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An Integrated Approach for Including Social Capacities, and Economic Valuation in Risk Assessment of Water Related Hazards in Uncertain Scenarios

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Abstract: We propose a conceptual framework, KR-FWK (i.e. KULTURisk Framework from the name of the European project within which it originated) and its implementation methods SERRA (Socio-Economic Regional Risk Assessment) for integrated (physical and economical) risk assessment, and economic valuation of risk prevention benefits on multiple receptors. The KR-FWK and the SERRA approach are characterised by: (i) integration of physical-environmental dimensions and the socio-economic ones in risk assessment; (ii) consideration of the role of social capacities (adaptive and coping capacity) in reducing risk and related costs, (iii) quantitative (even monetary) assessment of risks and of the benefits of risk reduction measures, and (iv) solutions to deal with multiple sources of uncertainty in view of including the change dimension in decision support.
Building on a widely adopted conceptual model, Risk is here considered as the combination of Hazard, Vulnerability and Exposure. In turn, Vulnerability is the result of the interactions between physical characteristics (susceptibility) and the capacities of the socio-economic system to adapt and cope with a given natural hazard. Exposure quantifies the natural and anthropogenic assets, which may be subject to the hazard. Whenever possible and desirable, exposure can be assessed in monetary terms, and thus the multiplicative combination of two indices ranging between 0 and 1 (H and V) with a third one (E) expressed in monetary terms produces a monetary quantification of risk.
KR-FWK and SERRA have been applied to a series of case studies to test and consolidate the approach in various contexts of data availability, scale, etc.

Keywords: Integrated risk assessment; flood; valuation; decision support.

1. BACKGROUND

The connections between climate change and development are out of question (IPCC, 2013), and they include both the anthropogenic contribution to changes and, in the opposite direction, the effects of climatic changes on economic activities. On one hand, it is evident that the magnitude of climatic changes in the coming years will depend on development pathways and in particular on greenhouse gases (GHGs) emissions and how they could be controlled by mitigation policies. On the other hand, notwithstanding the mitigation efforts that may be implemented now and in the coming years, climate dynamics will increasingly affect humans and ecosystems. Expected impacts are multifaceted and regard the alteration of water cycles, ice melting, sea level rise, but also and very importantly changes in climatic variability and extreme events. In the coming decades, the number of people at risk from extreme climatic events will very likely grow and thus a cascade of consequences is expected to affect social and ecological systems and their processes (Bouwer, 2011). Moreover, there are obvious links between climate change and the climate-related hazards, implying, in general, that a higher disaster risk should be expected (McBean and Ajibade, 2009)) as a consequence of both increasing hazards and exposed people and assets. This requires adaptation strategies to be put in place to increase resilience of socio-ecological systems, and allow them to exploit new opportunities. Here is where climate change adaptation (CCA) efforts meet disaster risk reduction (DRR) strategies (Gain et al., 2012; Mercer, 2010; Renaud and Perez, 2010; Thomalla et al., 2006). Both CCA and DRR measures need robust decision-making processes, inspired by specific policy references, and grounded on the available knowledge of past, current and future climate trends, with focus on extreme events and their return-periods much more than on average trends. At this regard, the uncertainty pervading our ability to explore the future raises new issues that should be carefully approached by scientists and policy makers. Uncertainty concerns in particular the limited capacity of climate sciences to provide future projections in terms of climatic variability and extremes, downscaled to local conditions, instead of approaches that use more traditional global average trends.

With the ambition to contribute to the issues discussed above, the EU-funded research project KULTURisk[1] aimed at developing a culture of risk prevention by evaluating the benefits of different risk prevention initiatives. Focusing on water-related hazards, and introducing the consideration of uncertainty deriving from climate change dynamics, the KULTURisk Project developed a methodological framework (KR-FWK) and an operational approach SERRA (Socio-Economic Regional Risk Assessment), with the following specific characteristics: (i) integration of physical-environmental dimensions (hazard and susceptibility) and the socio-economic ones (human dimension of vulnerability) in risk assessment; (ii) consideration of the role of social capacities (adaptive and coping capacity) in reducing risk and related costs, (iii) quantitative (even monetary) assessment of risks and of the benefits of plausible risk reduction measures, and (iv) solutions to deal with multiple sources of uncertainty in view of including the change dimension in decision support. Integrated risk assessment is here intended in particular as a novel approach developed upon the consolidated literature on risk assessment (in particular Regional Risk Assessment, RRA, according to Landis (Landis, 2004), to include economic valuation of risks and related potential damages.

