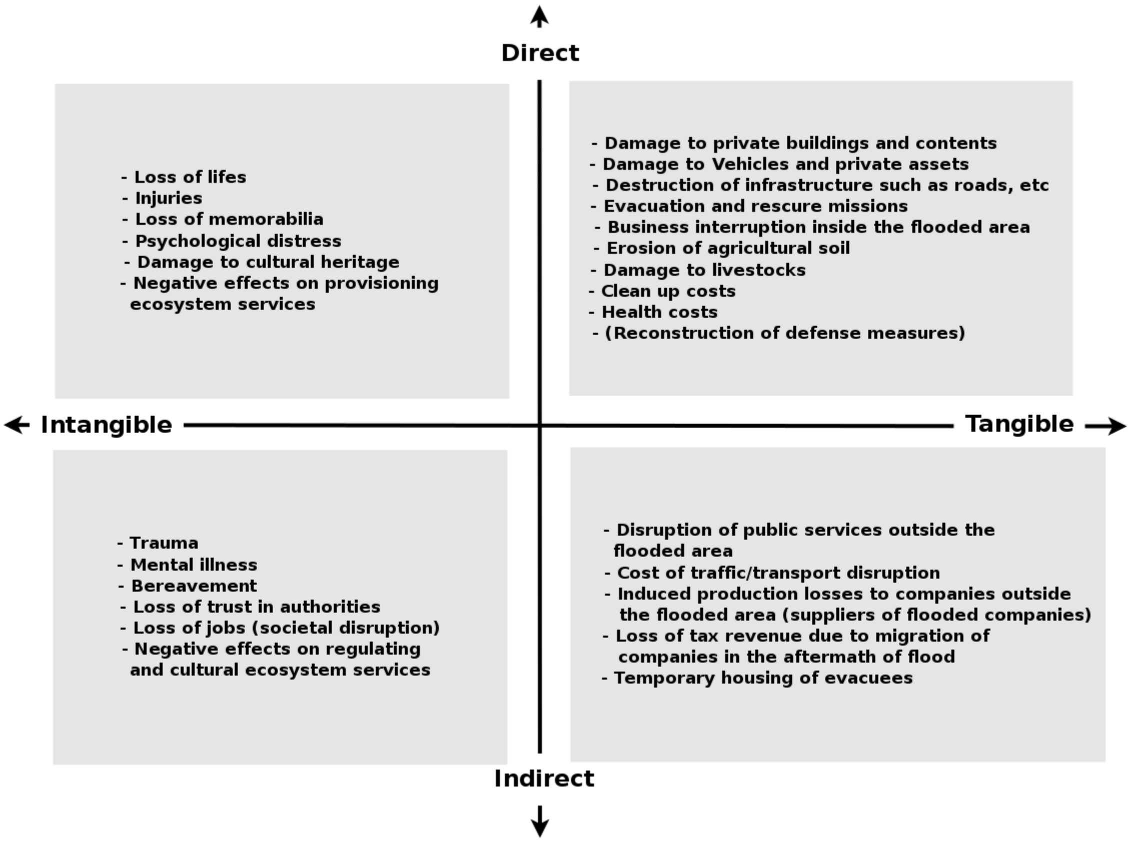

Figure 4: The Total Cost Matrix, adapted from: Penning-Rowsell et al. (2003), Jonkman et al. (2008), and Merz et al. (2010).

One may argue that most of the times a detailed estimation of direct tangible costs is sufficient to compare and justify the choice of alternative risk reduction measures (RRMs), in particular when structural RRMs are combined (e.g. dikes, dams, embankments, etc.). Whether this

still holds when it comes to evaluating the benefits of non-structural measures and of preparedness is an open issue, since, for instance, the importance of intangible and indirect costs and benefits might substantially increase.
For example, an early warning system might only partially reduce the amount of **direct tangible costs** (e.g. you can move your car but not your house), but it can:

a) save the lives of many people (**direct intangible costs**);
b) change behaviour of people by avoiding long lasting traumas(**indirect intangibles costs**);
c) prevent evacuation costs (**indirect tangible costs**).

