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The economic appraisal of adaptation investments under uncertainties: Policy recommendations, lessons learnt and guidance

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Executive Summary

Adaptation to climate change receives little if any attention during the phase of planning and appraisal of investments into infrastructure at the Member State and European level. Recently, efforts have been made to assist project planners with incorporating considerations of adaptation into their workflow, but no guidelines yet address adaptation projects in their own right.

Because adaptation projects face specific challenges, such as the necessity of dealing with large uncertainties, we endeavoured in this Deliverable of ECONADAPT to fill this gap and produce guidelines tailored to the appraisal of adaptation projects.

To enable the identification of the key steps and challenges in the appraisal, we conducted two case studies, appraising adaptation projects in the Vltava river, Czech Republic, and in Bilbao, Spain. From these we distilled the lessons learned into the guidelines here presented, which aim to address practitioners, and are therefore as straightforward and free of technical jargon as possible.

The guidelines are structured in 22 steps for the practitioner to follow, divided in the areas of: context analysis; hazard assessment; impact assessment; adaptation; economic assessment; and decision-making with consideration of stakeholders.

Each step is explained in a small section of typically half to two pages, containing: a brief overview of the problem; a display of the methods available to tackle it; a brief account of what was done in the ECONADAPT case studies, and what can be learned from them; recommendations about good practices.

In addition, we have compiled summary tables of the steps, aimed to provide: 1) an impression at a glance of all that needs to be accomplished in the adaptation appraisal; 2) a schematic map with the minimal amount of information that the practitioner should keep in mind at any moment.

Main finding 1: the appraisal, and wider evaluation and of the possible options for adaptation is by its own nature a comprehensive and multidisciplinary exercise. The practitioner should count on (access to) a range of expertise to carry out the exercise.

Main finding 2: it is possible to summarize the essential aspects of the appraisal in a set of steps that should be carefully considered and at least inspire the practice.

Future research could focus on the needs to tailor these guidelines in different contexts in Europe and elsewhere, to comply with the needs of local practitioners and circumstances. Especially, it would be very instructive to assess how frequently-adopted “light-touch” approaches to appraisals compare, in terms of their accurateness, to the more extensive practices recommended in our guidelines.

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1 Introduction

In Work Package 6 of ECONADAPT two case studies have been carried out, consisting of the appraisal of investments into large scale infrastructure that are related to climate change adaptation. These investments are projects for the reduction of impacts of flooding, in the present and with future increased impacts due to climate change, in the Vltava river basin (Prague, Czech Republic), and Bilbao (Spain). Besides representing advancements in the local and specific knowledge, the two case studies also allowed us to explore the challenges inherent to such appraisals, characterized by vast uncertainties of different sources.

In Deliverables 6.1, 6.2, and 6.3, we have presented the case studies context, the methods of appraisal, and the results, respectively. The present Deliverable 6.4 uses the previous documents as a starting point, and distils the lesson learnt in the two case studies to provide a set of general guidelines to the adaptation appraisal practitioner. The reasons for carrying out appraisals of investment are, first of all, to assess its net social benefits (whether the benefits outweigh the costs), and second, for the very pragmatic reason that it is often required by local or national law or regulations, or by the EU if the EU is co-funder of the investment.

Guidelines such as those proposed here have wide applications, in the contexts of infrastructure planning, strategic and regional development, risk management, etc., and have previously been advocated by organizations such as the United Nations International Strategy for Disaster Reduction (UNISDR), and the European Financing Institutions Working Group on Adaptation to Climate Change (EUFIWACC).

Previous efforts in this direction include the “Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient” (EC, 2011), focused on implementing climate resilience considerations into physical project developments. More recently, guidelines to adaptation projects have been proposed with special focus on the challenges of “assessing attribution, establishing baselines and targets, and dealing with long time horizons”, and stressing the importance of learning from case studies (Dinshaw et al., 2014). Also, the EUFIWACC (2016) has started to compile recommendations for project planning incorporating awareness of climate change, learning from experience gained in case studies.

In contrast with these efforts, where climate change and the need for adaptation are rather seen as complementary steps in wider project assessments, we here place the adaptation practice under the spotlight. In particular, we are interested in mapping out an effective and accessible workflow to evaluate the adaptation merits of investments in infrastructure with long lifetime. The outcome of such appraisals can be: 1) the verdict on whether to invest in the given project; or 2) a choice between a range of adaptation options; or 3) a decision not to decide yet, for example because uncertainties about future climatic outcomes are too large to handle.

For this reason, we dedicate special attention to the extra challenge posed by the large uncertainties inherent to the matter of climate change and of adaptation, and provide indications on how these can be addressed. While this is an aspect that still tends to be overlooked, both in practice and in the guidelines thus available, in recent years many new techniques have become available that can help address uncertainty when making decisions in adaptation (for a review see Watkiss et al., 2015). Uncertainty was the focal point of the appraisals carried out through the Vltava and Bilbao case studies in Deliverable 6.3, where some of these techniques where put to test. A considerable part of the following guidelines draws from this experience with the two cases, and from a vast range of expertise pooled within the consortium of ECONADAPT.

A further element of novelty of these guidelines are their step-by-step structure, tailored at enhancing the usability by the practitioner.

1.1 Aim and structure of this deliverable

The step-by-step structure adopted here reflects the appraisal practice. This grants the user/practitioner structured access to the guidelines, while explaining the reason for performing each step, and providing a clear overview of the amount and type of effort that is required for a correct investment appraisal.

The guidelines consist of a collection of methodological steps to be followed along the appraisal, organized in six topical sections. Chapter 2 synthesizes the experience acquired through the case studies and with the expertise of the ECONADAPT consortium, places it in the context of common practices, and aims to provide recommendations to the practitioner. Then chapter 3 presents very condensed tables of practical guidelines meant to facilitate appraisals of adaptation investments in a broad sense.

By following our guidelines, the practitioner will ensure that the appraisal is carried out in a manner that correctly considers all relevant problems that characterize the climate impacts and the adaptation matter, as emerging from the available range of expertise present in the ECONADAPT project. It is indeed not uncommon that appraisals of investments into long-term infrastructure does not include adequate handling of, for example, climate information of future scenarios, or applying a rational approach to discounting future values. Our guidelines aim to minimize the risk of incomplete or ill-formed appraisals that could deliver maladaptation or poor investment decisions.

2 Step-by-step recommendations – and lesson learnt from case studies

In this chapter, for each step of the appraisal, we present to the reader:

- a brief account of the state-of-the art practices, outlining which are the most common/plausible methodological choices;
- a recap on what we have done and achieved in the case studies, including the circumstances that have led to the decision;
- the pros and cons of our approach, and of other relevant existing approaches;
- recommendations of what should be done, based on the above. Here we include considerations as to: where are the main difficulties; what should an assessor be aware of; inter-model compatibility of inputs and outputs; feasibility of uncertainty assessment; handling datasets.

The guidelines are composed of 22 steps, divided into six topics of actions in the appraisal/assessment, corresponding to:

A. Context analysis;
B. Hazard assessment;
C. Impact assessment;
D. Adaptation;
E. Economic appraisal;
F. Decision-making with consideration of stakeholders.

2.1 Context analysis steps

Gathering a preliminary level of knowledge in a context analysis is essential to correctly aim the subsequent steps of the appraisal. Three layers of context need to be analyzed: Step A.1, the physical, Step A.2, the socio-economic, and Step A.3, the policy, institutional and stakeholder context. Once these steps are completed, it is highly important to adequately define the geographic and policy boundaries of the case. We have reported on this work for the two case studies of WP6 in Deliverable 6.1.

Step A.1: Characterize the physical context

Because the effects of climate change that filter into the socio-economy are first manifest in the physical system, the latter needs to be characterized. For the given area and the specific problem under analysis, it is important to examine:

- The main **geo-morphological, geographical and hydrographic features**. The relevant aspects need to be identified. For example, the **Vltava** case is centred on the impacts of floods on the city of Prague, situated in the hilly lower part of the Vltava river basin, surrounded by agriculture and natural forests. The area receives waters from the upper Vltava basin, where natural forests are more predominant. It is important to take note of the presence of an intensive system of electro-power dams along the river upstream of the study area. In the **Bilbao** case we assess flood risk in a new urban development in the Bilbao estuary, which is 15 km long and formed by the tidal part of the Nervión River. The river flows through the central parts of Bilbao creating a narrow valley with dense low-lying urban areas.
- The main **climatic features**. It is necessary to know the main climatic regime of the area: the annual hydrograph, from the instrumental and possibly for the pre-instrumental era (from documents). The **Vltava** site is characterized by mild European continental climate. The hydrological cycle is presently undergoing extremization, entailing that frequent intense convective precipitation in summer results in flash floods, and that hydrological and hydro-meteorological droughts are also more frequent. This is driven by the increasing temperature in the area, bringing about more uneven distribution of precipitation over the year. The **Bilbao** case area has a humid oceanic climate with moderate temperatures. The proximity of the sea and the complex topography strongly influence atmosphere dynamics in the city, generating mild winters and summers. The Atlantic coast of the Basque Country, and Bilbao in particular, is an area with high precipitation, mainly determined by orographic factors
- The main **hazard features**. The analyst needs to know which are the natural hazards that are likely to undergo shifts in their regime due to climate change. These can be river, pluvial and coastal floods, meteorological, agricultural and socioeconomic droughts, heat waves, or simply extreme temperatures and precipitation. The area of the **Vltava** case is characterized by frequent and intense flooding since at least the last 150 years, with three severe and highly damaging events afflicting the area at the turn of the millennium, the intensity of which may be partially attributed to recent climate change. Both hydrological extremes, floods and droughts, are projected to intensity along the rest of the century, which makes a strong case for the need of adaptation. The **Bilbao** area is also a flood-prone area, due a combination of high precipitation and steep orography, strong but also with high exposure, with most of its low-lying areas densely urbanised. The city was the scene for dramatic flood events, most notably that of 1983, when extreme precipitation coincided with river flooding and high tide.

Commonly, contact with the relevant university departments and research institutes facilitates the efficient collection of the necessary information. Alternatively, or to complement this, a number of web-based tools exist that can help in the characterization of some of this context information, at least at the regional scale. For example, ThinkHazard[1] is a new global tool that allows the user to get an immediate overview of the level of hazards of interest in specific region. For river floods, the Aqueduct Global Flood Analyzer[2] provides information on the present and future risk at the scale of the basin and the sub-country administrative unit.

Step A.2: Characterize the socio-economic context

Because natural hazards become problematic only when there are people and assets exposed to them, one needs to assess the main demographic and the economic traits of the area under study.

It is necessary to outline the boundaries of urban and rural areas, to map the main uses of the land (residential, industrial, infrastructure, agriculture, habitats, recreation, etc.), and to list the key economic activities which take place in the area, including their interactions among them and between them and the physical system. This work is also preparatory for Step C.2, where exposure data are collected. For the **Vltava** case, it was sufficient to revise the relevant economic and demographic features of the large and industrial city of Prague. For the **Bilbao** case, the district under scrutiny, and the adjacent areas up- and downstream, all of them either residential or industrial, were analysed.