The most widely adopted approach for the calculation of risk, in particular within the DRR research community, refers to risk as the expected damages, computed as a function of hazard (H), physical and environmental vulnerability (V), and exposure (E) (Crichton, 1999; UNDRO, 1980):

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

Hazard is characterized by probability distributions or specific return periods, and together with vulnerability, it is usually expressed as a dimensionless index, whereas exposure provides the unit of measurement of risk that can be expressed in physical or monetary terms. This framework is straightforward and widely adopted, but it has 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 challenging when the attention is driven to the human dimensions of vulnerability (Cutter, 1996), where it is distinct from biophysical vulnerability, but later aggregated into a single notion of "place vulnerability".

Several other conceptual frameworks have been proposed, such as the Probabilistic Risk Assessment is proposed by the CAPRA[2] Platform (Cardona et al., 2010), developed upon a combination of disciplinary models and cost-benefit analysis, or the more mechanistic approach based on system dynamics and the notion of socio-ecosystem modelling proposed by Turner et al. (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. Many other proposals are available for calculating vulnerability indices (Sullivan, 2011), but the functional structure is rather simplistic, typically an additive combination of indicators, without proper consideration of fundamental issues, such as normalisation effects, internal compensation, weighting, independence of variables, etc. In general, very limited attention has been given to economic valuation both in the CCA and in the DRR literatures. Furthermore, a common limit of those approaches is that risk assessment is usually focused on the evaluation of potential consequences in terms of expected direct and tangible damages. However, it is known that indirect and intangible costs are relevant components of total costs that must not be neglected when gauging the potential consequences of a natural disaster (Cochrane, 2004; Okuyama and Sahin, 2009).

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

[2] CAPRA is a Disaster Risk Information Platform for use in decision-making that is based on a unified methodology and tools for evaluating and expressing disaster risk. (http://www.ecapra.org/)

2. THE KULTURISK APPROACH FOR INTEGRATED RISK ASSESSMENT

A long process of collaboration and recursive exchange of intermediate drafts within the KULTURisk consortium brought us to a shared glossary, developed mainly by adopting or revising the definitions of the IPCC-SREX (Field et al., 2012) and UNISDR Hyogo Framework (UNISDR, 2005). However, for our purposes we needed a less generic, yet consistent with IPCC-SREX and UNISDR Hyogo Framework, definition of vulnerability: the combination of susceptibility and social capacities determining the propensity or predisposition of a community, system, or asset to be adversely affected by a specific hazard.

The implementation of the methodological framework into an operational procedure is developed upon the formalization of risk being a function of hazard, exposure, and vulnerability. Overall, Equation 1 holds in the various processes proposed in SERRA (e.g. risk being necessarily null, when hazard is zero), even if not necessarily the algorithm is forced to produce two independent and dimensionless indexes (H and V) to be used in a multiplicative combination with one monetary index of exposure.

Figure 1 depicts how the variables of Eq. 1 are assessed to produce a quantification of risk. In the case of a flood event, the hazard outcomes are typically represented as one or more maps of intensity (expressed in terms of depth, persistence, and/or velocity) of the flood, provided by the hydrological analysis and modelling, with reference to different return periods. On the other hand, vulnerability and exposure, also typically represented by means of maps, are reported on the characteristics of multiple receptors subject to the specified hazard. Receptors are physical or non-physical assets negatively harmed by a specific hazard, such as floods and landslides. The European Flood Directive identified four categories of receptors: people, economic activities, cultural heritage, and the environment (EC, 2007).

