CONHAZ
Costs of Natural Hazards

Costs of Natural Hazards - A Synthesis

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Date	**January 2012**
Report Number	**WP9 Report**
Location	**UFZ**
Deliverable Number	**D9.1-3**
Due date for deliverable	**31/01/2012**
Note	**PUBLIC**

Document information

Title	**Costs of Natural Hazards - A Synthesis**
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Distribution	Public
Document Reference	WP09_1

Document history

Date	Revision	Prepared by	Organisation	Approved by	Notes
17/10/11	1_0	Volker Meyer, Vasileios Markantonis, Nina Becker	UFZ		First internal draft
19/10/11	2_0	Volker Meyer, Vasileios Markantonis, Nina Becker, Reimund Schwarze	UFZ		Internal draft to be reviewed by partners
24/10/11 – 31/10/11	2_1 – 2_7	Volker Meyer, Vasileios Markantonis, Nina Becker	UFZ		Included contributions and comments from WP1-8
3/11/11	3_0	Volker Meyer, Vasileios Markantonis, Nina Becker	UFZ		Draft Report for the conference
19/12/11 – 22/12/11	3_1-3	Volker Meyer	UFZ		Included comments from partners
27/12/11	4_0	Volker Meyer	UFZ		Based on conference results: Added key recommendations (3.11), other minor changes
30/12/11 – 18/1/12	4_1-4	Volker Meyer, Nina Becker, Vasileios Markantonis	UFZ		Included comments from partners, added section 3.10 on con-ference results
20/1/12	5_0	Volker Meyer, Nina Becker	UFZ		Final corrections
30/1/12	5_1	Volker Meyer	UFZ		Added vision section (section 4), language proofreading
31/1/12	final	Volker Meyer	UFZ		Final version

Acknowledgement

The work described in this publication was supported by the European Community's Seventh Framework Programme with a grant to the budget of the Integrated Project CONHAZ, Contract 244159.

This report has been prepared by the CONHAZ Project Consortium that comprises partners from eight European institutions and was led by Reimund Schwarze and Volker Meyer. The achievements and successful contributions by CONHAZ were only possible due to our partners' outstanding engagement and dedication. We are grateful for all of their contributions and wish to express our gratitude to each partner. At the same time, we would like to thank our internal and external advisors, as well as colleagues, whose comments, discussions, suggestions and advice we benefitted from greatly during the project.

Disclaimer

Abstract

Effectively and efficiently reducing, or adapting to, natural hazard risks requires a thorough understanding of the costs of natural hazards to develop sustainable risk management strategies. The current methods assessing the costs of different natural hazards employ a diversity of terminologies and approaches for different hazards and impacted sectors. This impedes ascertaining robust, comprehensive and comparable cost figures.

CONHAZ (Costs of Natural Hazards) - a Coordination Action Project funded by the EU 7th Framework Programme - aimed at compiling and synthesising current knowledge on cost assessment methods to strengthen the role of cost assessments in the development of integrated natural hazard management and adaptation planning. In order to achieve this, CONHAZ has adopted a comprehensive approach, considering natural hazards ranging from droughts, floods and coastal hazards to Alpine hazards, as well as different impacted sectors and cost types. Its specific objectives have been 1) to compile the state-of-the-art methods for cost assessment; 2) to analyse and assess these methods in terms of technical aspects, as well as terminology, data quality and availability, and research gaps; and 3) to synthesise resulting knowledge into recommendations as well as to identify further research needs.

The present Synthesis Report summarises the main results of CONHAZ. These comprise findings regarding best practices, overall knowledge gaps and recommendations for practice and research as well as a vision on cost assessments of natural hazards and their integration in decision making.

CONHAZ differentiates between direct tangible damages, losses due to business interruption, indirect damages, intangible effects, and costs of risk mitigation. It is shown that the main focus of cost assessment methods and their application in practice is on direct costs, while existing methods for assessing intangible and indirect effects are rather rarely applied and methods for assessing indirect effects can often not be used on the scale of interest (e.g. the regional scale). Furthermore, methods often focus on single sectors and/or hazards, and only very few are able to reflect several sectors or multiple hazards. Process understanding and its use in cost assessment is poor, leading to highly uncertain results. However, sensitivity and uncertainty analyses as well as validations are hardly carried out.

Important recommendations are that costs can be assessed more comprehensively by including indirect and intangible effects. Furthermore, CONHAZ outlines the importance of identifying sources of uncertainties, of reducing them effectively and of documenting those remaining. One source of uncertainty concerns data sources. A framework for supporting data collection on the European level ensuring minimum data quality standards would facilitate the development and consistency of European and national databases. Furthermore, an improvement of methods is needed with regard to a better understanding and modelling of the damaging processes. In particular, there is a need for a better understanding of the economic response to external shocks and for improving models for indirect cost assessment based on this. However models to estimate direct economic damage also need to be based on more knowledge about the complex processes leading to damages. Moreover, the dynamics of risk due to climate and socio-economic change have to be better considered in the models to unveil uncertainties about future developments in the costs of natural hazards. Finally, there is a need for appropriate and trans-

parent tools and guidance to support decision makers integrating uncertain cost assessment figures into their decision making process.

Keywords: natural hazards, cost assessment, mitigation, adaptation, risk management, floods, droughts, coastal hazards, Alpine hazards, direct costs, indirect costs, intangible costs, mitigation costs, business interruption

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Structure

1 Introduction

1.1 Background and objectives of CONHAZ

In times of increasing disaster losses, the reduction (or mitigation[1]) of natural hazards risk needs to be effective and efficient. An in-depth understanding of the effects of disasters is required for the development of sustainable risk management, as well as risk mitigation and adaptation strategies, in particular considering the limited financial resources available. In this respect, reliable and comprehensive estimates of costs and benefits of natural hazards are crucial in contributing to informed decision-making and developing policies, strategies and measures to prevent or reduce the impact of natural hazards on societies as well as to improve their coping and adaptive capacities.

Current methods assessing the costs of natural hazards, both related to damages and mitigation, employ a diversity of terminology and methodological approaches for different hazards and impacted sectors. This obstructs the process of reaching robust, comprehensive and comparable cost figures. The use of various techniques and data, as well as the inclusion of different hazards was also emphasized by the joint World Bank Publication and United Nations report on 'Natural Hazards, Unnatural Disasters' (2010). Difficulties in comparisons across hazards and sectors are particularly relevant when cost assessments are utilised for decision support and policy development within a risk management framework. To support and guide decision makers in natural hazards management and mitigation and adaptation planning, it is therefore vital to synthesize current cost assessment methods and identify current best practices as a first step.

CONHAZ - a Coordination Action Project funded by the EU 7th Framework Programme - aims to synthesise current knowledge on cost assessment methods to strengthen the role of cost assessments in the development of integrated natural hazard management. In order to achieve this, CONHAZ takes a comprehensive approach, considering natural hazards ranging from droughts, floods, storms and coastal risks, to Alpine hazards, as well as different impacted sectors including housing, industry, transport, the environment and human health. From this perspective, hazards that incur direct and indirect costs, as well as intangible (non-market) effects are included. At the same time, CONHAZ takes into account the costs of risk reduction or mitigation as an important part of the overall costs of natural hazards. The *specific objectives* addressed with this approach are:

1. to compile state-of-the-art methods for cost assessment as used in European and international case studies;
2. to analyse and assess these compiled methods in terms of underlying assumptions and supporting theories, technical aspects, terminologies, data quality and availability, as well as research gaps; and
3. to synthesise resulting knowledge into recommendations and to identify further research needs.

[1] Please note that mitigation here refers to the reduction of natural hazard risk. Mitigation in other communities usually refers to the reduction of greenhouse gas emissions, or the enhancement of carbon sinks.

Eight complementary studies were carried out, addressing different cost categories and different hazards (see section 1.5). The main results from these studies are synthesised in this report. In the following, key findings on current practices and knowledge gaps will be described and recommendations for practice/policy and for research will be given (see sections 2 and 3). Prior to this, the attention is drawn to two overarching issues concerning costing of natural hazards. These include, firstly, the terminology of cost types that provided a framework for the setup of the CONHAZ project and its division of work (section 1.2). Secondly, the focus will be on the objective of a certain cost assessment study as it has major impacts on basic assumptions and, hence, the methods required. In this line, different reasons for cost assessment for different target groups are outlined in section 1.3. Subsection 1.4 presents the scope and goal of this report and provides a brief reading guide to this synthesis report.

1.2 Terminology of cost types

The terminology on cost categories sometimes differs across literature and among hazard communities (see e.g. Parker et al. 1987, Smith and Ward 1998, Wilhite 2000). CONHAZ defined a working terminology on cost categories, which takes these different definitions into account:

- **Direct tangible costs** are damages to property due to the physical contact with the hazard, i.e. physical destruction of buildings, inventories, stocks, infrastructure or other assets at risk. “Tangible” implies that a market exists for these goods or services.

- **Losses due to business interruption** occur in areas directly affected by the hazard. Business interruption takes place, for example, if people are not able to carry out their work because their workplace is destroyed or not reachable due to a hazard or if industrial or agricultural production is reduced due to water scarcity. In the literature, such losses are sometimes referred to as direct damages, as they occur due to the immediate impact of the hazard. On the other hand, they are often also referred to as primary indirect damages, because these losses do not result from physical damage to property but from the interruption of economic processes. However, the methods to evaluate losses due to business interruption are different from those used for direct and indirect damages respectively. For this reason, and in order to avoid terminological misunderstanding, ‘disruption of production processes’ will be used as a separate category in the following.

- In consequence, **indirect costs** are only those losses which are not caused by the hazard itself but which are induced by either direct damages or losses due to business interruption. This includes e.g. induced production losses of suppliers and customers of affected companies, or the costs of traffic disruption.

- **Intangible costs** are damages to goods and services which are not, or at least not easily measurable in monetary terms because they are not traded on a market (also referred to as non-market values or costs). The intangible effects of natural hazards include e.g. environmental impacts, health impacts and impacts on cultural heritage.

- The **costs of risk mitigation,** i.e. risk reduction, including adaptation to anticipated changing risks as a result of climate change, can be regarded as part of the total costs of natural hazards, and these investments are therefore considered an essential cost category in the CONHAZ project.

The main rationale for this working definition was to differentiate between cost types which are likely to require different cost assessment methods. In line with this, the above working terminology of cost types is also reflected in the work package structure of CONHAZ and associated reports (see section 1.4 for a further description of the CONHAZ structure and related publications). The work packages dealing with cost types, as well as the hazard-related work packages, used this working terminology as starting point for their review on existing methods and their application. One aim of CONHAZ is to examine whether this working definition suffices to differentiate cost assessment methods across the different hazard types. The issue of terminology will therefore be raised again in the different work package reports and concluded upon within the recommendation section of this report (section 3.1).

1.3 Objectives of cost assessment of natural hazards

Cost assessments may address different target groups and follow different objectives. Each target group and objective may require different methods of cost assessment (see also Messner et al. 2007, The World Bank and The United Nations 2010). The following overview distinguishes and presents three target groups, including national and regional governments, insurance companies, and private companies or house owners.

- **National and regional governments** are among the main target groups with a high interest in cost figures on past or future hazards. In this context, cost assessment figures provide crucial information to support several objectives:
  - **Supporting decisions about allocation of public budget**: Reducing natural hazard risk is of course only one of numerous issues public policy has to deal with. In this context, cost assessment figures can support policy makers in allocating budgets a) to natural hazard risk mitigation compared to other policy fields, b) to one specific hazard compared to other hazards or c) to one region compared to another. Therefore large-scale national or regional ex ante cost assessments[2] of the current risk situation and of future scenarios are required. Particularly for the spatial allocation of budget, the results of cost assessment have to be displayed in risk maps in order to show the spatial distribution of risk and, hence, to depict areas which suffer most (see e.g. EU Floods Directive[3]).
  - **Project appraisal for risk management**: One of the most important rationales for ex ante cost assessments is to support governmental decisions on alternative risk mitigation options. Decision makers in natural hazard risk management may want to consider (as far as possible) all benefits and costs of alternative courses of action

[2] Ex ante assessments estimate the costs of potential future events or synthetic scenarios, while ex post assessments consider events which have already happened.

[3] Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks, OJ of 6.1.2007 L288/27-34.

in their decisions to identify the best available option. This requires more detailed cost assessments for the area under consideration and for all alternative courses of action: which benefits in terms of risk reduction can be expected from each option and which costs are related to them? For both of the first two objectives costs assessments are furthermore important to justify and to demonstrate the appropriateness of spending public funds.

- **Ex post assessments of recent hazard event costs**: Following an event, the government of the affected nation or region is usually interested in the overall amount of damages that occurred to compensate or to effectively support recovery. Therefore quick, but robust initial damage estimates would be helpful. At a later stage, in particular for a target-oriented compensation, detailed, object-specific ex post cost assessments are required.

- **Insurance companies** are also interested in cost assessment figures. Primary insurance companies mainly need cost assessments to calculate individual insurance premiums, which requires more detailed, object-specific ex ante cost assessments (and of course, ex post cost assessments for compensation payments). Re-insurance companies, on the other hand, are keen to estimate Probable Maximum Losses (PML) of their portfolio in order to calculate their financial reserves. As most re-insurance companies operate internationally, large-scale ex ante cost estimations are required in this case. While public governments require assessments of the total costs to the economy (or society), insurance companies' interest lies mainly in assessing their insured losses. As insurance companies often have to compensate full replacement costs, cost assessments also have to be based on the full replacement value of assets in such a case, while economic assessments are usually based on the depreciated, time value of assets.

- Finally, **private companies or private house owners** can also be a target group for cost assessment studies as they are probably interested in the potential risk to their property due to natural hazards, in order to decide on private precautionary measures or to insure. This would require object-specific, i.e. household- or company-specific ex ante cost assessments. Furthermore, these cost assessments should estimate the company's or household's financial costs, i.e. their specific costs, which may differ from economic costs.

Among the different objectives, CONHAZ's main focus was on economic cost assessments for governments, in particular with the objective to support public decision making on the allocation of funds to particular hazards and on alternative risk mitigation measures (project appraisals). These can be regarded the most important fields of application, as the principal aim of CONHAZ is to strengthen the role of cost assessments in the development of integrated natural hazard management and adaptation planning. Cost assessments for the other objectives described above were not in the main scope of the project. Nevertheless, some of the CONHAZ reports also refer to methods particularly used for ex post costs assessments or for the insurance industry.