In order to go beyond the direct tangible costs, the following methodological and operational requirements emerge:

a) a more comprehensive and less reductionist notion of risk, but with a disaggregated structure as shown by TCM;
b) a functional description of the expected consequences of the hazard considered according to the quadrants of the TCM;
c) the consideration of other types of impacts, for which the issue of expression in monetary terms emerges;
d) the implementation of methods for economic valuation of non market goods, in order to provide monetary values to intangibles, whenever possible and desired for the support to decisions based upon the implementation of Cost-Benefit Analysis (CBA) methods;
e) the consideration of alternative evaluation methods in those cases in which CBA is not possible or desired, such as Cost-Effectiveness or Multi-Criteria Analyses (CEA and MCA, respectively).

Depending on the evaluation methods adopted, the benefits of risk prevention or mitigation measures will be expressed as the difference between the potential consequences determined by the baseline scenario and the alternative scenario with new risk prevention measures in monetary terms (CBA case), or as the combination of monetary estimations of some components (typically the expected costs of the measures considered, and direct and indirect tangible costs), with other performance indicators or indices (in case of CEA, MCA or other methods).

4 The social dimension: adaptive and coping capacities for risk prevention

One of the main innovations of the proposed framework is the inclusion of social capacities (adaptive and coping capacities) in the process of measuring risk by means of the TCM, which is a disaggregated way to structure the potential consequences. This is also an attempt to capture and make the concepts of social vulnerability operational and as far as possible quantifiable.

The main challenges for the analysis of social capacities in a risk assessment context can be identified with respect to:

a) tailoring the set of indicators to the context;

b) defining empirical functions for the estimation of indicators and aggregating them.

Social scientists usually investigate these capacities at the case study level by means of questionnaires and interacting with local stakeholders, mainly using a semi-quantitative research approach (e.g. Steinfuhrer et al.2009). Indeed, the variables measuring those capacities should be chosen according to the context of application. However, as shown in Cutter et al. (2003), a minimal set of indicators based on secondary data can be selected in order to approximate the magnitude of social vulnerability.

We propose a list of variables and indicators, as shown in Table 2, which may compose a minimal set of data to approximate those capacities. Furthermore, we declare our assumptions about their contributions to the TCM. Some of the indicators may affect both adaptive and coping capacities such as income level. A society with higher income level could have had a higher adaptive capacity by incorporating early warning systems at the community level, or at the individual level by taking precautionary actions such as fortifying their residential building. Equally, higher income can affect coping capacity when the communities' or individuals' ability in coping with flood is increased. Therefore, a careful scrutiny is necessary for empirically testing the significance of each indicator on adaptive or coping capacities, while avoiding double counting and internal correlations. While most of the indicators can be derived from secondary data or from the census and regional accounts, some variables might be difficult to derive without ad-hoc activities. This is particularly evident for trust or risk perception, which is an important component of the project and of the framework. Depending on the geographical scale, level of detail, available time, and financial resources, proxies could always be considered as substitutes to the proposed variables.

Table 2: Adaptive and Coping Capacity Indicators

				ASSUMED relationship with costs:			
Variable	**Adaptive Capacity**	**Coping Capacity**	**Indicators / *Proxies***	**Direct Tangible**	**Direct Intangible**	**Indirect Tangible**	**Indirect Intangible**
Age		X	Percent of population under five years old; Percent of population over 65 years; Median age;		+		+
Gender		X	Percent of females; Percent of female headed households;		+		+
Family structure		X	Percent of single parents households, Percent of households with more than 4 individuals,		+		+
Disabled	X	X	Percent residents in nursing homes, Percent ill or disabled residents,		+		+

Income level	X	X	Per capita income; Median monetary value of owner-occupied housing; Median rent for renter-occupied housing units; Credit rating of inhabitants	+		+	
Social disparity	X	X	Gini index of income; Percent of households earning more than X; Percent of households earning les than Y; Dependents on social services	+	+		
Education	X		Negative of percent of population 25 years or older with no high school diploma; Percent of population with higher education;			-	+
Employment	X		Percentage of labor force unemployed; Type of employment (full time, part time, self employed, etc.)			+	+
Safety network		X	Negative of quality of relationships within the community; *Percent of isolated population*; *Percent population change*; *Negative of percent with 1st to 2nd level connections to civil protection;*		+		+
Trust		X	Experts elicitation / measure of trust	+			-
Risk perception	X	X	Experts elicitation / measure of perception				
Risk governance	X	X	*Per capita number of community hospitals; Per capita number of physicians; Local gov. debt to revenue ratio; Access to places (number) of safety during the event; Number of red cross volunteers; Hours spent on training and maneuver*	-	-	-	-
Early warning capacity	X	X	*Number of early warning systems in place for typology of hazard;*	-	-	-	-
Risk spreading	X	X	% of hazard insured households; % of hazard insured economic activities;	-			
Economic diversification	X	X	Normalized Herfindahl index of sectorial (i.e. coarse: primary, secondary, tertiary) contribution to GDP and or to employment;	+		+	
Interconnectivity of economy	X	X	Net trade in goods and services (exports +); Percent of resident that travel to work outside the modeled area;	-		+	+
New comers		X	Percent renter-occupied housing units; Percent of recent residents/immigrants; Percent of people living in informal houses;	-	+		+