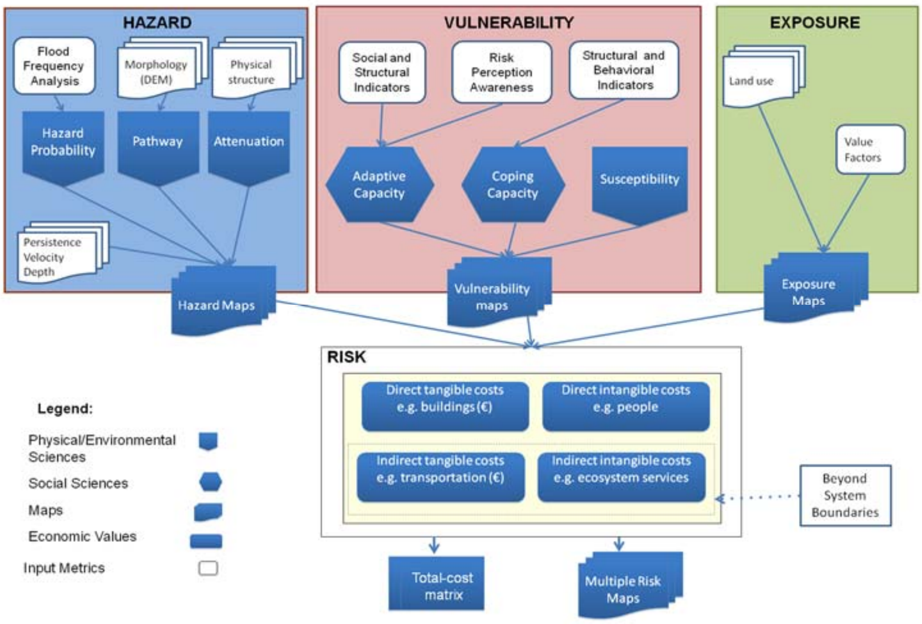

Figure 1. The KULTURisk Framework with the identification of the main sources of data for the quantification of nodes.

Exposure identifies the spatial presence of people and assets and their social, cultural, environmental, and economic values. Vulnerability maps result from the combination of physical-environmental and social components for each category of receptors. It is important to note that the vulnerability of one receptor can be different from another receptor based on their characteristics and their response to hazard. The physical-environmental components are captured by the likelihood that receptors located in the area considered could potentially be harmed (susceptibility of receptors). The social components can be described through the assessment of adaptive capacity and coping capacity. Adaptive capacity is the ex-ante preparedness and awareness of society, given its perception of risk, to combat hazard and to reduce its adverse impact, whereas, coping capacity is identified in the skills to cope with and to overcome ex-post impacts of the hazard considered.

The elements above allow calculating the expected damages for any given year related to the risks associated to different hazard scenarios (events with different return periods according to past records, or better with different probabilities according to climate change scenarios). Computational procedures are typically carried out with a GIS (Geographical Information System) software to take into account the spatial features of the variables.
The expected damages or risks mentioned above can be of varying nature. The KR-FWK considers risk as being composed of four components constituting the Total Cost Matrix (TCM) and deriving from the combinations of indirect/direct and tangible/intangible costs. Direct costs include costs in the exposed geographical location during the hazardous event, for example the losses and damages suffered by residential buildings and their contents (direct and tangible), or the damages to ecosystem services (direct and intangible). All the costs generated outside the time frame or the exposed geographical location of the hazardous event are represented by indirect costs, for example the costs propagated by disruption of public services and infrastructures (see (Balbi et al., 2013) for details).
The foreseen usage of the proposed approach is mainly in supporting decision-making and in particular in the process of identifying desirable (optimal or robust with minimum possible cost) adaptation and risk reduction measures, in which plausible solutions to be implemented are compared with a “Baseline scenario”. The effects expected from the measures are thus expressed either in terms of monetary benefits (avoided costs), or by means of effectiveness indicators and they are compared together with their expected costs, by means of Cost-Benefit (CBA) or Cost-Effectiveness Analysis (CEA), respectively. In case of full monetisation of risk the first step consists of identification of Baseline potential costs of a given disaster (e.g. a flood with a specific return period), while in the second step the expected costs of the same disaster are estimated with the risk reduction measures in place (Alternative scenarios) and their implementation costs. In case monetary units are adopted for all the dimensions, CBA is adopted for economic appraisal, it is applied to the analysis of the set of all plausible alternative solutions denoted by M. For each alternative m, we should then evaluate the stream of discounted expected benefits (reduction in monetary or non-monetary risks) and its total cost (design, construction, implementation, and maintenance). Also some of the costs could be not certain and may happen with certain probabilities, and similarly the probabilities of failures of the alternatives should be considered. The preferred measure is the one that produces the best benefit/cost ratio, or, in case of CEA, the one meeting the risk prevention objectives at the minimum cost, or the one obtaining greater benefits with a given cost.
The application of the KULTURisk conceptual framework (K-FWK) described in Giupponi et al. (2013) builds upon the combination of two components: the analysis of society’s capacity to deal with risk (S-RRA), and the economic valuation of risks (E-RRA). The combination of the two (SERRA, for Socio-Economic Regional Risk Assessment) is the approach proposed to implement integrated risk assessment (Mojtahed et al., 2013). It is briefly described below.