Step A.3: Characterize the policy, institutional and stakeholder context

It is critical to the appraisal that a complete picture of the relevant stakeholders is formed: i.e. of all people and entities that are either affected by the natural hazard and its consequences, or are somehow involved in addressing them. Such picture will serve mainly three purposes: 1) including in the appraisal advantages/benefits and nuisances/costs incurred by all stakeholders; 2) making explicit mention, in the course of the appraisal, of who will incur which costs and who will reap which benefits: this is fundamental for a transparent decision process; 3) involve all stakeholders or their representatives in the formulation of the policy objectives for the adaptation investment, and in the decision-making process that will take place in the form, e.g., of stakeholder-oriented meetings (see Step F.1).

Failure to perform this step correctly may lead: 1) to gross miscalculations of the pros and cons of the adaptation investment, and/or 2) to the legitimacy of the investment being questioned at a political level. In the **Vltava** river upstream of and in Prague the set of stakeholders is vast, as floods have the potential to affect residents as well as companies that have their assets located in the floodplain; the main authorities concerning the planning of flood protection measures are the City Hall of Prague and the Vltava River Basin Management, a state enterprise. In **Bilbao** the list of stakeholder is more compact, and it involves private citizens, companies and institutions that own the land and assets in the district of interest and along the upstream and downstream river traits (gathered in a Management Commission), plus the Basque Water Agency and the Bilbao city council.

It is probably not essential here to emphasize the need to analyze the policy and institutional contexts, because in the framework of a project appraisal the practitioner will likely already be familiar with them. If this is not the case, the practitioner should make sure to collect this information, especially on which entities are in charge for action related to the management of natural hazards and to the reduction of disaster risk.

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[1] http://thinkhazard.org/

[2] http://floods.wri.org/#/

2.2 Hazard assessment steps

Step B.1: Scenarios and time horizons

It is essential that a selection is made of a range of possible future outcomes, both in terms of the physical-climatic world and of the socio-economic world.

Future climatic projections that have been adopted by the latest IPCC report (2013) follow the so-called Representative Concentration Pathways (RCPs; Moss et al., 2010), which correspond to different emission pathways, which consist of different intensities and timing of greenhouse gas emissions. From the most moderate to the most severe, the four emission scenarios focused on in the IPCC report are RCP2.6, RCP4.5, RCP6.0 and RCP8.5, where the numbers indicate the radiative forcing achieved by year 2100 in W/m^2. Note that before RCPs, the so-called SRES scenarios were commonly used (IPCC SRES, 2000), but new practice should opt for RCPs. For each of these emission scenarios, and therefore for each corresponding radiative forcing, many Global Climate Models (see Step B.2) are employed to calculate the evolution of climate variables, such as temperature, humidity and precipitation, for the rest of the century and beyond.

On the other hand, future socio-economics are accounted for by the so-called Shared Socioeconomic Pathways (SSPs; O'Neill et al., 2014). By employing SSPs, Integrated Assessment Models and other models calculate spatially resolved economic growth and demographics.

Even though RCPs and SSPs are decoupled, it is important in this step to ensure coherence in the chosen combination of climate/emission and socio-economic scenarios. Indeed a few matchings are implausible: for example it does not make sense to use climate data from the highest emission scenario RCP8.5 along with socio-economic data from the SSP1 or SSP4, in which strong emission reductions are realized. If there is no time to gather a minimum of information on the scenarios to decide on how to explore future developments, the following combinations can be applied (O'Neill et al., 2016), which reflect the range of future possibilities represented by RCPs and SSPs:

- RCP2.6 and SSP1: Successful sustainable technologies are implemented, strongly reducing emissions and leading to the mildest climate change scenario. Further, diffused development enables even capacity for adaptation.

- RCP8.5 and SSP5: No implementation of policies to address climate change results in high use of fossil fuels to meet growing energy demand, and the intense climate change unfolds. Further, development equality is low, and capacity for adaptation is locally highly limited.

In the **Bilbao** case study we employed climate datasets from RCP4.5 and RCP8.5. In the **Vltava** case, we selected the following combinations of scenarios: RCP2.6 and SSP1; RCP4.5 and SSP3; RCP8.5 and SSP5.

Regarding time horizons, the practitioner should consider that climate change is a gradual process. Generally, impacts will be proportional to the time horizon selected. But while for a more moderate climate change scenario (i.e., RCP2.6) the situation is expected to stabilize after a few decades, for the highest one (i.e., RCP8.5), impacts will increase for a longer time. To sample the evolution of climate change-driven processes, often the approach is taken of selecting at least two time horizons of focus: the short term (ca. somewhere between year 2030 and 2050) and the long term (ca. 2070 to 2100).

Two notions matter particularly when deciding whether to focus on short- or on long-term future in the assessment.

- Stakeholder perspective: On the one hand, focusing on the shorter term often seems more appealing to meet the horizon of interest of many stakeholders (e.g., investors, local and national governments). On the other hand, reasoning in terms of the end of the century (or beyond) may seem to make little sense to many stakeholders, but it can be absolutely necessary: 1) because some large structural investments, as in sea dikes, have notably long lifespans, that cover multiple human generations; 2) because long-term strategic reasoning can help avoid maladaptation, such as lock-in situations or regrettable decisions (see Step D.3 for a more detailed account of this aspect).

- Time-horizon and scenarios: For some slowly-unfolding impacts, like sea level rise, short time horizons entail small differences between climate change scenarios, hampering the comparison of impacts and therefore of adaptation between high- and low-emission scenarios. On the other hand, in the long term drastic differences in impacts between scenarios become evident and can be quantified. Also, this forms the basis for studies of primary importance in the climate change discourse, such as the comparison of the costs of adaptation versus the investments needed to mitigate emissions.

For the **Bilbao** case study we have explored long term climate change for the 30-year period 2071-2100, while for the **Vltava** case simulations have been carried out at 10-year time steps until year 2100.

Step B.2: Climate datasets

While global and large-scale evolution of climatic patterns is studied by means of Global Climate Models (GCMs), studies on regional to local scale are generally based either on statistical downscaling of GCM results, or on Regional Climate Models (RCMs). The latter incorporate boundary and forcing conditions from GCMs to which they are interfaced ("embedded"), and are run at higher spatial resolution, which enables more accurate representation of specific climate mechanisms, such as those due to complex local topography.

In order to be able to provide realistic estimates of the impacts of climate change, ensembles of climate model projections should be used. It is not possible to know in advance which regional simulation is most correct, both with respect to general amplitudes of climatic changes and with respect to regional details; furthermore, impacts and costs may depend non-linearly on the amplitude of the change.

In the **Vltava** case, daily data from 14 RCM simulations from the EURO-CORDEX ensemble (Jacob et al., 2014) were processed and delivered by the Danish Meteorological Institute for the RCP4.5 and RCP8.5 scenarios, together with a single simulation for RCP2.6, to test the sensitivity of the hydrological system, to a wider range of forcing scenarios.

In the **Bilbao** case, climate inputs were handled by the University of East Anglia. The output of 11 RCMs with a horizontal resolution of 12 km from the EURO-CORDEX ensemble for both RCP4.5 and RCP8.5 was processed. This selection was considered necessary due to limitations in the scope of the study, which are common in the context of such appraisals. The choice fell on HIRHAM, forced by the ECEARTH GCM. This model was deemed most representative of future projections in consideration of the proximity to the EURO-CORDEX ensemble mean, in terms of its output of rainfall extremes over the relevant region. All 11 model simulations are considered equally plausible, thus their average was used for the hydrological modelling (Step B.5). While all are consistent in projecting higher temperatures, the size of the change varies across models. The consistency across models is considerably lower for rainfall – with some indicating larger increases in winter rainfall and/or larger decreases in summer rainfall. This results in an inter-model mean change rather close to zero. It is necessary to conclude that neither selecting a single model nor using the ensemble mean is satisfactory in terms of reflecting climate model uncertainties. In such circumstance where it is not possible to run an impacts model many times, the spread of climate projections across the full ensemble should be considered when interpreting and communicating outcomes from the impact assessment.

Step B.3: Weather generators and Statistical Downscaling

In the European continent precipitation patterns and their extremes will shift, under changing climate, in opposite directions in the southern and northern regions (Vautard et al., 2014). Further, large variability must be considered also on the temporal dimension. It is thus important to not just include weather averages, but the full spectrum of inter- and intra-annual variability, to better grasp the entity of the extremes that can unfold (Sexton and Harris, 2015).

The input from GCMs or RCMs comes in the form of temperature and precipitation data averaged over a grid point that typically represent quite large portions of land, and integrated over at least a day. For some applications, it is necessary to obtain information at higher spatial resolution, to resolve weather at point locations, and/or to capture the full extent of weather extremes. For this, the two most common practices are statistical downscaling (e.g., Maraun et al., 2010) or using a weather generator to produce time series of climatic variables at temporal resolution of one day or higher. Both methods use observed statistical relationships to obtain local information from the spatial and temporal scales resolvable by a climate model. This means that any effect of climate change on such statistical relationships will not be included; however, these will frequently be the only way to obtain data in sufficiently high spatial and temporal resolution.

For the **Bilbao** case, projected climate changes from the nearest 12 km RCM grid box were applied to a locally-calibrated stochastic meteorological model developed by the relevant statutory authority. For the **Vltava** case, the advantage of using daily RCM outputs for a number of grid boxes covering the catchment was that the variables required to drive the hydrological model retained their physical consistency in terms of both spatial and temporal variability and therefore the application of downscaling or weather generator was not necessary.

At the end of this step, the practitioner should dispose of time series of precipitation and temperature (this variable is important to calculate evaporation in hydrological models) at sufficient spatial resolution for the domain of the study. These series can be fed to hydrological/hydraulic models, to then enable the hazard (e.g., flood or drought) modelling.

Step B.4: Sea level rise

While sea level rises globally, non-negligible differences exist in the rate and even in the sign of change depending on the region. When the characterization of the hazards in the case calls for consideration of sea level rise, it is necessary to consult region-specific projections of the possible range of future changes, for the selected RCP scenarios. This information will then need to be processed in Step B.5, when hazard maps are produced via hydrological/hydraulic modelling. The **Bilbao** case study is concerned with sea level rise, and we considered an increase of sea level at the river mouth of 50 cm and 70 cm, for the RCP 4.5 and RCP 8.5 scenarios, respectively, which hampers the outflow capacity of the river, implying higher water levels also upstream.

If the location is exposed to the effect of waves, it should be considered whether sea level rise may bring about changes in waviness, which in turn could influence the hazard characteristics. As the Nervión River mouth is not exposed, the effect of waves was considered negligible.

Step B.5: Producing hazard maps

The previous steps enable the preparation of maps of the concerned hazard(s) for the future. For the case of the flood hazard, this is typically done using hydrologic and/or hydraulic modelling, which takes as inputs precipitation and temperature from the previous steps, and produces 1) discharge rates for rivers, and 2) flood maps, containing the water levels and the extent of floods. A characterization of the hazard intensity on a map allows for the spatial analysis of the impacts.