5 Towards an operational KULTURisk Framework

Given the ambition to deal with heterogeneous issues and application contexts, the proposed framework is necessarily generic, simplified in its overall conceptualisation, but still rather complex in its practical implementation, and tailored to specific cases. Practical applications should be developed upon the simpler conceptual model provided by the framework presented in Figure 3, and proceed by providing quantification of the nodes according to the specific objectives and conditions (e.g. data availability) of each implementation.

For instance, simpler versions can consider aggregated costs and/or indicators of social capacities. In addition, the methodology of aggregation and treatment of uncertainty can vary according to the data availability, etc. Therefore, the KULTURisk Framework indeed needs to be tailored to deal with different contexts of analysis.

The project case studies provide a quite diversified set of situations, allowing to consolidate the framework itself and to develop ad hoc tailored solutions for most common implementation cases. The process of tailoring has various degrees of freedom, which are summarized, in the following:

1. Identification of application context: scenarios and measures (baseline vs. alternatives).
2. Data availability.
3. Indicator selection.
4. Normalization.

5. Weighting.
6. Aggregation.
7. Uncertainty.

The first step towards the implementation of the framework is the **identification of the application context**. This is a strategic choice, which depends not only on the analyzed system but also on the application purpose thus affecting the detail level of analysis and the evaluation method to put the KULTURisk Framework into operation. Fundamental elements of such introductory step are the definition of the normative frame (for instance, in Europe, the Flood Directive of EC, (2007) in its national or regional implementations), the identification of information sources and management systems, the ambitions and preferences in terms of economic valuation methods.

Data availability and indicator selection for the traditional assessment of risk grounded on tangible costs, focus on historical river flow, precipitation, Digital Elevation Model (DEM), land use maps, maps of infrastructures etc., which are usually available from regional or national authorities and/or river basin districts. More challenging task for risk assessment is the identification of information sources for assessing social capacities. The list of indicators summarized in Table 2 can be considered as a reference basis, usually from the national census.

Normalization is the procedure of transforming indicator values of different metrics into a dimensionless number, with the aim to allow for valuation comparison, and aggregation of indicators with different units of measure. Normalisation issues emerge for the two components of the risk assessment formula [1] that are to be provided as dimensionless indices (H and V), but they may be also needed in E (exposure), whenever full monetisation is not performed, and in general in most of the applications of MCA methods. There exist a number of different normalization functions, and some are mentioned beneath:

1. Ranking
2. Standardization (z-score)
3. Value functions
4. Min-max normalization
5. Distance to a reference measures
6. Categorical scales

The type of normalization function depends on the indicators under consideration and on the preferences of the experts and decision makers involved in the evaluation process. The simplest normalization method consists of *ranking* each indicator value. The main advantages of ranking approach are its simplicity and the independence from outliers. Disadvantages are the loss of information on absolute levels and the impossibility to draw any conclusion about differences in performance. One of the most commonly used normalization procedure is *Standardization* (z-score) in which all indicators can be converted into a common scale with an average of zero and standard deviation of one. The *min-max* normalization is achieved through determining desirable and least acceptable (best and worst) values and to normalize the measured value between the two thresholds. *Value function* is one of the most widely used normalization procedures, using mathematical representations of human judgments, which offer the possibility of treating people’s values and judgments explicitly, logically, and systematically (Beinat, 1997). *Distance to a reference measure* takes the ratio of the indicator for a generic value with respect to the reference value. The reference could be a target to reach for example in terms of required effectiveness of the measure. In determining *categorical scale*, first, we select the categories. They can be numerical, such as one, two, or three stars, or qualitative, such as ‘fully achieved’, ‘partly achieved’, or ‘not achieved’. We, them, assign to each category a score, which is, to a certain extent, arbitrary.