One of the main innovations of the proposed framework is the attempt to operationalize the quantification of social capacities (adaptive capacity and coping capacity) in order to be able to quantify vulnerability. The main challenges for the analysis of social capacities in a risk assessment context are related to:

- the identification of a comprehensive and possibly standardised set of quantitative indicators;
- the definition of empirical functions for the estimation of their contribution to (reduce) vulnerability, and
- the choice of a method for their aggregation into a single vulnerability index.

A wealthy society should necessarily show a higher capacity to be prepared to possible risks, for example, by establishing efficient early warning systems at the community level, or, at the individual level, by taking precautionary actions such as fortifying their residential building, or by purchasing insurances. Therefore, a careful scrutiny is necessary for identifying and empirically testing the significance of various indicators on adaptive and coping capacities, while avoiding double counting and internal correlations. Social scientists usually investigate these capacities at the case study level by means of questionnaires and other interactions with local stakeholders, by means of a semi-quantitative research approach (Steinfuhrer et al., 2009). Indeed, the variables measuring those capacities should be chosen according to the context of application. However, as shown by Cutter et al. (2003), a common set of indicators based mainly on secondary data realistically available in most cases, can be selected in order to approximate the magnitude of social vulnerability.
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.
As it has been demonstrated by the application of the KR-FWK in the various case studies of the project, while it is possible to implement the methodology in different contexts and at different scales, there is neither a single set of variables, nor a unique procedure for their quantification and aggregation. The Framework instead must be tailored according to the specific objectives and conditions (e.g. data availability, study boundary, etc.) of each implementation. For instance, simpler solutions can consider aggregate costs and/or indicators of social capacities, instead of spatial ones. The process of tailoring has various degrees of freedom summarized as follows (Giovannini et al., 2008):

- identification of the application context in terms of scenarios and measures;
- selection of indicators and data mining;
- choice of normalization procedures;
- choice of weighting methods;
- selection of aggregation algorithms.

Mojtahed and colleagues (2013) provide an extensive treatment of the possible solutions available for the implementation of the various steps in SERRA in order to produce as a final outcome a quantification of the vulnerability index: a map, with values theoretically ranging from 0 (areas with no vulnerability and thus not subject to any risk) to 1 (areas with social capacities providing no beneficial effects to reduce the vulnerability of the receptor considered to the specific hazard).