1.4 Structure of CONHAZ and outline of this report

CONHAZ is organized in the work packages shown in Figure 1. Work packages 1 to 4 provide in-depth knowledge on methodological issues related to the different types of costs following the CONHAZ working definition (direct costs, cost due to business interruption, indirect costs, intangible costs, and costs of risk mitigation). The hazard work packages 5 to 8 then address the whole spectrum of the costs for different hazard types (droughts, floods, coastal and Alpine hazards) additionally using the knowledge gained from four hazard-specific workshops.

The combination of hazard-related work packages (WPs 5-8) and method-related work packages (WPs 1-4) in a matrix structure assured the extensive exchange of knowledge within the Consortium. This intensive cooperation between the various WPs enhanced the identification of best practices and knowledge gaps, and contributed to the provision of practical and research recommendations on the costing methods. Additionally, this CONHAZ matrix structure ensured that stakeholders from both politics and science were brought together to discuss and disseminate project results.

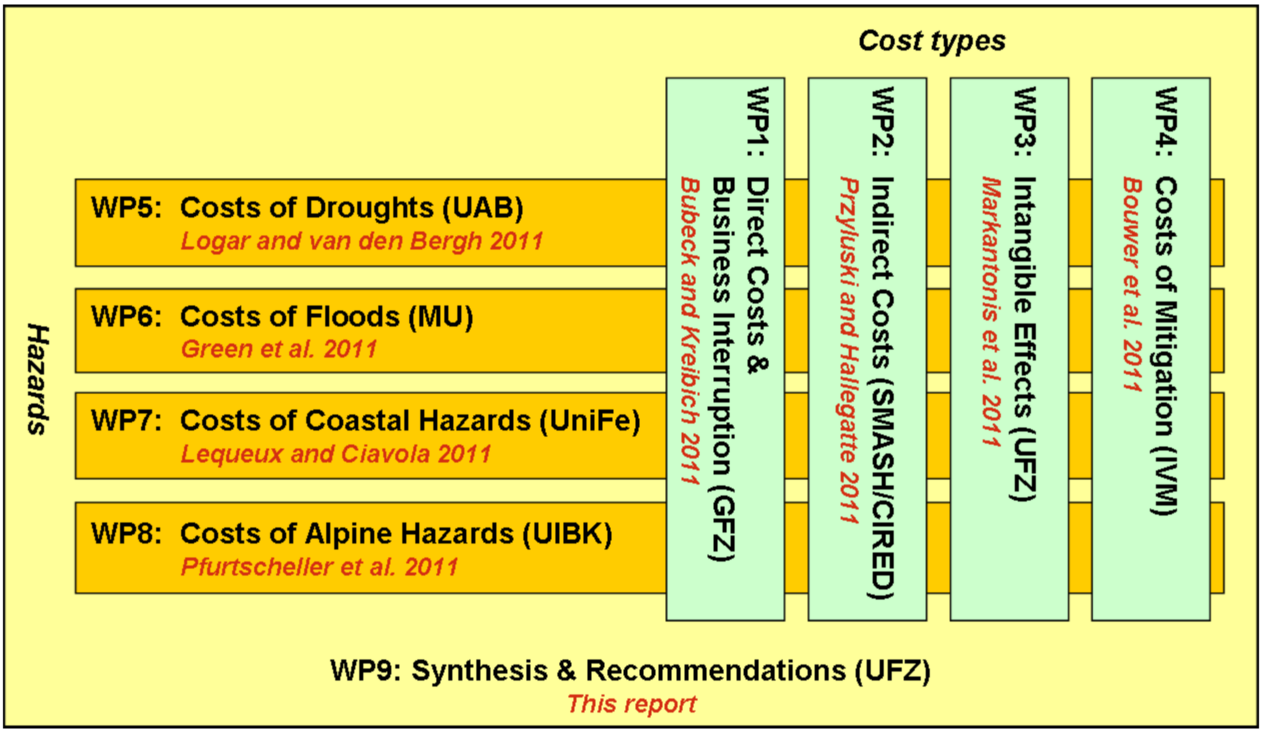

Figure 1: Project structure of CONHAZ and associated reports

At the finalisation stage of CONHAZ, four of the eight resulting reports present methodological aspects across impacted sectors concerning cost types, including;

1) direct costs and costs due to business interruption (Bubeck and Kreibich 2011),
2) indirect costs (Przyluski and Hallegatte 2011),
3) costs due to intangible, non-market effects (Markantonis et al. 2011), and
4) costs of risk mitigation (Bouwer et al. 2011).

The other four reports on different hazard types apply this knowledge for

5) droughts (Logar and van den Bergh 2011),
6) floods (Green et al. 2011),
7) coastal hazards (Lequeux and Ciavola 2011) and
8) Alpine hazards (Pfurtscheller et al. 2011).

Altogether, these eight CONHAZ reports provide the foundation for the present final synthesis report (WP9) and can be found on the project website: www.conhaz.org.

The remainder of this report is organised as follows: Section 2 presents the main findings concerning current best practices, while an overview on available methods for cost assessment for each cost type together with their application and/or examples is provided in the Annex. The findings of section 2 are structured along the cost types analysed under CONHAZ; i.e. direct costs and costs due to business interruption (2.1), indirect costs (2.2), intangible, non-market costs (2.3), and risk mitigation costs (2.4). These sub-sections present the findings from a general methodological perspective, but also include hazard-specific findings within each section. Evaluation frameworks used in decision support of risk mitigation options to a large extent determine the way cost assessment figures are utilised. Some of the most important evaluation frameworks and their specific implications assessing natural hazards costs are therefore briefly described in section 2.5.

Section 3 describes the overall knowledge gaps and recommendations which emerged from WPs 1-8. In this context, this part includes the core topics of CONHAZ, i.e. terminology of the cost types, comprehensiveness, uncertainties, data-related issues, improvement of methods, future dynamics, distribution of costs and knowledge exchange (sub-sections 3.1-3.8). The related knowledge gaps and recommendations are distinguished for practical applications, as well as for further research. The penultimate sub-section (3.9) goes a step further and provides recommendations on how cost assessment could be better integrated into decision support frameworks such as Cost-Benefit Analysis and Multi-Criteria Analysis. The final sub-section (3.10) provides some insights into the practitioners' view on best practices and recommendations for cost assessment of natural hazards by summarizing discussions and inputs at the CONHAZ Final Synthesis Conference. An overview at the end of section 3 summarizes the key recommendations for practice and research.

Section 4 will provide a vision on the future of cost assessments for natural hazards and their integration in decision making, based on the work conducted by the Consortium and stakeholders involved in the workshop as well as the Final Synthesis Conference in November 2011.

2 Current best practices of cost assessment for natural hazards – a summary

2.1 Direct costs and costs due to business interruption

General findings

Direct tangible costs refer to losses that occur due to the direct physical impact of a hazard on economic assets (asset losses). Examples for direct costs are, for instance, the destruction of buildings, contents and infrastructures e.g. due to landslides; or the loss of crops and livestock due to droughts.

A standard approach for the assessment of direct costs for all hazards examined under CONHAZ is the use of susceptibility functions (alias damage functions, see also Table 2 in the Annex). What all these functions have in common is that they describe the relation between a single or several hazard parameters, such as avalanche pressure, water depth or drought-induced soil subsidence, and a resulting monetary damage for a certain type or use of object at risk (Smith 1981, Parker et al. 1987, Wind et al. 1999, BUWAL 1999a, Keiler et al. 2006, Fuchs et al. 2007, Corti et al. 2009, Totschnig et al. 2010). In addition to these hazard parameters, some damage functions also take resistance parameters, such as differences in building structures or the level of undertaken risk mitigation measures (e.g. BUWAL 1999b, Keiler et al. 2006, BAFU 2010) into account. In comparison with the other types of natural hazards considered in CONHAZ, there is extensive literature on assessing the direct damage of flooding.

Commonly, assessment methods for direct costs describe complex damage-causing processes with rather simplified approaches. These are often based on a single hazard parameter, such as e.g. depth-damage functions in flood damage assessments. Many damage influencing parameters are hardly reflected by current models as their quantitative individual and combined effect on damages is largely unknown. With respect to flood damage assessment, it has been shown that the development of multi-factor models, taking multiple hazard and resistance factors into account, can improve the validity of cost estimations (see e.g. Apel et al. 2009, Elmer et al. 2010). In this respect, it would be especially important to consider precautionary measures as an important damage influencing variable. Currently, resistance parameters such as the level of precautionary measures are rarely taken into account by current cost assessment methods (for exceptions see e.g. Thieken et al. 2008 and Kreibich et al. 2010), which hampers the evaluation and development of effective risk mitigation strategies.

Assessment methods able to capture the effect of coinciding events (such as storms and coastal floods or different Alpine hazards) are lacking - the work of Huttenlau and Brandstötter-Ortner (2011) being one example for a few studies on complex scenarios. As a result, their costs are usually estimated using separate damage models, which may lead to errors. For example, it may involve double-counting. Comprehensive damage models providing a complete picture of direct damages from natural hazards are rare, as most cost assessment methods focus on specific sectors and hazard types.

Losses due to business interruption occur in areas directly affected by a hazard event and in all sectors of the economy. Such losses receive relatively little attention, even though they can significantly contribute to overall damages, especially for large-scale events. Mainly three approaches are currently applied to derive damage figures on this cost type, namely 1) applying sector-specific reference values, e.g. for loss of added value, wage losses or relocation expenses per unit affected, 2) comparisons of production output between hazard and non-hazard years, or 3) simple approaches that derive production losses using a fixed share of direct damage estimates (also see Table 2 in the Annex). While the latter can only be useful for a rapid approximation of losses due to business interruption, the former two approaches can be considered more appropriate. Overall, it can be concluded that this type of losses is mostly assessed using very simplistic models.

Many studies are available with respect to floods, ranging from these latter simple approaches to sophisticated assessments of losses to economic flows. In contrast to studies on floods, detailed ex ante assessment approaches of production losses are so far often lacking for other natural hazard types, especially for other large-scale events. As far as droughts are concerned, losses due to the disruption processes are mostly assessed ex-post or incorporated in assessments of indirect damages.

Hazard-specific findings

Floods

A standard approach to assess direct flood damages consists of the following three steps (Messner et al. 2007, Merz et al. 2010;):

1) Classification of elements at risk by pooling them in homogeneous classes.
2) Exposure analysis and asset assessment by describing the number and type of elements at risk and by estimating their asset value.
3) Susceptibility analysis by relating the relative damage of the elements at risk to the flood impact.

This three-step procedure holds true for relative damage functions that express damages as a ratio of the total asset value (0 = no damage to 1 = total destruction). Alternatively, absolute damage functions exist that directly provide an absolute monetary value for the element or object at risk. In this case, step 2 and 3 are combined within a single damage function. Damage functions can be derived either empirically, i.e. based on observed damage data, or synthetically, i.e. based on expert judgement. The three steps are discussed in greater detail in Green et al. (2011) and Bubeck and Kreibich (2011).

Even though there is extensive literature on assessing direct damage of flooding and numerous studies apply different methods, the available damage estimation methods have several shortcomings. Complex damaging processes are still commonly described by simple models, model validations are scarce, associated uncertainties are hardly known and thus not communicated. Additionally, the single and joint effects of many flood impact and resistance parameters on damage are not completely understood nor quantified and therefore widely neglected in damage modelling. As a result, the majority of modelling approaches estimate flood damage with susceptibility functions (alias damage functions) that are solely based on the type or use of an element at risk and inundation depth. As far as flood damage assessments are concerned, some recent studies on multi-parameter models exist. These demonstrate that the consideration of several influencing parameters can improve reliability of flood damage modelling (Apel et al. 2009, Elmer et al. 2010). However, such improvements should be set into relation to the additional effort required to apply such detailed models (Green et al. 2011). Methods used for the quantification of the asset values exposed to floods vary considerably in terms of detail, the stratification in economic classes and the spatial disaggregation of asset values. The transferability of average depth-damage curves from one country to another is therefore questionable (Green et al. 2011).

As far as losses due to business interruption are concerned, applying sector-specific reference values, e.g. loss of value added per employee and day (e.g. MURL 2000) or model approaches for traffic (Department for Transport 2009) or agriculture (Hess and Morris 1986) can be considered as most appropriate to deduce sound cost estimates (Bubeck and Kreibich 2011, Green et al. 2011). For rapid cost appraisals, it can also be an option to derive production losses using a fixed share of direct damage estimates. First empirical findings principally support this approach (Kreibich et al. 2010a). However, such an approach is not applicable for all sectors, e.g. not for agriculture and traffic, where losses heavily depend on the time of occurrence.

Droughts

The review by Logar and van den Bergh (2011) determined market valuation techniques (i.e. market prices, production function, avoided costs, replacement or repair costs) as the most suitable methods for assessing direct tangible costs of droughts. They hold the advantage of easy application, coverage of any economic sector, and precise estimations. In turn, Computable General Equilibrium (CGE) analysis and input-output analysis require more efforts in application. They are most frequently used either for estimating indirect costs or for a joint estimation of direct and indirect costs. In contrast to methods that cover all sectors, biophysical-agroeconomic modelling and Ricardian hedonic price modelling, both focus on the agricultural sector only. However, since these sectoral costs represent the largest share for direct costs of droughts, both approaches are considered good practices. The approach of coupled hydrological-economic modelling is limited as it assesses drought costs directly related to water use.

It was found that the methods presented, e.g. biophysical-agroeconomic and Ricardian hedonic price modelling approaches, could be applied in a complementary way to provide more detailed estimates and potentially to serve as input for a CGE analysis.

Coastal hazards

Across Europe, damage functions derived and constructed for assessing riverine flooding are also commonly applied to assess potential damages also from coastal flooding. This is problematic, given the different hazard characteristics that can be observed for riverine and coastal flooding. These result in considerably higher damages for coastal floods, due to wave activities, high flow velocities and the intrusion of saltwater (Penning-Rowsell et al. 1992, Nadal and Zapata 2010).

According to Lequeux and Ciavola (2011), it remains especially difficult to evaluate the combined effects of wind storms and storm surge flooding. Wind speed (for storm events) and water depth, flow velocity and wave parameters (for coastal flooding events) are among the most important factors to consider when assessing direct physical damages (see also Nadal et al.

2011). However, in the majority of the models these effects are not or cannot fully be taken into account. Moreover, among the approaches of 1) multivariate models, 2) damage function approaches, 3) zone-based damage estimations, and 4) probable maximum loss estimations, the models based on damage functions seem to be the best in terms of precision in results for direct losses.