Weighting is the procedure to express the relative relevance of individual indicators in composite indicators/indexes. Weights are essentially value judgments, thus essentially subjective, and have the property to make the objectives underlying the construction of a composite explicit. Depending on the subjective judgment, different weights may be assigned to different indicators and there is no uniformly agreed methodology to weight individual indicators before aggregating them into a composite indicator or index. Therefore, weights usually have an important impact on the composite indicator value and this is why weighting models need to be made explicit and transparent through involving the relevant stakeholders. To construct a composite indicator value and/or index, the weighting of indicators are carried out reflecting stakeholders’ views. Commonly used weighting procedures are the following:

a) Statistical weighting methods:
   - Equal weights
   - Principal Component Analysis
   - Factor Analysis
   - Multiple Regression Models

b) Participatory weighting methods
   - Expert judgment
   - Public opinion
   - Pair-wise comparison
   - Conjoint analysis

In the indicator-based assessment, the outcome (i.e. the index) is the result of **aggregation**, i.e. a – often hierarchical – combination of several indicators that need to be aggregated in each node in which they converge, or even to produce an overall index of risk. Aggregation of indicators is obviously not a trivial task since the chosen (among many) methodology has meaningful impacts on the computation of the final index; furthermore, the choice of the aggregation method typically involves trade-offs between loss of information, computational complexity, adherence to decision makers’ preferences, transparency of procedure, etc. Among the available aggregation operators are the following:

a) Averaging operators

- Quasi arithmetic means
- Order Weighted Average (OWA)

b) The ‘AND’ and ‘OR’ operators

c) Non-additive measures (NAM).

Averaging operators are still the most commonly used in practice, given the simplicity of their computation, immediacy, and transparency of the aggregation process. Nevertheless, averaging operators are typically compensatory (i.e. a bad score in one criterion can be offset by a good score in another one) and more importantly they are not able to consider any interaction among the criteria. *Quasi-arithmetic means* includes not only the simple arithmetic mean, but also geometric and harmonic means. OWA is still based on weighted sums, but the criteria are ordered by magnitude, and weights can be modelled to express vague quantifiers. ‘*AND’ operators* are a family of operators that express logical conjunction (pessimistic behaviour assigning the lowest value of the criteria to the aggregation), whereas ‘*OR’ operators* consider logical disjunction (optimistic behaviour). *Non-Additive Measures (NAM)* approaches such as *Choquet Integral* have been introduced to overcome the main drawbacks of the averaging operators.

6 Uncertainty

The sources of **uncertainty** in our estimation vary from those related to the environmental hazard (probability of flood) to those regarding the models used in the assessment of risk (hydrological, economical, and social ones), the parameters of the estimation (value factors, social indicators), etc.

In general, we can divide the uncertainties into two main types here: aleatory and epistemic, as reported in Table 3. *Epistemic uncertainty* is due to incomplete knowledge about a system and information gathering could reduce it, whereas *aleatory uncertainty* is due to natural phenomena and its reduction might be impossible. For instance, we can reduce the uncertainty regarding the values of the parameters of our estimation by acquiring more information by several means including running regressions on the historical or available data.

However, the uncertainty with respect to the frequency of flood or the effects of climate change is of aleatory type. Since climate change is in distant future, in the present time, we do not have sufficient knowledge about it. Moreover, flood frequency is an extreme event and we cannot know which extreme value probability distribution (Gamma, Gumbel, Weibull, GEV[7], etc) should be used. Therefore, in many cases we cannot reduce the uncertainty since it is not possible to increase our precision. One of the main motivation for the development of the KULTURisk Framework is reducing the epistemic uncertainty in risk assessment, by providing a scientifically sound and as far as possible quantitative

[7]Generalized Extreme Value.

approach for accounting for the social and economic dimensions, and in particular the capacities to adapt and their response to a specific natural hazard in a spatio-temporal context. In particular, the modelling of vulnerability is an important component of a receptor that influences the relationship between the source of hazard and the final adverse effect.

In case of risk assessment without socio-economic dimension, we represent the aleatory uncertainty in the flood frequency by means of a probability distribution. The product of this probability distribution and the potential consequences coming from different flood scenarios gives us the expected damage. The reason to do so is because the absolute uncertainty prediction for a given scenario is not very useful. Absolute uncertainty is less informative for a decision maker in comparison to a relative uncertainty prediction that takes into account different scenarios of flood and potential consequences.