Once a full characterisation of vulnerability is obtained, the SERRA approach can provide operational solutions for a full monetisation of risk to various receptors, whenever it could be useful for supporting decisions and in particular for the application of CBA. In line with the European Flood Directive, SERRA focuses on damages to four categories of receptors: people, economic activities (buildings, infrastructures, agriculture), environment and cultural heritage. Each of them may have different vulnerabilities in the same area and for the given hazard, which should be considered for the calculation of risk. In general, stage-damage functions are available to relate risk for the various receptors to different hazard types and intensity. With those functions damages can be estimated for all the assets somehow related to the market. Functions are available also for calculating possible casualties and fatalities, and they can be transformed in monetary units by consideration of the value of statistical life (VSL). The damages to the environment and cultural heritage (ECH) are usually estimated with similar methods considering the valuation intangible costs affecting of non-market goods and services. Ruijgrok (2006) defines the economic value of cultural heritage as the amount of welfare that it generates for the society, while Plaza (2010) defines the economic value of the cultural heritage as the benefits generated by it whether commercial, non-commercial, or both. Neoclassical economics develops a notion of value for those sites, upon measures of the preferences of people, which are usually manifested through their willingness to pay (WTP) for using a given commodity (Navrud and Ready, 2002). There is a vast literature about the valuation of public goods, which is typically the case of ECH, proposing a variety of methods, such as Contingent Valuation, Hedonic Pricing, Travel Costs (Garrod and Willis, 1999; Hanley and Spash, 1993). There is also a continuous debate about the possibility of expressing the values of ECH in monetary terms as the sum of the all individual visitors' WTP. Very importantly, ECH sites might generate some value for those who use them, but also for those that do not make a direct use, i.e. non-use values. Examples are values related to the desire that the site be available for others to visit (altruistic value); that the site be preserved for future generations (bequest value); that the current non visitor might decide to become a visitor in the future (option value); or simply the site be preserved even if no one ever actually visits it (existence value) (Iacob et al., 2012). The ambition to reach a quantification of the Total Economic Value (TEV) of ECH could be well beyond the efforts that can be put in place in ordinary decision cases. Therefore, the valuation activity is usually directed to those components of the TEV that are significantly affected by the decision and the alternatives considered. Finally and similarly to what regards the value of statistical life, not always the monetisation of ECH values is within the ambitions of policy makers and of the general public, as stated above.

3. RISK ASSESSMENT AND DECISION MAKING UNDER UNCERTAINTY

All the variables to be quantified for risk assessment are affected by multiple sources of uncertainty, as in the case of return times of extreme events to which the assessment is referred. But when global

change is considered on risk reduction decisions, as it should, the level of future uncertainty increases, as a consequence of both climatic and socio-economic factors. Therefore, it becomes more difficult to decide with the traditional probabilistic approaches, as the expected outcomes become very sensitive to the worst-case scenarios of unknown probability (Hallegatte et al., 2010).
Coarsely, the sources of uncertainty can be attributed to climate and socio-economic changes. The former are reflected in the hazard component of the KR-FWK and the latter in the vulnerability and exposure components. Uncertainty assessment requires a sequence of steps to be applied throughout the implementation of SERRA, and which can substantially improve the quality of the decision making process:

1) Identification of key uncertain parameters or variables, which can be included in the three components of risk (hazard, vulnerability and exposure);
2) Identification of the exploration boundaries for the identified key variables through a participatory process using experts' opinion;
3) Evaluation the risk reduction measures or policies under future plausible scenarios, defined through internally consistent combinations of values for the selected variables;
4) Analysis of the robustness of risk reduction measures through their performances over a widest range of scenario conditions, to determine their vulnerability spaces, and possible iterations to revise the set of measures to be considered.

Several methodologies can be applied, such as Robust Decision Making (Bryant and Lempert, 2010; Lempert, 2003; Popper et al., 2005), Scenario Planning (Schoemaker, 1995), Info-Gap (Ben-Haim, 2001), Real Options Analysis (Woodward et al., 2011) exist in the literature that addresses decision-making under deep uncertainty. In general, uncertainty assessment appears as one of the mandatory components of the assessment when DRR is brought into the context of CCA, given the little that is known in probabilistic terms about future climates. Many possible approaches have been proposed, all of them have in in common the consideration of multiple scenarios, which in some cases (RDM, for example) can be numerous (hundreds or even thousands). Preferable solutions are then identified as those that may be flexible enough, adaptable or resilient to survive to a higher number of plausible scenarios or even unforeseeable circumstances generated by simulation tools. Such analyses can provide quite useful insights on the possible performances of our decisions, but they require specific skills and tools, and resources, that are not always at disposal of decision makers.
The whole process of integrated risk assessment has to be implemented within a procedure well grounded in existing policies and regulations as in the example reported below (adapted from Giupponi et al., 2008)