Alpine hazards

Methods for estimating direct costs of Alpine hazards are mainly based on asset valuation techniques in combination with damage functions (Pfurtscheller et al. 2011), and multi-parameter models (Bubeck and Kreibich 2011). However, the transfer of lowland riverine depth-damage functions for Alpine floods seems problematic due to distinct damaging processes of flash floods. For debris flows, landslides and avalanches, specific damage functions have been developed. The latter two mainly take the intensity of the event as main hazard parameter into account. Simpler approaches exist for rock falls, and also partly for landslides, where it is assumed that an economic asset at risk is totally destroyed, once affected by a rock fall (except for small rock fall events with an intensity (energy) below 300 kJ, see Lateltin et al. 1997). In addition to hazard impact parameters, a number of susceptibility functions (alias damage functions) exist that also consider resistance parameters, e.g. by considering different building categories or precautionary measures (Bubeck and Kreibich 2011).

For estimating direct costs with damage functions, extensive research has already been carried out for single hazards. On the other hand, little attention has been devoted to multiple (cascading and coinciding) Alpine hazards that show very different damaging processes (Pfurtscheller et al. 2011). In addition, little is known about the transferability of damage models across regions and countries. Limited knowledge exists concerning losses due to business interruption by Alpine hazards. Although some cost figures of business interruption are available, e.g. by comparing estimates of income through tourism during average years with income in the year of the hazard event (see Bubeck and Kreibich 2011), no advanced approaches are applied for calculating losses due to business interruption caused by Alpine hazards.

2.2 Indirect costs

General findings

Indirect costs, also referred to as higher order losses, are caused by secondary effects and not by the hazard itself. In other words, indirect costs are initiated by the hazard destruction or by business interruptions but are at least one causal step away from them. In addition to this obvious criterion, costs are indirect if they span either a longer period of time or a larger spatial scale than the event itself. Indirect costs negatively impact the wider economy, for instance, resulting from production losses of suppliers, or costs of traffic disruption (e.g., Parker et al. 1987, Smith and Ward 1998, Messner et al. 2007, Przyluski and Hallegatte 2011).

Figure 2 illustrates that indirect costs span a longer period of time than the event itself and also heavily depend on the system's ability to recover, i.e. if and when it returns to its pre-disaster growth trajectory (for more detailed discussion, also with regard to the relation to direct losses and alternative recovery scenarios, see Przyluski and Hallegatte 2011).

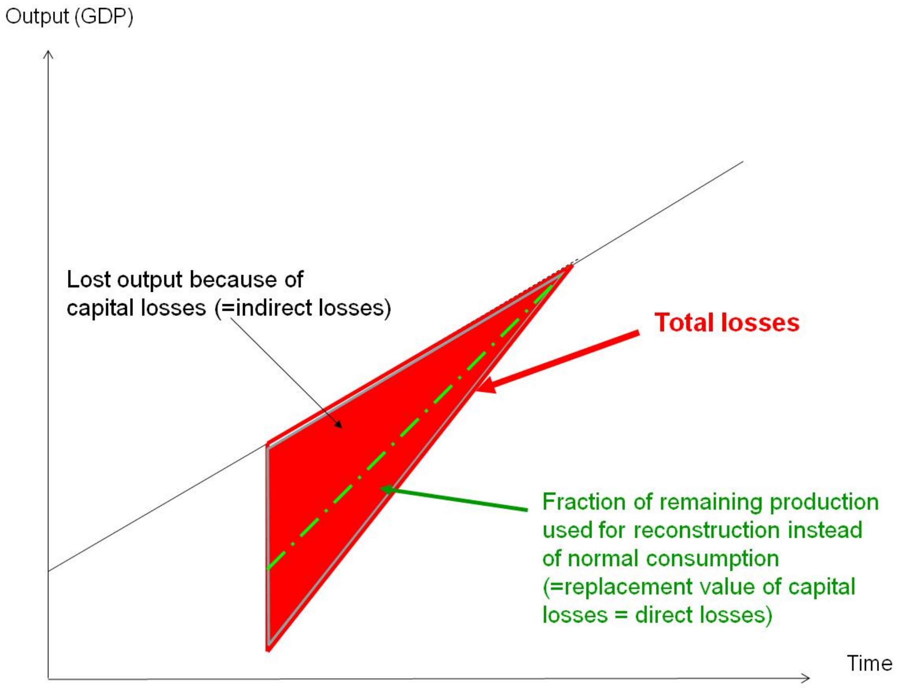

Figure 2: Direct losses, indirect losses, and "total" losses, i.e. consumption losses. This figure assumes that there is no flexibility in the production process. (Source: Przyluski and Hallegatte 2011)

The different methods used to assess indirect costs include firm- or household-level surveys, and more frequently economic models, such as 1) microeconomic models at the household level; 2) econometric models at the local, regional or the national level; 3) Input-Output (IO) models at the regional or national level; 4) Computable General Equilibrium (CGE) models at the regional or national level; or 5) network-production system models. Other approaches to estimate indirect costs regard the impact of natural disasters on public finances, or can refer to idealized models (see also Table 2 in the Annex).

The method of collecting data on past events, e.g. based on firm- or household-level surveys, considers a single event in a single location, and is quite simple to carry forward. It commonly seems to be used for assessing risk mitigation measures. Econometric approaches are based on statistics and do not investigate a single event but analyse several events to derive the main explanatory factors for estimating costs of future events. Econometrics is not a stand-alone methodology but can follow data collection on past events whereas, for instance, model-based approaches can be calibrated using econometric results.

IO models assume that prices are fixed and that no substitution can take place within sectors. As a result, they may generate conservative estimates of economic responses to hazards. CGE models allow for more flexibility and substitution at different levels, driven by markets and price changes. Their shortcoming may be that markets are often assumed to function perfectly (even in post-disaster situations). This implies that neither IO nor CGE are perfectly suitable to reflect reality, calling for more work on intermediate models, i.e. models that lie between these two approaches. Further, these intermediate models emphasize the importance of several sectors such as infrastructure, electricity and water for improving comprehensiveness.

Another approach to assess indirect costs is based on the impact of natural disasters on public finances. It aims at assessing these costs in terms of government's capacity to cope with large expenses caused by disasters and their subsequent abilities to deliver basic services while facing regular natural disasters.

Finally, another approach to assess indirect costs includes theoretical models which aim at emphasizing one or more particular relations or mechanisms at play in the economic system after a natural disaster. Even though their aim is not directly to assess the costs of extreme events, they contribute to identifying important mechanisms and investigating their role. This methodology of cost assessment is probably not easily replicable outside the academic community but provides an important scoping aspect in underlining important mechanisms that need to be specially investigated and taken into consideration for indirect costs assessment.

Hazard-specific findings

Floods

Current approaches for identifying and the measuring indirect or higher order losses are focused on the economic losses, not on other dimensions of sustainability and well-being. Two types of approach dominate: econometric approaches and model-based approaches (Przyluski and Hallegatte 2011). Econometric approaches aim at statistically analysing economic data to highlight the correlation between changes in economic growth and existing events. The lesson learnt can then be used to estimate future flood impacts on the economy. The data availability and its quality are the weakest points of such approaches. Model-based approaches consist in Input-Output models, Computable General Equilibrium models and hybrid models (intermediate between CGE and IO). These models require high skills and are often considered as a black box by the practitioners. Their use is mainly limited to the macro scale (at which scale sufficient information is available) and to disaster events in which case the effects are global and therefore not hidden or absorbed by the global economy.

Acknowledging the potential of these methods for other purposes, Green et al. (2011) question the potential use of these methods in the decision process as they fail to meet stakeholders' needs. For instance, most of the stakeholders are interested in assessing the indirect impact at micro (cities) or meso (catchment) scale for various types of events, small and large, with or without risk mitigation measures. However, most of the methods discussed can only generally assess the impacts of an extreme event on the national scale. Green et al. (2011) furthermore see their potential transfer to practitioners as quite unrealistic considering the skill requirements, the complex mechanisms and the uncertainties associated with such models.

Droughts

According to Logar and van den Bergh (2011), Computable General Equilibrium (CGE) analysis and input output analysis can be considered the most complete methods to assess indirect costs because they regard all sectors of the economy. General-purpose CGE models may be unsuitable to assess the costs of drought without adjusting to drought-sensitive sectors. As the largest share of the costs is frequently borne by the agricultural sector, a precise method to estimate direct (e.g. Ricardian hedonic pricing) or indirect (e.g. economic-physical hybrid models) costs can be used. Input-Output analysis is somewhat less precise than CGE as it does not acknowledge the substitution effects of production factors, market effects (price elasticities), and demand-supply interactions. However, it is easier to develop as it requires fewer assumptions and less data than a CGE model.

Other approaches, such as biophysical-agroeconomic or coupled hydrological-economic modelling, are useful if the impact of a drought on agriculture or in a limited spatial area is the focal point. They could therefore be considered complementary to the other methods. Assessing indirect costs of droughts by observing a change in GDP and agricultural production of a country can only be used for indicative purposes, but is unlikely to provide a reliable cost estimate.

Coastal hazards

Methodologies for assessing indirect costs of coastal hazards may be developed on the basis of multivariate models and econometric approaches. The first has the main advantage of being extremely flexible in the choice of parameters to valuate damages due to coastal hazards. The methodology does not require pre-determined data sets, but rather the development of a set of available and independent variables that can be correlated with total damage costs (Lequeux and Ciavola 2011, Przyluski and Hallegatte 2011).

Generally, Input-Output models are good approaches to estimate indirect impacts in the aftermath of natural disasters such as extreme storm events, even though the method may present some limitations, especially as it is unable to reflect the flexibility in economic systems, and also because the method is rather unsuitable for the local scale. Depending on the type of Input-Output model, efforts in data collection may be relatively high, as Input-Output tables often need to be adjusted to the spatial scale and the period of the hazard event. Alternatively, a Computable General Equilibrium model can be used to determine indirect costs. The latter is able to deal with more flexibility in economic processes; however, its application requires higher efforts.

Alpine hazards

With regard to indirect effects for Alpine risks, very few studies and assessments exist apart from macro-economic models and rough (expert) estimates. In the case of CBA for risk mitigation measures in Austria, for instance, indirect effects have been estimated based on expert judgement. Other existing methods, such as Input-Output analysis, Computable General Equilibrium models and impacts on Gross Domestic Product, have been developed to analyse macroeconomic effects and have occasionally been applied on the national scale. Due to the special situation of lateral valleys (see Pfurtscheller et al. 2011), indirect effects, however, are likely to be highly relevant for Alpine risk assessment on the regional to local scale. At this scale the available methods are, however, inadequate and alternative approaches are missing. Hence, there are only a few studies that look at indirect effects of hazard events in detail at the local or regional level e.g. based on local level surveys and micro scale assessments (e.g. households). In addition, engineering and mathematical methods can be used to analyse network failures and provide a coherent set of methods to assess indirect effects in lifelines. However, network engineering methods are often not applied because of missing data and high uncertainties.

2.3 Intangible (non-market) costs

General findings

Damages due to **intangible effects** are those damages that are not immediately visible in monetary terms because they have no 'market price', such as adverse health effects, loss of life and damages to many environmental goods or services (Smith and Ward 1998, Merz et al. 2010). Therefore, they can also be referred to as 'non-market costs'. As it takes some effort to express them in monetary terms, they are often not included in cost assessments of natural hazards resulting in incomplete and biased assessments. Intangible (non-market) cost can be included in decision support frameworks either in non-monetary terms in a Multi-Criteria Analysis or Cost-Effectiveness Analysis framework, or in monetary terms in a Cost-Benefit Analysis. For the latter, it would be necessary to put a monetary value on them by means of non-market valuation techniques.

Methods for estimating the monetary value of intangible effects of natural hazards consider the value that individuals derive from use or non-use values of environmental and health goods and services. According to each type of (non-)use value, different valuation methods are proposed which can be categorized into indirect or revealed preference, and direct or stated preference valuation methods (also see Table 2 in the Annex).

Revealed preference methods have the advantage of producing estimates of the value for a particular good based on actual market behaviour, i.e. ex post. Information derived from observed behaviour is used to estimate an individual's willingness to pay (WTP) for an environmental improvement or for avoiding environmental deterioration. The two most popular methods prevalent in environmental economics literature are the Hedonic Pricing (HP) (with Ricardian modelling as a special case) and the Travel Cost (TC) methods. Other methods include the Cost of Illness (COI) approach, specifically applied in estimating health effects, the Replacement Cost method (RC), as well as the Production Function Approach (PFA).

In contrast, stated preference methods create a hypothetical or contingent market, and analyse choices, either ex post or ex ante. Stated preference methods are survey-based approaches using WTP, or willingness to accept (WTA) compensation for relinquishing an environmental deterioration or to forgo an environmental improvement. Important approaches for estimating the environmental and health goods or services are the Contingent Valuation (CV) method and the Choice Modelling (CM) method. The Life Satisfaction Analysis (LSA), another stated preference method, provides welfare estimations of public goods (health, environment) based on life satisfaction surveys. Additionally, the Benefit or Value Transfer (BT/VT) method is based on transferring results of previously applied stated or revealed preferences methods to estimate the intangible costs.

So far, only a relatively limited number of case studies have been elaborated to estimate the intangible costs induced by natural hazards. In this context, only few examples exist for an ex post estimation of environmental and health costs of natural hazards. Also for ex ante estimations, intangible costs are currently rarely considered. These cost estimations are often fragmented, i.e. are not integrated into planning procedures or decision support frameworks like

Cost-Benefit Analysis or Multi-Criteria Analysis. Further, current cost assessment approaches mainly estimate the short term impacts of intangible effects.

Stated preference methods are the most common in valuing intangible costs, since they can estimate both use and non-use values. Stated preference techniques can be used for long-term and global effects but are more uncertain under these conditions in comparison with being applied for local and short-term cost estimations. Hedonic pricing is the most often applied revealed preference method.

When estimating intangible impacts for large areas and for longer time-frames, revealed preference methods are more precise and effective. They also often require less financial and human resources in comparison with stated preference approaches. However, there are serious distortions in the markets in reflecting the risks of natural hazards (e.g. missing signals, owner-tenant-relationships, etc.) with revealed preferences methods. Both the HP and TC methods are unable to capture the non-use values of environmental resources. Whereas the COI approach has been commonly implemented to value the health impacts of the natural hazards, the PFA, in turn, has not yet been applied for assessing the natural hazards intangible costs.