The other source of uncertainty is negligence of appropriate temporal scale. For instance, for estimating the damages to agricultural products one has to consider the month and seasonal effect to reduce the uncertainty of estimations. Similarly, for spatial scale, we need to look for a scale that minimizes the uncertainty. At a too coarse scale, either some receptors are not seen (e.g. vehicles) or receptors become too homogenous and the risk is underestimated. In addition, receptors' characteristics (type, location, material, structure, etc.) might change in time due to change in land-use or urban expansion and since risk assessments are very expensive and time consuming and not performed every year, we need to take into account the changes in the land use in a 6-10 years period by means of stochastic spatial mapping[8]. For instance, if we group all industrial or commercial buildings into one category, we simply overlook the differences among them in terms of their vulnerability to flood. A chemical plant can be at a different risk due to flood compared to a warehouse.

Table 3: Sources of Uncertainty

Source of uncertainty	Type of uncertainty	Description
Flood Frequency	Aleatory	Uncertainty about future hydrologic events, including future stream-flow and rainfall. In the case of discharge-probability analysis, this includes uncertainty regarding the choice of a statistical distribution and uncertainty regarding values of parameters of the distribution.
Model Uncertainty	Epistemic	Lack of complete knowledge regarding the form of a hydrologic, hydraulic, or economic function to use in a particular application.
Spatial Uncertainty	Epistemic	Delineating the sub-basin. Changes in urban, ecosystem.
Temporal Uncertainty	Epistemic	Uncertainty regarding time of exposure of agricultural crops, people, etc.
Parameters Uncertainty	Epistemic	Uncertainty in a parameter due to limited understanding of the relationship or due to lack of accuracy with which parameters can be estimated for a selected hydrologic, hydraulic, or economic function.
Risk mitigation policies	Epistemic	Uncertainty about risk reduction measures and their performance (reliability).

[8] The European Flood Directive requires the state to perform flood risk analysis every 6 years. This requires a probabilistic spatial model that envisages changes in land use for the uncertainty in the estimation.

7 *Two examples of operational solutions*

When considering the available solutions to the aforementioned issues, it is possible to envisage a continuum of cases according to the spatial representation of risk and its probabilistic description (i.e. related to single or multiple hazard scenarios or to a continuous hazard-risk function).

Two examples are proposed below (Figure 6) with reference to the two cases which stay at the extremes of this continuum:

1. **Case (A):** risk is spatially represented and refers to a single hazard scenario;
2. **Case (B):** risk is aggregated at the spatial level and refers to a continuous hazard-risk function.

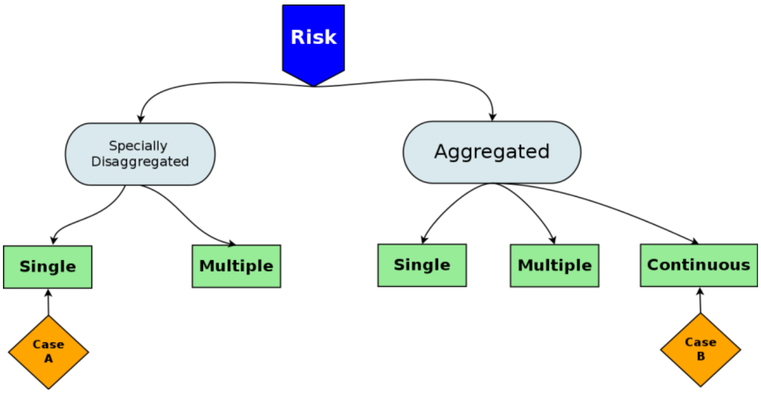

Figure 6: Proposed Solution for Implementation.

In Case (A), which is expected to be a frequent case according to the existing legislations, spatially disaggregated risk maps can be produced for each of the four cost quadrants (direct tangible, direct intangible, indirect tangible, indirect intangible) following RRA. The integration of the social capacity can be performed in analogy of RRA by overlaying the capacity maps (both coping and adaptive capacity) with risk maps using spatial Multi-Criteria Analysis (MCA) implemented through routines of overlaying GIS map. The results of such process are obviously spatial in nature, and they allow for exploring the geographical distributions of costs and identifying hot spots, i.e. areas at risk and with relatively high expected costs of different kinds (see example in Figure 7). Aggregation and weighting of the spatial indicators are important issues for developing spatially disaggregated risk maps. For example, Birkmann et al. (2010) proposed equal weighting and additive aggregation for developing spatially explicit vulnerability map, but solutions must be refined on a case-by-case basis with the involvement of relevant stakeholders.