It is essential that such maps be produced for floods of different magnitudes: small floods that are relatively frequent (with a short return period), and large floods that are relatively rare (with a long return period). This will allow the probabilistic estimation of flood risk, i.e. of the annual flood impacts, in the following Impact assessment Steps. A set of maps for 4-5 return periods is deemed adequate to this end (Ward et al., 2011).

Commonly, present, past and future modelled climate time series of a limited length are available, which doesn't allow to depict, for example, the 100-year flood, or larger ones. To extract values for extreme, rare events beyond the available observations, a curve is fitted to the probability distribution of the observed events, and values are therefore extrapolated for rarer events. Commonly used fits are the Gumbel distribution, and the Generalized Extreme Value distribution. This extrapolation inserts additional uncertainty into the assessment, which is larger for a lower quality of the fit. It is therefore advisable to not extrapolate values for events far beyond the plot area where the fit's quality is acceptable.

In the **Vltava case**, the changes in the flood extents of 5, 20, 50, 100, 250 and 500-year return period were estimated for the period 1970-2000, using a simplified approach based on predictions from a model relating (extreme) runoff to (extreme) precipitation, the under assumption that the relationship holds also under changed climate conditions.

In the **Bilbao case**, flood maps at return periods of 10-, 100-, and 500-year were produced with the HEC-RAS v4.1 model by the Basque Water Agency for ECONADAPT, under RCP 4.5 and 8.5, considering changes in precipitation, temperature and sea level.

2.3 Impact assessment steps

An efficient way to deal with the quantification of impacts, in the case of probabilistic phenomena such as the consequences of climate change (e.g., floods, heat waves), is to express them as changes in the risk faced. Risk can be conveniently schematized as a function of the *hazard* (characterized by intensity and probability of occurrence), the *exposure* of people and assets to the hazard, and the *vulnerability* of these people and assets to the hazard should it invest them (Kron, 2005). All of these three factors play a role in determining the risk, and addressing them in adaptation action is tantamount to addressing risk. For this reason it is essential that any risk assessment needs to quantify each of the three aspects to the best of the possibilities, to secure accuracy of the estimates.

Further, while likely impacts can be assessed based exclusively on historic datasets, it is very beneficial, to the ends of the adaptation appraisal to, to have access to a model that is able to simulate impacts. A model enables altering one or more of the risk components (hazard, exposure, vulnerability) to incorporate and to understand the effect (i.e., the risk reduction) of adaptation. We deal with adaptation in Section 2.4.

It is also important to consider that damages extend beyond the direct tangible harm to people and buildings, but more categories of damage exist: tangible and intangible, and direct and indirect (see Foudi et al., 2015). While intangible and indirect damages are often difficult to quantify (see Steps E.1 and E.2), it should be kept in mind that by quantifying only direct damage, the results may represent a significant underestimation.

Step C.1: Exposure datasets

Accounting for the people and assets that are located in the reach of the hazard is the second most important phase of the impact analysis. Outdated or inaccurate exposure maps drastically reduce the accuracy and therefore the value of any assessment. This step is based on the activity in Step A.2, where the socio-economic context was analysed. After the boundaries of the study area are defined, through performing Steps A.1 to A.3, the practitioner can aim the search for the exposure data. Because we are dealing with evolving impacts, exposure maps are needed to represent both the present configuration of people and assets, and future projections of it. To obtain exposure data for the future, an approach that is often taken is to correct data about current exposure of people and GDP, using available factors from future projections of socio-economic developments. These projections are built based on the narratives of the SSP scenarios of the IPCC (see Step B.1), and are nowadays available at coarse spatial resolution, and can be accessed at the IIASA website[3].

Often, exposure of assets can be adequately represented by maps of land use, which local authorities may have sketched also for the future.

For example, in the **Vltava case**, we used a land use map that differentiate between build land, agricultural land, roads, and water bodies. From the maps it is visible that a problem exacerbating flood risk is the widespread urbanization of flood-prone areas (Punčochář et al., 2012).

In the **Bilbao case**, the land use map used included residential properties, non-residential property, cultural heritage, and relevant infrastructural elements, such as bridges and dams. As in the previous case, exposure greatly determines flood risk as most of the urban and industrial development in the Bilbao Estuary is located in low-lying flood-prone areas.

Step C.2: Vulnerability information

Information about the vulnerability links the exposed people and assets to the hazard they may experience, and enables quantifying the damage suffered. Most often, vulnerability is represented in the so-called ”stage-damage” (or ”vulnerability”) functions, which report the proportion of damage for a given amount of hazard (de Moel and Aerts, 2011; see an example in Figure 1).

A global database of depth-damage curves has recently been developed, and can be used to find the most appropriate curve for the relevant region and assets/land-use (de Moel et al., 2016).

The practitioner will have to take care, in this step, of selecting from the literature stage-damage curves that are appropriate: 1) to each land use present in the available maps; and 2) to the context of the case (i.e., curves for high-rise buildings in Tokyo are likely inappropriate for residential buildings in Rome, and vice versa).

In the **Vltava** case stage-damage curves have been applied that have been produced for the Czech context, distinguishing between urban and rural built-up uses, between residential, industrial and agricultural uses.

In the **Bilbao** case we used the data of a study commissioned by the Bilbao City Council and developed by Oses et al. (2012). The study provides the damage curves before and after the opening of the Deusto canal.

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3 https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about

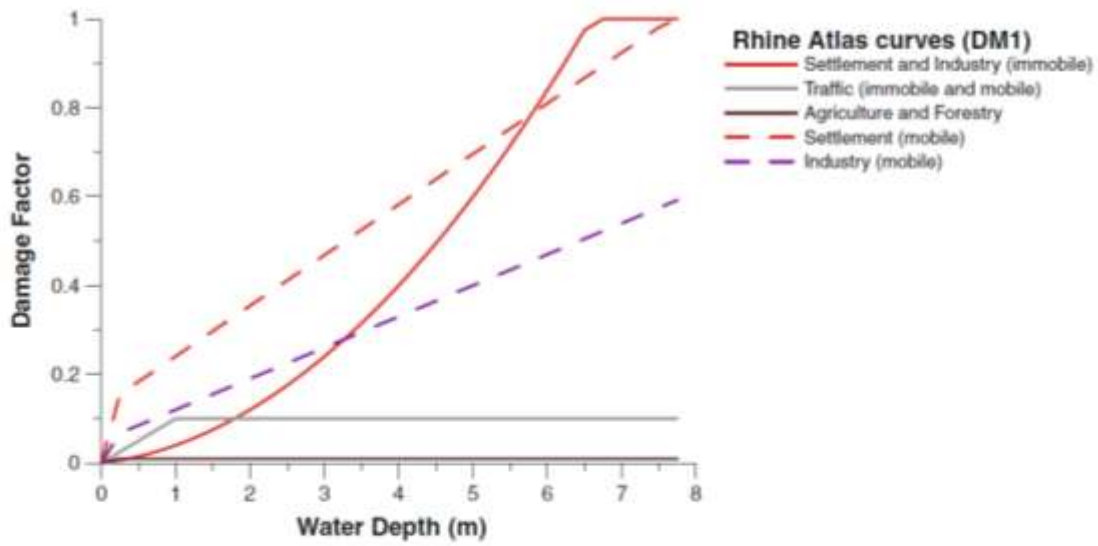

Figure 1. Example of stage-damage curves that are often used to represent vulnerability in impact assessments, from the Rhine Atlas (ICBR, 2001).

Step C.3: Impact modelling

Once hazard, exposure and vulnerability information are collected, the assessor needs to opt an existing model for use in the calculation of impacts, or set up a new one in case none are available or adequate. For the case of floods, a simple principle used in impact modelling is that employed by the Damagescanner model (as used, e.g., by de Moel and Aerts, 2011), which essentially calculates, per each map pixel/cell, the amount of damage to assets (buildings and their contents, and crops). It does so by taking into account the specific asset value per unit of surface for each land use, from the exposure maps; the proportion of that value that is lost to the specific flood height in that pixel, using the flood map and the relationship between water depth and % of damage from the vulnerability curves.

In the **Vltava** case the impact modelling includes damages to urban buildings (residential and non-residential), to infrastructure (roads), and to crops: the three land use classes that are more represented in the study area and for which location and damage functions are available.

In the **Bilbao** case, the impact modelling covered a large range of types of damage. Direct damage to residential and non–residential buildings, and to cultural heritage; and indirect and intangible damage due to aspects such as temporary accommodation, additional power needs, health, and foregone profits for enterprises.

2.4 Adaptation steps

If the appraisal refers to a specific adaptation project that is already defined, these steps will be skipped. If there is still scope in the planning of the adaptation measure, Steps D.1 to D.3 need to be followed.

Step D.1: Screening adaptation options

Once the climate-induced impacts are quantified, the practitioner has the chance to screen which options of adaptation appear, a priori, appropriate for reducing impacts in the case study. The impacts will then be simulated again, following the modelling framework adopted (Step C.3) with the inclusion of the selected adaptation measures. In this way, it will be possible to evaluate them.

Typically, the literature reports a large choice of adaptation measures that address the climate impact at stake, e.g.: drought. But each measure has features that make it more or less suitable to the given context. At this stage it is important to make use of the context analysis that has previously been carried out (Steps A.1 to A.3). Within ECONADAPT a simple spreadsheet tool has been set up that enables the screening of all available adaptation options, and filtering according to their characteristics (see Deliverable 6.2). Once the case context is clear, the practitioner can easily filter options in the spreadsheet and obtain a short list of measures that can be tested in the assessment. Another useful tool available to the practitioner is the free and user-friendly Climate App[4], that applies similar principles for the selection of adaptation options.

For our two case studies, we have included in the simulation adaptation measures that correspond to actual investments.

In the **Vltava case**, we evaluate ex-post the flood-adaptation measures that have been put in place from 1999 to 2014: line measures, such as earth dikes, reinforced concrete walls, mobile barriers, and backflow preventers in the waste-water system.

For the **Bilbao case**, we evaluate a measure that has been approved and will soon be implemented, the conversion of an extant Zorrotzaurre peninsula in the river's course into an island, modifying the topography of the river bed, to decrease flood peak height.

Step D.2: Including adaptation into the assessment

For this step it is necessary that the chosen modelling framework for the impact assessment is capable of simulate the inclusion of the adaptation measure(s) in the modelled system. The model will be then used to calculate impacts of climate-driven hazards both without and with the selected adaptation measure(s). Contrasting future outcomes under the two assumptions will then allow to evaluate the effectiveness of the measures.

In the **Vltava case** the modelled system incorporates an adaptation investment that has been in operation from year 2014 and the changes in the area exposed to risk after the implementation of the project are already known. The datasets used for the hydraulic and impact modelling therefore already include the recent adaptation.