Among stated preference methods, CV was the most commonly used method in valuating non-market goods and services for a long time, and has also been applied in some cases for the assessment of the intangible costs of natural hazards (see Turner et al 1993, Daun and Clark 2000, DEFRA 2004, Leiter and Pruckner 2007). Using CV methods to value non-market commodities holds several advantages, among others, the ability to estimate use and non-use values of assets affected by natural hazards. It also holds no assumptions about an individual's risk attitudes, personal discount rates, or level of risk knowledge. However, survey biases and motivational biases can be associated with it. Similar to CV, Choice Modelling (CM) has become more popular in recent years. It can estimate economic values for any environmental resource, and can be used to estimate non-use as well as use values. CM, however, also enables the estimation of the implicit value of its attributes, their implied ranking and the value of changing more than one attribute at a time (Hanley et al. 1998, Bateman et al. 2003). Further, it has the advantage that respondents are more familiar with the choice format used in CM, where price is one of the attributes in a choice set, rather than the payment approach of explicitly putting a price to a non-market good or service in CV.

The benefit transfer method is applied to estimate environmental costs of natural hazards in cases where time and/or money costs of primary data collection and human resources are prohibitive. However, this method presents some important difficulties, since valuation studies with very similar characteristics should be used and the simulation to the needs of the new case study should be done precisely.

Hazard-specific findings

Floods

Regarding the cost assessment of intangible effects, probably most applications have been carried out in the context of floods (see e.g. Daun and Clark 2000, DEFRA 2004). However, Green et al. (2011) highlight the importance to learn more on the impacts of floods on people and the environment, instead of trying to monetise them. The use of CBA is therefore questioned with regard to the monetisation and valuation of intangibles. The use of MCA tends to be preferred for assessing social, environmental and cultural heritage, although a lack of knowledge and methods exists in how and which indicators, scoring and weighting system should be used.

Droughts

Compared to floods, the intangible costs of droughts are more difficult to estimate and are usually underestimated because droughts last longer and develop much more slowly than other natural hazards (Markantonis et al. 2011). In general, a choice between the methods for estimating intangible costs of droughts is less clear. CV and CM can be used as alternative methods for eliciting individuals' willingness to pay and are expected to arrive at similar estimates (Logar and van den Bergh 2011). However, CM is a more recent approach which offers several advantages over CV. LSA can be regarded as a substitute approach for CV and CM, but so far it has been used for current and historical situations and not for estimating hypothetical or future non-market costs ex ante (Logar and van den Bergh 2011).

Coastal hazards

For assessing coastal hazards, both stated preferences and revealed preference methods can be considered appropriate to estimate intangible costs, depending on the characteristics of individual case studies. Especially CV applies when only little data on any actual economic transactions in a given region are available or usable. In practice, only a few applications occur in estimating intangible costs of coastal hazards and these include Hedonic Pricing (see e.g. Hamilton, 2007), Travel Cost (see e.g. Hartje et al. 2001) and Contingent Valuation (see e.g. Turner et al. 1993).

Alpine hazards

In the field of Alpine hazards, intangible effects and losses, such as loss of life (fatalities), injuries, ecological losses, and loss of cultural heritage or memorials have only partly been assessed in hazard risk management so far (see also Markantonis et al. 2011). Predominantly, loss of life as well as injuries and evacuation are assessed. In this context, Contingent Valuation has been used in different case studies to identify public preferences for risk reduction of mortalities, to estimate the value of a statistical life in the case of avalanches and to calculate the marginal costs derived from society's willingness to pay for reducing specific risks (Pfurtscheller et al. 2011). Other non-market effects such as damage caused to the environment, e.g. due to oil leakages, have not been analysed until now. Also, a systematic approach listing all potential intangible costs does not yet exist, but is seen as a good approach to include intangible effects in costing and decision making as a first step.

2.4 Costs of risk mitigation

General findings

The costs of mitigation, i.e. the reduction of natural hazard risks, can be regarded as part of the total costs of natural hazards. They can be classified according to the three cost categories – direct costs, indirect costs and intangible costs - that were adopted in the CONHAZ project (see also Bubeck and Kreibich 2011, Przyluski and Hallegatte 2011, Markantonis et al. 2011). The direct costs refer to any costs attributed to research and design, the set-up, and operation and maintenance of infrastructure/other measures for the purposes of mitigating (or adapting to) natural hazards. The indirect costs relate to any secondary costs (externalities), occurring to economic activities/sectors (or localities) that are not directly linked to such infrastructure investment. The intangible costs refer to any health or environmental impacts, for which no market price exists.

Risk mitigation measures identified in the CONHAZ project included the following categories: 1) risk management planning and adaptation plans; 2) hazard modification; 3) infrastructure; 4) mitigation measures stricto sensu; 5) communication; 6) monitoring and early warning; 7) emergency response and evacuation; 8) financial incentives; and 9) risk transfer. Costing of risk mitigation measures almost exclusively focuses on estimating direct costs, including research and design, set-up, and operation and maintenance (O & M) costs, as they are most often easily quantifiable. In line, the focus lies in the direct investments in 'hard' risk mitigation measures, i.e. the categories infrastructure and mitigation measures (strict sensu). Nevertheless, with a few exceptions (see e.g. Wegmann et al. 2007), comprehensive and comparable overviews on the total mitigation efforts and costs, e.g. at the regional or national level, are rarely available.

Although different approaches exist for estimating indirect and intangible costs of risk mitigation measures, less emphasis is given to these costs in studies that focus on the cost assessment of risk mitigation measures. Such costs can be important and their exclusion can lead to incomplete and biased estimates of the overall costs of risk reduction.

The costs (direct, indirect, and intangible) of any risk reduction measure naturally need to be contrasted against the implicit accruing benefits. These can again either be direct, indirect or intangible, i.e. in effect the avoided damages and losses of natural hazards. Usually, the analysis of the costs and benefits of measures for the mitigation of natural hazard risk focuses on structural and technical measures that include the categories of infrastructure (related to hazard reduction and protection of people and assets) and mitigation (stricto sensu) (measures aimed at vulnerability reduction, usually on a small scale). Any reliable Cost-Benefit Analysis of infrastructure investment (for mitigation or adaptation of natural hazards) requires an accurate estimation of all costs associated with the inception and implementation of the project (i.e. during the asset's entire life cycle). The Whole Life Cycle Costing (WLCC) approach attempts to provide such a systematic consideration of all present and future costs linked to risk mitigation investment (and assets more broadly).

Hazard-specific findings

Floods

There is rather a long tradition in evaluating flood risk mitigation measures in CBA frameworks in European practice (see e.g. MAFF 1999). However, as for natural hazards in general, often only structural and technical risk mitigation measures are regarded. Furthermore, there is much emphasis on implementation costs. The extent of O & M costs is not well included as these costs are often estimated by simply assuming percentages of construction costs. However, O & M costs can represent a major part of present value of costs. In contrast, costs of emergency services (and evacuation) for floods have been, although sometimes to a limited extent, assessed (Bouwer et al. 2011). In turn, the costs of failure of risk mitigation strategies are rarely taken into account. In assessing and comparing risk mitigation strategies and measures, direct implementation costs and economic benefits are obviously important but not sufficient criteria. In turn, a wider set of values and priorities, for instance, reliability, failure, effectiveness, and social relationships should be considered, understanding that traditional CBA cannot readily incorporate such factors.

Droughts

There are very few studies that attempt to assess the costs of drought prevention, mitigation or adaptation measures. Costs of emergency response (and evacuation), for instance, have been assessed less often (with a few anecdotal exceptions of recent severe events) than for other hazards (see Bouwer et al. 2011). According to our knowledge, no drought damage model exists that takes drought risk mitigation measures into account; and as a result, the damage reducing effect of drought risk mitigation measures is largely unknown (Bubeck and Kreibich 2011).

Coastal hazards

CBA and other methods, such as MCA or CEA, which enable the measurement of costs and benefits of different coastal protection options, are considered appropriate to measure the efficiency of different projects, notably in the perspective of climate change. In addition, CEA can be used for assessing the cost-effectiveness of emergency response in case of coastal disasters, while choice experiments can be used for comparing different adaptation measures.

Alpine hazards

Costing of risk mitigation measures, such as structural measures, but also monitoring and early warning, have received considerable attention in the areas of Alpine hazards, and there have also been first approaches to assess the associated costs of emergency response (and evacuation) (Bouwer et al. 2011). The most comprehensive study on the costs for risk reduction was performed by Wegmann et al. (2007) for Switzerland. It shows that Switzerland spends about 0.6% of the GDP for reducing natural risks (including private and public expenses, as well as insurance premiums) per year. The collection of similar data for other (Alpine) countries was hampered by missing and ambiguous data, as well as by the multiplicity of administrative bodies involved at the municipal, regional and national level. Therefore, the exact quantification of expenses for public safety remains difficult and cannot easily be compared between countries.

On the level of case studies and single authorities, there are already quite accurate estimates in terms of the initial (set-up) costs of risk mitigation, but there are often only imprecise estimates of follow-up maintenance costs and variable operation costs that occur in case of an event. With regard to CBA of risk mitigation measures, it has been found that CBA is fully implemented in many Alpine regions, but that the applied methods of public bodies differ with regard to the cost categories considered, the costing methods and to the administrative embedding of the cost analyses (Pfurtscheller et al. 2011).

2.5 Integrating cost assessment into decision support frameworks

Different methods or evaluation frameworks can be applied to include cost estimates – resulting from methods described in the previous sections - into decision support, the most commonly applied being Cost-Benefit Analysis (CBA), Cost-Effectiveness Analysis (CEA), and Multi-Criteria Analysis (MCA) (see also van Erdeghem 2010). While extensive literature is available on these methods, we will focus in the following on how these methods are applied in the field of natural hazards and, in particular, how cost figures are dealt with within these methods.

Although the steps of CBA, CEA and MCA differ in detail (see e.g. Hanley and Spash 1993, Munda 1995, Rauschmayer 2001) they share basic steps:

1. Define alternative options to solve a certain problem,
   i.e. in the context of natural hazards, the identification of alternative risk mitigation measures
2. Analyse and assess the effects of these alternatives to be considered in the evaluation
3. Evaluate the alternatives using certain decision rules
4. Rank and recommend alternatives

The differences between CBA, CEA and MCA are mainly related to step 2 (the type of effects considered in the evaluation) and step 3 (the decision rules applied). Both are relevant for the type of cost assessment needed for the evaluation.

Cost-Benefit Analysis (CBA)[4] is a main economic technique, which is commonly used by governments and public authorities for project appraisal. The roots of CBA are based in welfare theory. The overall goal is to select the most efficient alternative from a list of options (Hanley and Spash 1993, Turner et al. 2007). Hereby, economic efficiency (or pareto optimality) is defined as an allocation of resources such that no further reallocation is possible that would create gains in production or consumption satisfaction to individuals without simultaneously imposing losses to others (Young 2005).

[4] For general discussion of CBA see e.g. Hanley and Spash (1993), Hansjürgens (2004), Brouwer and Pearce (2005), Young (2005). For applications in the context of natural hazard management see MAFF (1999), Brouwer and Kind (2005), Pearce and Smale R (2005), Turner et al. (2007), BMLFUW (2008), Thöni et al. (2009) or Meyer et al 2011.

With regard to the second step described above, CBA requires considering all relevant effects (costs and benefits) of decision alternatives in monetary terms. Costs are all negative effects of a certain measure while benefits are all positive effects in comparison to a baseline option (usually the "do-nothing option" or "business as usual option"). In the context of natural hazards, the costs considered in a CBA typically refer to investment, and operation and maintenance costs of certain measures over the lifetime of a project (costs of risk mitigation). The benefits mainly refer to the damage reducing effects of a certain measure, i.e. the estimated reduction of annual average costs caused by natural hazards.[5] For the cost types described in the working definition of CONHAZ this would imply that all of these costs have to be assessed in monetary terms.

The decision rule of CBA is then the following: all relevant costs and benefits of a certain measure are discounted[6] and then related to each other. The usual criterion for the evaluation of projects in a cost-benefit framework is the Net Present Value (NPV) test. The NPV is defined as the sum of discounted benefits minus the sum of discounted costs over the lifetime of a project (Hanley and Spash 1993). The first test would be to check if the NPV of a project is positive, i.e. if its benefits exceed its costs. If yes, it could be stated that this project would lead to a gain in social welfare and should be accepted. However, if there is more than one alternative the second decision rule would be to choose the project with the highest NPV.

An alternative cost-benefit criterion is the Benefit-Cost Ratio (BCR), which is the ratio of discounted benefits to discounted costs. A BCR > 1 indicates a positive impact of the project on social welfare, similar to an NPV > 0. However, in contrast to the NPV, the BCR does not measure the total impact of the project on social welfare but the relation of its benefits to its costs. The choice whether the NPV or the BCR should be used depends on the decision situation: if e.g. one project should be chosen among a set of options then the decision rule would be to choose the one with the highest NPV. If, on the other side, capital budget is fixed and several projects should be carried out with this budget the right decision rule would be to rank the projects by their BCR and accept them in order of their ranking until the budget is exhausted (Pearce and Smale 2005).

Cost-Effectiveness Analysis (CEA)[7] is an economic evaluation approach that relates monetary costs of two or more courses of action to their outcomes (effects) with regard to a predefined (in most cases non-monetary) target indicator. Cost-Effectiveness analysis is often used in the field of health services, where it may be inappropriate to monetise health effects (as an intangible, non-market good). Typically, results of CEA are expressed in terms of a ratio where the denominator is an improvement of a certain indicator from a measure (years of life, premature births averted and years gained), while the numerator is the cost associated with the health gain. The applications of the CEA are restricted to comparisons between programmes that produce directly comparable outputs measured in the same unit (Birch and Gafni 1992).

[5] Note that certain measures could also have negative impacts on the annual average damages or costs. In that case these negative impacts would be counted as costs and not as benefits in CBA. This is also very much dependent on the definition of the baseline option.

[6] For a discussion on discounting and discount rates see e.g. Hanley and Spash (1993); Gowdy (2007); Turner et al. (2007)

[7] For discussion of CEA see e.g. Messner (2006), Rheinsberger and Weck-Hannemann 2007, The World Bank (2007), Meyer et al. (2011)

In the context of decision support for natural hazard management this implies for CEA that it is only necessary to evaluate the costs of certain risk mitigation measures in monetary terms. The defined target indicator (e.g. a certain safety or risk reduction level), on the other hand, can be expressed in non-monetary terms. In this case, a monetary cost assessment of the direct, indirect and intangible (non-market) costs of natural hazards would not be necessary for a CEA approach. However, also monetary target indicators could be chosen, such as a risk reduction target. In this case, a monetary cost assessment would also be required for this indicator, but then CEA comes rather close to a CBA framework.