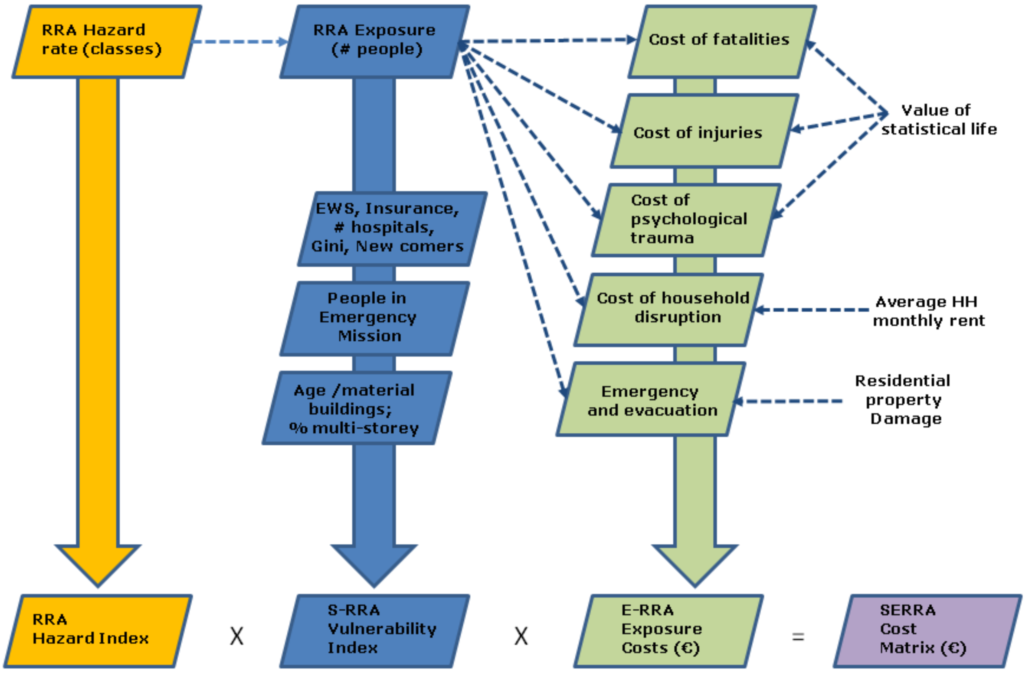

Figure 7: Cartographic model for the calculation of spatially explicit risk for people.

In Case (B), risk functions are estimated for each of the four cost quadrants (direct tangible, direct intangible, indirect tangible, and indirect intangible), including variables of adaptive and coping capacities. For example, indicators of risk perception, risk governance, and EWS (see Table 2) could be included in the mortality functions, expanding the work of Jonkman et al. (2008).

Building robust functions for sensitive indicators such as those related to injuries and casualties is, indeed, another challenging issue. Where data about intangible costs are not available or cannot be produced, a Bayesian Network (BN) approach can support empirical econometrics in the development of those functions, besides making use of experts' opinions. BN are known to facilitate the explicit modelling of uncertainties in a probabilistic framework based on acyclic graphs. BN provides a detailed evaluation of the joint influence of different input parameters on the risk allowing a traceable and concise representation of the causal relationships between the considered variables. The expected results could entail a monetized and probabilistic quantification of risk, although there remain issues regarding data gathering requirements and ethics (e.g. when controversial intangibles are monetized). A preliminary implementation of the KULTURisk Framework in a BN context was developed by Mojtahed et al. (See Figure 8).