In the **Bilbao case**, the model used considered an adaptation investment that consisted in opening a channel that turns the Zorrotzaurre peninsula into an island. The opening of the canal will lower water levels and therefore the flood prone area, not only in the new district and it surroundings, but also upstream.

In many cases, incorporation of adaptation in the modelling framework is rather straightforward, as in the case of the building of a dike (or a dam) to reduce river flooding to an urban area: in this case the most realistic solution is to alter the digital elevation model of the area (or the river discharge in the case of a dam), which is used for the hydraulic simulation, and rerun the simulation under the altered topographic conditions, to assess the difference in distribution of floodwaters and impacts. A simplified solution that can be applied in the case of small- to medium-scale dikes is to assume that a certain area is protected effectively by the dike against flooding of a certain return period, and simply subtract from the total damage calculation the portion corresponding to damages in that area (e.g., see Lasage et al. (2014) and their study on one central district of Ho Chi Minh City).

Still, it may often be unclear how the existing assessment model(s) can take into account adaptation, as in the case of so-called "soft" measures, like early-warning systems, or of increasing the copying capacity of residents through better training. The practitioner should

4 http://www.climateapp.nl/

therefore identify the steps in the modelling framework where the adaptation measure exerts its influence. According to time and resources, this influence should then be made explicit by means of a formula, a parameter, or similar.

Step D.3: Considering adaptation "pathways"

Adaptation measures are effective under some circumstances, while they lose part or all of their effectiveness past certain thresholds in the system. For example, a dam that is meant to protect the city downstream from river flooding will stop serving its purpose once precipitation and discharge in the basin, and thus water levels at the dam increase past some critical threshold, also called adaptation "tipping point" (e.g., Kwadijk et al., 2010). The moment when the tipping point is reached typically depends on the climate change scenario, and can be determined by modelling the system in multiple future time horizons. Because of large uncertainties related to future climate and to modelling limitations, the timing of tipping points is generally difficult to pinpoint.

At the tipping point the decision-maker will be faced with a constrained set of alternative adaptation options: e.g., raising the dam further, or alter the course of the river downstream. However, some options may at this point be precluded, such as, in the example of the dam, the possibility of managing the course of the river upstream of the dam. If no other option but the current can be adopted anymore, the current option is often called a"lock-in" option. The decision-maker needs to be very aware that decisions may lead to possible lock-in situations, when the choices of future generations are strongly limited.

Because of these constraints to the applicability of adaptation measures, long-term adaptation policy can be seen as unfolding in so-called "adaptation pathways" (Haasnoot et al., 2013). Recently Deltares has made publicly available a user-friendly software[5] that enables clear schematization of adaptation pathways (Figure 2).

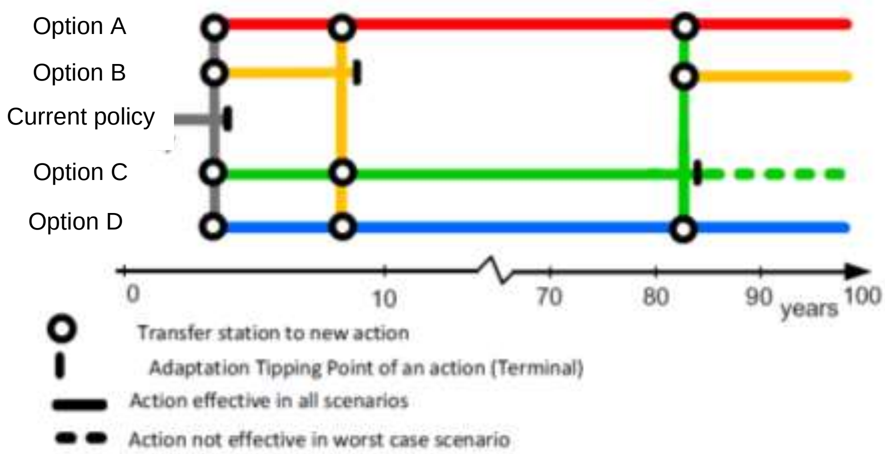

Figure 2. Example of adaptation pathways, showing how different adaptation options have different life-spans, and which are the other adaptation options available to the decision-maker once so-called adaptation "tipping points" are reached (modified from Kwakkel et al., 2015).

In the two case studies of WP6, one single future time horizon has been simulated, making it difficult to interpolate tipping points, and therefore to draw adaptation pathways.

5 https://publicwiki.deltares.nl/display/AP/Pathways+Generator

2.5 Economic assessment steps

Step E.1: Quantification of costs

The costs of adaptations should include different costing categories: the realization of the measure, i.e., capital costs, its maintenance, and any one-off/operational costs (e.g., due to the deployment of mobile flood barriers, or of rescue teams). These costing categories are relatively easy to quantify, but besides them, it is important that other negative effects that the adaptation measure might pose to society are also quantified as costs, even in the case these are not directly monetizable (see Step E.3). For example, these may include the loss of recreational use, or of habitat surface, or of landscape value that is typically associated with the building of a dyke or seawall.

Any costs occurring in the future need to be discounted (see Step E.5).

In the **Vltava** case, the total cost of 256 M € corresponds to the initial investment, i.e., the realization of the measures, to which maintenance, storage and operational costs have to be added, yearly amounting to 0.23-0.45 M €. Additionally, each flood event entails one-off costs of 0.34-0.7 M €.

In the **Bilbao** case, the realization of the Zorrotzaurre island will cost 12.1 M €, and no other cost categories are foreseen.

Step E.2: Quantification of benefits – Avoided damage

The quantification of damages avoided thanks to adaptation is the central step of the appraisal, as it provides a metric of how effective the adaptation investment is. The avoided damages constitute the benefits of the investment, which are to be compared to the costs. In contrast to the relative ease of calculation of the costs of adaptation (at least their direct and tangible share), accounting for its benefits is more challenging: while one single step in these guidelines is enough to account for costs (Step E.1), at least Steps from A.1 to D.2, and Steps E.2 and are required to produce an informed calculation of the benefits.

From the EU perspective, it is important to keep in mind that quantification of avoided damages can also provide a measure of how much adaptation succeeds in emancipating countries from the EU Solidarity Fund. For more on this aspect please see Section 4.6.

Generally, damages of natural disasters may be split into the categories tangible and intangible, and direct and indirect (based on Foudi et al., 2015) as outlined in Table 1. While in most assessments the scope is limited to the direct damages, it recently emerged that indirect economic damage can be as much as double the direct damage (Koks et al., 2015). Nevertheless, accounting for indirect damages requires information on the economic set-up of a domain much larger than the case study itself, and calls for a specific focus which may prove too challenging for typical project appraisals. Still, it may suffice, to the ends of the decision-making, to consider that any quantification of direct flood damage in all likelihood constitutes a considerable underestimation of the total economic disruption caused by floods.

In the **Vltava case**, we included damages to residential and non-residential property, damage to infrastructure, and loss of agricultural production.

In the **Bilbao case**, five categories of damages and impacts have been contemplated: 1) damages to residential property; 2) damages to non-residential property; 3) damages to cultural heritage; 4) impacts on human health; 5) disruption of transportation, increase in emergencies, and so-called ”second-round effects”.

Table 1. Categories of damage of natural disasters, following the example of floods.

Damage category	Direct	Indirect
Tangible	• damage to property, stocks, capital for production • damage to buildings - housing and commerce (including equipment) • damage to infrastructure (roads, underground services, irrigation systems, etc.) • damage on hydraulic structure and water management measures • damage to agriculture and livestock • cleaning costs	• disruption of the consumption of flows of goods and services (transport, supply of intermediate goods for production, supply of public services and electricity, water etc.)
Intangible	• loss of life • injuries • health • damage to cultural heritage • damage to ecosystems • recreation loss	• post-traumatic stress • trust in public interventions • modification of preferences • risk perception and acquisition of experience in flood prevention

Step E.3: Quantification of intangible/non-monetary benefits

It is important to consider that not all the effects of adaptation are tangible and/or evident in terms of monetary quantities. Examples of the effects of adaptation that elude easy monetization are: effects on health and on lives saved, on ecosystems' tangible and intangible services, on recreational and aesthetic value of the landscape. While efforts can be made to assign monetary value to such effects, such as on natural resources (Fenichel and Abbott, 2014), it can be argued that by lumping all effects into a single monetary metric, essential information is lost, impairing adequate understanding of the consequences of adaptation action and reducing the possibility of informed decision-making (e.g., Nassopoulos et al., 2012).

Non-monetary benefits and effects can be accounted for separately in a decision framework such as policy analysis with the use of scorecards (Walker, 2000) (see also Step F.1). In occasions, it is not possible, or there is not enough time and resources to produce a quantification of certain relevant effects, for example the impact on endangered migratory bird species when a reservoir for flood water is built. In these cases, it can be appropriate to resort to the so-called "expert judgment" practice, whereby experts in the matter are inquired to provide qualitative evaluation on the effect of adaptation, e.g., in form of pluses or minuses.

Other methodologies than Cost-Benefit Analysis (CBA) can be used to better consider non-monetary dimensions. Cost-Effectiveness Analysis (CEA) and Multi-Criteria Analysis in particular can help compare rank adaptation options including non-monetary metrics. For a description of CEA and Multi-Criteria Analysis see Step F.2.

In the **Vltava case** mostly direct and tangible impacts of flooding have been monetized and covered in the study.

In the **Bilbao case**, we have explicitly accounted, after conversion to monetary value, for indirect, intangible, and other non-monetary or non-easily-monetizable effects of flooding (from Oses et al., 2012), and therefore of flooding reduction by the implementation of adaptation. These included health effects (both physical and psychologic), forgone profit, temporary accommodation, disruption of rail traffic, etc.

Step E.4: Quantification of co-benefits

Often, well-planned adaptation measures bring about benefits beyond those relative to the reduction of the damage associated to the specific hazard that is tackled. It is therefore necessary to factor these co-benefits in the appraisal, along with the main planned benefits.

Typical co-benefits associated with flood adaptation measures are the recreational value generated by the building of a dam and a reservoir, and the potential production of hydroelectrical energy from the dam (even though this should be considered carefully, since for dams there is commonly a trade-off between flood protection and energy production, and thus a conflict of interest may arise).

In our case studies we did not foresee the emergence of co-benefits, and thus have not included this aspect in the economic appraisal.

Step E.5: Discounting of future values

Discounting future costs and benefits can have a large effect on the outcome of the appraisal, especially since investments into adaptation typically have long life span. A fervent debate on the issue has been going on, at least since the “Stern review on the Economics of Climate Change” (Stern, 2006), and goes on to the (for an overview see van den Bergh and Botzen, 2014). ECONADAPT has addressed the issue, especially with regard to the distant future (Deliverables 2.2 and 3.1).

In practical terms, in official guidance documents for CBA, there are now three different approaches to establishing a discount rate for long-term projects:

1. The official discount rate does not differ between short-term and long-term projects, but sensitivity analysis on the effect of the discount rate on the net present value is encouraged (e.g., EU guidelines, most national guidelines).
2. The official discount rate to be used for long-term projects is lower than the one used for short-term projects (US, China).
3. The official discount rate to be used for long-term projects has a declining term structure (UK, France, Norway).