Two alternative decision rules can be applied in CEA: either the alternative is chosen with the lowest costs to achieve a given target level of the defined indicator or, given a fixed budget, the alternative with the highest performance in that indicator is chosen. However, while CEA has fewer requirements on costs assessment than CBA, the evaluation of benefits is restricted to the defined target dimension, i.e. benefits not measured by this target indicator are neglected by CEA (Messner 2006).

Multi-Criteria Analysis (MCA)[8] is an alternative or complementary evaluation approach that involves judging the expected performance of each alternative option against a number of objectives or evaluation criteria (Belton and Stewart 2002). In contrast to CBA, none or not all of these evaluation criteria need to be measured in monetary terms. In the context of decision support for natural hazard risk mitigation, this implies that health and environmental effects of risk mitigation measures can be included in non-monetary terms so that problems of monetary valuation can be avoided. Instead, however, one faces the problem of criteria weighting.

Many different MCA techniques and hence decision rules exist, such as Multi Attribute Utility Theory (MAUT) and Outranking approaches (see e.g. Keeney and Raiffa 1993, Drechsler 1999, Klauer et al. 2006). What most of these approaches have in common is that the evaluation criteria need to be weighted by decision makers to aggregate them to a final evaluation and ranking of alternatives. In this line, decision makers or stakeholders have to express their valuation of the relative importance of the different evaluation criteria (see e.g. Munda 2006, Proctor and Drechsler 2006). This makes MCA a more deliberate and participatory evaluation approach than CBA and CEA. However, for the same reason it is often criticised to be subjective, especially since the preference elicitation methods have been tested and improved less extensively than it has been the case in monetary valuation with stated preference techniques.

In particular, CBA and MCA or combinations of both are already frequently applied in practice to utilise natural hazards cost assessment for decision support (see e.g. MAFF 1999, SMUL 2005). Another decision support framework in this context is the Robust Decision Making approach (Lempert and Collins 2007) which puts a special emphasis on considering the uncertainties in cost figures. Although such decision support methods and frameworks are not in the main scope of the CONHAZ project, we will at least briefly address them again in the recommendations section (see section 3.9).

[8] For general description of different MCA approaches see e.g. Bana E Costa (1990); Zimmermann and Gutsche (1991); Vincke (1992); Munda (1995); Belton and Stewart (2002). For applications in the context of natural hazards management see e.g. Bana E Costa et al. (2004), Brouwer and van Ek (2004), Akter and Simonovic (2005), Kenyon (2007) and Meyer (2007).

3 Knowledge gaps and recommendations

One of the main objectives of the CONHAZ project was to identify knowledge gaps in the area of cost assessment for natural hazards and to give recommendations based on further research needs and implications for policy and practice. Many specific knowledge gaps and related recommendations have already been addressed in the CONHAZ reports on the various cost types (Bubeck and Kreibich 2011, Przyluski and Hallegatte 2011, Markantonis et al. 2011, and Bouwer et al. 2011) and hazard types (Logar and van den Bergh 2011, Green et al. 2011, Lequeux and Ciavola 2011, and Pfurtscheller et al. 2011). As a result, the section will describe some overall knowledge gaps and recommendations which emerged from all background papers.

Below we start with a consideration of the terminology of cost types, as introduced in section 1.2 (section 3.1). Then, the main focus will be on cost assessment approaches, related knowledge gaps and recommendations for practical applications, as well as for further research (section 3.2-8). In section 3.9, some recommendations will be provided on the integration of cost assessment into decision support frameworks. As all these recommendations were presented and discussed at the CONHAZ Final Synthesis Conference section 3.10 summarises the results of this conference. On this basis key recommendations are summarised in section 3.11. .

Recommendations are split into *recommendations dedicated to policy/practice* and *recommendations for further research*. However, some of the recommendations are dedicated to both stakeholder groups.

3.1 Terminology of cost types

CONHAZ started with a working terminology on cost categories, which was reflected and used in the different WP reports (see section 1.2). According to this working definition, CONHAZ dealt with direct costs and costs due to business interruption (Bubeck and Kreibich 2011), indirect costs (Przyluski and Hallegatte 2011), intangible costs (Markantonis et al. 2011) and risk mitigation costs (Bouwer et al. 2011). It was one aim of the project to find out whether this working definition is sufficient to differentiate cost assessment methods across the different hazard types.

While reviewing the existing terminologies and methods two potential sources of misunderstanding arose:

Firstly, the differentiation between ***direct costs* and *indirect costs*** may lead to misunderstandings, in particular when looking at different hazard communities. Particularly in the floods community, direct damages are often defined by the direct physical impact of the hazard, i.e. a physical destructive process (cf. Smith and Ward 1998, Bubeck and Kreibich 2011). On the other hand, in the case of droughts, this direct contact or destruction is less obvious than for other natural hazards, making drought-related damages more difficult to delineate in space and time. For droughts, Logar and van den Bergh (2011) therefore recommend to define direct losses as impacts on resource-based sectors such as agriculture, hydropower production or livestock production, as well as structural damages induced by soil subsidence.

Secondly, the terms ***tangible/intangible*** are not always understood. While this terminology is frequently used in the flood, coastal and Alpine hazard community (cf. Green et al. 2011, Lequeux and Ciavola 2011, and Pfurtscheller et al. 2011), it is not common in the droughts community (cf. Logar and van den Bergh 2011). Logar and van den Bergh (2011) therefore recommend applying the terms ***market/non-market values*** or ***costs***, which are commonly used in environmental economics.

At this point it seems appropriate to take a step back and have a look at the different possibilities to differentiate cost types. Table 1 gives an overview of the most important classification arguments or criteria mentioned in the different CONHAZ reports.

Table 1: Classification criteria for cost types

Classification criteria	**Specification**		
1) Damaging process	**Physical destruction** e.g. destruction of buildings		**Interruption of processes** e.g. business interruption (in or outside the affected area)
2) Causal relationship	**Primarily or directly caused by the hazard** e.g. destruction of buildings, interruption of energy production due to water scarcity or flooding		**At least one causal step away** e.g. induced losses in production due to shortage of energy
3) Space	**Within the affected area** e.g. destruction of buildings, interruption of production		**Outside the affected area** e.g. interruption of production in other companies due to shortage in supply or energy
4) Time	**During the event: shock to the system** e.g. destruction of buildings, interruption of production		**After the event: recovery phase** e.g. loss of production or well-being until reconstruction, or under alternative growth trajectory
5) Market (tangible) vs. non-market (intangible) costs	**Effects on goods and services which are traded in markets** e.g. buildings, inventories, stocks, economic output		**Effects on goods/services not traded in markets** e.g. environmental goods, health, cultural heritage
6) Impact dimension	**Economy**	**Environment**	**Population**
7) Damage vs. abatement costs	**Costs caused by the hazard** e.g. destruction of assets, interruption of production		**Cost caused by efforts to mitigate risk** all types of risk mitigation costs

As mentioned above, the first classification criterion (*damaging process*) is mainly used in the floods community to differentiate direct from indirect costs, while the second (*causal relationship*) seems to be preferred to distinguish between direct and indirect costs in the droughts community. Space and time are often used as additional or alternative indicators to identify indirect costs, i.e. if costs arise *outside* the affected area and *after* the event it is very likely that they will be called indirect (see also Thieken et al. 2010).

As the terms for cost categories are obviously not always used in the same manner in literature, we recommend using the classification arguments as described in Table 1, not to invent a new classification but to explain and differentiate cost types more precisely and to avoid misunderstandings. The seven criteria can be used as a kind of a multi-dimensional space to get an overview of the type of costs which are relevant for a certain study. However, it should not be the goal to establish an even more complicated typology of cost types which would not be applicable in practice. From our point of view the most important aspect of categorisation is to identify cost types which require the same methods of assessment. Using such an overview cost types can be more easily identified, prioritised and related to the methods required to assess them. In this respect, the CONHAZ working definition of cost types (see section 1.2) already serves as a good basis.

⟶ Practice/Research recommendation: Since terminology (especially with regard to "direct" and "indirect" costs) differs in literature, we recommend using the seven classification criteria shown in Table 1 to obtain an overview of the relevant costs to be considered. Cost types can then be grouped according to the methods required to assess them.

⟶ Practice/Research recommendation: Both classification criteria, the *damaging process* and the *causal relationship*, seem to be important, as they suggest different cost assessment methods. However, the classification according to the *causal relationship* seems to be a more intuitive way of differentiating direct from indirect costs. In this case, it would be important to differentiate within direct costs between *destruction* and *interruption* processes, as both require different methods of assessment.

⟶ Practice/Research recommendation: Space and time can be used as additional indicators which help to identify indirect costs. If costs arise *outside* the affected area and *after* the event it is very likely that they are at least one causal step away from the hazard impact.

⟶ Practice/Research recommendation: The terms market and non-market costs can be used as synonyms for tangible and intangible costs, respectively. They have the advantage that they immediately connect to market and non-market valuation techniques, a common distinction (and terminology) in environmental economics.

⟶ Practice/Research recommendation: With regard to the aforementioned aspects the CONHAZ working terminology of cost types (see section 1.2) has proved to be useful terminology.

3.2 Comprehensiveness

The review of existing methods and practices of cost assessments for natural hazards in CONHAZ illustrated that there is a strong focus on direct costs of natural hazards. In contrast, the costs due to business interruption, intangible/non-market costs such as health and environmental effects, and especially indirect costs are often neglected (cf. Lequeux and Ciavola 2011 p 56, Pfurtscheller et al. 2011 p 78). This could lead to incomplete and biased cost estimates.

⟶ Practice Recommendation: To receive a complete picture of the costs of natural hazards, not only direct costs but also costs due to business interruption, indirect and intangible/non-market costs, as well as the costs of risk mitigation should be considered (see also section 3.4).

3.3 Uncertainties

Although considerable improvements have been made over the last decades there are still high uncertainties in all parts of cost assessment, related to, among others, insufficient or aggregated data sources, or lack of appropriate models (cf. Bubeck and Kreibich 2011 p 55, Przyluski and Hallegatte 2011 p 37). The objective should be on the one hand to 1) identify and reduce the main sources of uncertainties and to 2) document the remaining uncertainties in the results of cost assessments.

→ Research Recommendation: In order to reduce the uncertainties in cost assessments further research efforts should be undertaken to improve the availability and quality of input data (see section 3.3), as well as to advance models for the estimation of the different types of costs (see section 3.4).

→ Research/Practice Recommendation: However, all data and cost estimations are inaccurate to some extent. Efforts for data and model improvements should be concentrated where it is worth spending that effort, i.e. where the largest improvements could be expected.

→ Practice Recommendations: In any appraisal it is important to identify the main sources of uncertainty at an early stage and try to reduce or handle them. Remaining uncertainties in cost estimates should be documented and communicated to decision makers.

Currently, existing damage models are hardly validated. However, such validations are needed because they enable determining the accuracy of cost assessments (Bubeck and Kreibich 2011, p 54). While such analyses have been partly carried out with respect to flood damage modelling, similar exercises for droughts, coastal flooding or Alpine hazards are lacking. In addition, many damage models are currently being transferred in space and time, e.g. from region to region or from one event to the other. However, it is still an open question as to what extent and under which conditions this is at all possible. Model validations in different regions and at different time steps, as well as model inter-comparison studies could provide insights into this aspect.

→ Research/Practice Recommendation: Validating the results of existing damage assessment methods should be intensified and more uncertainty analyses, as well as model inter-comparison studies have to be carried out before we arrive at a set of sound and useful models within Europe.

3.4 Improvement of data sources

One of the main sources of uncertainty in the ex ante estimation of the costs of natural hazards is the lack of sufficient data. Improvements can be made with regard to 1) the collection of ex post event data and 2) the availability of secondary input data sources for ex ante cost estimations.

Firstly, ex post event damage or loss data is needed to better understand damaging processes, to identify the most important damage influencing factors, and to develop, calibrate and/or validate models based on this. This is the case for direct damage data, data on business interruption, health and environmental effects, indirect costs, but also for the specific costs of risk mitigation measures (cf. Bubeck and Kreibich 2011 p 54, Bouwer et al. 2011 p 56, Logar and van den Bergh 2011, p 50). Different databases may include different biases, e.g. small events are missing in global databases in comparison with national databases, and consistencies, e.g. different figures for the numbers of fatalities and disaster costs (see Pfurtscheller et al. 2011 for some examples for Alpine hazards). Although several data collection activities in different countries and for different cost types have been conducted (e.g. HOWAS 21, EM-DAT, Munich Re, Swiss Re Sigma, StoreMe), there is still a lack of data that link object-specific damage costs with event/impact parameters and object characteristics.

⟶ Research & Practice Recommendation: A framework for supporting data collection, storage and availability should be established on the European level, both for object-specific ex post damage data (analysis of damaging processes) and risk mitigation costs. Such a framework should ensure minimum data quality standards to facilitate the development and consistency of European and national databases.

Secondly, there is often a lack of sufficient input data for ex ante cost assessment models. For example, models for direct costs assessments require high spatial resolution data on land-use, type of buildings, asset values of buildings and contents, industrial production and crop yields etc. as input data (Green et al. 2011 p 76). Such data is often not available at a high spatial resolution but at a highly aggregated level only. Furthermore, the different data sources are often incompatible to each other in terms of categorisation and/or spatial resolution. For revealed preference approaches, for example, detailed and normalized long-term data on housing market values is necessary (cf. Markantonis et al. 2011 p 77). Methods for the estimation of indirect effects would require data on networks and input-output relationships between different sectors (cf. Przyluski and Hallegatte 2011 p 77). Such data is often not available at a local or even regional level. A further drawback is that some of these data sources are often either costly (land-use data) or not accessible at a high spatial resolution due to security or privacy protection considerations (e.g. asset value data). Primary data collection can be an alternative to close such data gaps, but is fragmented, costly and time consuming.

⟶ Policy/Practice Recommendation: Unrestricted access to high spatial resolution land-use data and statistical data etc. would facilitate the cost assessment of natural hazards.

3.5 Improvement of methods

In addition to the improvement of data sources, a second important way to reduce uncertainties in cost assessments is to improve models. In this sub-section, recommendations will be given for the improvement of methods with regard to the different cost categories.

Direct costs and losses due to business interruption

As mentioned in section 2, susceptibility functions – as the most common approach to estimate direct costs – often only refer to single hazard and resistance parameters, like e.g. inundation depth and building type. This may result in an oversimplification of the processes leading to damage and, hence, to inaccurate cost estimates (cf. Bubeck and Kreibich 2011 p 55). Some recent research has shown that models that include more parameters may outperform simple models (Thieken et al. 2008).