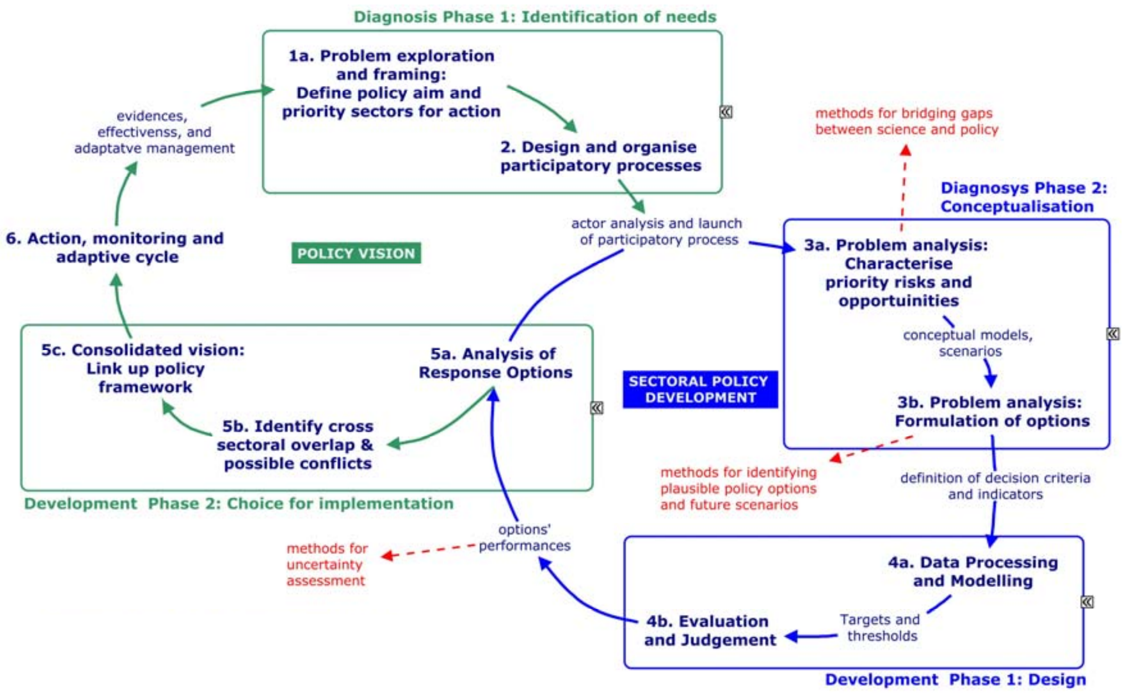

Figure 1. Cyclic Decision-Making Flowchart for CCA and risk management.

4. CONCLUSIONS

There is a need for a holistic and scientifically sound approach towards risk and uncertainty assessment of water related hazards and such approach should necessarily be well grounded in climate change science and thus also synergistic with adaptation efforts. In this work we focused on developing a framework based on the integration of different components of risk from a multidisciplinary perspective, with innovative solutions in particular for the social and economic dimensions of risk. We underline the fact that a comprehensive estimation of risk should not only be based on direct tangible costs, but it should go beyond, considering also indirect and intangible costs. We propose to consider social indicators, which have been often neglected in the literature of risk assessment, to be taken into consideration the capacities of local communities to cope with risks and adapt to them and thus reduce overall vulnerability. We drive also the attention of decision makers to the need for proper uncertainty assessment techniques when climate change is taken into consideration, as it should.

The proposed Total Cost Matrix can provide a solid basis for Cost-Benefit Analysis of alternative strategies and measures to deal with water related risks. However, we recognise that in many cases CBA is not applicable, because the full monetisation of costs and benefits (including in particular intangibles) is not envisaged or desired, for example when the use of the statistical value of life is not considered. In those cases it is impossible to make the intrinsic multidimensionality of risk assessment to be reduced to a single unit (money) and thus the KULTURisk Framework can be implemented to support Cost-Effectiveness Analysis and techniques proposed by the Multi-Criteria Analysis literature can be adopted to aggregate the multiple dimensions and obtain a final ranking of plausible solutions to the given risk problem.

The experience developed during the tests of the methods in the various case studies of the KULTURisk Project and in follow-up activities suggests that the proposed approach can be applied at various scales and in different situations of data availability, providing more accurate estimation of risks as compared to consolidate RRA approaches. Indeed, it requires tailoring to the various cases, first of all to meet the required level of scale and detail and to compromise them with data availability, but also in order to meet the specific institutional and legislative contexts of application.

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