The first perspective is the standard approach in CBA, and it is slowly giving way to the other approaches. The second perspective often comprises the normative element that it is considered ethically indefensible to discount the utility of future generations[6] and a positive element that has to do with the uncertainty of future consumption growth. This perspective has been taken in the **Vltava** case study, where in the sensitivity analysis the discount rate was based on the mean and variance of the growth rate of consumption from socio-economic scenarios compatible with the climate change scenarios used. This is therefore an example of scenario-consistent and uncertainty-adjusted discount rate.

The third perspective, the declining term structure, is gaining a consensus among academic economists (Gollier, 2012; Arrow et al., 2014; Groom, 2014), and governments have included schedules for declining discount rates in their official CBA guidance (UK, France, Norway, potentially US). Governments have adopted a step-wise decline in discount rate, where the first step commonly occurs after 30 to 40 years (Table 2). Applicability extends to time horizons that exceed the century.

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[6] The rate of discounting the utility of future generations is governed by the parameter ρ in the well-known Ramsey Formula: $\delta = \rho + \eta g$. The parameter ρ is also known as the pure rate of time preference. The value of the parameter ρ can be based on ethical considerations or on (market) observations on intertemporal trade-offs that people actually make.

Table 2. Declining social discount rate (%/year) term structures (for risk-free projects) in European countries. Source: Groom (2014) and national CBA guidelines.

Country	Year 1-30	Year 31-40	Year 41-75	Year 76-125	Year 126-200	Year 201-300
UK	3.5	3.0	3.0	2.5	2.0	1.5
Norway	2.5	2.5	2.0	2.0	2.0	2.0
France	4.0	2.0	2.0	2.0	2.0	2.0

Hence, there is growing professional interest in using different discount rates for long-term projects such as in adaptation. But simplicity in the approach should also be considered, as recommended by the Norwegian Committee (NMOF, 2012: p.77), that "*[…] we also need to take into consideration the decision structure within which this will be applied. [...] it may be preferable to recommend simple and transparent rules that capture the most important aspects of the matter, without being too complex to understand or to apply*."

In the **Vltava** case, four discounting approaches have been explored:

a) constant rate of 0 % is used as a baseline, and 4% is selected to reflect the common practice of in economic appraisals in the Czech Republic;

b) Ramsey formula with scenario-dependent discount rate;

c) expanded Ramsey formula with uncertain growth;

d) expanded Ramsey formula with RIRA. Also, two different sources of GDP projections are used (OECD, IIASA).

Indeed, the sensitivity study of this case shows that discounting is the factor with primary influence on the final economic assessment, and therefore on the decision-making.

In the **Bilbao** case, results are provided for a range of all plausible discount rates. The threshold between the investment and non-investment zones is then plotted in a multi-dimensional space that accounts for ranges in discount rates, in increases in future damage (due to climate and socio-economic changes), and in investment costs.

Our experiences with the ECONADAPT case studies suggest that alternative approaches to discounting of long-term adaption projects are certainly warranted, but also confirm the need for simple and transparent rules in common appraisal practice.

A further factor that should also be considered is that of attitude to risk. Specifically, a growing body of evidence suggests that discount rates should be adjusted to account for local risk aversion (Rieger et al., 2015). Deliverable 2.2 of ECONADAPT presents country-specific values that could be used. These have the effect of lowering the discount rate.

Step E.6: Incorporating future preferences

If adaptation options affect the future provision of ecosystem services, future preferences for these services constitute an additional source of uncertainty in the appraisal of adaptation options. Strong evidence has emerged that future generations will tend to be more sensitive about the environment ('greening' of preferences) leading to higher values of willingness-to-pay (WTP) for ecosystem services. Deterioration of environmental assets in combination with the depletion of natural resources constitute the main reason for this tendency. The evolution of WTP values for non-market ecosystem assets will be influenced mainly by the growth of income, depletion of environmental assets, elasticity of substitution between man-made and environmental goods and services and change in preferences of future generations.

So, for example, if an investment in public infrastructure is expected to protect a valuable habitat, now and in the future, ideally the future WTP for this protection, in terms of saved habitat, should be taken into account in the appraisal of this investment. In principle, the future WTP is unknown, but the Box 1 below discusses a practical approach to project future preferences and WTP, developed in Deliverable 2.2 of ECONADAPT.

Box 1: Assessing the future value of ecosystem services

Preferences for ecosystem services are measured by an individual's or household's or community's WTP for a marginal increase in the provision of that service (such as an increase in water quality in forested area). A relatively simple formula for computing the evolution of the value of WTP over time uses a simple growth factor α that is the sum of three independent factors: the income growth factor α_{inc}, the environmental depletion or scarcity factor α_{sc}, and an autonomous preference shift factor α_{pr}.

The income growth factor α_{inc} is the product of the projected annual income growth (*g*) over the considered period and the income elasticity of WTP (ω that measures by how much WTP changes given a rate of income growth): $\alpha_{inc} = \omega \cdot g$.

The scarcity factor α_{sc} is the product of the projected annual change in the provision of the ecosystem service (*q*) over the considered period and the demand elasticity of WTP (*λ*) that measures how much the WTP changes given a rate of change in the provision): $\alpha_{sc} = \lambda \cdot q$.

The preference shift factor α_{pr} should be based on scenario assumptions, for example differentiating scenarios where preferences shift towards "green" and where they shift towards more "materialistic".

Part of the data needed to compute future preferences are sometimes collected in other parts of the appraisal, such as projected income growth of the population concerned. Other parts may have to be estimated, such as the projected change in the provision of ecosystem services. The basic socio-economic scenarios on which the appraisal is based may give information on the preference shift factor. For the income elasticity and the demand elasticity of the WTP, Deliverable 2.2 provides a literature review with values of these elasticities that can be adopted in the appraisal. Further, it also presents an advanced approach for probabilistic simulations of future preferences.

In the **Vltava** case we considered only potential changes in future time preferences, not preferences about the environment itself.

In the **Bilbao** case we did not include consideration of future preferences.

2.6 Decision-making with consideration of stakeholders

It should be noted that decisions about adaptation investments need to be made in the broader context of sectoral and cross-sectoral development objectives. Therefore, climate risks are likely to be one of a number of different risks that will be considered by the decision-maker.

Step F.1: Economic decision-making tools

CBA and ROA

Once costs and benefits are quantified, including the relevant sources of uncertainty, it is necessary to synthesize them into an actionable, concise result using an economic assessment tool. In ECONADAPT, we applied CBA in the **Vltava** case and Real Option Analysis (ROA) in the **Bilbao** case study.

In short, CBA evaluates all costs and all benefits to society that are expected to occur over the lifetime of the project, and provides as a summary measure either the Net Present Value (NPV) or the Benefit/Cost ratio of the investment. If the NPV is positive or the Benefit/Cost ratio is greater than 1, the investment is worthwhile from an economic perspective.

In the adaptation context, ROA is a useful tool to determine the value of a long-term investment when the future is uncertain, and when there are options to adjust the investment in some ways when the future unfolds and the uncertainty dissolves. For example, ROA can guide the decision on when to invest, i.e., whether to invest now or to postpone the investment and reconsider the decision at a later point in time in the light of new information (Watkiss et al., 2015). For more detailed explanations, refer to ECONADAPT Deliverable 6.3 (section 1.3.4).

In the Bilbao ROA, we also illustrate an application of two well-known risk metrics, which are adequate in situations of uncertainty and are widely used in the field of finance regarding the probability of rare, adverse events. These are Value-at-Risk (VaR) and Expected Shortfall (ES). If we have an idea of the probability distribution of damages, the VaR measures the maximum value of damages that can occur at some pre-determined probability. VaR(95%), for example, measures the maximum damage that can occur in the 95% confidence interval of the damage distribution. For comparison, VaR(50%) is equal to the median damage. In other words, if the risk management objective is to have a level of protection that ensures, with 95% probability, that the economic damage will not exceed a given threshold, this amount of money is the VaR(95%). The ES is a related concept and measures the expected damage when the VaR is exceeded. Thus, the ES(95%) measures the expected damages in the worst part (100% - 95% = 5%) of the distribution of damages.

Step F.2: Comprehensive decision-making tools

Whilst established economic appraisal techniques, such as CBA and ROA, used in **Vltava** and **Bilbao** cases respectively, reflect the need for economic rationality in the investment decision, in some cases relevant aspects of the impacts of adaptation are either difficult to convert into monetary values (e.g., requiring Willingness-to-pay studies, or indirect approaches), or it is an explicit political choice not to convert these impacts into monetary values, to avoid taking a decision based on a single, economic metric (e.g., NSW Treasury, 2007). In this cases the practitioner will need to resort to techniques that go beyond the purely economic decision-making tools. We review the most appropriate techniques in the following.

To evaluate adaptation measures, their performance according to specific criteria has to be assessed, using adequate quantitative or qualitative indicators. The criteria need to reflect the policy objectives that have been pre-determined with the involvement of the relevant stakeholders, identified during Step A.3.

Once the impact assessment Steps C, the adaptation Steps D, and the economic appraisal Steps E are complete, the necessary information is available to support a comprehensive decision process. Affirmed decisional frameworks/tools that enable this are: cost-effectiveness analysis, multi-criteria analysis, policy analysis with scorecards (Walker, 2000), or multi-actor multi-criteria analysis (Macharis et al., 2012). Use of these frameworks should be concerted, and count on the involvement of as many relevant stakeholders as possible. In the following we provide brief guidance on the application of each of these tools.

Cost-effectiveness analysis (CEA)

CEA provides an assessment based on the identification of the least financially-costly adaptation option for achieving a single pre-defined policy target across a set of alternatives. CEA is used to compare and rank alternative options in terms of their financial cost per unit of benefit (effectiveness) delivered. Table 3 presents some example of metrics used in CEA.

Table 3: Examples of monetary and non-monetary metrics used for Cost Effectiveness Analysis of adaptation projects.

Policy area	Metrics used in CEA (and units)
Flooding (river and coastal)	Level of reduction of flood levels, damages or risk [cm, €, €/year, %] people in the risk zone [#] Extension of early warning period [% or hours] Increase people's awareness [ ] Land loss [km²]
Health	Disability Adjusted Life Years averted [€/DALY] Morbidity reduction range [%] Deaths through heat waves prevented [#] Reduction in disease incidence [# cases averted/year] Loss of life per decade [#/year]
Agriculture	Change in storage additions and withdrawals [%] Increased nutrient and water efficiency [€/ha and m^3/ha] Savings of decreased soil erosion [€/t] Decrease in labour costs and costs for machines [€/year] Increase carbon sequestration in soil [t humus/ha/year]
Water management	Area of floodplain restored [ha] Assets exposed [%] Organic compounds load reduction [kg/year]
Buildings and infrastructure	Saved Wealth [€] Effect on house price and the total value of property transactions [%] Assets exposed [€/year] Subsidence damage to buildings [€]
Biodiversity	Area of habitat/protected area created maintained/restored [ha, %] Area sustainably managed [ha] Species conserved/reintroduced [#]
Energy	Change in energy demand and associated CO_2 emissions [%] Energy output through hydropower: No and 50% reduction in effective glacier runoff [GWh] Energy demand for cooling [GWh]

The foremost advantage of CEA is that it does not require the economic, monetized evaluation of benefits. However, major limitations of the method are: i) the appraisal technique may guarantee that the selected measure is the most cost-effective in terms of financial costs but not necessarily the most efficient, in terms of delivering net economic benefits to society as a whole, as no economic costs or benefits are included in the analysis; ii) as only one indicator is typically considered in the appraisal, the method does not allow for the inclusion of co-benefits from single or combination of measures; and iii) although it is in principle possible, classic CEA does not explicitly deal with uncertainties and therefore have limited informative value and need to be interpreted carefully, in the context of uncertain climate change impacts.