⟶ Research Recommendation: Further research is needed to develop multi-parameter damage models that better capture the variety of damage influencing parameters. In particular, resistance parameters need to be better included in damage models. Information on the effectiveness of preventive, precautionary and preparative measures provides key insights for risk management, as it enables evaluating and comparing various structural and non-structural risk mitigation strategies. Furthermore, special attention should be given to the identification of critically vulnerable elements at risk like e.g. hospitals.

Existing methods often focus on cost assessments for single sectors (cf. Bubeck and Kreibich 2011 p 56). For instance, damage models for floods often focus on the private housing (residential sector) or damage models for droughts on the agricultural sector. However, damaging processes may differ significantly by sector and hazard, and, for example, direct as well as indirect damage to infrastructure may be enormous. Furthermore, the combined effects of coinciding hazards like, for example, storms and coastal floods are mostly not reflected in the models (cf. Lequeux and Ciavola 2011 p. 48).

⟶ Research/Practice Recommendation: There is a need to integrate several sector- and hazard-specific damage models in a tool-box which would allow modelling the costs of natural hazards over several sectors and which is able to estimate the interplay of possible coinciding hazards, in particular for coastal and Alpine hazards.

In this respect, especially the role of preventive measures or management schemes is often not well reflected in the models to assess damages. However, in particular the failure of existing defences can be one of the most damage influencing factors (cf. Green et al. 2011 p 83). As an example, PLANALP (2008) already recommends testing the performance of risk mitigation structures in case of overload (see Pfurtscheller et al. 2011 p 69).

⟶ Research/Practice Recommendation: More attention should be given to the risk of failure of risk mitigation measures, also in direct damage models. An assessment of failure scenarios should be compulsory.

Although it is widely acknowledged that direct costs or costs due to business disruption are the cause for indirect effects, little attention has been paid so far in the models to the link between the estimation of direct costs and indirect costs.

⟶ Research Recommendation: Models for direct cost assessment should be enhanced in a way that more emphasis is given to the direct effect on critical infrastructure or network nodes, which may lead to considerable indirect costs. Such information can form an important input for approaches to estimate indirect effects.

Indirect costs

Although models exist to estimate the indirect costs of natural hazards (cf. Przyluski and Hallegatte 2011 p 37), there is still little understanding of the economic response to external shocks, i.e. how the economic system can react and adapt in the recovery and reconstruction phase.

⟶ Research Recommendation: More research is needed to understand and to model how markets function outside equilibrium. This regards, in particular, the dynamics of return to equilibrium after a hazardous event, the associated social and institutional interactions and how agent expectations are formed in situations of high uncertainty.

Existing models often operate on an aggregated scale, i.e. the total direct impact of a natural hazard is used as an input for the models, such as CGE models or IO models. Only little attention is paid to the micro scale, i.e. how the impact on single elements of critical infrastructure or single nodes or hubs in network systems such as the electric system, water distribution, transportation but also critical industries in the supply chain may influence the economic system as a whole.

⟶ Research Recommendation: The link of indirect cost assessments to the models of direct cost assessment could be improved. This implies a better understanding of the role of networks such as the electric system, water distribution, transportation and economic supply chains, and how the affectedness of critical nodes and hubs in these systems will impact the economic system.

This would also imply a better understanding of interactions between the economic intrinsic dynamics (e.g. business cycles) and external shocks (e.g. natural disasters). The coexistence of these two dynamics explains why it is so difficult to 'extract' the effect of natural disasters from macroeconomic data series (cf. Przyluski and Hallegatte 2011 p 37).

⟶ Research Recommendation: A better understanding of the interaction of the economic intrinsic dynamics (e.g. business cycles) and external shocks (e.g. natural disasters) would contribute to a better measurement of disaster costs and relevant processes.

Intangible (non-market) costs

As stated in section 2, intangible/non-market effects such as environmental and health impacts have, up to now, been rarely included in cost assessments despite a variety of valuation methods (cf. Markantonis et al. 2011). However, as such costs may represent an important part of the overall costs they should be considered in decisions on risk mitigation measures.

→ Practice Recommendation: Intangible effects should be considered in decisions on risk mitigation measures. A decision should be made at the beginning if such effects should be included into the decision making process in a non-monetary or in a monetary form.

If a monetary assessment of these effects is favoured, several methods are at hand for the monetary valuation of non-market goods and services, such as revealed and stated preference approaches. The accuracy and effectiveness of these cost assessment methods depend on the data availability and quality, the available resources and the decision made in each case on the most appropriate method for estimating the intangible effects. The advantages and disadvantages, as well as potential methodological pitfalls of these methods are discussed in section 2 and more detailed in Markantonis et al. (2011).

→ Practice recommendation: Several methods are available for the monetary valuation of intangible (non-market) costs, but more applications in practice are essential to demonstrate their applicability and usefulness for natural hazards cost assessment. Some guidance on the choice of the appropriate valuation method for different applications is given in Markantonis et al. (2011).

Although there is still some need to improve or to validate these valuation techniques in detail, our review showed that the more crucial knowledge gap often lies in the precise description and estimation of the physical processes or effects (cf. Markantonis et al. 2011 p 77). The environmental, as well as health impacts of natural hazards are often not well understood and therefore not easy to model. For instance, effects on mental health have rarely been analysed until now.

→ Research Recommendation: More research is needed especially on the *physical* impacts of natural hazards on environment (e.g. ecosystems, pollution) and health (e.g. post-traumatic stress, depression, infectious diseases). If these effects are better understood they can be better assessed and included in decision making processes in either non-monetary or monetary form.

Costs of risk mitigation

The costs of risk mitigation measures constitute an essential part of the total costs related to natural hazards and should be considered, especially in the decision making process on alternative mitigation options. However, as the review by Bouwer et al. (2011 p 57) shows, the cost assessment of risk mitigation measures almost exclusively focuses on direct costs, and especially on investment costs, as well as research and design costs. Operation and maintenance costs are rarely considered, and particularly the indirect and intangible costs of risk mitigation measures are often ignored.

→ Research & Practice Recommendation: More attention should be given to the assessment of operation and maintenance costs, as well as indirect and intangible costs of risk mitigation measures. This includes a more consistent collection of data (also see section 3.3).

Furthermore, cost assessments for risk mitigation measures mainly focus on structural measures, aiming at hazard prevention, such as dikes and avalanche protection. In comparison, there are relatively few cost assessment approaches for non-structural measures, such as small-scale risk mitigation actions, monitoring and warning systems, emergency response, land-use planning or risk transfer systems (Bouwer et al. 2011 p 57). For a comparative evaluation of alternative structural and non-structural risk mitigation options, it would be necessary to obtain reliable cost figures for both (cf. Green et al. 2011 p 71). Furthermore, special attention should be given to the question of who bears the costs of the alternative measures.

→ Research/Practice Recommendation: Further research is needed for a better estimation of the costs of non-structural measures, together with structural alternatives, in order to consider them appropriately in decision support frameworks.

3.6 Future dynamics of risk

Natural hazard risk is essentially dynamic depending on climate variability, as well as on changes in vulnerability patterns. Risk and, hence, natural hazards costs will continue to change in future due to the dynamics in the different risk drivers. Such dynamics in risk drivers are, on the one hand, changes in the probabilities or intensities of hazards due to climate change, and, on the other hand, socio-economic developments which lead to land-use changes, changes in the population and asset values at risk and changes in the susceptibility and adaptive capacity of communities (cf. Bouwer et al. 2011 p 15, Przyluski and Hallegatte 2011 p 37). In the current practice of cost assessment these dynamics are only rarely reflected. In other words, costs are estimated for the current risk situation in terms of annual average damages and – e.g. in Cost-Benefit Analyses – extrapolated to the future over the lifetime of the alternative risk mitigation options to be evaluated. Only few scientific studies try to integrate climate change scenarios as well as socio-economic change scenarios (see e.g. Bouwer 2010, Grossmann et al. 2011)

→ Research Recommendation: More research is needed on the effects of future climate and socio-economic change on the costs of natural hazards and costs from adaptation to these changes and how such findings can be integrated in the cost assessment approaches.

→ Practice recommendation: When cost assessments are carried out for alternative risk mitigation options, it should be reflected 1) what are the most important risk (or cost) drivers, and 2) if major changes can be expected for these risk drivers in the future and 3) if these changes might influence the evaluation or ranking of the alternative options.

3.7 Distribution of costs and risk transfer

Besides the total amount of costs of natural hazards, also their distribution within society is an important issue which has received only little attention so far (cf. Green et al. 2011 p 71). For decision making purposes it would be important to know who has to suffer most due to natural hazards, who bears the costs of potential risk mitigation options and who benefits from them. Some improvements have already been made in the development of risk mapping approaches to identify the affected population more precisely in a spatial sense. The lack of financial resources among the affected people or companies may be a critical point for society's ability to recover from the shock. Risk transfer systems such as insurance and re-insurance schemes are an important means of distributing such costs within society to make the system as a whole more resilient to such shocks (cf. Raschky et al. 2009, Przyluski and Hallegatte 2011 p 37, Schwarze et al. 2011). Also, there is some evidence that insurance systems provide the opportunity to include incentives to reduce risks in the policies (see e.g. Bouwer et al. 2007, Warner et al. 2009, Botzen et al. 2009, Thieken et al. 2006).

→ Research recommendation: More research is needed on the distribution of costs of natural hazards within society, on potential risk transfer systems (including insurance) and on how this would improve society's ability to recover, and incentivise risk mitigation.

3.8 Exchange of knowledge

The review of existing methods and their application in practice showed that sometimes there are already cost assessments at hand for various hazard communities but with limited interchange of information across them. For floods, for example, extensive knowledge is presently available, particularly for the estimation of direct costs which, in turn, has already been transferred to coastal or Alpine floods. However, there is a need to adapt these approaches developed for riverine flooding to the special conditions of coastal floods or Alpine floods, respectively.

The potential to transfer such direct cost assessment approaches to drought is rather limited, due to the different nature of drought hazards, which are mostly slow onset, long-lasting events. On the other hand, it seems that for droughts more experience is available on the coupling of methods for direct and indirect cost assessments. In general, methods for assessing direct costs are more hazard specific, i.e. less easy to transfer from one hazard to the other than methods for assessing indirect costs.

Both, cost assessments for coastal and Alpine hazards have to deal with multiple and coinciding hazards, so there may be potential for an exchange within and between these communities on how to deal with such issues, although, of course, the hazard types are very different. Furthermore there seems to be a need for further exchange between the natural hazard risk community and the climate change community.

In addition to these potentials for knowledge exchange across the different scientific communities, there is a broader need for further knowledge transfer from science to practice. Workshops carried out in CONHAZ showed that practitioners are aware of the potential importance of indirect and intangible costs but that they are still lacking expertise of methods and tools to assess them (cf. Pfurtscheller et al. 2011 p 79).

- ⟶ Research/Practice recommendation: Training is needed to transfer knowledge on cost assessment methods from science to practice. This is especially the case for methods assessing indirect and intangible (non-market) costs, which are rarely applied in practice.
- ⟶ Research/Practice recommendation: The exchange of knowledge between the natural hazard risk community and the climate change community should be enhanced.

3.9 Cost assessment as decision support

The previous recommendations have focused on the core topic of the CONHAZ project, on approaches for the cost assessment of natural hazards. The following section departs to some extent from this as it deals with the question of how such cost assessments could support decision making on risk mitigation options. It is the main objective of cost assessment to provide a basis and support for better decision making and an improvement of risk management. Therefore, the members of the CONHAZ Consortium emphasise the importance that also this issue needs to be addressed.

The traditional framework for an economic assessment of the costs of natural hazards is Cost-Benefit Analysis. The main objective is to find the most efficient, i.e. optimal course of action to implement. All benefits of alternative risk mitigation options are related to their costs to identify the course of action with the highest net benefit, compared to a baseline option. However, as the brief listing of knowledge gaps in the preceding sections has revealed, the current state-of-the-art of cost assessment is still far from delivering comprehensive and precise monetary figures of all costs of natural hazards and, hence, on all costs and benefits of all possible risk mitigation measures.

Nevertheless, monetary cost assessments and CBA can provide crucial support for decision makers. Furthermore, many improvements have been made in the past and will be made in the future to improve the comprehensiveness and precision of cost estimates. On the other hand, it should be acknowledged that such cost estimates will always be uncertain and imprecise to some degree. These uncertainties in cost estimations should be documented as good as possible (see section 3.1). At the end, it is the choice of the legitimised decision makers to what degree these monetary cost figures are useful for them to make better decisions, or, on the other hand, to what degree non-monetary decision criteria should also be considered. In this context, CBA can be a useful tool, but it could be embedded in a wider MCA-framework, allowing stakeholders and decision makers to decide on the relative importance of the different decision criteria and their related uncertainties. If decision makers can agree upon a single non-monetary target indicator, even CEA can be a helpful economic evaluation tool to achieve a desired target level in a cost-efficient manner. The steps and decision rules of each of these decision support methods should be made transparent to the decision makers.

→ Practice recommendation: It is up to the decision makers to decide to what extent they wish to make use of monetary cost assessments to support their decisions (Green et al. 2011). In this context, Cost-Benefit Analysis can provide very useful information but should be embedded in a participatory Multi-Criteria Analysis framework in which legitimised decision makers can decide upon the relative importance of monetary and non-monetary evaluation criteria.

→ Practice recommendation: A step-by-step evaluation process can be applied: A first evaluation step based on approximate cost estimations and/or non-monetary evaluation criteria to rule out inferior risk mitigation options, is followed by a second evaluation step for risk mitigation options selected in the first step, based on more detailed cost assessments and additional non-monetary evaluation criteria.

→ Research recommendation: There is a need for appropriate tools and guidance to support decision makers in the integration of cost assessment figures into decision making. Such tools or frameworks should communicate and consider uncertainties in cost figures and ensure the transparency of the decision rules.

Furthermore, it should be acknowledged that cost assessments are always purpose related. In that line, cost assessments for the insurance industry or a private company would be based on different assumptions and would lead to cost figures that differ from cost assessments for the economy. Secondly, costs are always dependent on the baseline option, i.e. the course of action to which all other options´ costs and benefits are compared to.

→ Research/practice recommendation: The purpose, system boundaries and assumptions of cost assessments should be clarified, documented and communicated in order to avoid misunderstandings.

3.10 Best practices and recommendations - the practitioners' view at the CONHAZ Final Synthesis Conference

The CONHAZ Final Synthesis Conference

The CONHAZ Final Synthesis Conference brought together more than 60 scientists and stakeholders, including representatives from the European Commission, insurance companies and consultancies, from different natural hazard communities. It took place on 17 and 18 November 2011 in Leipzig, Germany at the Helmholtz Centre for Environmental Research – UFZ.