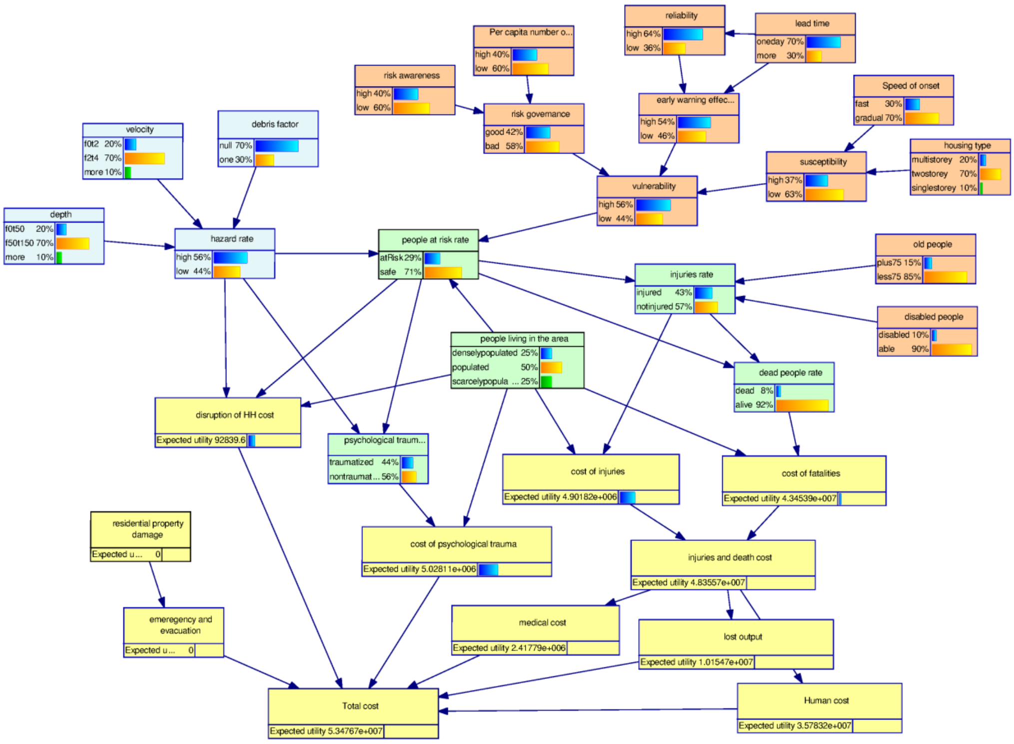

Figure 8: Bayesian Network for damages to people (Mojtahed et al., 2012).

8 Final Remarks

As mentioned in the introduction, there is a need for a holistic and scientifically sound approach toward flood-related risk assessment. In this work we focused on developing a framework based on integrating different components of risk from a multidisciplinary perspective, with focus on the social and economic dimensions of risk. We propose that the estimation of risk should not only be based on direct tangible costs but also should go beyond to contain indirect and intangible costs. Moreover, we add social indicators, which have been often neglected in the literature of risk assessment, to shape our framework, which will be applied to several case studies in the future.

An effective (more successful with lower cost of implementation) risk reduction policy that is mainly based on developing a culture for risk abatement requires more emphasis on social capacities of individuals or society (whether be coping or adaptive) in order to abate all damages as summarized in the Total Cost Matrix of the KULTURisk Framework.

The key feature of the Framework is integrating the multidisciplinary nature of flood-related risk assessment. From a hydrological point of view, the evaluation of the potential benefits of actions to cope with hydrological risk is maintained. In addition, we go beyond the traditional approaches to assess risk by looking into social vulnerability besides the mainstream, which was mainly considering P/E vulnerability. Our other distinction from the mainstream risk assessment is by enhancing cost estimation well beyond the tangibles and direct damages. For this purpose, we proposed solutions for estimating total cost matrix that reckon with indirect, beyond time and geographical limit of hazard, and intangible costs. However, we do not guarantee or even search for a full monetization of intangibles. The KULTURisk Framework now requires testing and tailoring to the specific approaches adopted for risk assessment, especially in the selected case studies. As stated above, we expect that further refinements and generalized implementation rules will derive from the testing phase.

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Appendix: Abbreviations

AC	Adaptive Capacity
BN	Bayesian Network
CBA	Cost-Benefit Analysis
CC	Coping Capacity
CCA	Climate Change Adaptation
CEA	Cost-Effective Analysis
DEM	Digital Elevation Model
DM	Decision Maker
DRR	Disaster Risk Reduction
EVF	Economic Value Factor
EWS	Early Warning System
IPCC	Intergovernmental Panel of Climate Change
NAM	Non-additive measures
OWA	Order Weighted Average
P/E	Physical / Environmental
RRA	Regional Risk Assessment
RRM	Risk Reduction Measure

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