Overall, CEA is most useful for near-term assessment of climate adaptation measures, particularly for identifying low- and no-regret options. In sum, it is advisable for the prioritisation of measures against one single, uncontroversial policy objective.

Multi-criteria analysis (MCA)

MCA establishes preferences between options by reference to an explicit set of objectives and for which is has established criteria to assess the extent to which the objectives are achieved. In contrast to CEA, where measures are assessed against one single criterion, in MCA several criteria are included to consider uncertainty or various elements of good adaptation, and the approach brings the flexibility to work with qualitative information, which is particularly useful given data gaps that are normally found in economic assessments of climate adaptation. Table 4 presents criteria typically used in MCA, focusing on those more relevant to adaptation. Furthermore, the capability of MCA to accommodate criteria pertaining to different socio-economic sectors makes it particularly suitable to reflect the cross-sectoral character of the adaptation practice. A disadvantage of MCA is that it requires that each criterion be assigned a weight, or that criteria are somehow assigned specific priority, in order to enable the final decision. This practice can give rise to disagreement between stakeholders.

Table 4: Indicators used in Multi Criteria Analysis as stated in the reviewed studies.

Indicator	Definition
Standard indicators in MCA	
Importance/effectiveness	Expected capacity for achieving target, with the aim of maximising effectiveness
Costs/financing	Costs involved in design and implementation, with the aim of minimising public and private spending
Co-benefits	Benefits additional to those targeted or primarily sought for, with the aim of maximising co-benefits. This often refers to the protection of environmental resources and biodiversity, but can encompass other types of co-benefits such as on health, cultural heritage, etc.
Time lag	Time to achieve full effectiveness, with the aim of minimising it
Implementation ease	Suitability of existing regulatory and institutional framework to facilitate implementation
Policy integration (synergies/conflicts)	Institutional coherence between measures and existing policy targets and incentives, with the aim of maximising use of the existing framework and contributing to multiple policies
Feasibility	Availability of data, knowledge and technical capacity to design and implement measures
Acceptance	Level of social and political support and acceptability
Public participation	Level of engagement with non-expert actors and the broader society, and level of integration of local/traditional knowledge with scientific knowledge
Private investment	Capacity to trigger investments from the private sector
Improve economic performance	Capacity to foster competitiveness and increase economic output
Employment	Capacity to create jobs
Spill over effects	Distribution of positive and negative impacts to other economic sectors
Distributional impacts	Distribution of positive and negative impacts to different actor group, including specific attention to vulnerable groups. This may include attention to impacts on poverty levels and inequality.
Fiscal sustainability	Capacity to contribute to fiscal sustainability through impacts on government revenues and expenditures
Additional indicators used in adaptation	
No-regret	Non-climate benefits exceed costs of implementation so that benefits are secured under all potential futures
Urgency	Need of implementing options immediately or possibility to defer implementation at later point in time
Climate mitigation potential	Capacity to induce a reduction in greenhouse gas emissions
Extreme events	Capacity to deal with extreme climatic events such as heat waves, high wind speed, floods, and droughts
Robustness	Capacity to maintain effectiveness under different climatic and socio-economic development scenarios

Scorecards

Another suitable means to clearly organize the outcomes of the appraisal are scorecards. These report results after a number of indicators (reflecting policy objectives and criteria), for all future scenarios considered (Fig. 3). They differ from Multi-Criteria Analysis mainly in that they do not require to assign weights to each criterion, a practice which arguably should be substituted by plenary stakeholder meetings. For this scope, stakeholder meetings should be organized, where the outcomes of the evaluation exercise are presented in a manner that ensures clear reception of the main results and critical points by all stakeholders. The scorecards are used in these contexts to enable transparent, explicit and concerted decision-making, and to prevent misunderstanding between stakeholders.

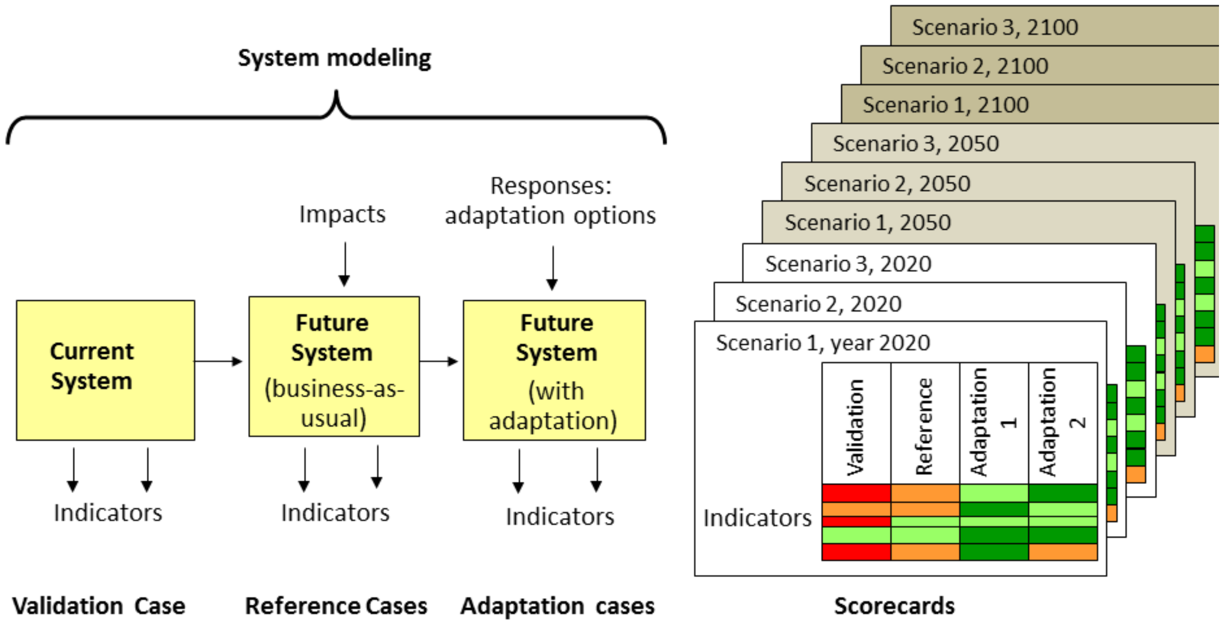

Figure 3. Conceptual functioning of the Scorecards framework (based on Walker, 2000) for the evaluation of adaptation options. Scorecards report the results of the adaptation assessment to stakeholders and decision-makers. (Figure adapted from Scussolini et al., 2014).

In the **Vltava** case exercise, the decision-making was based on CBA. We have endeavoured to go beyond classic deterministic CBA, and incorporated stochastic processes in considering factors that are subject to uncertainty.

For this case, the policy objectives are clearly defined, and consist in reducing flood risk in the area. Therefore the choice of adaptation was to build a system of flood protection structures that would protect the main built-up areas from the floods such as the largest that occurred in the past. The involvement of stakeholders in the decision-making process changed conspicuously during the realization of the project (1997-2014), from relatively autonomous decisions by the City Hall of Prague to a much more participatory practice that involved also the urban planning stakeholders.[7]

[7] The decision on the original version of the project in year 1997 was defined by the City Hall of Prague. In the first years of the flood protection project realization in Prague, the flood protection was subject only to one planning document - the Guide Water Management Plan from year 1975. The municipalities could relatively autonomously decide on the flood protection measures that they paid for themselves. After year 2000, new legislation came into operation, making the decision-making process more participatory - the following phases of the flood protection project in Prague had to comply with

In the **Bilbao** case, two main policy areas are involved: the urban design of Zorrotzaurre and flood protection. In the first area several agents are involved. In 2001 several public institutions and private entities created the Management Commission for the Urban Development of Zorrotzaurre. This deals with daily decisions regarding the urban development, while executive decisions are adopted within the Board of Directors, where the major property owners are represented. The members of the Management Commission own 65% of the land in Zorrotzaurre. Thus, the design of the new urban development has been carried out in close collaboration with land-owners, but excluded other types of stakeholders. In the second policy area, related to flood protection, the main stakeholder is the Basque Water Agency. The final adaptation measure of opening the Deusto canal was a mandatory condition of the Basque Water Agency during the approval procedure of the Urban Special Plan for Zorrotzaurre, and its main objective was to cope with the severe flood risk to which the area is currently subject.

Step F.3: Private role in adaptation decision-making

To date, much focus in the academic literature and in policy is on the role of the public sector (i.e., ministries, municipalities) in delivering adaptation action. Nevertheless, effective adaptation will necessarily be based on the involvement of a large range of non-public or "private" actors, including businesses, non-governmental organisations and citizens. Private actors can contribute to climate change adaptation in several ways. Private involvement can act as a driver for innovation and technological development, as well as for the diffusion of adaptation technologies and practices, for example through appropriate investment policies and the provision of consulting services. A more resilient private sector could also protect society from large-scale economic impacts of climate change. The timely delivery of food or other traded goods is an important dimension in a business operation in order to avoid loss of economic opportunities (e.g. temporary closure of facilities).

Guidance for exploring the role of private actors in adaptation was developed in ECONADAPT (see Rouillard et al., 2016). The guidance is based around three assessment questions for identifying, in a defined decision-making context, the potential for private actors to benefit from and deliver adaptation. These three assessment questions or steps are described below, with illustrations drawn from the two Vltava and Bilbao case studies, and are aimed to provide guidance to the practitioner.

1. The first step is to identify the scope for private provision of adaptation. This involves examining the benefits of adaptation to public and private actors. The key assumption is that the private provision of adaptation is preferable where there is a clear benefit to the private sector (see Table 5 for examples) or where private actors exacerbate vulnerabilities to climate change and thus have a responsibility in reducing impacts. We illustrate these ideas below using the case studies.

River basin plan of Vltava river and River Basin Management (Povodí Vltavy, state enterprise) had to include the anti-flood measures in the Action plan of the River basin plan of the Vltava river. The process from year 2002 on is more participatory (the River basin plan is approved by municipalities). The flood protection planning is also part of the urban planning process and the other stakeholders may also participate through this process....

2.