One of the main aims was to include the view of end-users on cost assessment. In order to accomplish this focus on stakeholders' needs and preferences, parallel discussion sessions on two thematic topics were held, where the participants had the lead to initiate and participate in parallel discussion groups. During these discussion sessions, the participants successfully analysed various issues of concern related to:

→ Topic I: The future of cost assessment methods for natural hazards

→ Topic II: The future of integrating cost assessment in decision-making,

and presented results or recommendations with regard to the costing of natural hazards. These results and recommendations of the different discussion sections were prioritized afterwards by all conference participants to highlight the most important outcomes. Additionally, during the first day of the conference the final background papers regarding the costs of the four types natural hazards (droughts, floods, coastal and alpine hazards) were presented and each one followed by an expert's critical statement and discussion. This section briefly presents the outcome of these discussion sessions, highlights other important contributions of the conference, and concludes by linking these results with the CONHAZ project results as presented in chapter 2 and 3.

The future of cost assessment methods and their integration into decision-making

Uncertainty was ranked by the conference participants as the most important discussion theme. Uncertainty related issues such as precision, accuracy and reliability of cost assessment methods and their results, uncertainties occurring at various spatial scales, lack of appropriate data, assessment of uncertainty and how it affects decision-making were analysed under this theme. In order to minimize and handle uncertainties, it was strongly recommended that firstly, the different sources of uncertainty should be identified. In this context, it was also recommended that communication and visualization of uncertainties, as well as decision-making under uncertainty should be improved. Moreover, sensitivity analysis, validation of data and experts consultation could contribute in monitoring uncertainty.

Data collection and usage was evaluated as a very important point for improving the output of costing methods. Data requirements, data collection approaches, data update, accessibility and privacy were the main issues under discussion. In this context, it was recommended that continuous data collection and reporting by public institutions should be established. Also data requirements have to be clarified by different types (government, research, insurance) and a standardization process is necessary at a national and European level.

The question of whether a **comprehensive framework** can be developed for including and estimating all the types of costs was one the most important discussion topics. Existing methods and frameworks such as CBA and MCA were discussed, and whether they are able to include and estimate all relevant cost types. Furthermore, the limitations and uncertainties when estimating all the types of costs were discussed as well as the question of whether it is always necessary to estimate all costs. The recommendations given at this point suggest that for developing more comprehensive frameworks, first, a better understanding of the damaging processes is needed. Secondly, comprehensiveness is enhanced by data availability and quality as well as collecting data in a bottom-up manner at the regional level, which makes data more comparable across regions and fosters rigorous comparative analysis. Finally, multi-dimensional tools and frameworks can be used, which will combine various methods according to the needs of each case.

The interaction of **the climate change and the natural hazards community**, e.g. through the integration of climate change scenarios in cost assessment, was pointed out as an important theme regarding the future of natural hazards cost assessment. In this context, uncertainty of natural hazards impacts modelling due to climate change, the development of robust risk management measures and decisions based on climate change scenarios and the approaches to adjust risk management to climate change adaptation were the main discussion points. From such a perspective, it is essential to enhance the knowledge exchange between the climate change community, natural hazards risk community and decision makers. That can be done by e.g. developing integrative models, scenarios and policies.

The problems and the potential of **Multi-Criteria Analysis, Cost-Benefit Analysis and Cost-Effectiveness Analysis towards integrating cost assessment into decision-making** was also an important discussion theme. The combination of MCA and CBA, necessity and limitations of criteria aggregation, discounting, good and bad practices of CBA and MCA, pros and cons of monetary valuation were the most remarkable issues discussed under this point. It was highly recommended that all steps of CBA and MCA should be made more transparent and participatory by involving experts, citizens and policy-makers in the selection and weighting of criteria, and valuation. Furthermore, it was suggested that a valuation framework should start with CBA and along the process criteria can also be added which cannot be captured in monetary terms and hence interpreted with MCA.

The theme of **system modelling** and under which methods modelling can be conducted for different types of natural hazards was also discussed. Modelling of social and institutional interactions was highly recommended as a step towards a better understanding of the recovery phase and hence for a better assessment of the costs to society. Additionally, more cooperation between the various involved disciplines would foster the coupling of models.

Furthermore, **Loss/Exceedance Probability Curves (LEPC)** were examined as a decision-making tool for cost assessment of natural hazards. Issues discussed under this theme concern the incorporation of LEPC (portfolio target) into Cost-Benefit Analysis (project target) to accomplish strategic planning in a multi-stakeholder risk governance process. Regarding this tool, it was suggested that LEPC take a multi-hazard approach to contribute to making decisions across time and spatial levels.

Costs of early warning systems and how they are estimated are an important issue when dealing with costs of risk reduction. For a more efficient and accurate estimation of the early warning systems' costs, a more intensive knowledge transfer is demanded between the various hazards communities. Further, early warning systems should be included more systematically into Cost-Benefit and Cost-Effectiveness Analysis.

The question whether the **Value of Statistical Life (VSL)** should be included into cost assessment frameworks was discussed. Under this topic, the ethical implications, the magnitude and the variations across population groups and geographical regions were discussed. Although it was recommended as a useful tool, it has to be applied complementarily to other methods. In this case, VSL should be based on a better physical modelling of the loss of life. Regarding other methods, it was suggested that **risk aversion** also be considered in risk assessment and decision support frameworks. Practical issues, the added value and examples of implementing risk aversion were addressed. It was recommended that considering risk aversion is important to better understand risk and risk assessments, and that public participation is therefore crucial for the application of the concept of risk.

Finally, **decision-making related to cost assessment** was another discussion theme, analysing issues such as the costs and benefits of risk transfer methods, decisions for funding allocation, change of losses and risks over time, different scales of decision-making, social solidarity versus individual responsibility influencing decision-making among others.

Discussions related to types of natural hazards

Droughts

The use of CGE models was the most important issue discussed under this topic. CGEs are more demanding but give more precise estimates and therefore they are generally preferred to I/O analysis if one aims to assess indirect effects or costs of droughts. Although CGEs are applied in many cases, they are not always well designed around susceptible (resource-based) sectors and therefore adaptation of general-purpose CGE models may be necessary. Additionally, more emphasis should be given to different geographical scales and thus make CGEs more explicit. Furthermore, it was suggested that the ecosystem service approach could also be related to the assessment of the costs of droughts contributing in this way to the identification of the disruption of the provisioning of ecosystems services. Another important issue was how the results from the CONHAZ project can be disseminated properly to influence the new EU policy regarding droughts and their costs.

Floods

What is of great importance in floods is that cost estimations should ideally not only reflect losses and damages of assets but they should include a general change in well-being. These changes are difficult to estimate due to uncertainties in defining the recovery time, as well as the recovery funding sources. It was mentioned that floods can also cause environmental benefits. It was recommended that such benefits should also be included into CBA and land use management. Furthermore, communication between various disciplines of flood-related sciences (e.g. sociologists, economists, ecologists) is important for estimating the costs of floods. The critical statement of WP6 (costs of floods) pointed out that resilience could include non-structural interventions (knowledge and reliability) as well as the cases where flood risk acts as a benefit towards sustainable development.

Coastal hazards

The discussion stressed the point that it is important to consider events of different probabilities to estimate annual average costs (which is of course true for all types of hazards). Furthermore, the inequalities of coastal protection investments, which vary between different European regions, were discussed.

Alpine hazards

Regarding Alpine hazards, data quantity, quality and validation was declared as a pre-requisite for accuracy when applying cost methods and further on for making better decisions. However, even when data is available and accurate it is difficult to comprehensively estimate all types of costs. Regarding the issue of communication, the EU's role becomes more important in enhancing collaboration among relevant projects, in fostering communication with the end-users, and in ensuring the projects' continuation through follow-up projects. Methods in this case are mainly used to estimate losses of assets, but more emphasis should be given to estimating losses in other categories (e.g. companies and infrastructure). The WP8 (costs of Alpine hazards) critical statement highlighted the need for high-quality national databases, which are closely linked and the need for collaboration between insurance companies and researchers.

3.11 Key Recommendations

Based on the discussion sessions and the prioritisation of topics on the synthesis conference, as well on an internal discussion and prioritisation of recommendations it was possible to extract some key recommendations (see box on the next page).

CONHAZ - Key Recommendations

- Cost assessments are often incomplete and biased. In order to receive a complete picture of the costs of natural hazards, not only direct costs but also costs due to business interruption, indirect and intangible/non-market costs as well as the costs of risk mitigation should be considered.
- Although considerable improvements have been made over the last decades there are still high uncertainties in all parts of cost assessment, related to, among others, insufficient or aggregated data sources, or lack of appropriate models. In any appraisal it is therefore important to identify the main sources of uncertainty at an early stage and try to reduce or handle them. Remaining uncertainties in cost estimates should be documented and communicated to decision makers.
- One of the main sources of uncertainty in the ex ante estimation of the costs of natural hazards is the lack of sufficient data. A framework for supporting data collection should be established on the European level, both for object-specific ex post damage data (event analysis) and risk mitigation costs. Such a framework should ensure minimum data quality standards to facilitate the development and consistency of European and national databases.
- In general, there is a need for a better understanding of the damaging processes to model them appropriately.
    - Regarding direct damages multi-parameter damage models are needed that better capture the variety of damage influencing parameters, also considering resistance parameters.
    - With regard to indirect costs more research is needed to understand and to model how markets function outside equilibrium, in particular the dynamics of return to equilibrium after a hazardous event, the associated social and institutional interactions and how agent expectations are formed in situations of high uncertainty.
    - For intangibles costs more research is needed especially on the *physical* impacts of natural hazards on environment and health.
    - With regard to the costs of risk mitigation special emphasis should be given to a better estimation of the costs of non-structural measures.
- More research is needed on the effects of climate and socio-economic change on the future costs of natural hazards and costs from adaptation to these changes and how such findings can be integrated in the cost assessment approaches. In this respect, the exchange of knowledge between the natural hazard risk community and the climate change community should be improved.
- There is a need for appropriate tools and guidance as well as knowledge transfer to support decision makers with integrating cost assessment figures into their decision making process. Such tools or frameworks should communicate and consider uncertainties in cost figures and ensure the transparency of the decision rules.

4 A vision: The future of cost assessments of natural hazards

Losses caused by natural hazards frequently initiate discussions on how to better manage and reduce risks in the future. Due to limited budgets and increasing risks, economic assessments of the costs of natural hazards as well as of the costs and benefits of mitigation measures are becoming increasingly important for decision makers to support their choice of appropriate risk mitigation measures, their prioritisation and efficient combination.

Based on the compilation and synthesis of currently available and applied methods for cost assessments of natural hazard risks (see section 2), and especially the identified knowledge gaps and recommendations described in section 3, this section outlines the vision of the CONHAZ project for a cost assessment integrated into risk management. “Vision” in this context means that it is not our intention to develop and describe a cost assessment and risk management framework in detail. Instead, it includes an outline of what cost assessment could look like in Europe in about ten or fifteen years from now considering the various recommendations given in the previous section as well as in different CONHAZ reports. This vision particularly emphasises the following aspects:

- Integrated cost assessment aims at accounting for the various stakeholders that can play a role in risk management, e.g. governments, individuals, enterprises, as well as their views and context that, in turn, influence cost assessment.
- It furthermore aims at including all relevant types of costs, i.e. direct cost, costs due to business interruption, indirect costs, non-market/intangible costs, but also the costs of various measures and combinations of risk mitigation.
- Cost assessments should also consider all costs occurring in the different phases of the risk management cycle, i.e. costs that occur during or immediately after an event (direct tangible or intangible damages, losses due to business interruption, emergency management cost), costs occurring in the reconstruction and recovery phase (depending on the system’s response, these long-term costs may be different from the costs of reconstructing damages) and costs of planning and implementing risk prevention measures.
- Cost assessments usually provide a basis for decisions on risk mitigation measures before potential events happen (ex ante cost assessments). However, cost assessments should also be carried out in the aftermath of an event or after the implementation of risk mitigation measures to quantify actual damages and mitigation costs (ex post cost assessments). In this context, cost assessment should be integrated into the risk management cycle, through both ex ante and ex post analyses.
- The latter is particularly important for the improvement of data sources and data availability, which is regarded by experts as a crucial step for reducing uncertainties in cost estimates (see section 3.10 on conference results).
- In this way, improved data is expected to lead to a better understanding of the processes causing damages and costs, and hence to a validation and improvement of ex ante cost assessment methods for the different cost categories.
- Special emphasis should be given to the possibility of combining various methods to estimate costs in different sectors of the economy, for different hazards and their combined effects, and for different types of costs.

- A cost assessment framework should consider the various uncertainties related to cost assessments and make them explicit and transparent to the decision makers.
- Furthermore, the framework should account for the dynamics of risk drivers and their potential influence on the future costs of natural hazards.
- Finally, cost estimates and their related uncertainties should be integrated in appropriate decision support frameworks that allow decision makers and stakeholders to make more informed and better decisions.

The objective of this vision is to outline a cost assessment framework that can be applied by different actors in risk management for their specific aims (context-specific and applicable), which includes all relevant cost types (comprehensive), considers and communicates uncertainties in an appropriate way (transparent) and accounts for changing hazards and risks (considers dynamics). In the following, basic steps of a framework which would integrate these guiding principles are proposed and outlined (also see Figure 3).