Table 5. Opportunities for adaptation in the private sector. Adapted from SCCIP (2010).

Type of risk	Description	Opportunities	Benefits
Production risks	Changes in type, quality and quantity of primary products (e.g. crop varieties)	Development of alternative supply sources (e.g. development of new crop variety)	Reducing risk of supply scarcity, responding to future regulatory changes, and securing competitive advantage
Logistical risks	Disruptions and damages to operations, transportation, infrastructure, and products (e.g. damages to rail network)	Redundancy and flexibility in supply chains and business operations (e.g. alternative trade routes)	Reducing losses during extreme events, enhancing trust in company, and attract investment
Demand risks	Change in consumer behaviour and regulatory requirements for more products increasing climate resilience	Developing products increasing climate resilience (e.g. improved insulation material)	Securing competitive advantage and reducing losses
Financial risks	Climate vulnerable investments, customer default, loss of value	Diversification of portfolio and activities (e.g. alternative income sources, investment in climate proofed projects)	Reducing vulnerability to future environmental and financial shocks
Human risks	Human health and safety	Good risk management	Enhancing reputation and attracting investment

In both case studies, proposed adaptation measures are expected to deliver public and private benefits. Avoided damages in the **Vltava** case include reduced flooding of residential infrastructure and production, and of cropland. In the **Bilbao** case they include reduced flooding of private property. In addition, a protected area is developed in Bilbao: a total of 390,000 m^2, divided in 208 urban plots owned by 59 different institutions, private entities and citizens.

Overall, measures proposed in both case studies offer benefits for the private sector in terms of reduced production risks (e.g. from loss of crops) and logistical risks (e.g. reducing losses due to traffic disruptions), and increased economic opportunities. The private sector could thus be stimulated to contribute to the implementation of flood protection measures, through e.g. financing, implementing measures, providing land, thereby reducing financial and logistical strain on the public sector. More generally, other adaptation measures with more emphasis in private involvement could have been considered in the two case studies, for example increased preparedness by households and businesses and adaptation to agricultural practices to reduce run-off in the fields.

3. The second step is to examine the scope of public involvement in fostering private participation. Private provision of adaptation should occur: when market failure is minimal; when private actors have good awareness of climate; when there is a clear private benefit in taking action; and when benefits materialise in the short term. The degree of public involvement in supporting private adaptation should depend on considering (i) how it helps maximise welfare of individuals and groups disproportionately impacted by climate change and by adaptation, or (ii) how it helps maximise public benefits (see Rouillard et al., 2016 for a longer discussion). Four types of public policy instruments are proposed to encourage private involvement (Table 6). More coercive types are warranted when public benefits of adaptation are stronger, while more informational and economic incentives may suffice when private benefits are stronger.

Table 6. Instruments and their means of involving private actors.

Policy instrument	Economic incentive	Non-monetary benefits	Altruism	Coercion
Awareness-raising		X	X	
Regulation				X
Public-private partnerships	X	X		
Subsidies	X	X		
Tariff, charge and tax	X			X
Trading	X	X		
Payment for Ecosystem services	X	X		
Insurance		X		

In the ECONADAPT case studies public bodies have taken forward the adaptation measures and have not sought strong private involvement. In the **Vltava** case the administration of Prague financed and delivered the proposed measures, as it is normally the case in the Czech Republic. In **Bilbao** public authorities financed and delivered the opening of the channel. However, some private involvement was realised: land raising was financed from five property owners of the district (who own 79% of the 1st Implementation Unit). They constituted a Contracting Board in charge of the development and financing of the works in Phase 1, including the elevation of the urbanization level. The budget for this earthmoving works is estimated at 2.3 M €.

4. The last step is the examination of the performance of proposed instruments against key factors (e.g., effectiveness, efficiency, distributional impact), and how can they be combined or sequenced in time. It is further recommended to develop, early on, an appropriate engagement strategy in order to explore and enhance private involvement in taking forward adaptation measures. This dimension was not explored in the ECONADAPT case studies.

3 Step-by-step summary tables

In this chapter we provide tables that condense the Steps presented in chapter 2. Here we stress on the aspects that we deem essential to a successful and correct appraisal of long-term infrastructural investments and in adaptation to climate change. The scopes are:

- to provide at a glance to the practitioner a schematic overview of all the Steps to be considered in the appraisal, to be kept in mind at any moment;
- to help the assessor determine in an early phase the requirements as to models, datasets and expertise that are needed to carry out the appraisal.

Because the practical contingencies in which appraisal studies take place often considerably constrain the scope of the study itself, with these table we intend to facilitate the decision by practitioner on which of our indications should be applied in full or in a light-touch manner.

In the tables in the following pages we provide:

- the main strength of the approaches taken in the two case studies;
- remaining challenges;
- our resulting recommendations.

3.1 Context analysis

Step	Main strengths in our approach	Remaining challenges in our approach	Recommendations
A.1 Characterize physical context	We synthesized knowledge on the geo-morphological and hydrographic features, the climate, and the hazard prone-ness of the cases' area	-	Contact with the relevant local scientific departments facilitates the efficient collection of the necessary information. Also, global tools are available for first-cut hazard information
A.2 Characterize socio-economic context	We defined the boundaries of the cases, identifying which people and activities are exposed to climate-related risk	High-quality quantitative datasets would permit better assessment of the network of people and goods at stake	Contact with the local economic departments in universities and institutions can provide access to the most updated information
A.3 Characterize policy, institutional and stakeholder context	For the **Bilbao** case we compiled an extensive list of the people, companies and institutions involved, and of the normative and executive responsibilities. Also, several stakeholder meeting were organized	Due to the ex-post nature of the **Vltava** appraisal, stakeholder engagement in the decision-making was not possible.	It is necessary to engage with stakeholders at different stages in the project, in bilateral and multilateral meetings, and to ensure good communication and exchange of information

3.2 Hazard assessment

Step	Main strengths in our approach	Remaining challenges in our approach	Recommendations
B.1 Scenarios and time horizons	In the **Vltava** case we selected different combinations of climate and socio-economic scenarios that are compatible	We only simulated conditions at present and at the end of the century, while it would be useful to simulate a few time horizons in between	It is essential to sample the range of possible climate and socio-economic outcomes. Simulating multiple future time slices greatly improves the appraisal of future benefits of adaptation
B.2 Climate datasets	In the **Vltava** case we used climate data from a wide range of climate models, and thus adequately sampled the inter-model uncertainty	For the **Bilbao** case we could only use the results of one climate model. However, we justified this choice by demonstrating that this dataset is representative of multiple models' ensemble mean	Use datasets from multiple models, and sample the range of their outcomes. When limited resources imply that few model datasets can be used, it is necessary to carefully select the model(s) and nevertheless provide some

			estimation of the uncertainty around its or their outcome(s)
B.3 Weather generator / Statistical downscaling	Due to practical limitations, we could not test the potential benefits of this step	Especially for the **Bilbao** case, either of these techniques could have provided interesting insights into local changes in weather variables	When the expertise available to the practitioners allows, especially when climate data resolution is coarse, it is worth applying either weather generation or statistical downscaling
B.4 Sea level rise	Besides changes in precipitation patterns, in the **Bilbao** case we also included projections of regional sea level rise	It was not possible to conduct a study of the joint probabilities of river and sea level extremes	When the case context requires, it is imperative to include sea level rise amongst the impacts. Although not yet common, it is advisable to address the impacts of compound floods, from river, precipitation, and storm surges
B.5 Hydrological modelling and hazard maps	For both cases we produced flood maps for floods of multiple return periods, which allows addressing floods as stochastic events. For the **Vltava** case applying simplified relationships and data interpolation allowed to satisfactorily obtain flood extents from maximum precipitation	In the **Bilbao** case we treated floods of different magnitude as discrete possibilities, thus likely underestimating the expected annual damage resulting from their joint probabilities. Full on hydrological modelling for the **Vltava** case area proves challenging	Depending on the resources and expertise, using either simplifications such as the relationships we applied, or run hydrological/hydraulic modelling. The second will yield more reliable results. For each future scenario, it is necessary to produce multiple flood maps, for at least 4 return periods. The expected annual damage can thus be calculated stochastically

3.3 Impact assessment

Step	**Main strengths in our approach**	**Remaining challenges in our approach**	**Recommendations**
C.1 Exposure datasets	We used updated information on exposed land uses, in the case of **Bilbao** with very high spatial detail	For the whole city of Prague (**Vltava** case) it was not possible to differentiate many land uses. Also, a big pending challenge is the representation of future changes in land uses, population and assets	Liaising with the local authorities, the most updated maps should be retrieved, reporting land uses or, if the case scale is small, even buildings. It should be investigated whether any study exists on future change in exposure

C.2 Vulnerability information	Country-specific vulnerability curves, i.e., depth-damage curves, were applied (**Vltava** case)	Large improvements can be achieved by using site-specific vulnerability curves	The availability of local vulnerability curves / information should be checked. Alternatively, if the case scale is small, a survey could be conducted. If resources do not allow, apply the most representative curves available from literature
C.3: Impact modelling	Exposure datasets were intersected at the spatial scale with flood maps, using vulnerability curves	This step critically depends on the quality and reliability of the datasets obtained in steps B.5, C.1 and C.2	The spatial integration of maps of flood and of land uses, through the application of vulnerability curves, is straightforward

3.4 Adaptation

Step	**Main strengths in our approach**	**Remaining challenges in our approach**	**Recommendations**
D.1 Screening adaptation options	We build an easy-access tool for screening every possible adaptation measure	Due to the ex-post nature of the appraisals, we did not actually select options from the general list we created, but appraised already set options.	When the case context is well characterized (Steps A) it should be relatively straightforward to filter adaptation measures that befit the case, using our tool
D.2 Including adaptation into assessment	Due to practical limitations, we could not simulate alternative measures in the cases	As our cases consisted on the evaluation of existing investments or plans, we did not simulate alternative options	Careful consideration on the part of the impact modeller should be taken, to identify the part of the modelling framework where the adaptation plays out its role and can therefore be simulated
D.3 Considering adaptation "pathways"	Due to practical limitations, we did not carry out this step	A single future time horizon was simulated, making it harder to pinpoint adaptation "tipping points" and therefore draw pathways. Also, we didn´t simulate different measures	When different measures are simulated, it is really worth exploring this step. Also beneficial to enable drawing pathways is the simulation of multiple future time steps, to locate adaptation "tipping points". Pathways greatly help decision-making discussions

3.5 Economic assessment

Step	Main strengths in our approach	Remaining challenges in our approach	Recommendations
E.1 Quantification of costs	Official costs figures (**Vltava**) or quotes (**Bilbao**) where used	-	The practitioner should consider whether part of the investment could be realized in a later stage, so as to increase the chances of a positive outcome of the cost/benefit analysis (taken into account discounting of future values)
E.2 Quantification of benefits–Avoided damage	Especially in the **Bilbao** case, several categories of damages were included, accounting also for damages to cultural heritage, human health, disruption of transportation and such	In the case with larger scale (**Vltava**), quantifying damages beyond the direct and tangible is a considerable challenge	This step is based on Step C.3 and therefore depends on its quality. Multiple categories of damages should be considered, where possible, including indirect and intangible damages
E.3 Quantification of Intangible/non-monetary benefits	For the **Bilbao** case, it was possible to account for some intangible and non-directly monetizable damages (see Step E.2)	In case such as the **Vltava**, where this was not possible, those benefits/impacts should be accounted for separately in the decision-making framework	The monetization of non-money damages needs the application of dedicated approaches. Alternatively, separate accounting for non-monetary benefits/impacts should yield a fair representation in the decision-making stage
E.4 Quantification of co-benefits of adaptation	We did not identify co-benefit of the adaptation measures investigated	-	Often adaptation may bring co-benefits that should not be overlooked. An efficient way in which these can be made evident is via meetings with local stakeholders and experts
E.5 Discounting of future values	We explored a large variety of approaches to discounting, and of values, in the **Vltava** case, also considering their compatibility with the climate scenarios adopted. In the **Bilbao** case, results were produced for any plausible rate of discount	-	As this step is crucial to the outcome of the economic appraisal, a serious investigation (i.e., sensitivity analysis) of the effects of different discounting approaches and rates should be carried out
E.6 Incorporating future preferences	We did not incorporate changes in preferences in the cases	-	As future generations may value environmental services more, it is advisable to apply a growth factor (α) to extrapolate future values of, e.g., ecosystems that may be saved/created by the adaptation

3.6 Decision-making with consideration of stakeholders

Step	Main strengths in our approach	Remaining challenges in our approach	Recommendations
F.1 Economic decision-making tools	The decision-making in our cases was implicitly covered in the economic appraisal: when benefits exceed costs, the decision is to invest	With a larger scope in the assessment, it would be necessary to adopt more techniques that comprehend more aspects of the decision on whether and on what to invest	Apply Cost-Benefit Analysis or Real Option Analysis, with the adjustments we provide to make room for consideration of uncertainties typical of climate adaptation
F.2: Comprehensive decision-making tools	We did not apply decision-making tools that comprehend criteria beyond the non-economic domain	Because both the **Vltava** and the **Bilbao** case present a rich stakeholder context, decisions should have been taken with comprehensive tools and in explicit consideration of the stakeholders' instances	Depending on the stakeholder complexity of the case, apply one or more of the tools and techniques that we present. Use the tools to engage stakeholders in evaluating pros and cons of each adaptation option
F.2 Private role in adaptation decision-making	Adaptation in both case studies creates benefits to private parties, which should motivate private investment into the measures. In **Bilbao**, in fact, property owners financed the elevation of plots of land	A range of adaptation options specifically involve private actors, but have not been contemplated in the cases	Stakeholders that will substantially benefit from the adaptation (e.g., farmers, industries), may be considered to share the public investment burden, applying specific policy instruments proposed in ECONADAPT

4 Implications

4.1 Positive success-factors

The single greatest advantage for the work that is here summarized came from the possibility of tapping knowledge from a wide range of expertise present within the ECONADAPT consortium, from climatology and climate services to economic decision-making. Thanks to this the guidelines here provided are not the recommendation of a few individuals who learned from two concrete case studies, but reflect a considerable body of knowledge and experience from multiple disciplines. Linked to this is one of our main conclusions, that the appraisal of adaptation is a multi-disciplinary exercise, and that the practitioner should therefore count on (access to) a range of expertise to address all its steps.

Another point of strength in our case studies' exercise was the already established access to local knowledge stakeholders, especially the water institutions in the Czech Republic and the Basque country. The implication of this is that (as reported in Steps A) the practitioner should aim for developing such contacts as soon as possible, to maximize the chances of a successful appraisal.

Further, the fact that the realization of the two case appraisals was itself constrained, in the amount of time and effort available, turned out extremely instructive in understanding which should be the right compromise between accuracy and comprehensiveness on the one hand, and efficiency and expeditiousness on the other.

4.2 Main pending challenges

While the limitations in carrying out the case studies had benefits, they clearly presented the disadvantage that we could not try out different approaches to the same problem (same Step). By doing that, we could have provided even more extensive and informed recommendations, also about the time and effort required for each plausible approach. As we outline below, this can be explored in future research.

In relation to this, we need to stress that, as evident from the Steps in section 2, we have not had the chance to perform all Steps in our case studies, and that some of the practices we concretely adopted in the cases are sub-optimal. Nevertheless, we could still compile valuable recommendations for those Steps by filling the cases' gap with knowledge and experience gathered within the ECONADAPT partnership.

One further possibility we did not adequately explore is the implementation of so-called “nature-based solutions” to adaptation. These are increasingly being recognized as measures that generate a host of co-benefits, mostly in terms of the preservation/creation of ecosystem and of emissions mitigation. However, due to their still limited application, the effectiveness of these measures in meeting their adaptation goals, and their economic efficiency have not been systematically investigated yet (e.g., Temmerman et al., 2013).

4.3 Gap in present adaptation decision-making processes in the EU

The EU's Adaptation Strategy (2013) lists a number of actions to promote EU's preparedness for the current and future impacts of climate change. It encourages and supports action by the Member States on adaptation, it encourages better informed decision-making on adaptation, and promotes adaptation in key vulnerable sectors. Regarding adaptation in the water and flooding context, the main documents on EU level are the Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC). While the "Common Implementation Strategy" for these Directives emphasises participatory approaches in decision-making, it gives little guidance on the way adaption options should be appraised or selected. The EU has published a number of guidance documents on appraisal and decision-making processes on long-term investments[8]. The guidance documents discuss the need to enhance the resilience of (long-lived) infrastructure in consideration of climate change and offer tools for appraisal and decision-making. While the more adaptation-oriented guidance documents discuss 'robust' appraisal methods and, for example, alternative discounting procedures, this has not yet been totally 'mainstreamed' in the body of guidance for appraisal that need to be followed for a major infrastructure project to become eligible for EU co-funding.

For example, while the "Guide to Cost-Benefit Analysis of Investment Projects: Economic Appraisal Tool for Cohesion Policy 2014-2020" acknowledges the importance of the counterfactual (Business–as-Usual, or Do-minimum), the project should be evaluated against one common baseline that is based on "clear evidence about the most feasible situation that would occur in the absence of the project." This seems to exclude (or not account for) the use of multiple possible climate and socio-economic developments that is a prerequisite for 'robust' decision-making in the adaptation context (see, e.g., Deliverables 1.2 and 2.1 of ECONADAPT). In addition, the European Commission recommends for major projects the social discount rate of 5% in Cohesion countries and of 3% for the other Member States. Member States may establish a benchmark for the social discount rate which is different from 5% or 3%, on the condition that: i) justification is provided for this reference on the basis of an economic growth forecast and other parameters; ii) their consistent application is ensured across similar projects in the same country, region or sector. This recommendation, while understandable, seems to give little scope for approaches using risk-adjusted or endogenous discount rates for climate-vulnerable projects, as is for instance, discussed in Deliverables 2.3 and 4.2 of ECONADAPT.

8 Among others: Adapting infrastructure to climate change (SWD (2013) 137); Technical guidance on integrating climate change adaptation in programmes and investments of Cohesion Policy (SWD (2013) 135); Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient, The EC Guide to Cost Benefit Analysis of Investment Projects (DG REGIO, 2008); Guide to Cost-Benefit Analysis of Investment Projects: Economic Appraisal Tool for Cohesion Policy 2014-2020; Guidance for Integrating Climate Change and Biodiversity into Environmental Impact Assessment.

4.4 Impact on the EU Solidarity Fund

The EU Solidarity Fund (EUSF) was created in the aftermath of a set of flood disasters that severely impacted central Europe in 2002. It is meant to reflect the principle of solidarity among Member States, by providing relief to regions hit by natural disasters in their living conditions, environment and economy, when consequences exceed 3 billion € or 0.6% of the country's GDP. The aid is provided in form of financial supplement to public spending for recovery after the disaster.

The **Vltava** basin suffered severe flooding during the last 14 years in which the EUSF has been in place. The floods of the summers 2002 and 2013 received 129 and 16 million € in EUSF aid, respectively[9]. These amounts constitute a non-negligible portion of the total EUSF expenditure so far (ca. 4%), but only covered for a fraction (about 4%) of the estimated damage losses of the floods.

Regarding the **Bilbao** case, it should be noted that Bilbao nor Spain in general have yet benefited from the EUSF for floods.

It has approved 3.785 billion in aid in the aftermath of natural disasters, from its institution in 2002 (as of 10th of July 2015[10]). A majority of the disasters that required the intervention of the EUSF are floods, or fall within the types of disasters that are exacerbated by climate change.

Investments in climate change adaptation are targeted to reduce the risk posed natural disasters (i.e., those related with climate change), and therefore by definition contribute to reducing the need for disaster-recovering funds. On the one hand, the reduction in total economic impacts that adaptation typically achieves lowers the probability that a given natural disaster is classified as "major" and therefore considered eligible for the EUSF. On the other hand, because consequences of disasters are mitigated by adaptation, the will be less scope for the restoration works that the EUSF covers for.

4.5 Development and adaptation

It is important to emphasise that adaptation should be seen in the context of the wider sectoral or cross-sectoral development objectives. Pursuit of these objectives, such as the recently adopted United Nations' Sustainable Development Goals[11], may dwarf the importance of mitigating climate risks. On the other, another way to regard these apparently independent sets of goals, is that the goal of adapting to climate change may be subsidiary to addressing this other broad set of goals.

A balance between the pursuit of these different objectives needs to be established, and possibly the available synergies be explored, since this helps determining the most appropriate appraisal method to use. An effective way to make these trade-offs transparent, and therefore to help minimise conflict between stakeholders who are pursuing alternative objectives, is to estimate and present the economic measure, (e.g., the net present value), under alternative development scenarios. Deliverable 2.1 in the ECONADAPT project demonstrates how this can be done using a simple matrix format.

[9] http://ec.europa.eu/regional_policy/sources/thefunds/doc/interventions_since_2002.pdf retrieved on 8th March 2016.

[10] http://ec.europa.eu/regional_policy/sources/thefunds/doc/interventions_since_2002.pdf (retrieved 8 March 2016)

[11] http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

4.6 Future research directions

In this document we have included recommendations for steps in the appraisal that objectively require a considerable amount of work, and whose success critically depends on the availability of specialist expertise, such as in hydrology or econometrics. On the other hand, it is often the case, in the practice that constrains of different nature - - limit the possibilities to carry out parts of this work, especially in the case of investments of medium-small size, and depending on the legislation in force. In other words, the practitioner is often confronted with the need to opt for so-called “light touch” approaches, i.e., pragmatic shortcuts to extensive modelling and evaluation.

It is therefore of primary interest to understand the extent to which such light-touch practices can be considered valid approximations of more accurate ones, and their results be taken as proxies of results of a complete appraisal. This could be investigated in an experimental set-up that comprises carrying out appraisals using both approaches for a set of case studies.

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