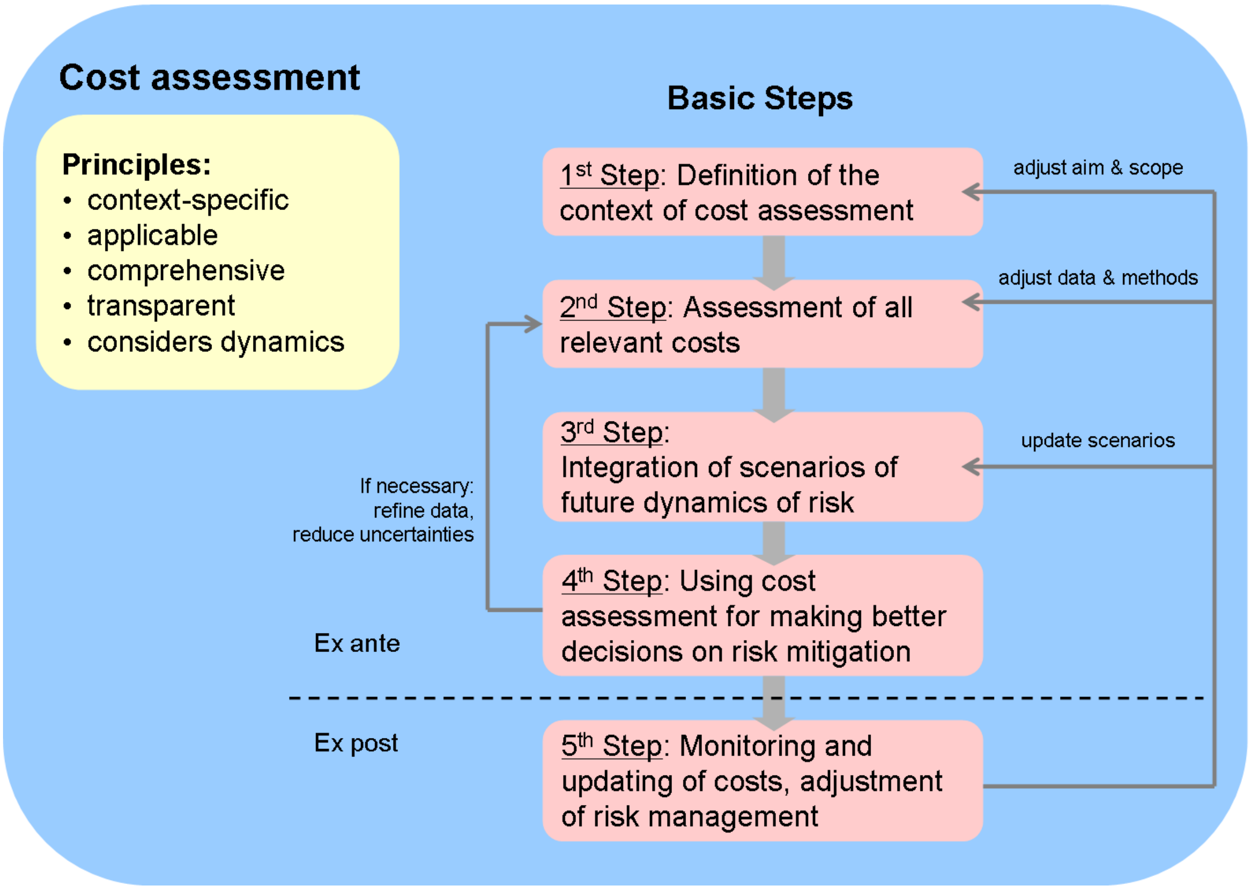

Figure 3: Cost assessment framework: guiding principles and basic steps

Step 1: Definition of the context of cost assessment

- Cost assessments are always purpose-related. Consequently, the aim and scope of the assessment are defined first. This includes the system boundaries and relevant hazard(s) to be considered.
- Socio-economic aspects which may influence the system's recovery or response after a hazardous event are also taken into account.

- Based on these aspects the appropriate spatial scale and time horizon are determined.
- Taking preliminary assessments or expert judgements as a starting point, relevant cost categories are defined. “Relevant” means that there is a) a considerable impact expected for these cost categories and b) that these cost categories could make a difference when evaluating alternative risk mitigation options. Relevant cost categories can be of any cost type, i.e. direct cost, costs due to business interruption, indirect costs, non-market/intangible costs, but also the costs of risk mitigation.
- Together with stakeholders potential strategies and measures, which may help to reduce natural hazards’ risks, are identified and pre-selected. This also includes the discussion about potential target levels of risk or risks which are considered unacceptable (even if costs for mitigating these risk are very high). Defining these constraints is an important social discourse of defining system boundaries for cost assessments.

Step 2: Assessment of all relevant costs

- Costs are assessed for all relevant cost categories identified in step 1. Appropriate methods can be identified and selected from a toolbox which provides an overview of existing methods for assessing different cost types along with their specific properties and potential fields of application. Table 2 in the Annex provides an overview of the best practice approaches currently being used for floods, droughts, coastal hazards and Alpine hazards.
- For intangible/non-market costs decision makers have to decide if it is necessary or helpful to include them in monetary terms or if they wish to consider them in a non-monetary or even qualitative way. This decision has to be reflected in the choice of the decision support framework used in step 4.
- In order to ensure comprehensiveness, it is important to not only evaluate the shock to the system (i.e. the immediate impact of the event on the economy), but also the long-term welfare effects, that are based on the ability and path of the system to recover from and respond to the shock. Considering different scenarios of recovery, their effects on the growth trajectory of the system and hence their opportunity costs are also relevant for estimating total costs.
- The toolbox further provides guidance on how to combine methods (e.g. for different impacted sectors, for different hazards and combinations of hazards, and for different cost types). This also contributes to achieving comprehensiveness of the cost assessment, but also prevents double-counting.
- Additionally, the toolbox contains information on the data requirements of the chosen methods and provides a link to potential databases or to the required data collection approaches in the case that no secondary data sources are available. A meta-database, linked to the toolbox, provides information on existing databases relevant for cost assessment of natural hazards, such as for example ex post damage data, mitigation costs, land-use and asset value data, and Input-Output tables.
- For all measures selected in step 1 (including a baseline scenario) costs are assessed for a range of different hazard scenarios with different intensities and different probabilities of occurrence. Including cost estimates under various scenarios enables a proper estimate of the shape of a loss-probability curve, ranging from frequent, high probability events to extreme, low probability events. Based on this, the potential variety of costs can

be outlined and the expected annual average costs can be estimated. Scenarios assuming the failure of risk mitigation measures are also included to consider the risk of failure.

- Natural and epistemic uncertainties in cost estimates are made transparent in the results and are communicated to the decision makers. While natural uncertainty stems from the variability of the underlying stochastic process and cannot be reduced, epistemic uncertainty results from incomplete knowledge about the process under study, e.g. from aggregated input data or model uncertainties. The latter can be at least partly reduced by improving the database and the models.

Step 3: Integration of scenarios of future dynamics of risk

- Natural hazard risk is essentially dynamic depending on climate variability and change, as well as on changes of vulnerability patterns. In order to account for this, dynamic scenarios for the future development of major risk drivers are developed and included in the cost assessment as described in step 2.
- Stakeholders should be involved in all the stages of developing such scenarios to ensure a realistic and deliberately democratic representation of the evolution of risk drivers. Potential or likely changes in the cost estimates based on these scenarios are described and their influence on the evaluation of risk mitigation measures is depicted (step 4).
- Uncertainties pertinent to the dynamic scenarios should be clearly communicated. If necessary, a sensitivity analysis could study alternative dynamic scenarios and their implications for hazard impacts and mitigation policies.

Step 4: Using cost assessment for making better decisions on risk mitigation

- The aim of cost assessment is to support decision makers in selecting alternative risk mitigation options by providing them with informed and well-reasoned arguments. Cost estimates are therefore integrated in decision support frameworks (as, for example CBA or MCA), which help the decision makers to evaluate the different risk mitigation options.
- It is made transparent to the decision makers of how the choice between different decision support frameworks, their associated decision rules or the selection and weighting of evaluation criteria influences the outcome of the evaluation and the ranking of options.
- Uncertainties in the results are explicitly communicated to the decision makers and guidance is provided on how to interpret or use this uncertain information. If decision makers feel that more detailed or precise cost figures are needed for making a decision, more efforts on data collection and modelling is required for the pre-selected options to reduce the most important sources of epistemic uncertainty (see step 2).
- Other criteria, such as robustness (performance of an option with regard to different risk development scenarios) and flexibility (ability to adjust an option according to future risk developments), are also considered in the evaluation of risk mitigation options to show their ability in dealing with different development scenarios.

Step 5: Monitoring and updating costs and adjusting risk management

- Actual losses caused by natural hazards and real expenditures for risk reduction are frequently monitored. Such ex post evaluations of object-specific damages or risk mitigation costs are entered into databases and are utilized to update, improve, validate and adjust cost assessment models (see also recommendations in section 3.5) and, hence, cost estimates (see step 2).

- Furthermore, new or updated information on the expected development of major risk drivers is used to update cost estimates (see step 3).
- Regular checks confirm if such new insights or other developments lead to necessary adjustments in the decision context of risk management (see step 1: aim, scope, scale of the assessment).
- Updated cost estimates are used for a new evaluation of risk mitigation options (step 4). If necessary, decisions are revised or chosen risk mitigation options are adjusted (if possible, see “flexibility” in step 4).

The presented integrated cost assessment framework relates to a better decision making in natural hazard risk management. This can be understood as a starting point towards a more long-term perspective that emphasizes the integration of cost assessment into a wider sustainable development (SD) framework. Furthermore, it is a step towards a more iterative understanding of decision making which focuses on learning and revision, and at the same time allows for but also requires stakeholder engagement.

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Abbreviations and Acronyms

BCR	Benefit- Cost Ratio
BT	Benefit-Transfer
CBA	Cost-Benefit Analysis
CE	Choice Experiments
CEA	Cost-Effectiveness Analysis
CGE	Computable General Equilibrium
CM	Choice Modelling
COI	Cost of Illness
CONHAZ	Costs of Natural Hazards
CV	Contingent Valuation
GDP	Gross Domestic Product
HP	Hedonic Pricing
IO	Input-Output
LEPC	Loss/Exceedance Probability Curves
LSA	Life Satisfaction Analysis
MCA	Multi-Criteria Analysis
NPV	Net Present Value
PFA	Production Function Approach
PML	Probable Maximum Loss
TC	Travel Cost
WTP	Willingness to pay
WTA	Willingness to accept
O&M	Operation and maintenance
VSL	Value of Statistical Life
WLCC	Whole Life Cycle Costing

Annex

Table 2: Overview of methods, applications and examples per cost type for damage costs and mitigation costs[9]

Cost type	General method	Specific method (using specific parameters, hazard-specific)	Application a/o Examples
Direct costs	Susceptibility function	Single-parameter models (based on single hazard impact parameter)	Floods: Model of ICPR (2001); Model of MURL (2000), adopted by Glade (2003); Model of Hydrotec (Emschergenossenschaft and Hydrotec 2004)
			Droughts: Corti et al. (2009)
			Alpine hazards: Fuchs et al. (2007), Huttenlau et al. (2010), Totschnig et al. (2010)
		Multi-parameter models (based on several hazard impact and /or resistance parameters)	Floods: HAZUS-MH (FEMA 2011, Scawthorn et al. 2006); FLEMOps and FLEMOcs models (Apel et al. 2009, Elmer et al. 2010, Kreibich et al. 2010a, Thieken et al. 2008); Model of Multicoloured Manual (Penning-Rowsell et al. 2005); HIS-SSM (Kok et al. 2005); Model of Maiwald and Schwarz (2010)
			Coastal hazards: FEMA (2011); HIS-SSM (Kok et al., 2005); Nadal and Zapata (2010)
			Alpine hazards: BUWAL (1999a,b), Keiler et al. (2006)
	Event analysis	Comparison hazard and non-hazard time periods based on reported cost figures	Benson and Clay (1998), COPA-COGECA, (2003), Fink et al. (2004), Martin-Ortega and Markandya (2009), Rijkswaterstaat (2004)
	Integrated Assessment Analysis	Biophysical-Agroeconomic Models	Holden and Shiferaw (2004)
	CGE Analysis	CGE Models	Horridge et al. (2005)
Costs due to business interruption	Susceptibility function	Losses to economic flows	Booysen et al. (1999), Parker et al. (1987); HAZUS-MH (FEMA 2011); Model of MURL (2000); Model of Hydrotec (Emschergenossenschaft and Hydrotec 2004);
		Percentage/share of direct damages	ANUFLOOD (NR&M 2002); RAM (NRE 2000)
	Event analysis	Comparison hazard and non-hazard time periods based on reported cost figures	Benson and Clay (1998), COPA-COGECA, (2003), Fink et al. (2004), Martin-Ortega and Markandya (2009), Rijkswaterstaat (2004)
	CGE Analysis	CGE Models	Horridge et al. (2005)
	Integrated Assessment Analysis	Biophysical-Agroeconomic Models	Holden and Shiferaw (2004)

[9] The overview presents available methods for the assessment of damage costs and risk mitigation costs. The general methods are specified further and when applicable, examples or their application are provided based on the assessments of the CONHAZ project.

Cost type	General method	Specific method (using specific parameters, hazard-specific)	Application a/o Examples
Indirect costs	Event analysis	Surveys	Firm-level: Boarnet (1998), Kroll et al. (1991), Tierney (1997)
	Gross domestic product effect assessment		Alabala-Bertrand (1993), Cavallo and Noy (2009), Hochrainer (2009), Jaramillo (2009), Noy (2009), Loayza et al. (2009), Noy and Nualsri (2007), Raddatz (2009), Skidmore and Toya (2002)
	Gross regional/local product effect assessment		Noy and Vu (2009), Strobl (2008)
	Input-Output Analysis	I/O Models	HAZUS-E (see also McCarty and Smith 2005); Haimes and Jiang (2001), Haimes et al. (2005), Okuyama (2004), Rose and Liao (2005), Rose and Miernyk (1989)
	CGE Analysis	CGE Models	Horridge et al. (2005), Rose et al. (2007)
	Hybrid Analysis	Hybrid Regional I/O CGE Models	Hallegatte (2008)
		Hybrid I/O CGE Model	TERM Model (Horridge et al. 2005)
	Idealized Analysis	Idealized Models	Hallegatte and Dumas (2008), Hallegatte and Ghil (2008)
	Integrated Assessment Analysis	Biophysical-Agroeconomic Models	Holden and Shiferaw (2004)
		Coupled Hydrological-Economic Models	Booker (1995), Grossmann et al. (2011)
	Public finance coping capacity Analysis	Public finance model	IIASA CATSIM model (Mechler et al. 2006)
Intangible effects	Revealed preferences methods	Travel Cost (TC) method	Hartje et al. (2001)
		Hedonic Pricing (HP) method	Hamilton M.J. (2007), US Army Corps of Engineers (1998)
		Cost of Illness (COI) approach	DEFRA (2007)
		Replacement Cost (RC) method	Leschine et al. (1997)
		Production Function Approach (PFA)	n.a.
	Stated preferences methods	Contingent Valuation (CV) method	Birol et al. (2006), Daun and Clark (2000), DEFRA (2004), Leiter and Pruckner (2007), Pattanayak and Kramer (2001), Turner et al. (1993), Zhai and Ikeda (2006), Zhongmin et al. (2003)
		Choice Modelling (CM) method	Brouwer and Schaafsma (2009), Daun and Clark (2000), Hensher et al. (2006), Olschewski et al. 2011
		Life Satisfaction Analysis (LSA)	Carroll et al. (2009)
	Benefit or Value Transfer methods (BT/VT)		Martin-Ortega and Markandya (2009)